September 2026

Watershed

Cannon River Watershed Restoration and Protection Strategy Report Update 2026

MINNESOTA POLLUTION CONTROL AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT

Authors

Kristen Dieterman

Jeff Strom

Justin Watkins

Contributors/acknowledgements

Joe Magee (MPCA)

Kevin Kuehner (MDA)

Ashley Ignatius (MPCA)

Sean Morrison (MPCA)

Jessica Massure (DNR)

Ian Ackman (MPCA)

Sagor Biswas (MPCA)

Mandy Kauffman (MPCA)

Tiffany Schauls (MPCA)

Dustan Hoffman (DNR)

Lindsey Albright (Dakota SWCD)

Al Kraus (Rice SWCD)

Editing and graphic design

Jinny Fricke (Public Notice_9.15.26)

Cover photo credit: Kristen Dieterman

Document number: wq-ws4-111a

Contents

List of figures

List of tables

Key terms and abbreviations

1W1P	One Watershed, One Plan
AQL	aquatic life
AQR	aquatic recreation
ATS	Akritas-Theil-Sen
BMP	best management practice
BWSR	Board of Water and Soil Resources
CDOM	colored dissolved organic matter
chl-*a*	chlorophyll-a
CLP	curly-leaf pondweed
CRWJPO	Cannon River Watershed Joint Powers Organization
CWMP	Comprehensive Watershed Management Plans
DO	dissolved oxygen
DNR	Minnesota Department of Natural Resources
E. coli	Escherichia coli
EAO	Environmental Analysis & Outcomes
EPA	U.S. Environmental Protection Agency
EQuIS	Environmental Quality Information System
FIBI	fish community-based Index of Biological Integrity
FQI	FQI
FWMC	flow weighted mean concentration
HSPF	Hydrologic Simulation Program–Fortran
IBI	index of biological integrity
IWM	intensive watershed monitoring
LA	load allocation
LGU	local government unit
mg/L	milligrams per liter
MPCA	Minnesota Pollution Control Agency

MS4	Municipal Separate Storm Sewer System
N	nitrogen
NCHF	North Central Hardwood Forest
NPDES	National Pollutant Discharge Elimination System
NRS	Nutrient Reduction Strategy
P	phosphorus
SAM	Scenario Application Manager
SDS	State Disposal System
SID	stressor identification
SSTS	Subsurface Sewage Treatment Systems
STS	Score The Shore
SWCD	Soil and Water Conservation District
TMDL	total maximum daily load
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solids
USGS	United States Geological Survey
WASCOBs	water and sediment control basins
WPLMN	Watershed Pollutant Load Monitoring Network
WLA	Wasteload Allocation
WRAPS	Watershed Restoration and Protection Strategy
WWTF	Wastewater Treatment Facility

Executive summary

The *Cannon River Watershed Restoration and Protection Strategy (WRAPS) Report Update 2026* provides a comprehensive reassessment of water quality conditions, trends, and management priorities across the Cannon River Watershed over the past decade. Building on the original 2016 WRAPS, this update integrates findings from the second cycle of intensive watershed monitoring (IWM; 2022), recent stressor identification (SID) studies, long-term trend analyses, and targeted research efforts. The report is intended to guide local governments, watershed organizations, state agencies, and stakeholders in prioritizing cost-effective strategies for both restoring impaired waters and protecting those that remain healthy.

The Cannon River Watershed drains over 1,400 square miles in southeastern Minnesota and encompasses a diverse landscape of agricultural lands, urban areas, lakes, streams, and ecologically significant bluff lands. While the watershed provides important ecological, recreational, and economic benefits, it continues to face persistent water quality challenges. Primary stressors include excess nutrients (phosphorus [P] and nitrogen [N]), sediment, bacteria (largely driven by agricultural runoff) tile drainage, urban stormwater, and altered hydrology.

Key assessment findings

Water quality assessments confirm that impairments remain widespread across the watershed. Nearly 200 impairments identified in earlier assessment cycles persist, affecting aquatic life (AQL), aquatic recreation (AQR), and drinking water uses. In the most recent cycle, 27 new impairments were added, largely reflecting additional data and expanded biological monitoring rather than new or emerging problems. Notably, this cycle included the first comprehensive lake fish community assessments, which identified 12 lakes with degraded biological conditions, and 2 vulnerable to degradation.

Streams continue to exhibit impairments related to elevated bacteria, turbidity, nutrients, and degraded biological communities. However, improvements were documented in several mainstem river reaches, suggesting that conservation and restoration efforts in upstream tributaries are beginning to yield measurable downstream benefits.

Watershed condition and stressors

Updated SID analyses reinforce that nutrient-driven eutrophication and physical habitat alteration are the dominant factors limiting AQL in lakes and streams. Most assessed lakes show high levels of watershed disturbance; often exceeding thresholds associated with fewer sensitive species and reduced habitat complexity.

Research, including paleolimnological studies, shows that current nutrient levels are significantly elevated compared to pre-settlement conditions – often 6 to 10 times higher. This long-term perspective confirms that widespread land use changes have fundamentally altered lake and watershed processes. Recovery potential varies by lake type, with seepage lakes generally more responsive to nutrient reductions and flow-through systems requiring sustained, large-scale watershed interventions.

Subwatershed-level analyses provide more targeted insights. For example:

- The Upper Straight River and Upper Medford Creek are priority areas for nitrate reduction due to elevated concentrations linked to tile drainage and agriculture.
- Belle Creek and Rush Creek represent high-quality systems where protection strategies should be prioritized.
- Crane Creek highlights the importance of wetlands such as Moonan Marsh as natural treatment systems influencing downstream water quality.

Trends and progress

Long-term monitoring data indicates mixed but encouraging trends. Biological conditions in streams, including fish and macroinvertebrate communities, show statistically significant improvement between monitoring cycles. In addition, long-term data from the lower Cannon River demonstrates decreasing trends in total phosphorus (TP), total suspended solids (TSS), and nitrate concentrations, reflecting both point source controls and broader watershed efforts.

Water clarity trends are more variable. While a small number of lakes show improving clarity, several continue to degrade. Stream clarity trends are more positive overall, with many stream sites showing improvement.

Importantly, major investments in wastewater treatment infrastructure have significantly reduced point source P loading, particularly upstream of Byllesby Reservoir. However, nonpoint sources, especially agricultural runoff, remain the dominant contributors to nutrient loading, particularly during high-flow conditions.

Restoration and protection priorities

The findings of this update emphasize the need for targeted, watershed-scale implementation strategies. Key priorities include:

- Nutrient reduction through agricultural best management practices (BMPs) such as cover crops, nutrient management, conservation tillage, and drainage water management.
- Shoreline and habitat restoration, including riparian buffers, native vegetation, and improved aquatic habitat complexity.
- Hydrologic restoration, such as wetland restoration and floodplain reconnection, to reduce peak flows and pollutant transport.
- Urban stormwater management, particularly in regulated MS4 communities.
- Protection strategies for high-quality waters to prevent future degradation.

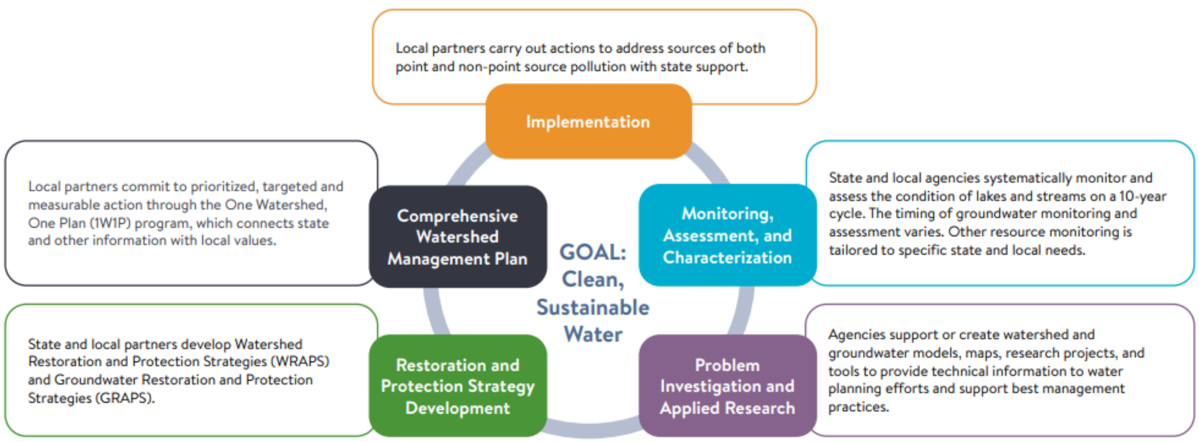
Overall, the Cannon River Watershed shows signs of progress, particularly in stream biological condition and reductions in point source pollution. However, widespread impairments and persistent nutrient loading underscore the need for continued, coordinated action. This WRAPS Report Update provides a data-driven framework for targeting investments, improving water quality, and enhancing resilience in the face of increasing precipitation and climate variability. Sustained collaboration among local, state, and regional partners will be essential to protect water resources and ensure long-term ecological and community benefits.

1. Watershed approach

Minnesota is rich with rivers, streams, lakes, wetlands, and groundwater aquifers that support the human and natural world. Voter passage of the Clean Water Land and Legacy Amendment in 2008 demonstrated the public's long-term commitment to actions needed for clean and sustainable water. Minnesota's state water agencies developed the Minnesota Water Management Framework to clarify roles and enhance coordination at the major watershed scale. Minnesota has adopted a watershed approach to address the state's 80 major watersheds. The Minnesota Watershed Approach incorporates **water quality assessment, watershed analysis, public participation, planning, implementation, and measurement of results** into a 10-year cycle that addresses both restoration and protection.

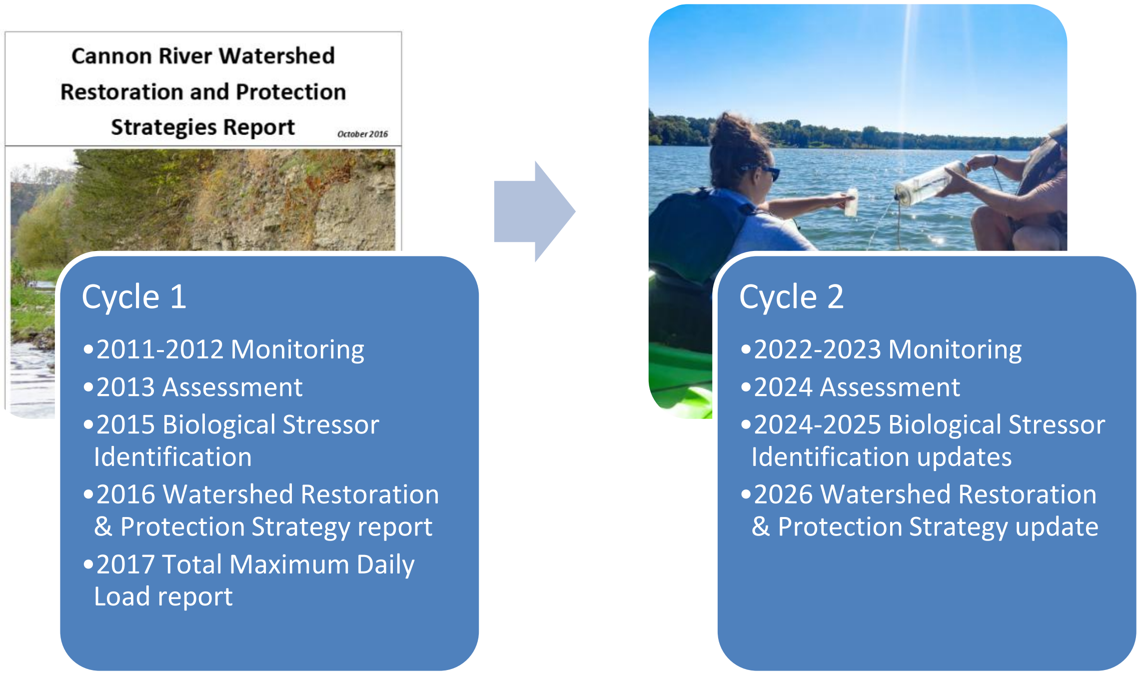
As part of the watershed approach, the Minnesota Pollution Control Agency (MPCA) developed a process to identify and address threats to water quality in each of these major watersheds.

Figure 1. Minnesota's Watershed Approach cycle.



This process is called WRAPS development. The WRAPS reports have two parts: impaired waters have strategies for restoration, and waters that are not impaired have strategies for protection.

Waters not meeting state standards are listed as impaired. When appropriate, a total maximum daily load (TMDL) study is developed for the impairments. The TMDLs are incorporated into the WRAPS reports. In addition, the watershed approach process facilitates a more cost-effective and comprehensive characterization of multiple water bodies and overall watershed health, including both protection and restoration efforts. A key aspect of this effort is to develop and use watershed-scale models and other tools to identify strategies for addressing point and nonpoint source pollution with the goal of achieving water quality targets. For nonpoint source pollution, the WRAPS report informs local planning efforts, but ultimately the local partners decide what work will be included in their local plans.



Watershed Approach assessment work began in the Cannon River Watershed in 2011 and was revisited for monitoring in 2022.

Information produced in earlier Watershed Approach work, prior to the development of this WRAPS Update, is available at Cannon River Watershed information webpage. This list includes reports related to Cycle 1 and Cycle 2:

- Cannon River Watershed Monitoring and Assessment Report (MPCA, 2014)
- Cannon River Watershed SID Report (MPCA, 2015)
- Cannon River Watershed WRAPS Report (MPCA, 2016)
- Cannon River Watershed TMDL Report (MPCA, 2017)
- Jefferson-German Lake Chain TMDL Report (MPCA, 2014a)
- Lake Volney TMDL Report (MPCA, 2014b)
- Lower Cannon River Turbidity TMDL Report (MPCA, 2007)
- Lower Cannon River Turbidity TMDL Implementation Plan (MPCA, 2009)
- Straight River Watershed SID Report (MPCA, 2024b)
- Bell Creek Watershed SID Report (MPCA, 2025a)
- Crane Creek Watershed SID Report (MPCA, 2025b)
- Rush Creek Watershed SID Report (MPCA, 2025d)
- Cannon River Watershed Assessment and Trends Update (MPCA, 2025)
- Medford Creek Watershed SID Report (MPCA, 2026)
- Cannon River Watershed SID Report – Lakes (DNR, 2026)

The *Cannon River WRAPS Report Update 2026* is an update of the 2016 WRAPS Report (MPCA 2016). This WRAPS report update summarizes water quality findings from the second round of IWM (MPCA 2025), SID (MPCA 2024b, 2025a, 2025b, 2025d, 2026, DNR 2026), water quality research projects, and studies.

The goals of this updated WRAPS report are to:

1. Highlight differences and trends in watershed conditions over the last 10 years.
2. Share updated surface water quality resources, information, and tools for watershed stakeholders as they plan and implement BMPs.
3. Provide updated recommendations for prioritizing and targeting implementation throughout the watershed.

Local governments, watershed organizations, landowners, and state agencies collaborate to implement WRAPS. Key efforts include implementation strategies consistent with MPCA guidance:

- Wetland restoration and floodplain reconnection to reduce peak flows and pollutant loading and increase flood resilience.
- Municipal Separate Storm Sewer System (MS4) best practices to manage urban runoff.
- BMPs that reduce nutrient and sediment loading from agricultural and developed lands.
- Coordinated WRAPS planning and implementation through Comprehensive Watershed Management Plans (CWMP) and the One Watershed, One Plan (1W1P) program.

These approaches support compliance with water quality standards while improving long-term resilience and maximizing the return on public investments. By working together, communities across the Cannon River Watershed can protect clean water, reduce flooding, and preserve this valuable natural resource for future generations.

2. Watershed description

The Cannon River Watershed is a large river system in southeastern Minnesota that drains water from more than 1,400 square miles of land. Rain and snow that fall within the watershed flow into local streams, lakes, and wetlands, eventually reaching the Cannon River and then the Mississippi River at Red Wing (Figure 2).

Figure 2. Cannon River Watershed land use.

The watershed includes parts of Rice, Goodhue, Dakota, Steele, Le Sueur, Scott, Waseca, Freeborn, and Blue Earth counties, and connects many communities through shared water resources. The *Cannon River WRAPS Report* completed in 2016 includes a comprehensive watershed description; this WRAPS Update Report presents a summary of that information.

The Cannon River Watershed is a shared natural resource that directly affects public infrastructure, economic vitality, public health, and regulatory compliance across multiple jurisdictions. Land-use and infrastructure decisions made by cities, counties, and townships influence water quality, flood risk, and long-term maintenance costs downstream.

2.1 Key Features of the Watershed

Rivers, Lakes, and Wetlands

- Major rivers include the Cannon River, Straight River, and Little Cannon River
- Numerous smaller streams and ditches
- Headwaters include many lakes and wetlands
- Wetlands that help store floodwater and filter pollutants

Topography and Geology

- Rolling till plains in the west
- Transitions to deeply incised river valleys and bluffs in the east
- Eastern section is influenced by karst geology, increasing groundwater-surface water interaction
- Karst geology contributes to many cold and cool water streams
- Steep ravines and bluff lands near the Mississippi River confluence

Land Use (See Figure 2)

- Primarily agricultural, with corn and soybean production (~72.5% of watershed area)
- Cities and towns such as Owatonna, Faribault, Northfield, and Red Wing (~9.6% of watershed area)
- Forested river corridors and bluff lands, especially in the lower Cannon, near the Mississippi River (~9% watershed area forest)

Natural resources for wildlife and recreation

- Habitat for fish (including trout in some areas), wildlife, and pollinators
- Scenic river valleys and bluff lands
- Important groundwater and surface water connection
- Cannon Valley Trail supports biking and hiking
- Scenic river valley with high aesthetic and tourism value
- Strong cultural and historic importance to indigenous peoples and early settlers

2.2 Current Challenges

Several waters within the Cannon River Watershed are identified by the MPCA as impaired waters under Section 303(d) of the federal Clean Water Act (see Section 3.2). Key stressors include:

- Excess nutrients (P and N)
- Sediment and turbidity
- Escherichia coli *(E. coli)* bacteria affecting recreational use

Primary sources include agricultural runoff and leaching, urban stormwater, and altered hydrology including subsurface tile drainage. These impairments require development and implementation of

TMDLs, the *Minnesota Nutrient Reduction Strategy* (NRS; MPCA, 2026a), and coordinated restoration strategies outlined in the Cannon River Watershed CWMP (CRWJPO, 2020).

Groundwater is an important component of the Cannon River Watershed's water resources and is closely connected to surface water systems in portions of the watershed. This connection is particularly important in areas of karst geology, where groundwater and surface water can exchange rapidly and where pollutants entering the landscape can more readily reach groundwater and groundwater fed streams. The 2017 Minnesota Department of Health (MDH) Cannon River Groundwater Restoration and Protection Strategy (GRAPS) report identifies Rice, Dakota, and Goodhue counties as areas where these conditions warrant particular attention. This not only poses challenges to water quality management, but also water quantity management. In these areas, it is important to protect groundwater quantity to continue to support groundwater fed streams.

Flooding has also been a challenge for the Cannon River Watershed. In June 2024, the city of Waterville was inundated with floodwater, damaging hundreds of homes and businesses. Floodplains provide natural water storage but are constrained in developed areas and weather trends suggest increasing intensity of rainfall events, leading to increased erosion.

3. Assessing water quality

Each water body in Minnesota is assigned designated uses – such as AQL, AQR, fishing and fish consumption, or drinking water - MPCA assesses lakes, rivers, and streams to determine whether they are meeting standards for designated uses. If the water doesn't meet those standards, it may be unhealthy or unsafe.

The federal Clean Water Act requires every state to assess the quality of its waters and report results to the EPA every two years. This report includes a list of waters that don't meet quality standards. The MPCA's Assessment Manual (2024) explains how the MPCA does these assessments in a consistent and legal way.

The MPCA's water quality assessment process checks the health of the state's water bodies.

1. Gather samples and data.
2. Compare them against guidelines.
3. Decide whether the water is healthy.
4. If not, add to impaired waters list so plans can be made to fix it.

How assessments are done

First, the MPCA and many partners collect information about Minnesota's waters. This information comes from state labs, local partners, volunteers, and other agencies.

This includes:

- Chemical samples (levels of bacteria, nutrients, and other pollutants)
- Biological data (how many fish or insects live in a water body)
- Physical measurements (water clarity, temperature)

Once data are collected, scientists compare the measurements to the water quality standards that apply to each water body – standards that reflect how clean the water should be to support designated uses. If enough measurements show the water doesn't meet these standards, the water body might be assessed as impaired.

Assessing water quality isn't just about one sample, MPCA staff review all the data to decide:

- How many times must a pollutant concentration be too high before the water is deemed impaired
- Whether natural events (like storms) might have biased a dataset
- How confident they are in the data quality

This careful process helps make sure the assessment decisions are accurate and consistent.

After reviewing the data, MPCA decides whether a water body:

- Meets water quality standards
- Fails to meet standards – impaired
- Has too little data to make an assessment at this time

Waters that do not meet water quality standards (see Section 3.2) are placed on Minnesota's Impaired Waters List, which is part of the report sent to the EPA.

Listing a water as impaired triggers actions to improve it. For example, TMDLs and strategies are developed to reduce pollution and restore healthy water conditions. These strategies guide restoration projects and help protect waters for people and wildlife in the future.

3.1 Cycle 1 monitoring sites and assessment conclusions

Previous monitoring and assessment efforts resulted in nearly 200 impairment listings in the watershed affecting five main designated uses: drinking water, AQL, aquatic consumption, AQR, and wild rice production. Sites that were monitored for chemistry in Cycle 1 are shown in Figure 3 and sites that were monitored for biology in Cycle 1 are shown in Figure 4. These impairments are covered in detail in the previously listed reports. For streams, common impairments include:

- Lower numbers and/or fewer species of fish and macroinvertebrates than expected
- High levels of bacteria
- High levels of turbidity, meaning soil and other particles in the water
- High levels of nitrate/N

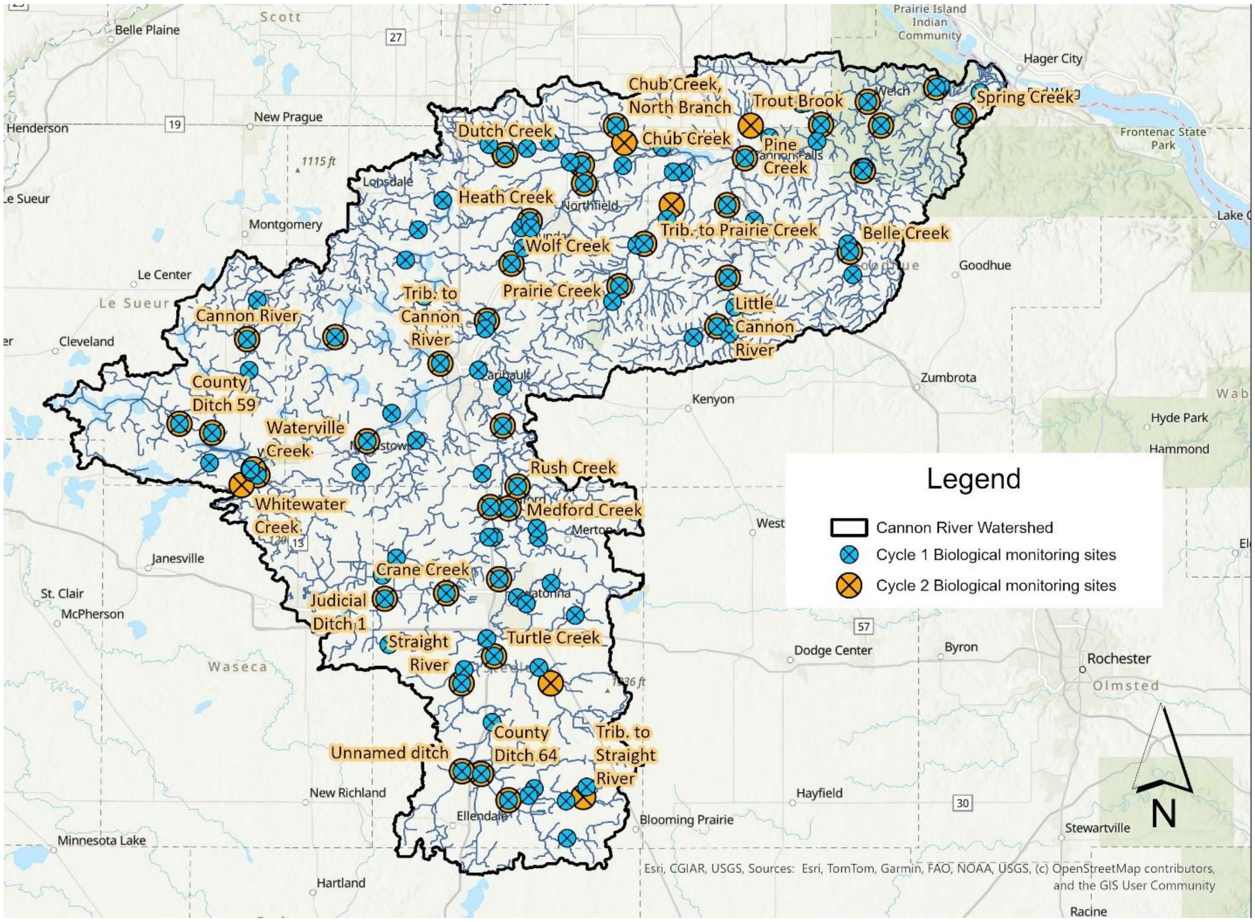
For lakes, common impairments include:

- High nutrients, often causing excessive algal blooms
- Elevated levels of mercury in fish tissue

Cycle 1 impairments, excluding lake, aquatic consumption, and waters used for the production of wild rice, are displayed in Figure 5. Cycle 1 lake impairments are shown in Figure 6.

Figure 3. Stream water chemistry monitoring sites in Cycle 1 (C1) (2011-2012) and Cycle 2 (C2) (2022-2023).

Figure 4. Cycle 1 and Cycle 2 stream biological monitoring sites with repeated stream names labeled.



3.2 Cycle 2 monitoring sites and conclusions

The most recent monitoring and assessment efforts resulted in 27 new impairments (MPCA, 2025). Cycle 2 chemistry monitoring sites are shown in Figure 3 and Cycle 2 biological monitoring sites are shown in Figure 4. Cycle 2 stream impairments, excluding lake, aquatic consumption, and waters used for the production of wild rice are shown in Figure 5. Almost half of these new impairments are due to lower numbers and/or fewer species of fish in many of the watershed's lakes, shown in Figure 6. This cycle marked the first time fish assessments and SID were completed in lakes in the Cannon River Watershed, building on over a decade of fish-based IBI assessments conducted across the state. Overall, the new impairments reflect additional data confirming known issues rather than indicating new problems or sources of pollution.

Twelve lakes were found to have fish communities that are not as healthy as to be expected (Table 1). These are shown in Figure 6 and discussed in more detail in Section 4 Watershed Condition. These highly productive southern lakes often have high numbers of fish but lack the sensitive and/or habitat-dependent species that are expected to be present.

Six stream reaches were also found to have biological communities below expectations, see Table 2.

Nine stream reaches had bacteria or pollutant exceedances, see Table 3.

Figure 5. Cannon River Watershed stream impairments, excluding aquatic consumption and waters use for the production of wild rice (Cycle 1 and Cycle 2).

Figure 6. Cannon River Watershed lake assessments (Cycle 1 (C1) and Cycle 2 (C2)).

Table 1. Cannon River Watershed lakes with impaired fish communities, 2026.

Lake Name	Water Body Identification	County
Tetonka	40-0031-00	Le Sueur
Volney	40-0033-00	Le Sueur
Frances	40-0057-00	Le Sueur
German	40-0063-00	Le Sueur
East Jefferson	40-0092-01	Le Sueur
West Jefferson	40-0092-01	Le Sueur
Roberds	66-0018-00	Rice
Fox	66-0029-00	Rice
Hunt	66-0047-00	Rice
Cedar	66-0052-00	Rice
Shields	66-0055-00	Rice
Clear	81-0014-01	Waseca

Table 2. Cannon River Watershed stream reaches with new biological impairments, 2026.

Stream Name	Water Body Identification	Concern	County
Pine Creek	07040002-520	Benthic macroinvertebrates	Dakota
Unnamed Creek	07040002-525	Fish	Steele
Judicial Ditch 1	07040002-556	Benthic macroinvertebrates	Steele
Crane Creek	07040002-743	Benthic macroinvertebrates	Steele
Unnamed Creek	07040002-760	Benthic macroinvertebrates	Rice
Unnamed Creek	07040002-774	Benthic macroinvertebrates	Rice

Table 3. Cannon River Watershed stream reaches with new pollutant impairments, 2026.

Stream Name	Water body Identification	Pollutant	County
Cannon River	07040002-502	Nutrients	Goodhue
Pine Creek	07040002-520	*E. coli* bacteria	Dakota
Medford Creek	07040002-547	*E. coli* bacteria	Steele
Unnamed Creek (Spring Brook)	07040002-561	TSS	Rice
Unnamed Creek (Trout Brook)	07040002-567	*E. coli* bacteria	Dakota
Dutch Creek	07040002-572	*E. coli* bacteria	Dakota
Unnamed Creek (Trout Brook)	07040002-573	*E. coli* bacteria	Dakota
Crane Creek	07040002-743	*E. coli* bacteria	Steele
Turtle Creek	07040002-772	Fecal coliform	Steele

Many of the impairments presented in the Cycle 1 reports were confirmed to persist; however, conditions were found to have improved in six stream/river reaches, see Table 4 and Figure 8. Many of these reaches are parts of the mainstems of the Cannon and Straight rivers, including some reaches in the Lower Cannon River, representing very large drainage areas. Although the improvements couldn’t be tied to specific restoration efforts, it is promising to see improvements in the integrative mainstem reaches, suggesting these reaches are benefitting from conservation and restoration work occurring in the tributaries.

Figure 7. Cannon River Watershed stream reaches with improved conditions.

Table 4. Cannon River Watershed stream reaches with improved conditions.

Stream Name	Water body Identification	Pollutant	County
Straight River	07040002-536	Benthic macroinvertebrates	Steele
Prairie Creek	07040002-504	Benthic macroinvertebrates	Rice
Cannon River	07040002-509	Benthic macroinvertebrates	Dakota
Cannon River	07040002-509	Fish	Dakota
Straight River	07040002-503	Turbidity	Steele
Cannon River	07040002-501	*E. coli* bacteria	Goodhue

4. Watershed Condition

4.1 DNR Lake Stressor ID

The *Cannon River Watershed SID Report – Lake*s, prepared by the Minnesota Department of Natural Resources (DNR), evaluates stressors limiting AQL in lakes within the Cannon River Watershed using a fish-based index of biological integrity (FIBI) and a formal SID framework consistent with MPCA and EPA guidance. The FIBI utilizes fish community data collected from a combination of trap nets, gill nets, beach seines, and backpack electrofishing. From this data, an FIBI score that incorporates various measures of species diversity and composition can be calculated for each lake. The FIBI score indicates the overall health of a lake by comparing it to what is expected of a healthy lake.

4.1.1 Study scope and assessment framework

Twenty lakes in the Cannon River Watershed were monitored and assessed for AQL use using DNR lake FIBI models between 2017 and 2023. FIBI integrates multi-gear fish sampling (trap nets, gill nets, beach seines, and backpack electrofishing) and evaluates species richness, trophic structure, tolerance, and habitat guild composition relative to expectation for minimally disturbed reference lakes. Lakes were assessed under four FIBI models (models 2, 4, 5, and 7), selected based on morphometry and shoreline complexity. A weight-of-evidence approach was applied to validate assessment decisions, accounting for sampling effort, model applicability, and lake-specific context (DNR, 2026).

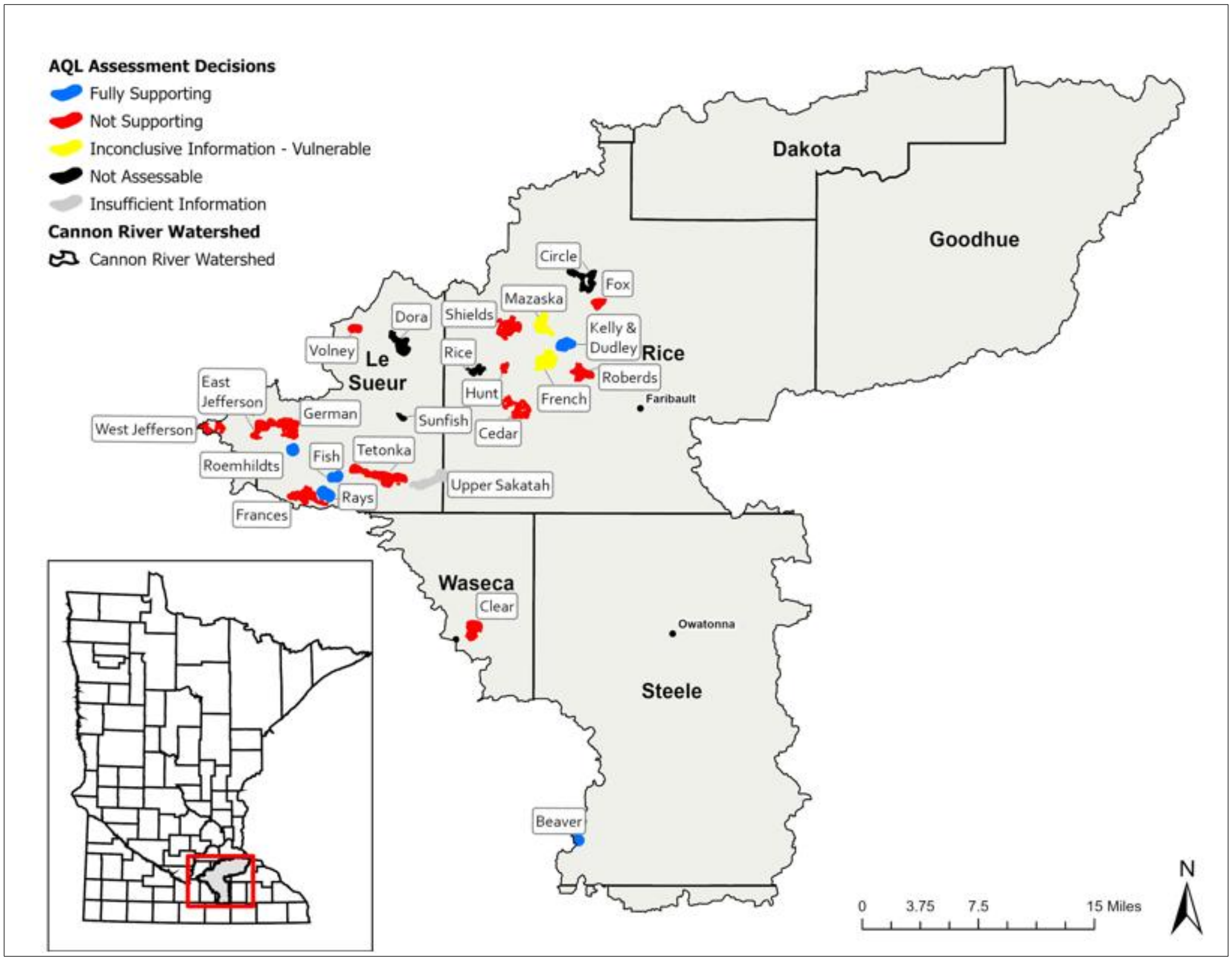
4.1.2 Aquatic life use assessment results

Of the 20 assessed lakes, 5 were determined to be fully supporting AQL (Kelly & Dudley, Roemhildts, Fish, Rays, Beaver), 12 were not supporting AQL (Clear, Cedar, Hunt, Shields, Roberds, Tetonka, Frances, East & West Jefferson, German, Volney, Fox), 2 were classified as inconclusive information-vulnerable (French, Mazaska), and 1 had insufficient information (Upper Sakatah) (See Figure 9 and Table 5). Notably, Kelly and Dudley, Roemhildts, Fish, and Beaver were identified as high-quality protection lakes in the 2016 Cannon River WRAPS Report and continue to fully support aquatic life, reinforcing their importance as watershed protection priorities. Several additional Cannon River Watershed lakes were excluded from assessment due to small size (<100 acres) or recent winterkill events (Circle, Rice) (Figure 9 and Table 5). Impaired and vulnerable lakes were distributed across both deep and shallow lake classes, indicating watershed-scale stressors rather than isolated lake-specific issues.

Table 5. Summary of lakes assessed for aquatic life in Cannon River Watershed.

Lakes fully supporting aquatic life	**Lakes not supporting aquatic life**	
Kelly and Dudley	Clear	Cedar
Roemhildts	Hunt	Shields
Fish	Roberds	Tetonka
Rays	Frances	East and West Jefferson
Beaver	German	Volney
	Fox	
Lakes inconclusive information- vulnerable	**Lakes excluded – winter kill**	
French	Circle	
Mazaska	Rice	

Figure 8. Cannon River Watershed lakes with FIBI models and their assessment decisions (DNR, Cannon River Watershed Stressor Identification Report- Lakes, 2026).



4.1.3. Lake evaluation

Several tools are used to evaluate lake health, including FIBI, percent watershed disturbance, watershed to lake area class, watershed transport capacity class, water quality influence, Score the Shore (STS), dock density, nonnative species, connectivity, aquatic plant surveys, floristic quality index (FQI), and physical and chemical characteristics of the water (DNR, 2026). The values for each of these tools are summarized in Table 7 for each of the lakes evaluated, information and data in this section come from DNR, 2026.

Percent watershed disturbance

Utilizing the most recent National Land Cover Dataset (NLCD), watershed disturbance is generally provided as a percentage of the lakeshed that is classified as cultivated cropland or residential/urban development (including open space, low, medium, and high intensity classes). Lakes with large amounts of disturbed land cover in their lakesheds are more likely to contribute polluted surface water to the lake. DNR researchers T. Cross and O. Jacobson concluded in their 2014 article "*Landscape factors influencing lake phosphorus concentrations across Minnesota",* watershed disturbance exceeding 40% often results in significantly elevated TP levels in the lake.

Watershed to lake area class

The watershed to lake area class explains how much land drains into a lake-compared to the size of the lake itself (watershed acreage : lake acreage) and how strongly the land can affect the lake's water quality (Table 6).

- <5 : Low class – Shoreline driven
    - Small watershed compared to the lake size. The lake is less affected by what happens far away
    - Water quality is influenced most by the shoreline – lawns, docks, and plants right around the lake. Taking care of the shoreline can make a big difference.
    - Examples: Frances, Hunt, Clear, French, Mazaska lakes
- 5-10 : Middle class
    - Medium watershed compared to the lake size. Both the land farther away and the shoreline matter.
    - Water quality is influenced by farms, roads, and towns in the watershed and shoreline activities. Fixing problems both around the land and upstream work best.
    - Examples: Volney, Cedar, Shields lakes
- >10 : High class – Watershed driven
    - A lot of land drains into a relatively small lake. What happens far from the lake strongly affects water quality.
    - Water quality is influenced most by farming, roads, stormwater, and land use across the whole watershed.
    - Examples: Tetonka, German, East Jefferson, West Jefferson, Roberds, Fox lakes

Table 6. Watershed to lake ratio class and water quality implications.

Watershed-to-Lake Ratio	Class	Water Quality Implication
< 5 : 1	Low	Shoreline – driven
5 – 10 : 1	Moderate	Mixed (shoreline + watershed)
>10 : 1	High	Watershed – driven

Watershed transport capacity class

The watershed transport capacity class describes how easily water (and pollution) can move from the land into a lake.

- 1-2 Low class: low transport capacity, water moves slowly, and pollution has more time to settle out or get filtered. The lake is less affected by far-away land use. (Examples: Frances, Hunt, Cedar, French, Mazaska lakes)
- 3-5 Middle class: medium transport capacity, water reaches the lake at a moderate speed. Both upstream land use and shoreline activities affect water quality. (Examples: Volney, Cedar, Shields lakes)

- 6-7 High class: water moves quickly, little filtering happens before water reaches the lake. The lake is strongly affected by what happens across the watershed. (Examples: Tetonka, German, East Jefferson, West Jefferson, Roberds, Fox lakes)

Water quality influence

Water quality influence explains where most of the lake's water quality problems are coming from.

- Lakeshed/watershed driven lakes: most influence comes from the watershed. A large area of land drains into the lake, and pollution from far away reaches the lake easily. Watershed projects are needed: buffers, cover crops, stormwater treatment. (Examples: Tetonka, German, East Jefferson, West Jefferson, Roberds, Fox lakes)
- Intermediate influence lakes: both watershed and shoreline matter. A moderate amount of land drains into the lake and water moves at a medium speed. Pollution comes from both upstream and near the lake. A mix of shoreline and watershed BMPs are needed. (Examples: Volney, Cedar, Shields lakes)
- Shoreline driven lakes: most influence comes from the shoreline. Only a small amount of land drains into the lake, and water moves slowly before reaching the lake. What happens right next to the lake matters most; lawns, docks, and plant removal or restoration have a large impact. Shoreline buffers, native plants, septic systems, and protecting aquatic vegetation. (Frances, Hunt, Cedar, French, Mazaska lakes)

Score the Shore

Minnesota's STS program helps people understand how healthy a lake's shoreline is. It looks at what the shoreline is like and gives it a score from 1 to 100, like a report card for the lake's edge. STS looks at small sections of shoreline and records things like plants (trees, grasses, and aquatic plants), developed areas (lawns, houses, retaining walls), docks/ boat access, and erosion (DNR, 2012).

- High score: mostly natural shoreline, lots of native plants, good habitat for fish and wildlife, better water quality protection.
- Medium score: some natural areas, some development, moderate protection for the lake.
- Low score: mostly lawns, hard shorelines of cleared vegetation, less habitat, more runoff and pollution reaching the lake.

Dock density

Dock density is used to evaluate the level of disturbance occurring along the shoreline of a lake. Dock densities exceeding 16 docks per mile (i.e. average spacing of 330 feet or less between docks) can negatively affect fish communities and habitat (Jacobson et al, 2016; Dustin and Vondracek, 2017) and during FIBI model development, dock density was found to be correlated with lower number of intolerant species (Bacigalupi, 2021).

Nonnative species

Nonnative species have the potential to alter physical habitat, including aquatic plant community structure, which indicates that various species including common carp, curly-leaf pondweed (CLP), Eurasian watermilfoil (EWM), flowering rush, and rusty crawfish are present in a majority of lakes within the Cannon River Watershed.

Biological community patterns

Fish communities in impaired and vulnerable lakes exhibited reduced representation of intolerant, insectivorous, small benthic-dwelling, vegetation-dwelling, and leuciscid species relative to comparable fully supporting lakes in the nearby Mississippi River-Twin Cities Watershed. Notably, several taxa that positively influence FIBI scores (e.g. brook silverside, spotfin shiner, rock bass, Iowa darter, tadpole madtom) were absent or rare, despite adequate sampling effort. These patterns suggest habitat degradation and nutrient-driven food web alterations rather than simple species loss due to sampling limitations (DNR, 2026).

Table 7. Summary of lake quality information for lakes studied in DNR Lake Stressor ID, 2026.

Lake	AQL Status	Nutrient Impairment	Watershed disturbance	Median/10 yr Mean TP (ug/L)	Watershed: Lake Area class	Watershed transport capacity	Water quality influence	Primary stressors	Unique findings/Prioritization
Tetonka	NS	Yes	73%	274	>10	7	L	Eutrophication, Habitat Alteration	Extremely high TP; large lakeshed control point; strong candidate for watershed BMP stacking
Volney	NS	Yes	78%	51.3	5-10	4	I	Eutrophication, Habitat Alteration	Highly disturbed watershed; shoreline and watershed actions both needed
Frances	NS	insufficient data	37%	--	<5	2	S	Eutrophication, Habitat Alteration	Low macrophyte diversity; shoreline-focused restoration likely high ROI
German	NS	Yes	54%	87.5	>10	7	L	Eutrophication, Habitat Alteration	Lakeshed-dominated; nutrient load reductions critical despite moderate STS
East Jefferson	NS	Yes	63%	107	>10	6	L	Eutrophication, Habitat Alteration	High dock density & nutrient impairment; strong candidate for combined BMPs
West Jefferson	NS	Yes	63%	99.5	>10	6	L	Eutrophication, Habitat Alteration	Joint implementation with East Jefferson
Roberds	NS	Yes	58%	255	>10	7	L	Eutrophication, Habitat Alteration	High TP and road density; priority for nutrient reductions
Fox	NS	Yes	66%	73	>10	7	L	Eutrophication, Habitat Alteration	Strong lakeshed signal; prioritize agricultural BMPs
Hunt	NS	Yes	55%	113	<5	1	S	Eutrophication, Habitat Alteration	Shoreline dominated nutrient response; buffer restoration likely effective
Cedar	NS	Yes	51%	87.5	5-10	4	I	Eutrophication, Habitat Alteration	Intermediate influence; phased shoreline and watershed approach

Lake	AQL Status	Nutrient Impairment	Watershed disturbance	Median/10 yr Mean TP (ug/L)	Watershed: Lake Area class	Watershed transport capacity	Water quality influence	Primary stressors	Unique findings/Prioritization
Shields	NS	Yes	60%	--	5-10	4	I	Eutrophication, Habitat Alteration	Strong aquatic plant community potential; habitat protection leverage
Clear	NS	Yes	65%	92	<5	1	S	Eutrophication, Habitat Alteration	Low FQI; shoreline restoration essential before watershed gains realized
French	IC-V	No	47%	--	<5	2	S	Eutrophication, Habitat Alteration	Near disturbance threshold; protection-focused funding opportunity
Mazaska	IC-V	Yes	51%	73.3	<5	2	S	Eutrophication, Habitat Alteration	Vulnerable but responsive; early intervention can prevent full impairment

Aquatic Life Status: NS = Nonsupport, IC-V = Inconclusive- Vulnerable;

Water Quality Influence: L = Lakeshed-driven, I = Intermediate (lakeshed & shoreline), S = Shoreline-driven

Primary identified stressors

Eutrophication (excess nutrients)

Eutrophication was identified as a primary stressor in 12 of the 14 impaired or vulnerable lakes. Ten year mean summer TP concentrations were elevated (mean ~117 ug/L; range 15-439 ug/L), and approximately 80% of assessed lakes were also impaired for AQR based on MPCA nutrient standards. Table 8 provides a summary of the sources, impacts, and recommendations for eutrophication stressor. Contributing watersheds were highly disturbed (mean ~53%; range 3% to 78%), with most exceeding the ~40% disturbed-land threshold associated with significant TP increases. Lakes exhibited varying watershed transport capacities, indicating that both watershed land use and shoreline development influence nutrient delivery, depending on individual lake hydrology. Additionally, widespread CLP dominance contributes to internal nutrient loading through mid-summer senescence, exacerbating seasonal eutrophication effects (DNR, 2026).

Table 8. Summary of sources and impacts of eutrophication stressor.

Element	Description
Stressor category	Eutrophication (nutrient enrichment)
Primary sources	Agricultural runoff, cultivated and pasture lands, urban stormwater, shoreline disturbance, septic systems, internal loading (CLP senescence)
Biological response	• Reduced intolerant and insectivorous fish species • Increased tolerant/omnivorous taxa • Simplified trophic structure • Declines in vegetation-dwelling and sight-feeding species
FIBI metric affected	decrease number and abundance of intolerant species decrease insectivore richness increase proportion of tolerant/omnivorous biomass
Supporting evidence	• Elevated TP concentrations (10 year means often > nutrient thresholds) • ≥40-78% watershed disturbance for most impaired lakes • Widespread nutrient impairments • Seasonal TP and chlorophyll-*a* increases linked to CLP die-off
Causal pathway	Watershed and internal nutrient loading lead to phytoplankton dominance, resulting in light limitation, macrophyte loss, habitat simplification, and fish community degradation
Implementation pathways	• Agricultural BMPs (cover crops, nutrient management, buffers, reduced-no till) • Urban stormwater BMPs • Watershed-scale load reductions • Internal load management (CLP control strategies)
Tracking & effectiveness measures	TP trends, chlorophyll-a, Secchi depth, FIBI reassessments, macrophyte recovery

Physical habitat alteration

Physical habitat alteration was identified as a second primary stressor. Table 9 provides a summary of the sources, impacts, and recommendations for physical habitat alteration stressor. Shoreline condition assessments using the DNR STS protocol indicated moderate overall habitat quality (mean score 69), below the statewide average. Approximately 72% of shoreline sites were developed, with reduced riparian vegetation, increased hard armoring, and aquatic plant removal. Aquatic plant survey results further documented degraded macrophyte community condition in several impaired lakes, consistent with loss of structurally complex habitat required by sensitive fish guilds (DNR, 2026).

Table 9. Summary of sources and impacts of physical habitat alteration stressor.

Element	Description
Stressor category	Physical habitat alteration
Primary sources	Shoreline development, riparian vegetation removal, aquatic plant removal, high dock density, invasive species (e.g., carp, EWM, CLP), altered hydrology
Biological response	• Loss of vegetation-dependent fish guilds • Reduced small benthic and nursery habitat • Lower fish community resilience
FIBI metric affected	decrease vegetation dwelling species decrease small benthic species decrease intolerant species richness
Supporting evidence	• Score the Shore ratings below statewide averages • Dock densities exceeding ecological thresholds (>16 docks/mile) • Low FQI in impaired lakes • Documented aquatic plant removal permits
Causal pathway	Shoreline alteration and plant removal result in a loss of structural habitat, reducing spawning and nursery areas and contributing to fish community simplification
Implementation pathways	• Shoreland restoration (native buffers, habitat complexity) • Aquatic plant management reform (protect native assemblages) • Dock and shoreland best practices • Carp and invasive species management
Tracking and effectiveness measures	Score the Shore, FQI, native littoral vegetation change, FIBI response

Secondary and inconclusive stressors

Other evaluated stressors – including altered interspecific competition, increased ionic strength, metal contamination, and pesticide application- were considered but lacked sufficient evidence to be identified as primary causes of impairment at the watershed scale. These stressors remain potential localized contributors but were classified as inconclusive under the weight of evidence framework (DNR, 2026).

Conclusions and management implications

The DNR SID analysis concludes that nutrient-driven eutrophication and physical habitat alteration are the dominant stressors limiting fish community integrity in the Cannon River Watershed lakes. The report recommends prioritizing watershed-scale nutrient reductions (e.g., agricultural BMPs, urban stormwater controls), shoreline protection and restoration (e.g., riparian buffers, reduced vegetation removal), and targeted aquatic plant management that supports native macrophyte recovery. Table 9 provides a summary of prioritization of stressors to be addressed in lakes assessed for AQL in the

Cannon River Watershed. Stressor prioritization varies by lake based on watershed transport capacity, supporting differentiated restoration and protection strategies across the watershed (DNR, 2026). Table 11 provides a tiered recommendation for addressing specific lakes in the Cannon River Watershed based on the information provided in this section.

Table 10. Prioritization of stressors to be addressed in lakes assessed for aquatic life in the Cannon River Watershed.

Priority by Stressor	
Primary	Eutrophication Physical habitat alteration
Secondary / Watch	Altered interspecific competition Increased ionic strength
Informational	Pesticides Metals (mercury)

Table 11. Prioritization of lake restoration for lakes assessed for aquatic life in the Cannon River Watershed.

Priority	Description	Lakes	Management
Tier 1	High TP, watershed disturbance, and transport capacity	Tetonka, Roberds, German, Fox, East & West Jefferson	Watershed driven nutrient reductions, agricultural and stormwater BMPS
Tier 2	Low watershed : lake ratios, shoreline dominated influence	Hunt, Clear, Frances, Mazaska, French	Shoreline focused restoration, shoreland buffers, native aquatic vegetation restoration
Tier 3	Intermediate transport capacity	Volney, Cedar, Shields	Hybrid/phased approach, pair shoreline actions with targeted watershed BMPs

Impaired Lakes – Restoration Priority

(Not supporting aquatic life – FIBI Impaired) (Figure 8)

Tetonka Lake (40-0031-00)

Lake Tetonka is impaired for AQL due to severe eutrophication and physical habitat alteration. The lake exhibits extremely elevated TP concentrations (10-year mean ~ 273.6 ug/L) and a highly disturbed contributing watershed (73%) with a high watershed transport capacity (Class 7) indicating strong lakeshed control on water quality. Restoration requires watershed-scale nutrient load reductions paired with habitat restoration to address internal loading and degraded fish community structure. The lake represents a high-priority investment for implementation due to its size, regional importance, and potential downstream benefits. (DNR, 2026)

Volney Lake (40-0033-00)

Volney Lake is impaired for AQL with high watershed disturbance (78%) and elevated nutrient concentrations. Intermediate watershed transport capacity (Class 4) indicates both shoreline and lakeshed sources contribute to impairment. Implementation focused on agricultural BMPs, shoreline buffers, and stormwater controls is necessary to reduce nutrient inputs and restore biological integrity (DNR, 2026).

Frances Lake (40-0057-00)

Frances Lake is biologically impaired with degraded fish and aquatic plant communities. Although nutrient impairment status is inconclusive, shoreline dominated influence (transport capacity Class 2) and poor macrophyte diversity indicate physical habitat alteration as a primary stressor. Shoreland restoration and aquatic habitat enhancement represents cost-effective strategies with high likelihood of biological response (DNR, 2026).

German Lake (40-0063-00)

German Lake's fish community is impaired by eutrophication driven by a moderately to highly disturbed watershed (54%) and high watershed transport capacity (Class 7). Nutrient concentrations exceed levels protective of AQL, indicating the need for watershed-scale load reductions. Restoration funding should support agricultural BMPs and complementary in-lake habitat improvements (DNR, 2026).

East Jefferson Lake (40-0092-01)

East Jefferson Lake is impaired for AQL with elevated nutrient concentrations and high watershed disturbance (65%). High watershed transport capacity (Class 6) indicates lakeshed land use is the dominant driver of impairment. Coordinated nutrient reduction strategies are needed to restore fish community integrity (DNR, 2026).

West Jefferson Lake (40-0092-02)

West Jefferson Lake exhibits similar impairment patterns to East Jefferson lake, including nutrient enrichment and habitat alteration driven by a highly disturbed watershed (63%) and high transport capacity. Joint restoration efforts across both basins provide an efficient and defensible implementation strategy (DNR, 2026).

Roberds Lake (66-0018-00)

Roberds Lake is impaired due to severe eutrophication (10 year mean TP ~254.9 ug/L) and high watershed disturbance (58%), with a high watershed transport capacity (Class 7). Coordinated nutrient reduction strategies are needed to restore fish community integrity (DNR, 2026).

Fox Lake (66-0029-00)

Fox Lake is impaired for AQL due to eutrophication driven by extensive watershed disturbance (66%) and strong lakeshed influence (Class 7). Nutrient reductions through agricultural BMP implementation are critical to restoring biological condition (DNR, 2026).

Hunt Lake (66-0047-00)

Hunt Lake is impaired with elevated nutrient concentrations (~113 ug/L TP) and shoreline dominated influence (Class 1). Shoreline restoration, buffer establishment, and aquatic vegetation recovery are priority actions to yield biological improvement (DNR, 2026).

Cedar Lake (66-0052-00)

Cedar Lake is impaired by nutrient enrichment and habitat alteration with intermediate watershed transport capacity (Class 4). Both shoreline and watershed actions are necessary to reduce nutrient inputs and improve fish community structure (DNR, 2026).

Shields Lake (66-0055-00)

Shields Lake is impaired for AQL with elevated watershed disturbance (60%) and intermediate transport capacity. Despite relatively stronger aquatic plant communities compared to other impaired lakes, nutrient and habitat stressors persist. Protection of existing habitat combined with targeted nutrient reduction is recommended (DNR, 2026).

Clear Lake (81-0014-01)

Clear Lake is impaired for AQL with elevated nutrient concentrations (~92 ug/L TP) and shoreline dominated influence (Class 1). Low aquatic plant diversity indicates habitat limitation. Shoreline restoration and aquatic vegetation recovery are necessary prerequisites for broader water quality improvement (DNR, 2026).

Vulnerable Lakes – Protection & Early Intervention

(Inconclusive information – vulnerable) (Figure 9)

French Lake (66-0038-00)

French Lake is vulnerable to future AQL impairment, with watershed disturbance near the 40% threshold associated with elevated nutrient concentrations. Shoreline dominated influence suggests early protection actions, including shoreland restoration and nutrient input prevention, can prevent progression to full impairment (DNR, 2026).

Mazaska Lake (66-0039-00)

Mazaska Lake shows early signs of eutrophication stress with nutrient impairment present and moderate watershed disturbance (51%). Shoreline dominated influence indicates that targeted shoreline and near lake BMPs can effectively protect AQL. Early intervention represents a cost-effective opportunity to prevent long-term impairment (DNR, 2026).

Fully Supporting Lakes – Protection Priority

(Fully supporting aquatic life – Prevent Degradation) (Figure 8)

The importance of protecting high-quality lakes in the Cannon River Watershed was first identified in the Cycle 1 Monitoring and Assessment Report (MPCA, 2014) and discussed again in the 2016 WRAPS Report (MPCA, 2016). While many lakes in the watershed are highly eutrophic, Roemhildts, Fish, Dudley, Kelly, and Beaver lakes were recognized as exceptional recreational and ecological resources due to their relatively intact watersheds and favorable lake depth characteristics. These lakes continue to be identified as protection priorities here and in the Cannon CWMP, emphasizing the ongoing need for proactive strategies to preserve their high water quality and biological integrity.

Fish Lake (40-0051-00)

Fish Lake currently supports AQL but shows exposure to physical habitat stressors, including shoreline development and invasive species presence. Protection-focused funding can help maintain high biological integrity through shoreline best practices and habitat preservation (DNR, 2026).

Rays Lake (40-0056-00)

Rays Lake is fully supporting AQL but exhibits substantial shoreline development. Proactive shoreline restoration and invasive species management will protect existing biological conditions and prevent future degradation (DNR, 2026).

Roemhildts Lake (40-0039-00)

Roemhildts Lake supports life and is primarily shoreline influenced. Protection strategies focused on shoreland buffers and vegetation management are appropriate to maintain water quality and biological integrity (DNR, 2026).

Kelly and Dudley Lakes (66-0014-00 & 66-0015-00)

Kelly and Dudley Lakes remain fully supporting but have moderate watershed disturbance. Protection funding will preserve existing habitat quality and prevent nutrient driven degradation (DNR, 2026).

Beaver Lake (74-0023-00)

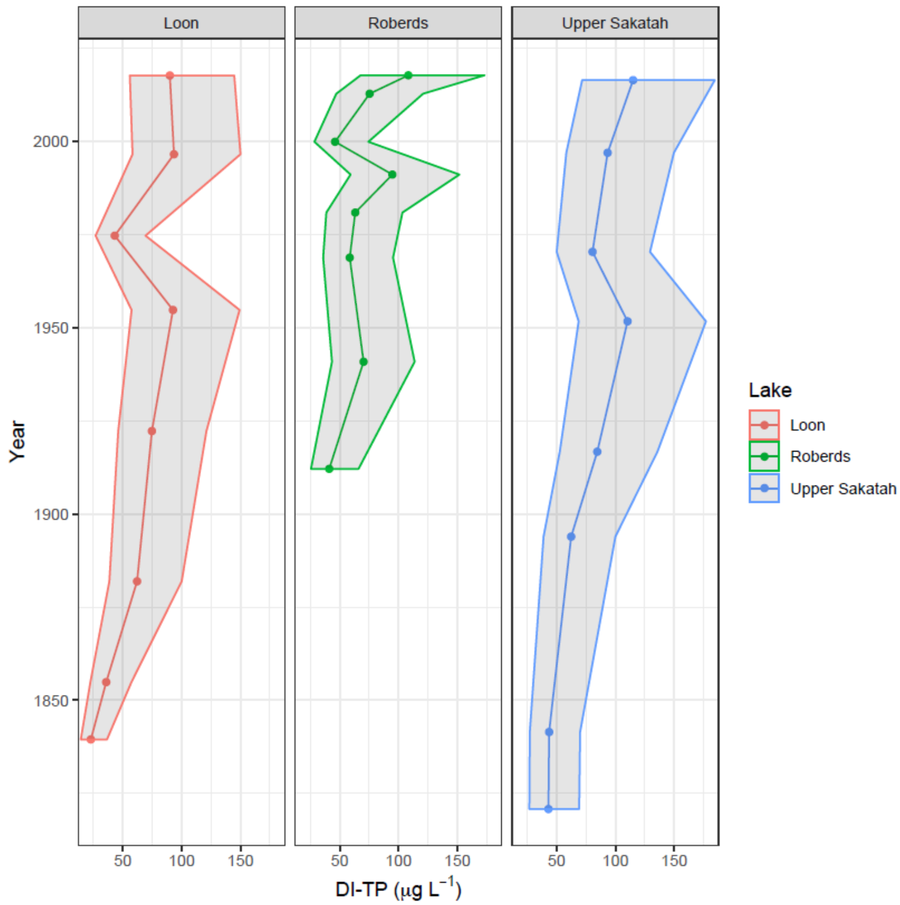
Beaver Lake supports AQL despite extensive shoreline development. Strategic habitat protection and shoreline restoration are needed to prevent future impairment (DNR, 2026).

4.2 Paleolimnological study of phosphorus-impaired lakes in the Cannon River Watershed

In response to requests made by LGUs in the Cannon River Watershed for more detailed P loading in the watershed's lakes to help focus funding for restoration, a study was completed in 2019 by the St. Croix Watershed Research Station on the paleolimnology of P -impaired lakes in the Cannon River Watershed. The study evaluated 16 P-impaired lakes using sediment cores and mass balance modeling to reconstruct historical conditions and assess current nutrient dynamics. Across all lake systems, the findings indicate a consistent trajectory of eutrophication driven by watershed disturbance and increased nutrient loading (Engstrom et al, 2019).

Prior to European settlement (pre-1850), most lakes in the study area existed in relatively low-nutrient states, typically mesotrophic and, in many cases, dominated by submerged aquatic vegetation. These conditions reflect limited external nutrient inputs and strong internal processing capacity. Sediment records, Figure 9, confirm that P loading has increased substantially since that time, with modern loading rates estimated at approximately six to ten times higher than pre-settlement levels. These P concentrations were reconstructed from fossil diatom assemblages in the sediment cores collected from the study lakes. Correspondingly, current lake conditions are predominantly eutrophic to hypereutrophic, with elevated P concentrations, reduced water clarity, and, in many cases, a shift toward phytoplankton dominated systems.

Figure 9. Lake TP concentrations reconstructed from fossil diatom assemblages (Engstrom et al, 2019).



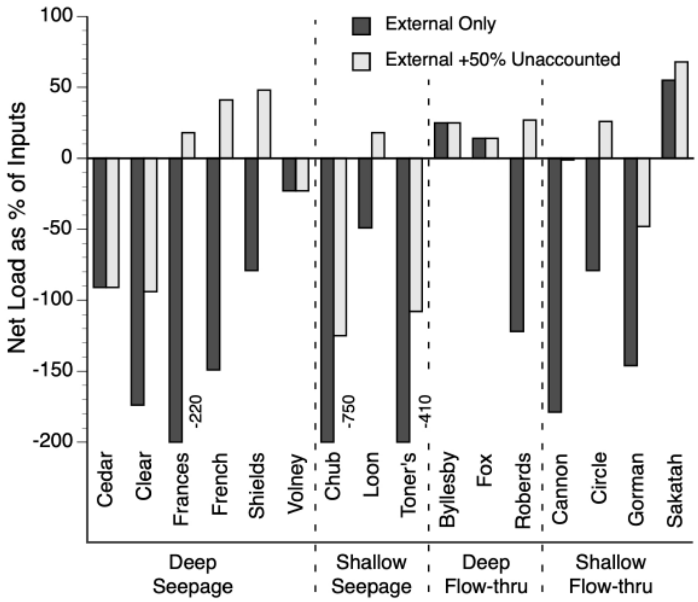
A key conclusion of the study is that lake response to nutrient enrichment – and therefore recovery potential – is strongly governed by lake type, particularly hydrologic setting (seepage vs. flow-through) and depth (deep vs. shallow). These factors influence residence time, internal nutrient cycling, and the relative importance of external versus internal loading.

Deep seepage lakes (Cedar, Clear, Frances, French, Shields, Volney) generally exhibit lower external loading and longer residence times, allowing for greater P retention through sediment burial. Several of these lakes currently demonstrate negative P mass balances, indicating that they are acting as net sinks of P. These systems retain some capacity for recovery, particularly where external loading is controlled. However, lakes such as French and Shields show evidence of internal loading, suggesting that recovery may be constrained without additional in-lake management.

Shallow seepage lakes (Chub, Loon, Toner's) show a different dynamic. While they also lack strong watershed inflows, their shallow depths promote sediment resuspension and internal P release. These lakes are now strongly influenced by internal loading, and reductions in external inputs alone are unlikely to produce rapid improvements. Restoration will likely require active management of internal P sources.

Flow-through lakes, both deep (Byllesby, Fox, Roberds) and shallow (Cannon, Circle, Gorman, Upper Sakatah), are dominated by watershed inputs and hydrologic transport. As shown in Figure 11, These systems typically exhibit positive P mass balances, indicating that inputs exceed losses. Water quality in these lakes is closely tied to upstream conditions and current-year loading, rather than long-term sediment storage. As a result, they are the most difficult to restore. Substantial reductions in watershed P inputs are required before meaningful in-lake improvements can be expected, and internal management strategies are generally less effective due to shorter residence times and frequent flushing.

Figure 10. Net P mass-balance as a percentage of total-P inputs - external load only or external + 50% of unaccounted load (Engstrom et al, 2019).



Across all lake types, the study demonstrates that achieving TMDL targets – requiring P reductions ranging from approximately 32% to 96% - would shift most lakes toward negative P mass balance conditions. However, the degree and timing of recovery will vary significantly depending on lake-specific characteristics. Seepage lakes are expected to respond more directly to load reductions, while flow-through systems will require larger and more sustained watershed-scale interventions.

Overall, the findings emphasize that restoration strategies must be tailored to lake type and dominant nutrient pathways. While external loading reductions are necessary across all systems, internal loading and hydrologic transport processes play a decisive role in determining outcomes. Effective management will require a combination of watershed-based nutrient reduction and, in some cases, targeted in-lake interventions.

4.3 Watershed Stream Stressor Identification and Pollutant Sources

The initial Cannon River Watershed SID Study was completed on streams with biological impairments and to determine chemical or physical stressors causing those biological impairments (MPCA, 2015). The 2024-2026 updates (MPCA, 2024b, 2025a, 2025b, 2025d, 2026) were investigations into priority subwatersheds identified by the local government units in the Cannon River Watershed Comprehensive Management Plan (CRWJPO, 2020). The Cannon River SID Report (Cycle 1) functions as a summary of stressors for the watershed based on region-wide data and biological assessments. The subwatershed SID updates represent focused work at the direction of the local water planning group (Cannon River Watershed Joint Powers Organization [CRWJPO]) and provide a closer look at both local stressors and pollutant sources. Nutrients, especially nitrate, and physical stressors (habitat and flow alteration) show the strongest and most consistent alignment from the watershed to subwatershed scale.

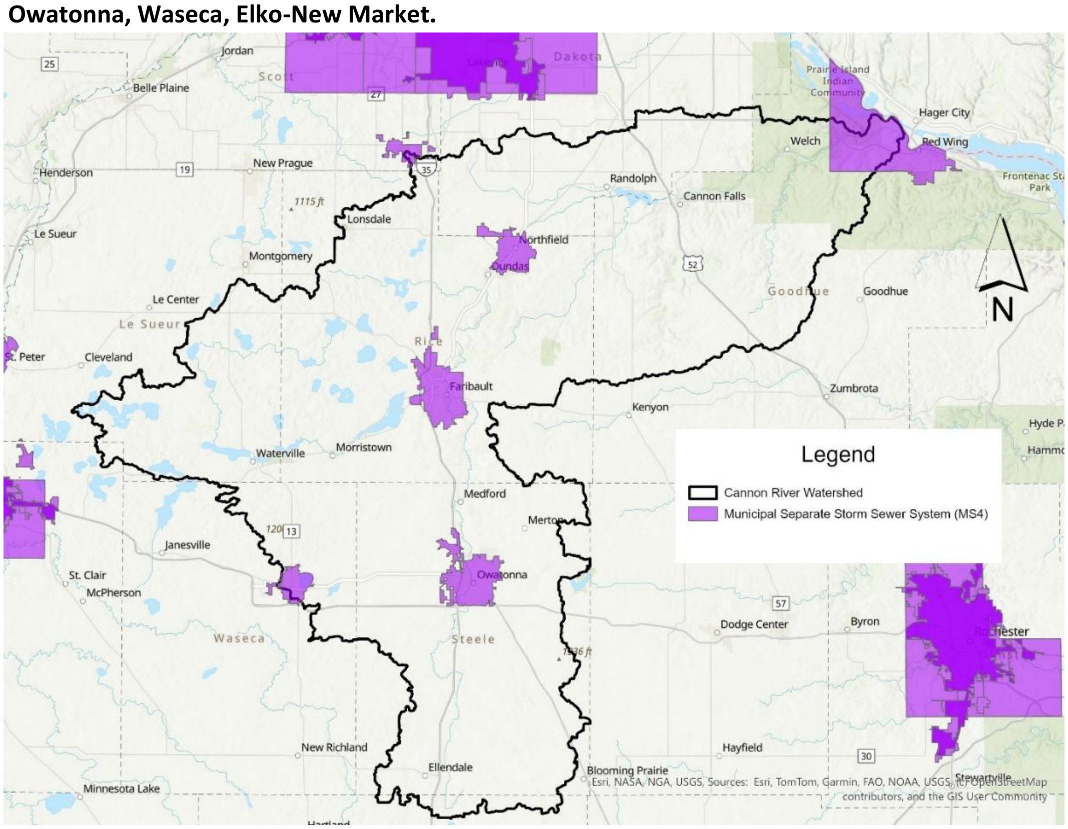
Overall, the SID updates identified nitrate focus areas in the Upper Straight River and Upper Medford Creek, habitat/flow restoration work needed in Belle Creek headwaters, Crane Creek near Moonan Marsh, and mid-lower Medford Creek. Rush Creek and the mainstem of Belle Creek were identified as protection priorities.

Major pollutant sources include those defined as nonpoint or diffuse sources and point or permitted sources, these are detailed more extensively in the 2016 WRAPS (MPCA, 2016) and TMDL (MPCA, 2017) reports.

Point/Permitted sources include:

- Wastewater Treatment Facilities (WWTF)
    - Municipal and industrial wastewater discharges contribute P and other nutrients to streams and rivers within the watershed
    - These facilities receive wasteload allocations (WLA) under the TMDL framework to limit their pollutant loading
- Regulated Stormwater (MS4)
    - MS4 in developed areas carry runoff loads to surface waters and are regulated under stormwater permits (Figure 11).

Figure 11. MS4 regulated communities in the Cannon River Watershed; Red Wing, Northfield, Faribault, Owatonna, Waseca, Elko-New Market.



Nonpoint/Diffuse sources include:

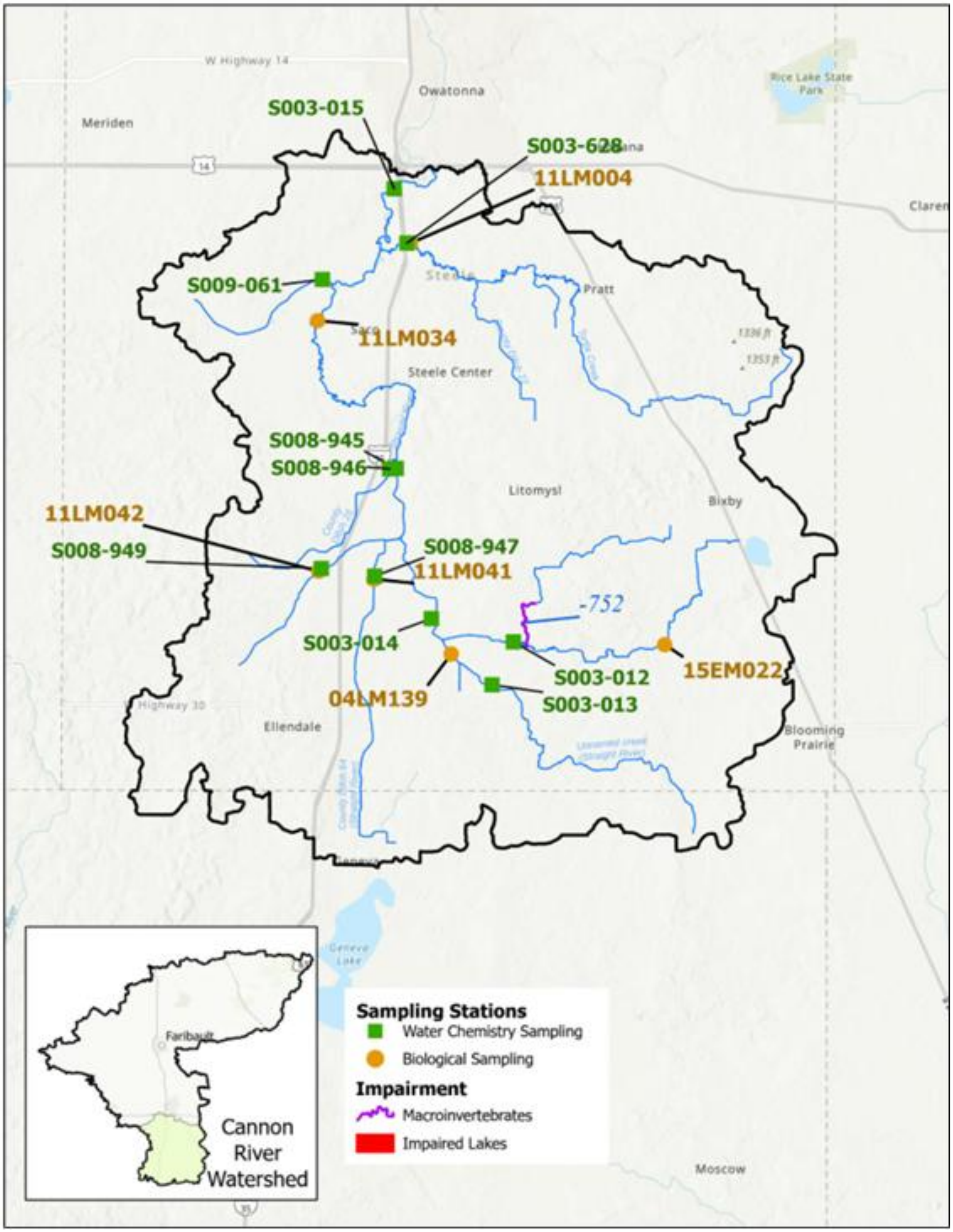
- Agricultural (Cropland)
    - Cropland is a dominant contributor of P, nitrate, and sediment to surface water
    - Sediment and attached P erode from fields during rain events
    - Tile drainage in cropland plays a key role in transporting nitrate to streams and groundwater, especially in porous karst areas common in the lower parts of the watershed
- Streambank and near-channel erosion
    - Banks erode during high flows, contributing sediment and attached P loads
- Urban stormwater (not regulated as MS4)
    - Urban areas that don't meet the definition to be included in the MS4 program contribute to nutrient and sediment loads, especially from stormwater carrying fertilizers, soil, pet waste, and other urban surface particles
- Atmospheric deposition
    - Particles and nutrients deposited from the air contribute nutrient loading across the watershed landscape

4.3.1 Key findings for the Straight River – nitrate reduction

(SID Update - Straight River Watershed Nitrate Summary, MPCA, 2024b)

Nitrate concentrations in the warmwater, largely tiled drainages of the Straight River Watershed, Figure 12, vary significantly with precipitation and are moderate to elevated, ranging from 0.2 to 13 mg/L (average 3.9 mg/L). Macroinvertebrate communities show an abundance of nitrate-tolerant species, which is consistent with the elevated nitrate levels. Tile drainage underlying widespread agricultural land use is the primary pathway for N delivery to streams. Higher nitrate concentrations were observed in spring/early summer influenced by precipitation patterns. The upper Straight River area is a priority for N reduction efforts within the watershed. These findings complement broader watershed reports (e.g. Cannon River WRAPS and CWMPs) by providing fine-scale local data for targeting practices like cover crops, nutrient management, and drainage management.

Figure 12. Biological and water chemistry sampling stations in the Upper Straight River (MPCA, 2024b).



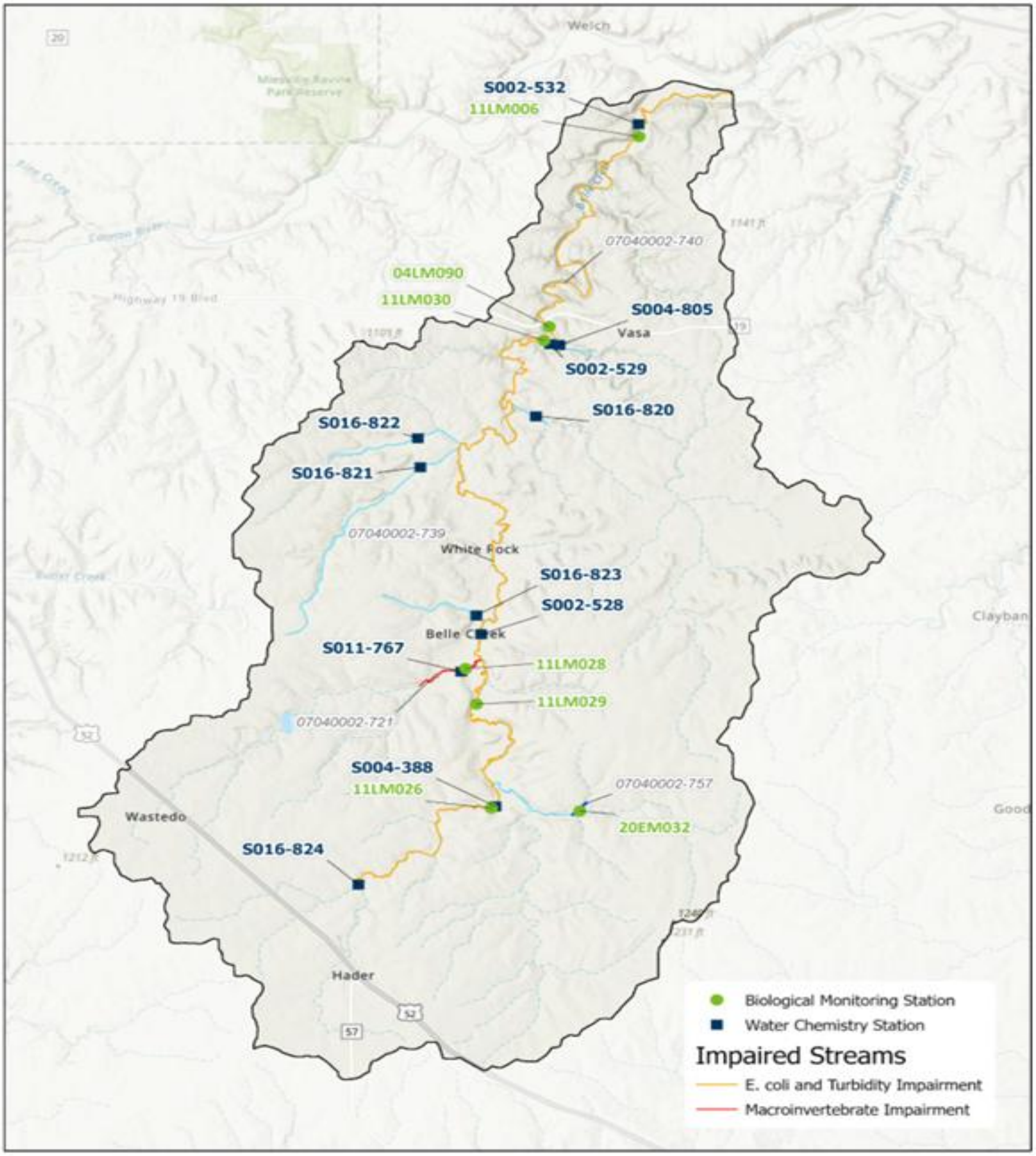
The highest priority for nitrate reduction needed is in the Upper Straight River Headwaters. There is a significant amount of tile-drained cropland present and this subwatershed exhibited the highest nitrate concentrations. Additionally, macroinvertebrate data indicate the presence of many nitrate tolerant species. The Middle/Lower Straight River is a moderate priority as elevated nitrate concentrations persist, although the biological condition is somewhat improved. N reduction practices are needed in the Upper Straight River with targeted BMP placement, rather than a watershed-wide general approach.

4.3.2 Key findings for Belle Creek – protect healthy reaches

(SID Update - Belle Creek Watershed, MPCA, 2025a)

No biological impairments had been previously identified in Belle Creek Watershed (Figure 14); therefore, no SID was previously completed. Overall, the biological communities of Belle Creek are healthy. Potential stressors identified are habitat and flow alteration. One small headwater tributary indicates the only impairment (macroinvertebrate community); the mainstem is functioning well and needs protection. Protecting the current biological condition should be prioritized along with restoration of the impaired reaches, using the 2025 Belle Creek Subwatershed report to refine planning and prioritize where habitat improvements matter most. Focus should be given to addressing localized habitat/flow problems in the headwaters and activities that degrade high quality downstream reaches should be avoided. According to the SID Update (MPCA, 2025a), in general, nutrient and sediment concentrations were lower downstream of the flood control structures. Flood control structures throughout the Belle Creek Watershed help store water and pollutants in headwater areas, reducing downstream nitrate, P, sediment, and peak flows during runoff events. Maintaining these structures will remain important for supporting healthy fish and macroinvertebrate communities.

Figure 13. Belle Creek Subwatershed monitoring stations and impairments, Belle Creek Watershed SID Update, 2025.



4.3.3 Key findings for Crane Creek – marsh influence

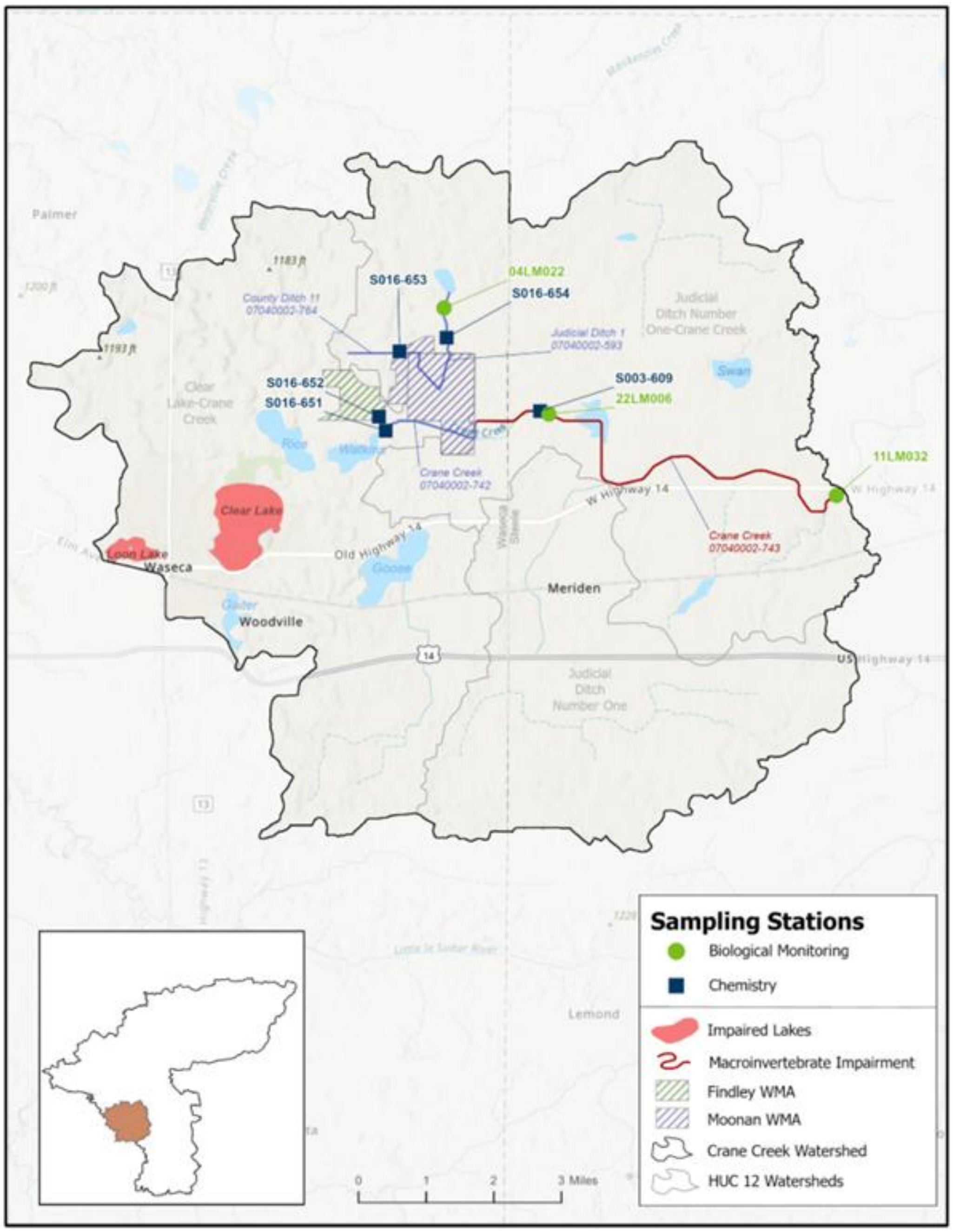
(SID Update - Crane Creek Watershed, MPCA, 2025b)

The 2025 subwatershed study was conducted on the upper portion of the Crane Creek Subwatershed (Figure 14), in the Moonan Marsh area. Biological monitoring indicates mixed conditions – some reaches are impaired, and others are healthy. Eutrophication, low dissolved oxygen (DO), habitat degradation and flow alteration were identified as stressors. Nitrate was inconclusive and TSS was generally not a stressor, likely due to marsh and wetland processes that buffer sediments. This is a distinct finding in the

Crane Creek Subwatershed; the nuance reflects site-specific processes related to marsh influence. Moonan Marsh appears to act as a natural treatment zone and influences downstream water quality and hydrology, so is emphasized for restoration and conservation focus.

Moonan Marsh is a control point affecting downstream water quality, nutrient processing and sediment moderation occur here, but low DO and altered flow remain issues. Nutrient inputs upstream of the marsh should be reduced and more natural flow regimes should be restored to protect the wetland and marsh, as well as downstream waters.

Figure 14. Crane Creek Subwatershed monitoring stations and biological impairments (Crane Creek SID Update, 2025).



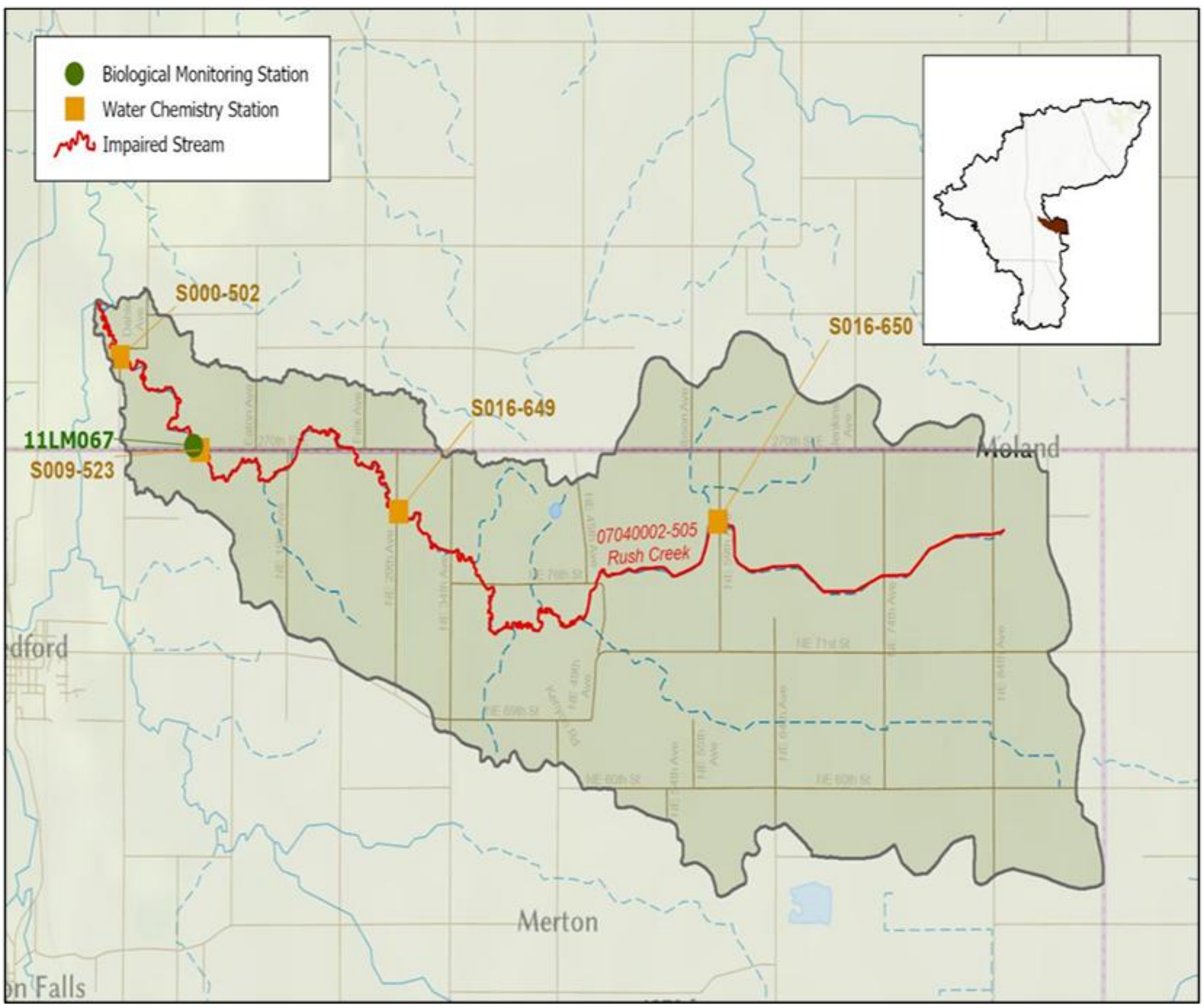
4.3.4 Key findings of Rush Creek – protection focus

(SID Update - Rush Creek Watershed, MPCA, 2025d)

Rush Creek also lacked biological impairments in Cycle 1 and the biological community remained healthy in Cycle 2. As such, no biological stressors were identified, though nutrient and sediment reductions remain important to protect the condition. As shown in Figure 15, Rush Creek has an AQL impairment of excess turbidity (listed in 2006) and an AQR impairment for fecal coliform bacteria (listed in 2002). Some elevated nitrate concentrations have been documented, but these are not currently driving any impairments. Habitat remains generally supportive, though fine substrate and bank erosion are present. Flow data indicate periodic no-flow conditions, which can affect habitat and fish passage episodically.

Local managers should focus on maintaining and protecting the currently healthy conditions. To prevent emerging stressors, monitoring nutrient and sediment trends and habitat quality should continue. Riparian buffers should be maintained along with the employment of other BMPs that prevent increases in nutrients and sediment reaching the stream. Additionally, fish passage opportunities should be investigated given some limited connectivity noted during low flows. This is an uncommon example of a nonimpaired stream, and it is easier and less costly to protect a stream than it is to restore later.

Figure 15. Rush Creek Subwatershed monitoring stations (MPCA, 2025d).

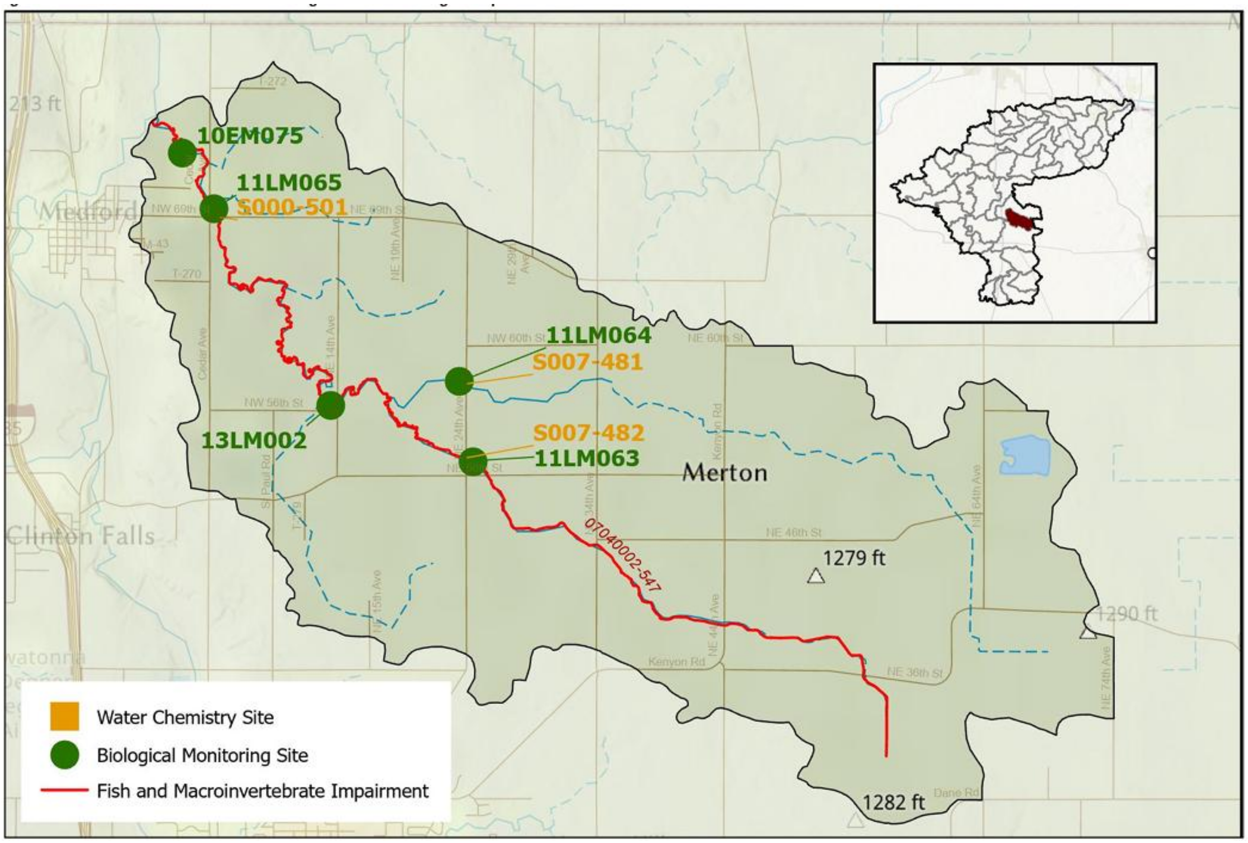


4.3.5 Key findings for Medford Creek – restoration focus

(SID Update - Medford Creek Watershed, MPCA, 2026)

The initial SID work in the watershed described nitrate and habitat as key stressors in Medford Creek, and the 2026 update confirmed these are still key stressors (Figure 16). Additionally, fish passage and flow alteration are newly confirmed stressors. The upper portion of Medford Creek stands out as a high-priority area for N reduction efforts; nitrate concentrations were consistently elevated across monitoring stations due to upstream cultivated fields and tile drainage. There are signs of habitat degradation in Upper Medford Creek. The Middle and Lower portions of Medford Creek exhibit fish passage barriers altered flows, and embedded substrate. Habitat work should target embeddedness and fine sediment impacts, as well as address flow alteration and fish passage connectivity issues. Implementation should focus on N reduction upstream, culvert/barrier assessment and replacement, and flow/habitat restoration.

Figure 16. Medford Creek Subwatershed monitoring stations and biological impairments (MPCA, 2026).



5. Water Quality Trends

5.1 Flowing Forward

The MPCA's 2025 "*Flowing Forward: Trends in Minnesota's lakes and rivers*" (https://www.pca.state.mn.us/sites/default/files/wq-ws1-42.pdf) report provides a comparison of river and stream biological conditions and nutrient and sediment conditions. The comparison of river and stream biological conditions looked at Fish IBI scores at 702 monitoring stations across 37 major watershed and Macroinvertebrate IBI scores at 676 stations (MPCA, 2025c).

Looking specifically at the Cannon River Watershed, the comparison of river and stream fish and macroinvertebrate community conditions between IWM Cycle 1 and IWM Cycle 2 shows improved conditions (Figure 17 and Figure 19). In this analysis, improved means there is a statistically significant increase in average F-IBI and M-IBI scores in Cycle 2. These results are consistent with findings from the Cannon River Watershed Assessment and Trends Update (MPCA, 2025c), which documented improving conditions in several stream reaches and mainstem river segments (Table 12).They are also supported by the stream water clarity trends discussed in Section 5.4, where many monitoring sites show improving transparency, suggesting reductions in sediment and other pollutants that can negatively affect aquatic habitat and biological communities.

Table 12. Percentage of assessed water bodies supporting beneficial uses in Cannon River Watershed.

Assessment type	Assessed water bodies supporting beneficial uses in Cannon R Watershed
Stream Aquatic Life Use – Fish, Invertebrates, Chemistry	33%
Lake Aquatic Life Use – Fish	29%
Lake Aquatic Recreation Use – Eutrophication	16%
Stream Aquatic Recreation Use – *E. coli* bacteria	8%

Figure 17. Comparison of river and stream macroinvertebrate community condition between IWM Cycle 1 and Cycle 2 (MPCA, 2025c).

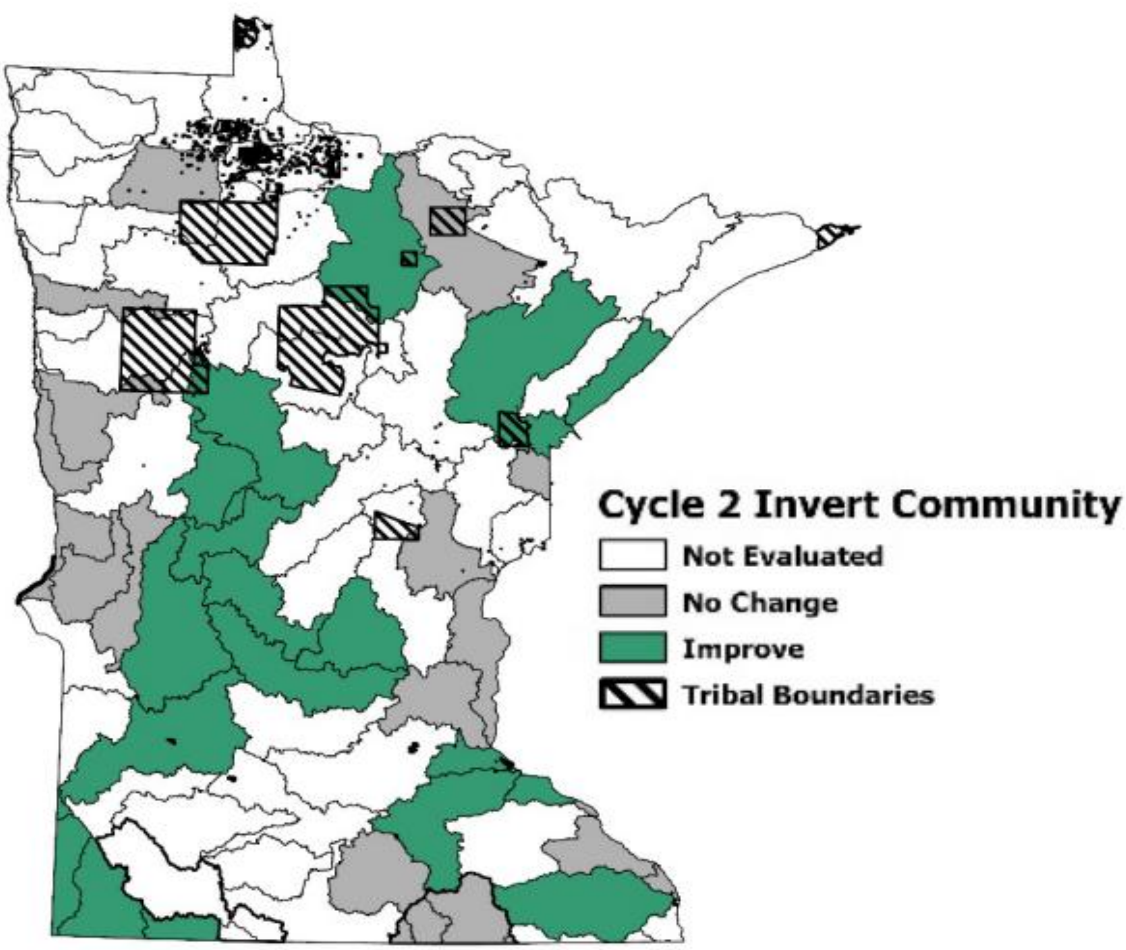
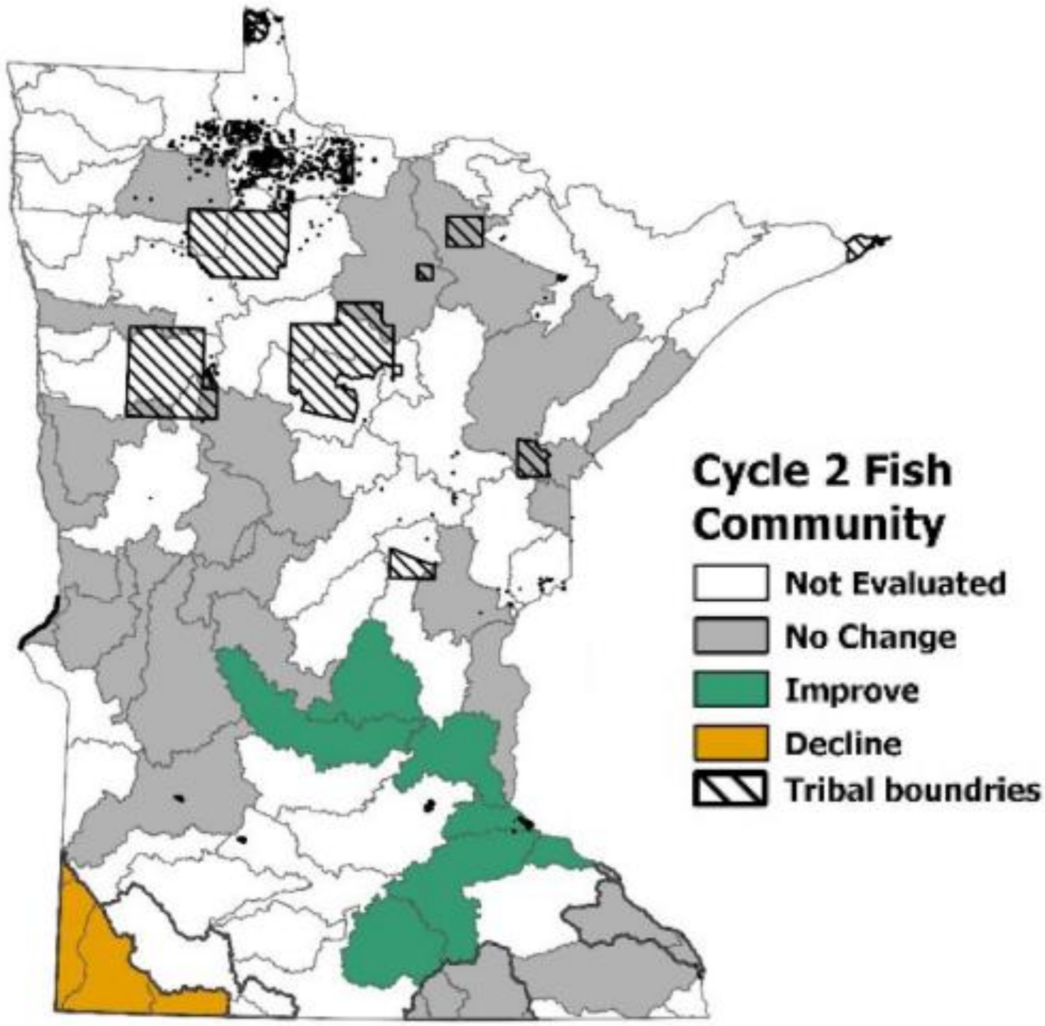


Figure 18. Comparison of river and stream fish community condition between IWM Cycle 1 and Cycle 2 (MPCA, 2025c).



5.2 Watershed pollutant load monitoring - streams

The Watershed Pollutant Load Monitoring Network (WPLMN) is a network of partners and MPCA staff that collect data to understand long-term trends and observe changes over time. Operating since 2007, the MPCA personnel and partners collect 18 to 25 samples per season at almost 200 sites in Minnesota. Subwatershed sites are sampled from spring ice-out to October 31 while other sites are sampled year-round.

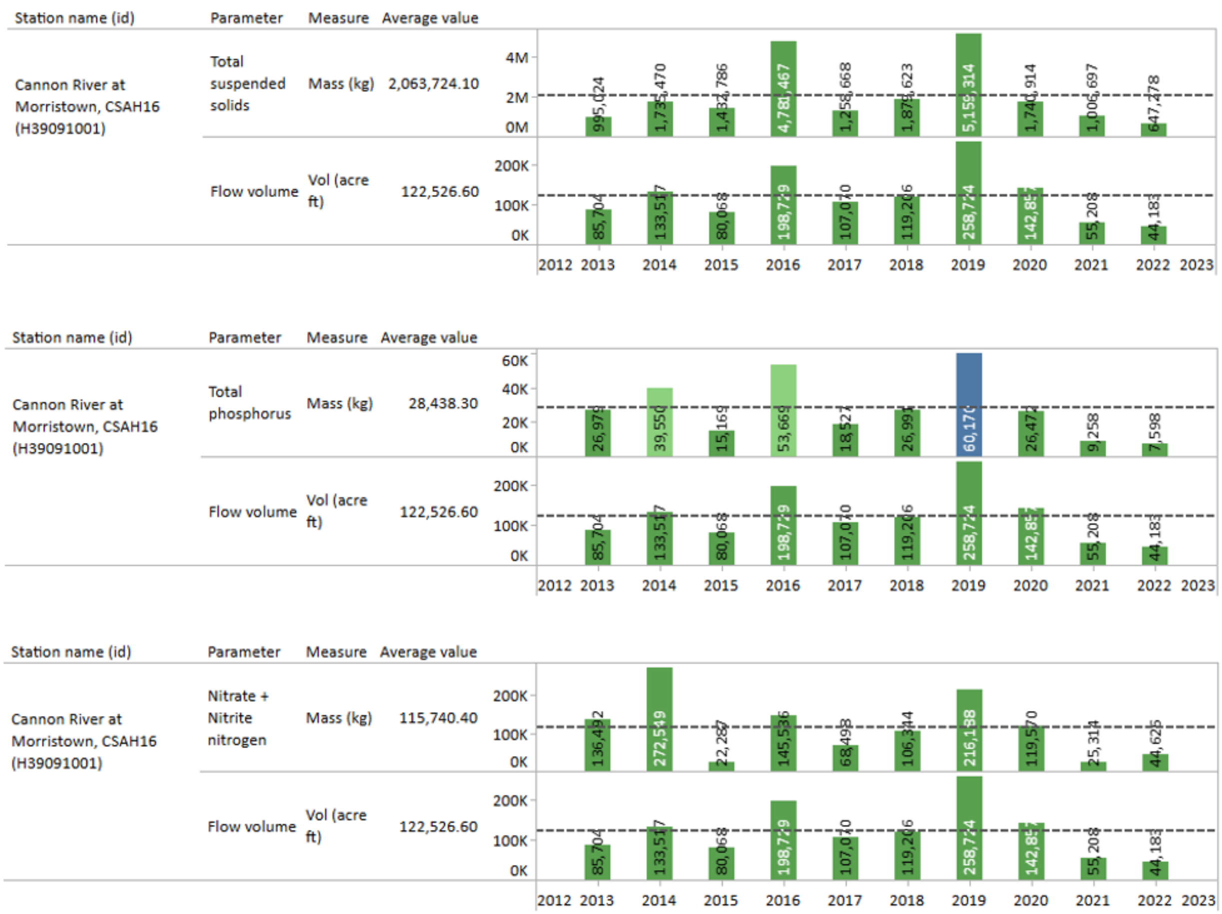
A pollutant load is the amount of a pollutant that passes a monitoring station over a period of time. Data is collected for a standard set of key pollutants, including suspended solids, nitrates, and P. Each monitoring site is equipped with a datalogger that tracks water levels and precipitation. Data are available through the WPLMN Data Viewer.

Table 13. WPLMN stations in Cannon River Watershed.

WPLMN station name	Site ID
Cannon River at Welch, MN	E39004002
Cannon River nr Waterford, Canada Ave	W39019001
Cannon River at Morristown, CSAH16	H39091001
Straight River nr Faribault, MN	E39101001

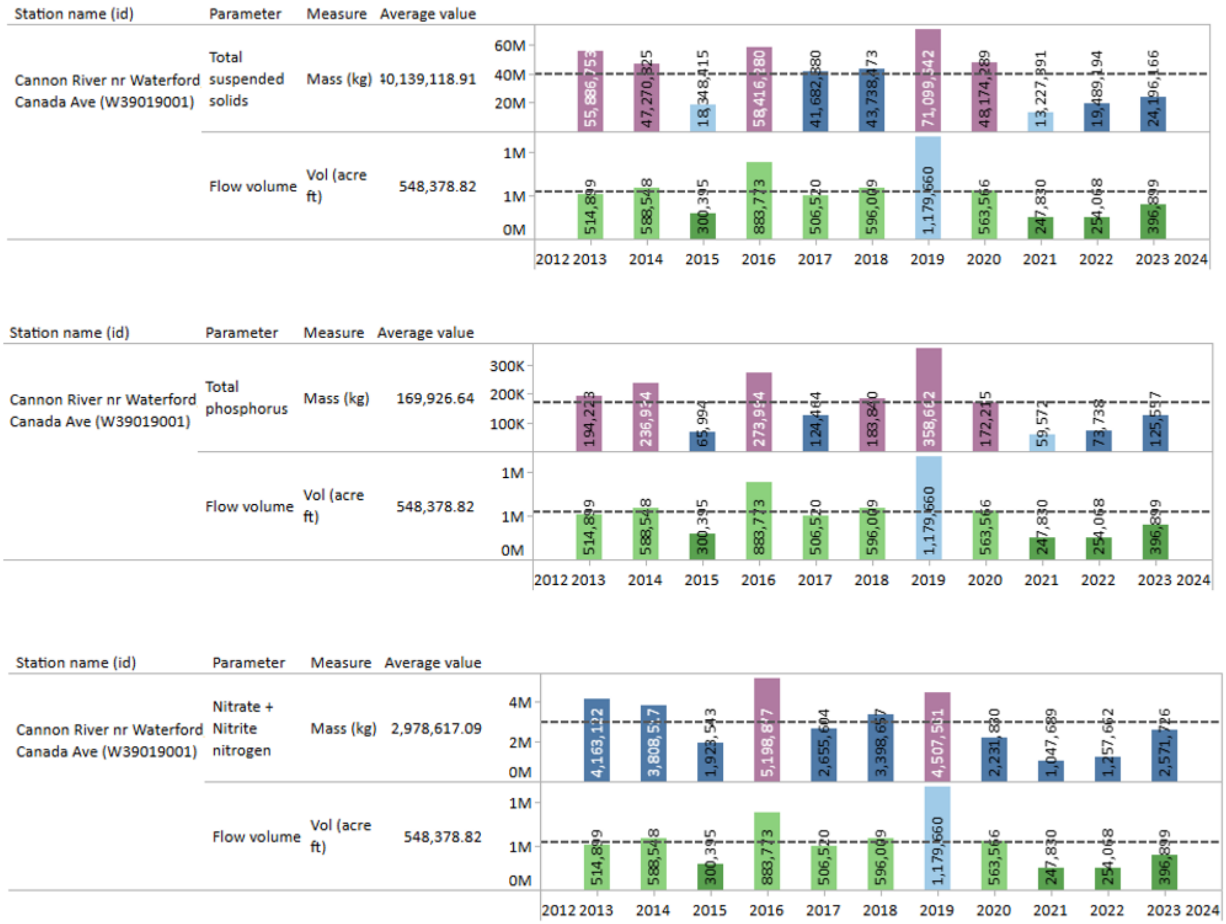
There are four load monitoring stations in the Cannon River Watershed (Table 13); three of these WPLMN sites have sufficient data for trend analysis: Cannon River at Welch (METC), Cannon River at Morristown, and Cannon River near Waterford. Trend analysis was completed on all parameters, TSS, TP, and N, and no significant trend was found at these sites (Figure 19 and Figure 20).

Figure 19. Annual loads of TSS, TP, and Nitrate (kg) along with annual flow volume (acre ft) at Cannon River WPLMN site at Morristown, MN (MPCA WPLMN Data Viewer).



***Colors indicate pollutant mass categories; classification thresholds differ among parameters and are based on the distribution of values for each pollutant at each site.**

Figure 20. Annual loads of TSS, TP, and Nitrate (kg) along with annual flow volume (acre ft) at Cannon River WPLMN site near Waterford, MN (MPCA WPLMN Data Viewer).



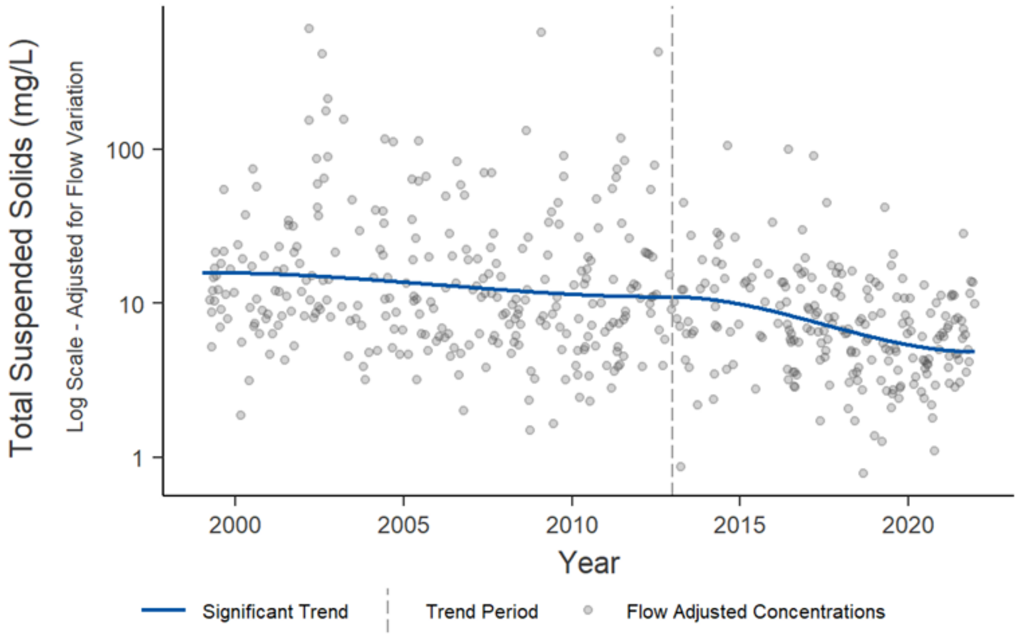
***Colors indicate pollutant mass categories; classification thresholds differ among parameters and are based on the distribution of values for each pollutant at each site**

5.3 Metropolitan Council Cannon River Pollutant Trend Update

The Metropolitan Council monitors water quality at an additional site on the Cannon River, near County Road 46 and Highway 61 in Vasa Township. Monitoring at this location started in 1999, with flow monitoring at nearby Welch station. Trend analysis was performed using the United States Geological Survey (USGS) R-QWTREND package. This is a statistical model specifically designed to investigate pollutant trends, which tests potential trends (increase or decrease in concentration) against a no-trend model. The model is designed to investigate trends in flow-adjusted concentrations by removing the variability of annual flow and seasonality from the statistical analysis. The resulting trend line shows how pollutant concentrations have changed over time due to factors in the stream or watershed, other than flow (Metropolitan Council, 2023).

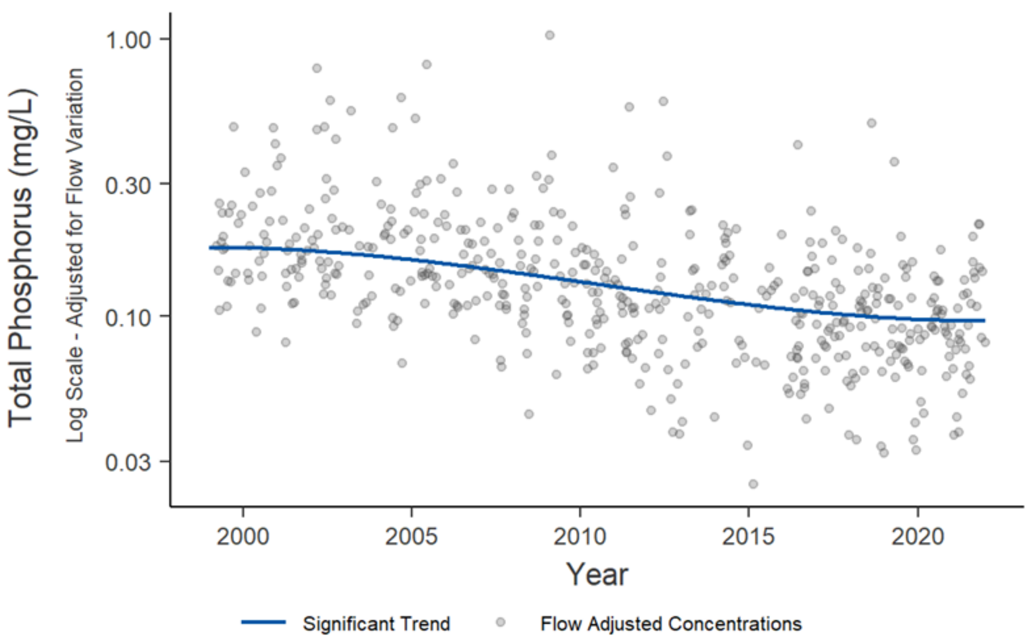
TSS trend was calculated using data from 1999-2021 and shows a statistically significant, steadily decreasing trend (Figure 21).

Figure 21. TSS (mg/L) data and trend line at Met. Council station on Cannon River in Vasa Township, 1991-2021 (Metropolitan Council, 2023).



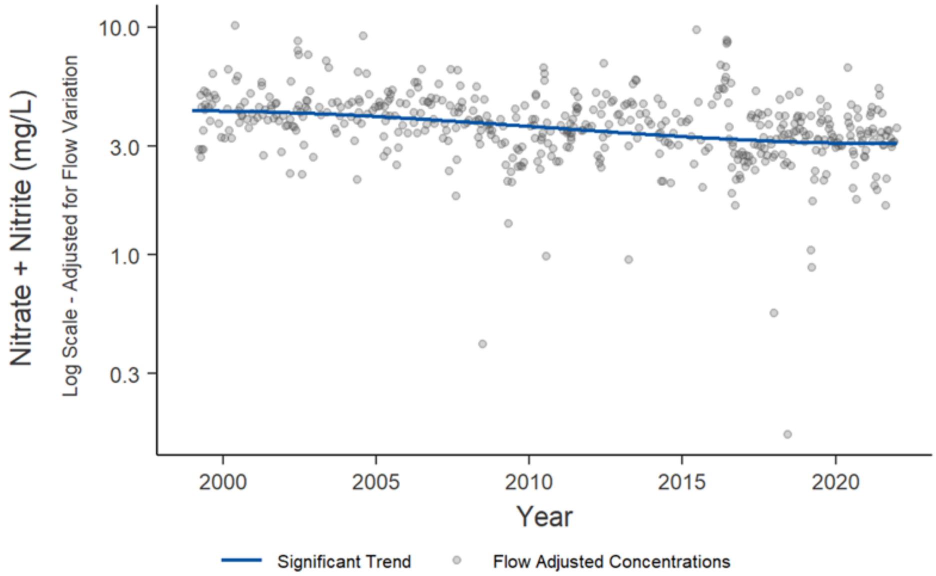
The TP trend was calculated using data from 1999-2021 and shows a statistically significant decreasing trend (Figure 22).

Figure 22. TP (mg/L) data and trend line at Met. Council station on Cannon River in Vasa Township, 1991-2021 (Metropolitan Council, 2023).



A nitrate+ nitrite trend was calculated also using data from 1999-2021 and shows a decreasing trend over that time period (Figure 23).

Figure 23. Nitrate (mg/L) data and trend line at Met. Council station on Cannon River in Vasa Township, 1991-2021 (Metropolitan Council, 2023).



The statistically significant decreasing trends in TSS, TP, and nitrate observed over more than 20 years at the Metropolitan Council monitoring site near Welch indicate improving water quality conditions in the lower Cannon River. These trends suggest that watershed-wide conservation practices, wastewater treatment upgrades, erosion control efforts, and nutrient reduction strategies are collectively reducing pollutant loads reaching the river. Long-term improvements at a large downstream monitoring site are especially meaningful because they reflect the cumulative benefits of restoration and protection efforts occurring throughout the watershed.

5.4 Water clarity trends

Lakes

Secchi transparency is a low-cost water quality indicator that is easily collected by volunteers and has a long history of use on many Minnesota lakes. For most lakes in Minnesota, Secchi transparency provides an indirect measure of the amount of algae in the water, which is related to the lake's trophic status (nutrient richness), a measure of water quality. For these reasons, the MPCA annually analyzes its Secchi transparency dataset to determine trends in lake water quality over time.

The statistical trend analysis performed by the MPCA requires that a lake has a minimum of eight years and 50 points of Secchi disk data collected between May and September. The eight years don't need to be consecutive or recent. Lake transparency may vary from year to year in response to changes in rainfall amounts, watershed runoff and many other factors. Using datasets with more than eight years of data helps to account for these factors.

All applicable Secchi transparency data from the MPCA's water quality databases are used in the annual assessments. The majority of these data are collected by the hundreds of volunteers in the MPCA's Volunteer Water Monitoring Program.

Trend analysis details are provided in Appendix A.

Fifty-five lakes in the Cannon River Watershed were analyzed for clarity trends using data through 2025. Results from this analysis show three lakes in the watershed with improved water clarity trends and four with degrading (Table 14, Figure 25). All the other lakes (48) had insufficient data, or analysis showed no change or trend.

Figure 24. Cannon River Watershed lakes with clarity trends, France Lake 1976-2025, Cannon Lake 1974-2012, Beaver Lake 1986-2022, Fish Lake 1997-2022, Upper Sakatah 1980-2022, Dudley 1974-2022.

Table 14. Cannon River Watershed lakes with clarity trends (waterbodies highlighted in blue show improving water clarity trends for all sites).

Lake	Water body ID	Trend
Beaver	74-0023-00	Improving
Cannon	66-0008-00	Improving
Frances	40-0057-00	Improving
Dudley	66-0014-00	Degrading
Fish	40-0051-00	Degrading
Fox	66-0029-00	Degrading
Upper Sakatah	40-0002-00	Degrading

The 2016 WRAPS report featured clarity trends for Upper Sakatah, Volney, and Fox lakes. At the time, Upper Sakatah had evidence for possible decreasing trend, Volney had evidence for improving water clarity, and Fox Lake showed strong evidence for decreasing clarity. The updated analysis indicates that both Upper Sakatah and Fox lakes continue to exhibit degrading water clarity trends, suggesting persistent factors affecting lake condition. Of particular note, Fish Lake – a high quality lake that fully supports aquatic life and aquatic recreation uses and is identified as a watershed protection priority (Section 4.1) – also shows a degrading water clarity trend. While Fish Lake remains in good condition, the declining clarity warrants further investigation to better understand potential stressors and to inform future protection efforts. Addition information on Fish Lake water quality conditions and potential drivers can be found in the lake water quality studies found in Appendix F.3. Figure 26 and Figure 27 provide updated lake water clarity trends for Fox and Frances lakes as examples of continued trends or changes since the 2016 WRAPS report.

Figure 25. Lake water clarity trend Fox Lake 66-0029-00, 1971-2025.

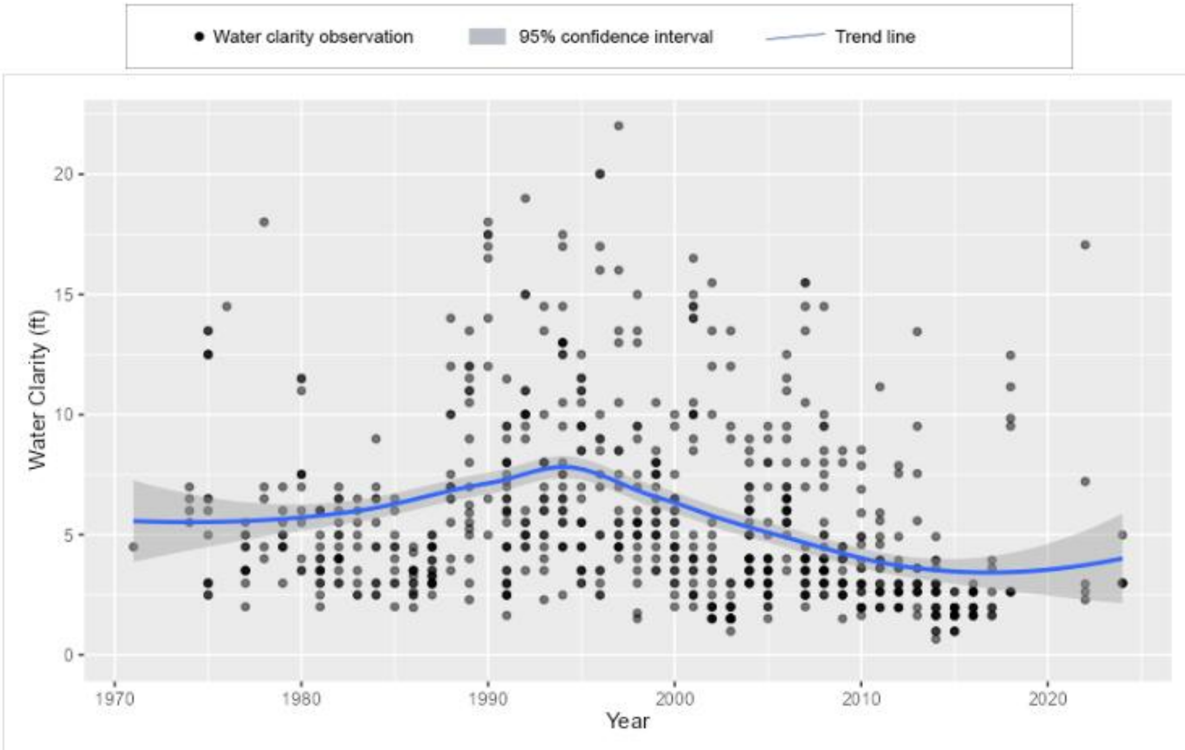
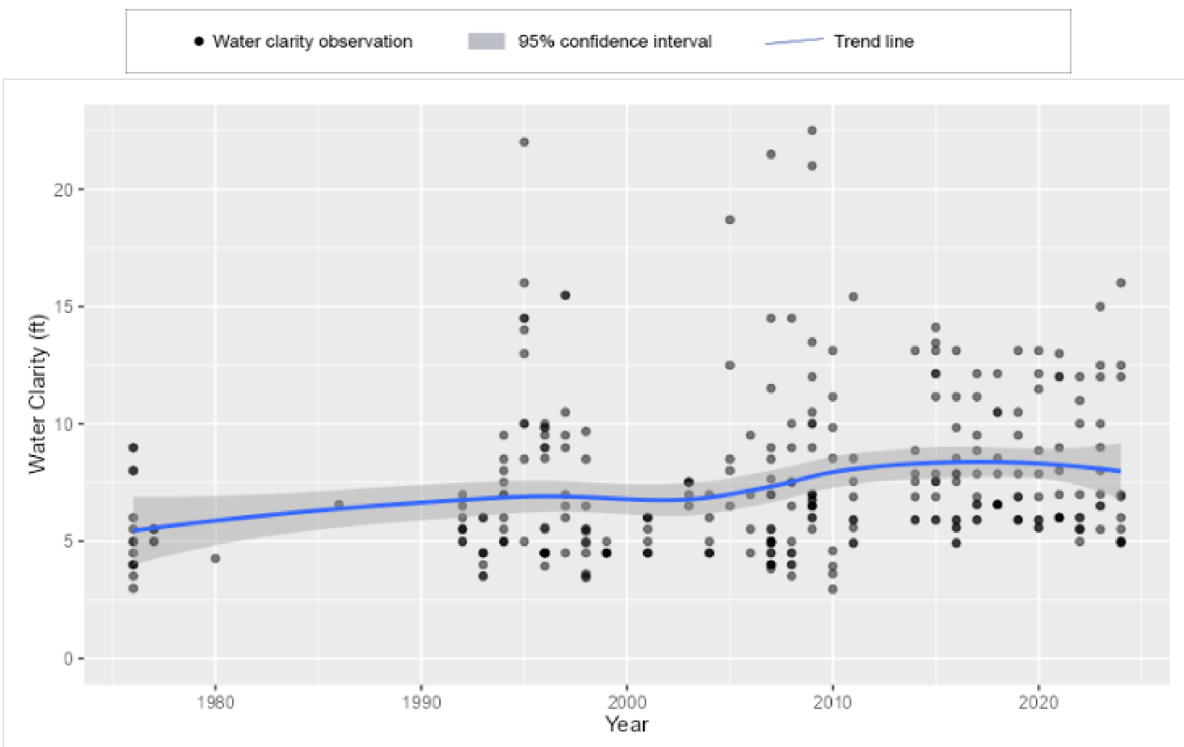


Figure 26. Lake water clarity trend Frances Lake 40-0057-00, 1976-2025.



Streams

Like Secchi transparency in lakes, stream transparency is a low-cost water quality indicator that is easily collected by volunteers. Stream transparency is an indirect measure of the amount of dissolved and suspended materials present in water. For most streams in Minnesota, the amount of solids suspended in the water is the most important factor: the more suspended materials, the lower the water transparency. In streams and rivers, soil particles (predominantly silts and clays) have the strongest influence on transparency, as water flows downstream, carrying and depositing this sediment. Too much sediment in the water is a significant pollutant itself, whether it is suspended in the water column or deposited on stream bottoms. Suspended sediment reduces light penetration, which is needed for the growth of beneficial aquatic plants. It also interferes with the ability of fish to see and capture their prey. For these reasons, the MPCA conducts an annual analysis of its stream transparency dataset to determine trends in stream water clarity over time.

Results from this analysis show several river and stream monitoring sites in the Cannon River Watershed with improved water clarity trends with a few degrading (Figure 28 and Table 15).

Figure 27. Stream clarity trends in Cannon River Watershed.

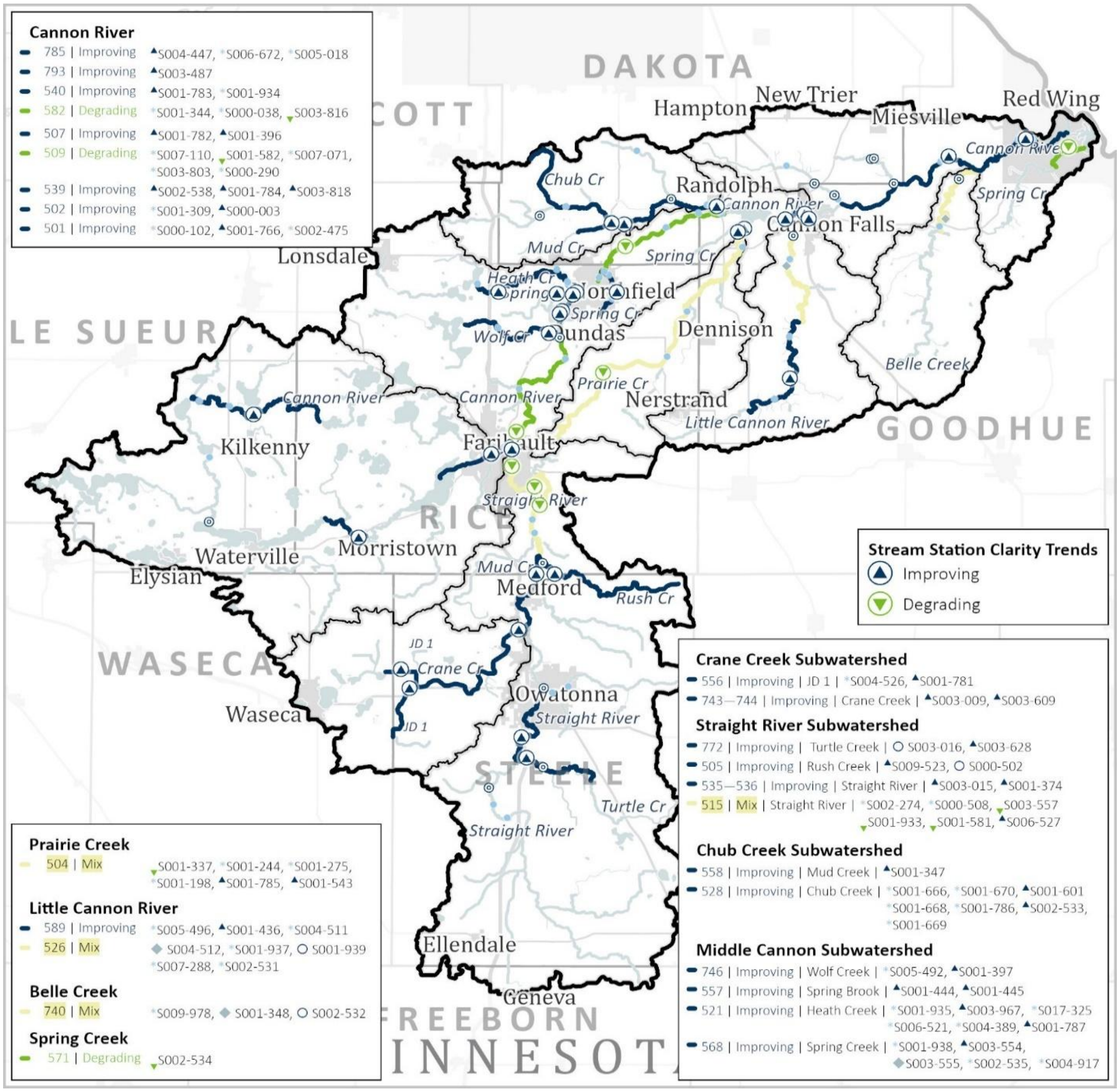


Table 15. Cannon River Watershed streams with water clarity trends (waterbodies highlighted in blue show improving water clarity trends for all sites).

Water body name	Water body ID	Site ID	Trend
Cannon River	07040002-501	S001-766	Improving
Cannon River	07040002-502	S000-003	Improving
Prairie Creek	07040002-504	S001-337	Degrading
Prairie Creek	07040002-504	S001-543	Improving
Prairie Creek	07040002-504	S001-785	Improving
Rush Creek	07040002-505	S009-523	Improving
Cannon River	07040002-507	S001-396	Improving

Water body name	Water body ID	Site ID	Trend
Cannon River	07040002-507	S001-782	Improving
Cannon River	07040002-509	S001-582	Degrading
Straight River	07040002-515	S001-581	Degrading
Straight River	07040002-515	S001-933	Degrading
Straight River	07040002-515	S003-557	Degrading
Straight River	07040002-515	S006-527	Improving
Heath Creek	07040002-521	S001-787	Improving
Heath Creek	07040002-521	S003-967	Improving
Chub Creek	07040002-528	S001-601	Improving
Chub Creek	07040002-528	S002-533	Improving
Straight River	07040002-535	S003-015	Improving
Straight River	07040002-536	S001-374	Improving
Cannon River	07040002-539	S001-784	Improving
Cannon River	07040002-539	S002-538	Improving
Cannon River	07040002-539	S003-818	Improving
Cannon River	07040002-540	S001-783	Improving
Judicial Ditch 1	07040002-556	S001-781	Improving
Unnamed creek (Spring Brook)	07040002-557	S001-444	Improving
Unnamed creek (Spring Brook)	07040002-557	S001-445	Improving
Mud Creek	07040002-558	S001-347	Improving
Unnamed creek (Spring Creek)	07040002-568	S003-554	Improving
Spring Creek	07040002-571	S002-534	Degrading
Cannon River	07040002-582	S003-816	Degrading
Little Cannon River (Goodhue County)	07040002-589	S001-436	Improving
Crane Creek	07040002-743	S003-609	Improving
Crane Creek	07040002-744	S003-009	Improving
Wolf Creek	07040002-746	S001-397	Improving
Turtle Creek	07040002-772	S003-628	Improving
Cannon River	07040002-785	S004-447	Improving
Cannon River	07040002-793	S003-487	Improving

5.5 Point source phosphorus and Byllesby Reservoir

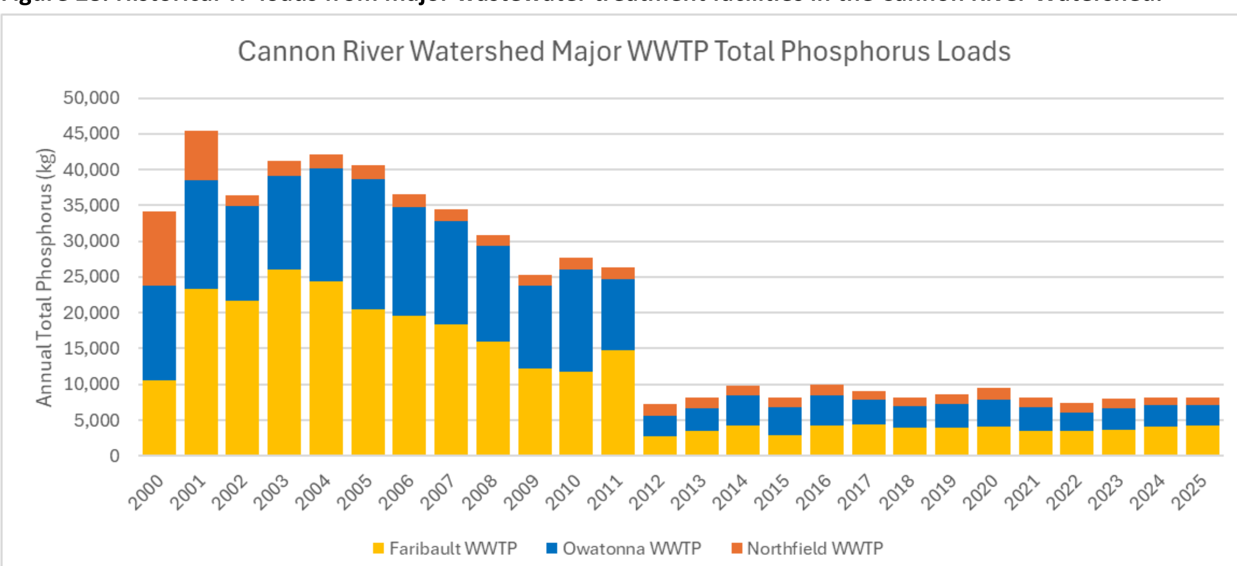
Byllesby Reservoir was added to the impaired waters list in 2002 due to excess nutrients driving eutrophication and impairing recreational use. Prior to listing, MPCA and partners initiated intensive monitoring at upstream inflow sites and within the reservoir. These data supported watershed and reservoir modeling, development of site-specific criteria, and completion of the Byllesby Reservoir TMDL. The 2017 Cannon River TMDL report provides full documentation of technical analysis, stakeholder engagement, and resulting WLA (MPCA, 2017).

Six HSPF model simulations were used to derive seasonal (June-September) WLAs for the three major upstream WWTFs: 15.9 kg-P/day for Faribault, 11.36 kg-P/day for Owatonna, and 11.81 kg-P/day for Northfield (MPCA, 2017). These WLAs reflect modeled point source delivery and in-stream P dynamics under an equitable reduction scenario that included both point and nonpoint source reductions. The modeling process iteratively “stepped down” from permitted load to those corresponding to attainment of Cannon River inflow goals for Byllesby Reservoir.

A key outcome of the loading analysis was the identification of a required Cannon River inflow flow-weighted mean concentration (FWMC) of approximately 0.150 mg/L to achieve reservoir water quality goals. This value aligns with the river eutrophication standard (RES) for the Cannon River at Byllesby Reservoir and served as the inflow target used in derivation of upstream WLAs (MPCA, 2017).

At the time of TMDL completion, MPCA milestone monitoring sites on the Cannon and Straight Rivers were already indicating improving (decreasing) P trends (MPCA, 2017). These improvements were attributable in part to a pre-TMDL P strategy under which the three largest municipal dischargers - Faribault, Northfield, and Owatonna - implemented major capital upgrades to enhance P removal. The Public Facilities Authority data shows that $146 million have been invested in capital wastewater treatment improvements in the Cannon River Watershed since 2008.

Figure 28. Historical TP loads from major wastewater treatment facilities in the Cannon River Watershed.

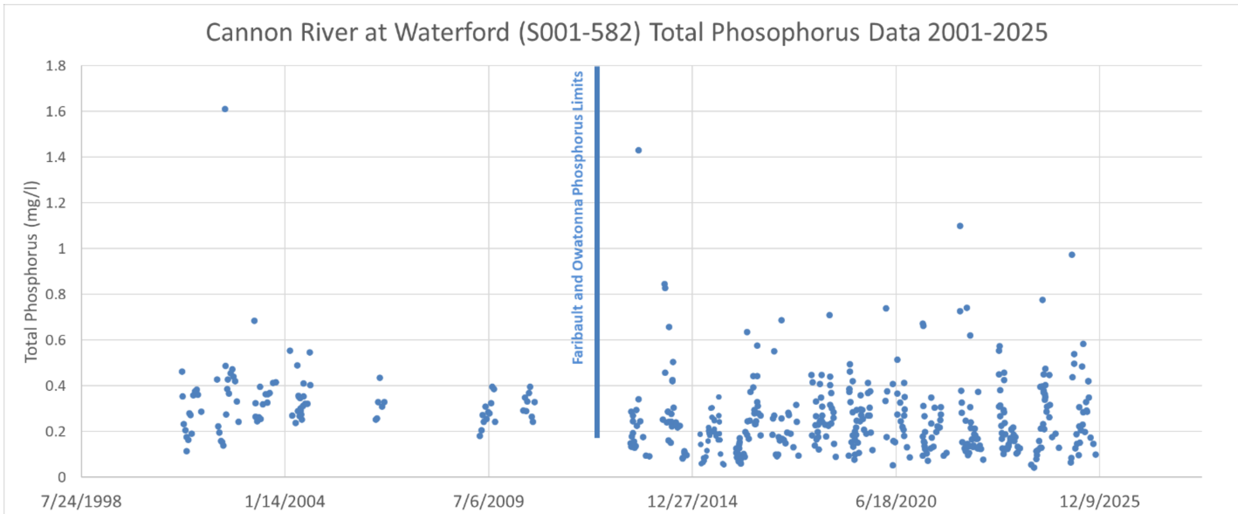


Response in river concentrations

Data collected at the WPLMN site upstream of Byllesby Reservoir documents substantial changes in low-flow P concentrations following implementation of P limits at WWTFs. During low-flow conditions, point sources like WWTFs can dominate in-stream P loading. Whereas, at high-flow conditions, most P loading comes from nonpoint sources such as stormwater and erosion.

Prior to facility upgrades, TP concentrations at the Cannon River inflow were elevated during both high-flow events and low-flow conditions (Figure 29). Low-flow TP concentrations commonly ranged from 0.2 to 0.4 mg/L, with a significant dissolved fraction readily available for primary productivity in the reservoir.

Figure 29. TP concentrations at the Cannon River inflow to Byllesby Reservoir, illustrating reductions in low-flow concentrations following implementation of WWTF P limits.

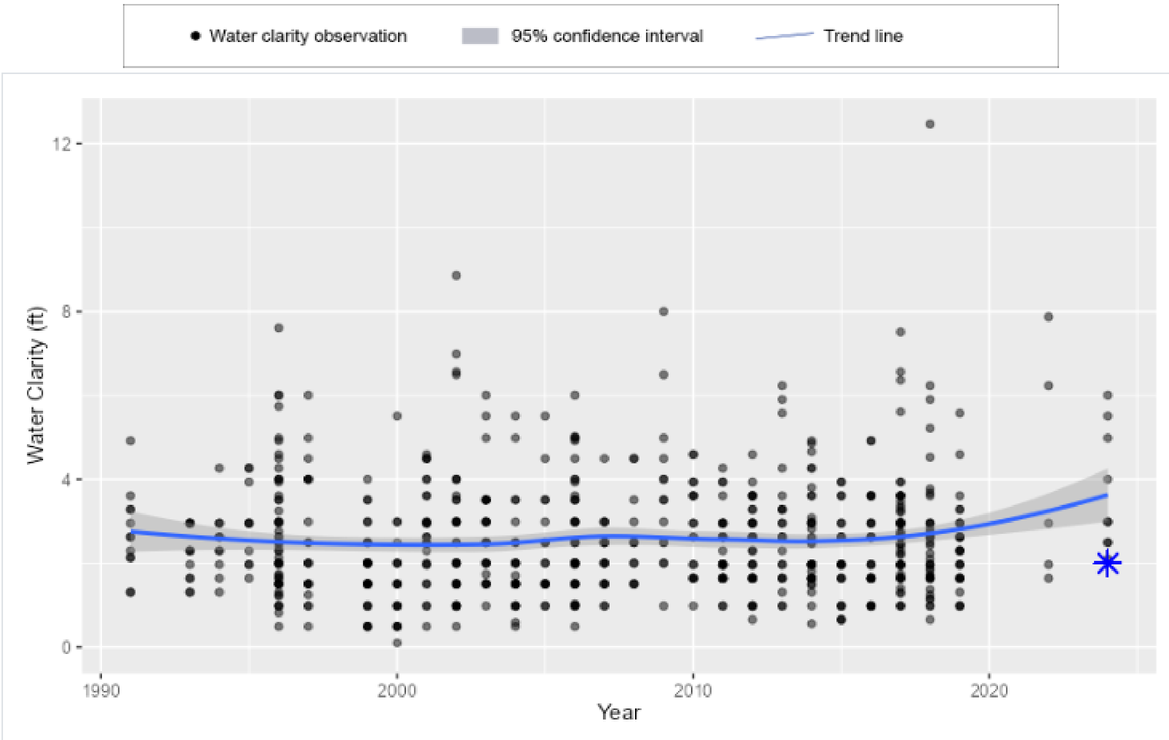


Following implementation of P limits at WWTFs, monitoring indicates marked reductions in low-flow TP concentrations (Figure 29, starting in 2012). Current low-flow concentrations typically range from 0.05 to 0.4 mg/L, with many observations below the 0.15 mg/L inflow goal. These reductions reflect the measurable influence of upstream point source controls on river and reservoir water quality.

Flow data, TP loads and FWMCs for the Cannon River at Waterford (and other sites) can be examined and downloaded at the MPCA's Watershed Pollutant Load Monitoring Network Data Viewer. The full period of record of raw data can be viewed and downloaded at MPCA's Environmental Data Access (EDA) web tool. WWTF pollutant loads and reduction progress can be reviewed at the MPCA Healthier Watersheds webpage.

The Environmental Data Access system (EDA) also provides summary and trend analysis for the water clarity data collected at Byllesby Reservoir sites. These data date back to the 1990s and provide an invaluable long-term record of reservoir conditions. For the period 1991 to 2024, EDA identified no statistically significant long-term water clarity trend. However, Figure 30 suggests water clarity may have increased in recent years, particularly since 2020. This apparent improvement coincides with a substantial reduction in monitoring frequency, making it difficult to determine whether the observed pattern reflects actual changes in reservoir conditions or limitations in the available dataset. EDA also notes that zebra mussels were first documented in Byllesby Reservoir in 2024, a factor that may influence future water clarity. The CWMP and Lake Byllesby Improvement Association should prioritize reinvigorating the Volunteer Water Monitoring program to improve data continuity and support robust trend analysis going forward.

Figure 30. Lake water clarity trend analysis Byllesby Reservoir 19-0006-00, 1991-2025.



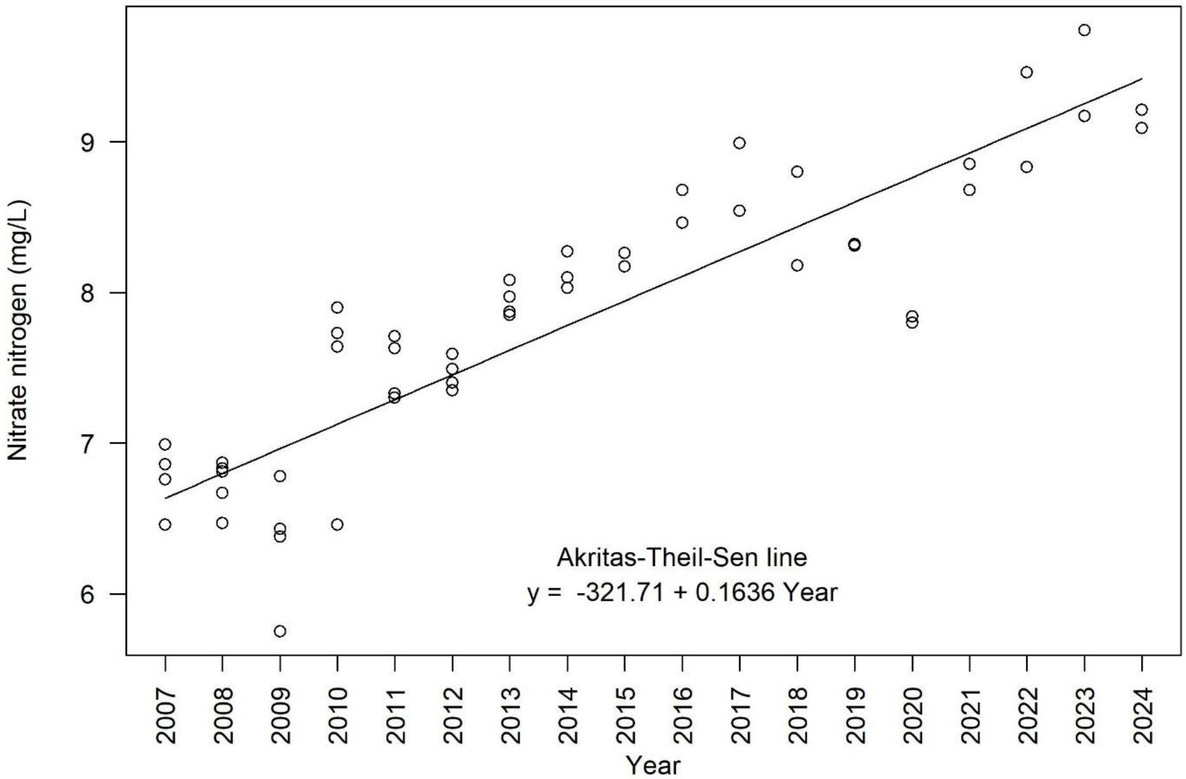
*** indicating zebra mussels discovered in the lake in 2024**

5.6 Nitrate

Spring Creek Spring (Goodhue County)

The Minnesota Department of Agriculture (MDA) collects pesticide and nitrate/nitrogen water quality samples from approximately 13 springs in southeast Minnesota. Samples are collected twice per year and are intended to target baseflow (groundwater periods) instead of stormflow (rain event) periods. In addition, MDA monitors approximately 12 domestic wells in the fall to supplement regional spring monitoring. The MDA publishes an annual work plan that provides specific information for the upcoming year and an annual report with monitoring results available at their MDA Monitoring Website. A headwater spring of Spring Creek (Goodhue County) in the Cannon River Watershed is one of the springs MDA has sampled since 2007. Trend analysis for nitrate samples from Spring Creek (Goodhue County) spring were reported in the 2016 WRAPS report, showing a statistically significant increasing trend over the period of record. This analysis has been updated using MDA's data through 2024, Figure 30, and still shows a statistically significant rising trend in nitrate concentrations. Interestingly, concentrations collected in 2020 were the lowest collected since 2012, however samples collected in 2021, and subsequent years continue to rise above those collected in 2019. This trend analysis is detailed in Appendix C. The results indicate a statistically significant ($p<0.05$) increasing trend in nitrate-nitrogen over time, Figure 31.

Figure 31. Trend analysis of nitrate concentrations (mg/) of Spring Creek (Goodhue County) spring, 2007-2024.



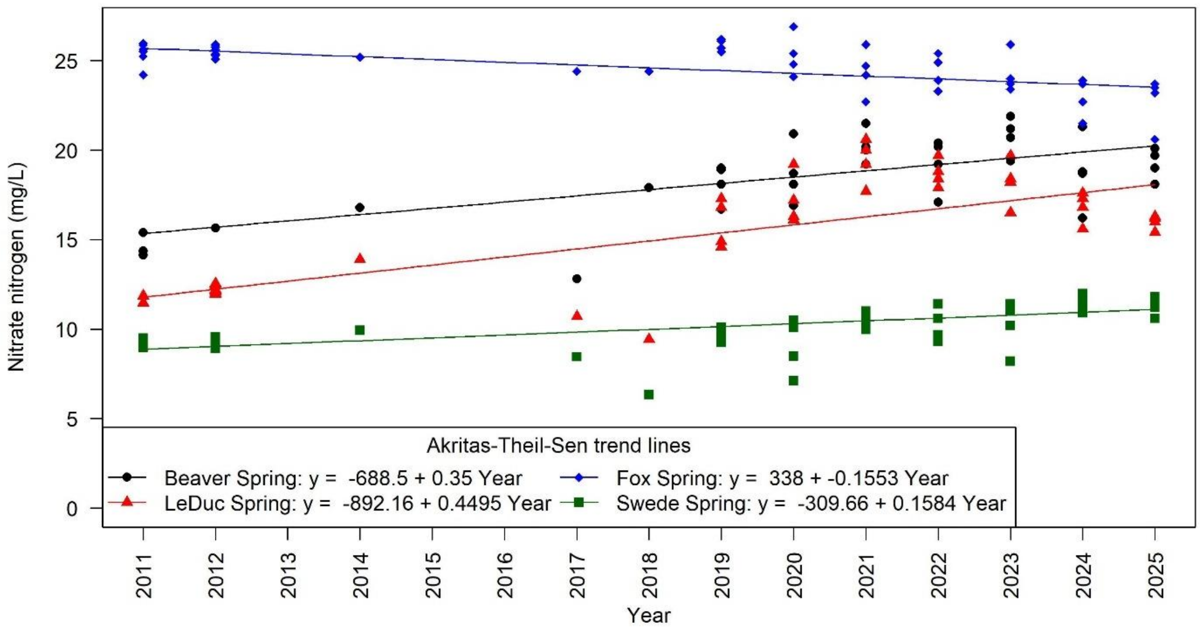
Trout Brook Springs

Trout Brook is a groundwater-fed stream located in southeast Dakota county. The majority of its perennial flow is contained within the Miesville Ravine Park Reserve and enters the Cannon River immediately after leaving the park. The lower section is a designated trout stream. This part of the Cannon River Watershed contains karst, a geologic system that is characterized by underground drainage systems such as caves and sinkholes and is dotted with springs. High nitrate levels in the Trout Brook Subwatershed have been a concern for many years. The mainstem of Trout Brook and two headwater tributaries are impaired by nitrate, additionally, those tributaries have impaired benthic macroinvertebrate communities with nitrate and physical habitat as confirmed stressors (Dakota SWCD, 2017).

Spring monitoring in the Trout Brook Subwatershed began as a one-time effort in 1985. A monitoring strategy was then developed as part of the North Cannon River Watershed Management Organization Watershed Management Plan, resulting in regular monitoring at the same four springs beginning in 2011. Sampling frequency has changed over time and has increased to quarterly to get a higher resolution dataset to better understand nitrate levels in the watershed over time. This monitoring effort receives support from partners including Dakota County Parks (Dakota SWCD, 2022).

Four spring sites are sampled: Beaver, Fox, LeDuc, and Swede. Nitrate levels at three sites continue to rise over time (Figure 32). Fox Spring has the highest levels of all four sites and Swede Spring has the lowest nitrate levels in the Trout Brook Subwatershed. All the sites have nitrate levels above the state drinking water standard, 10 mg/L, and the natural background concentration of 1 mg/L (Barry et al., 2026), reinforcing concerns about groundwater nitrate contamination that have been documented in the watershed for decades (Groten and Alexander, 2013).

Figure 32. Trend analysis of nitrate concentrations (mg/) of springs in Trout Brook Subwatershed, 2011-2025.



Detailed hydrogeologic analysis of the Trout Brook subwatershed springs was conducted by Groten and Alexander (2013), who documented the influence of karst geology, groundwater flow paths, and land use on nitrate transport within the subwatershed. Their findings highlighted the vulnerability of the region's groundwater and spring systems to nitrate contamination and provided important context for understanding long-term nitrate trends observed at Beaver, Fox, LeDuc, and Swede springs. As Dakota SWCD continues to sample these sites, the data is evaluated, and spring nitrate conditions are documented in its annual Cannon River Watershed Water Quality Monitoring Report (https://dakotaswcd.org/reports/water-monitoring/)

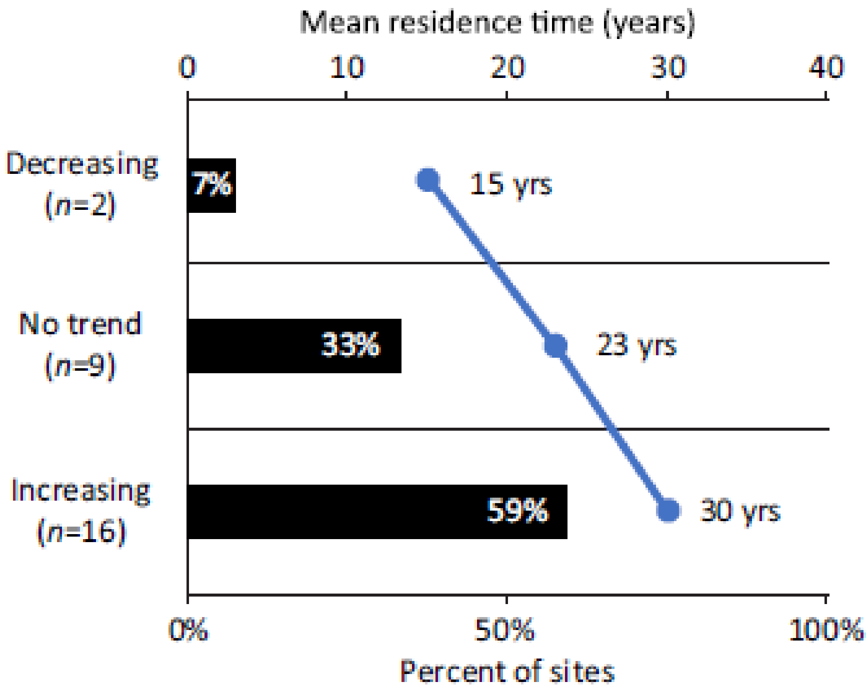
The MDH Cannon River Groundwater Restoration and Protection Strategies (GRAPS) report identifies nitrate contamination as a particular concern in areas with high groundwater pollution sensitivity and karst geology, highlighting the importance of addressing nitrate sources to protect both groundwater and groundwater-fed surface waters.

Regional geologic context

Some of the springs discussed here were studied by researchers at MDA, DNR, and Minnesota Geological Survey to better understand nitrate concentration trends through estimating groundwater residence time. Residence time was estimated using man-made tracer chemicals like agricultural herbicide alachlor. This research suggests groundwater mixtures from shallow (<60m) springs have apparent residence times of one to two decades. In contrast, springs in deeper settings have residence times ranging from two to four decades. These systems with longer groundwater travel times may exhibit slower response to land use change (Kuehner et al, 2025).

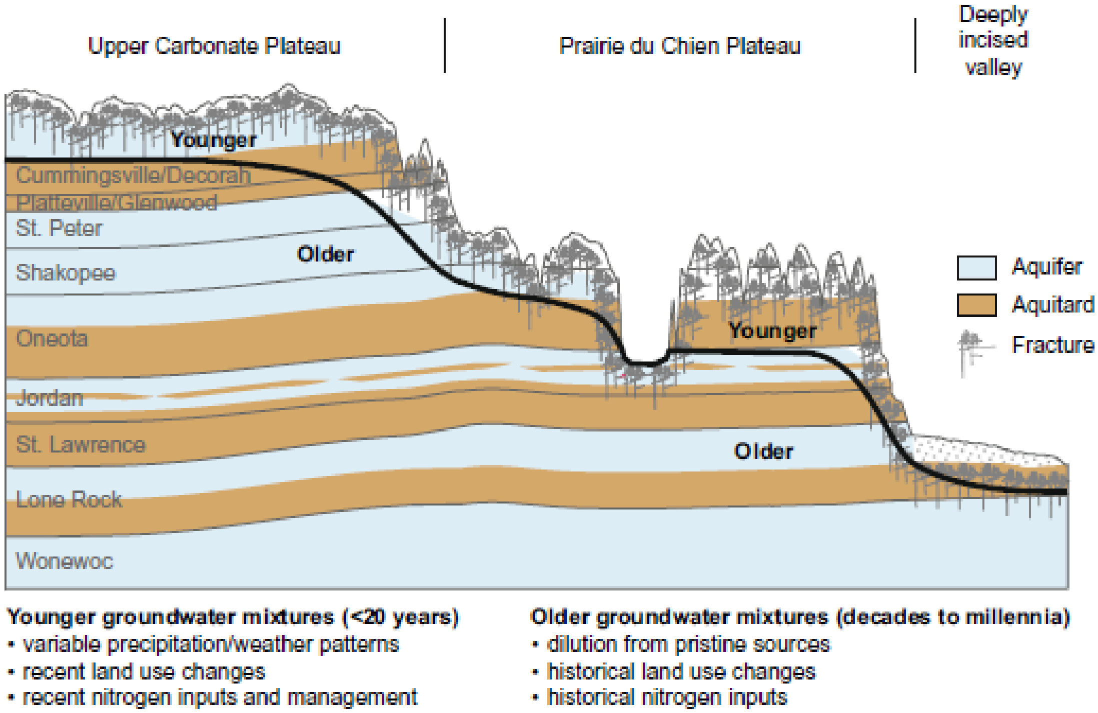
Combining these estimates with trend analysis (Figure 33), implies legacy sources of contaminants, such as nitrate, have not fully migrated through some aquifers and that concentrations in certain springs, streams, and wells will continue to increase (Kuehner et al, 2025).

Figure 33. Relationship between modern mean residence time and nitrate trends for 27 springs and wells in the study (Kuehner et al, 2025).



This and other programs monitoring long term trends in groundwater quality in the watershed are essential for understanding the impact of land use at the surface on groundwater, the primary source of drinking water in this region (Figure 34).

Figure 34. Dominant factors affecting nitrate concentrations and trends in the Driftless Area of southeast Minnesota (Kuehner et al, 2025).



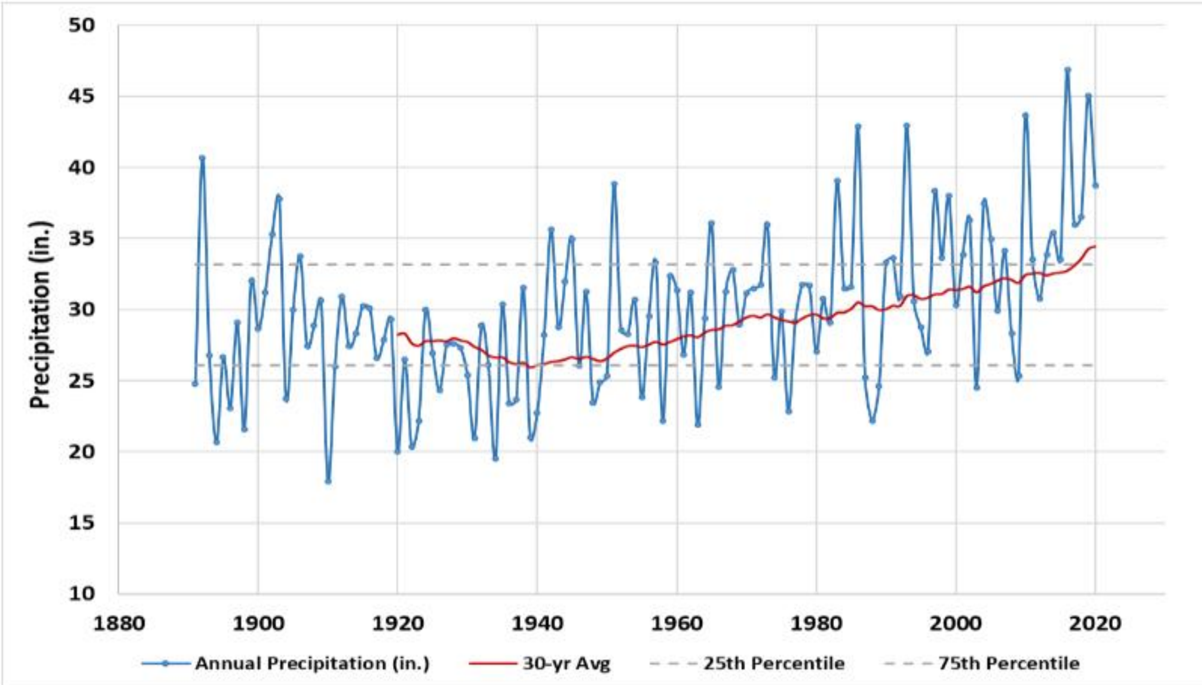
6. Climate change

6.1 Evaluation of Hydrologic Change for the Cannon River Watershed

The DNR's 2023 Evaluation of Hydrologic Change (EHC) for the Cannon River Watershed presents a clear and compelling picture: climate-driven changes in precipitation and hydrology are fundamentally reshaping how water – and the pollutants it carries – move through the landscape.

Over the past several decades, the Cannon River Watershed has experienced a measurable shift toward wetter conditions. Annual precipitation has increased, as shown in Figure 35, which documents a long-term upward trend in total precipitation. More importantly, the nature of that precipitation has changed, with rainfall occurring in more intense events and with greater volumes delivered over shorter periods. This shift reflects a broader transition toward sustained wet conditions punctuated by high-intensity storms, setting the stage for downstream hydrologic and water quality impacts (DNR, 2023).

Figure 35. Averaged annual precipitation for the Cannon River Watershed (Minnesota Climatology Office, 2020).

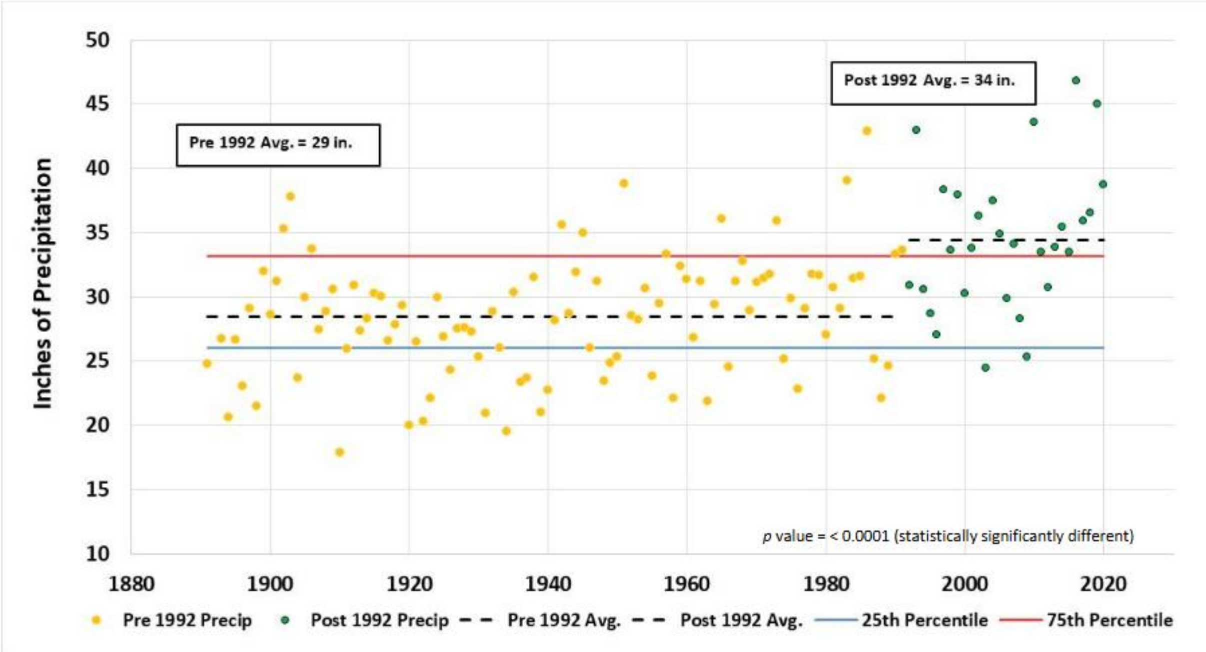


This shift is reflected in a well-documented "change point" in the hydrologic record, generally occurring in the late 20th century (Figure 36 and Figure 37). Following this transition, the Cannon River system began to behave differently:

- Stream flows increased
- Runoff volumes rose
- Variability of flows became more pronounced

What was once a system with significant natural storage – where water could be temporarily retained in soils, wetlands, and shallow groundwater – has increasingly become a system dominated by rapid conveyance. In practical terms, more of the water that falls on the landscape is now moving quickly into streams and rivers rather than being stored or slowly released.

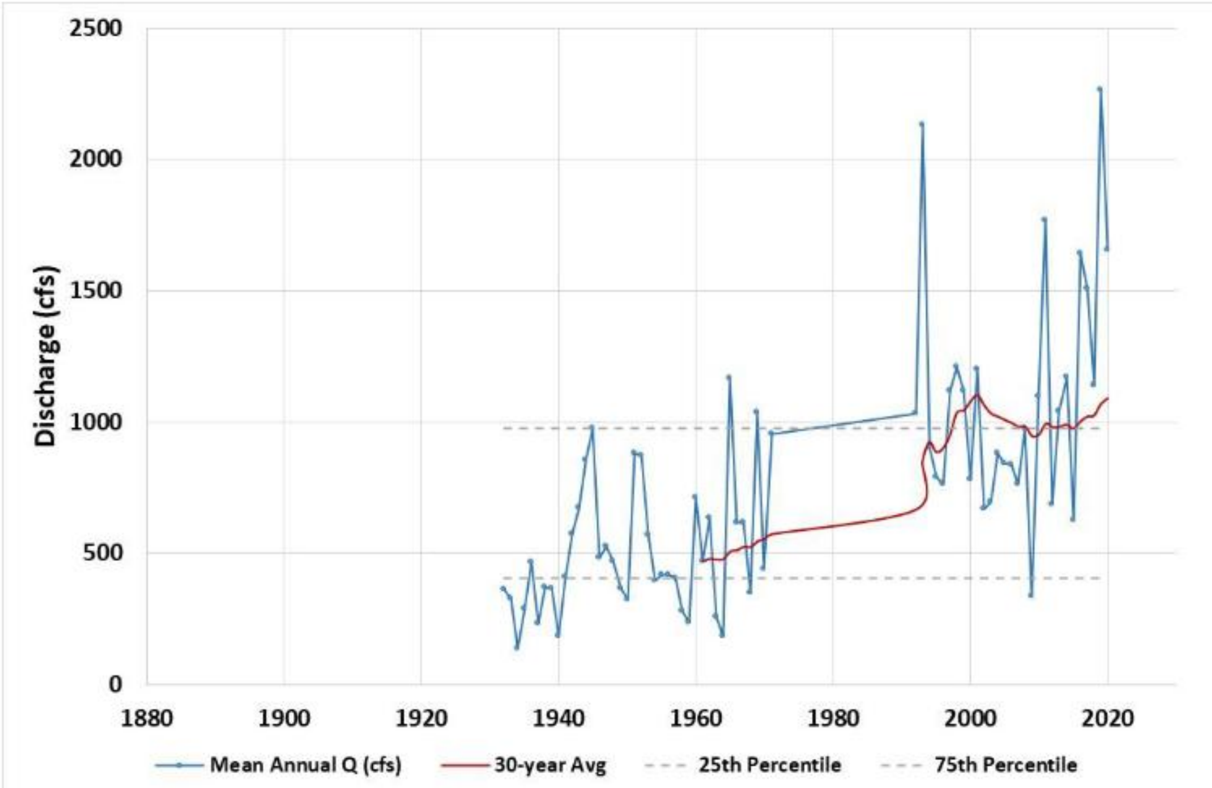
Figure 36. Averaged annual precipitation for the Cannon River Watershed at Welch (DNR, 2023).



One of the clearest indicators of this transformation is the significant increase in runoff efficiency. A growing proportion of precipitation is now converted directly into streamflow, suggesting reduced infiltration, diminished storage capacity, or both (DNR, 2023). This change has profound implications for water quality because it shortens the amount of time water spends interacting with soils, vegetations, and microbial communities – processes that are essential for filtering sediment and transforming or retaining nutrients.

Streamflow patterns themselves have also changed. Higher annual flows are now accompanied by more frequent and more intense peak flow events. The DNR report documents an increase in bankfull flow of roughly 19%, indicating that the flows most responsible for shaping stream channels are occurring more often and with greater force (DNR, 2023). These conditions accelerate channel erosion, destabilize streambanks, and mobilize large quantities of sediment. As sediment is transported downstream, it carries with it P and other attached pollutants, contributing directly to water quality impairments.

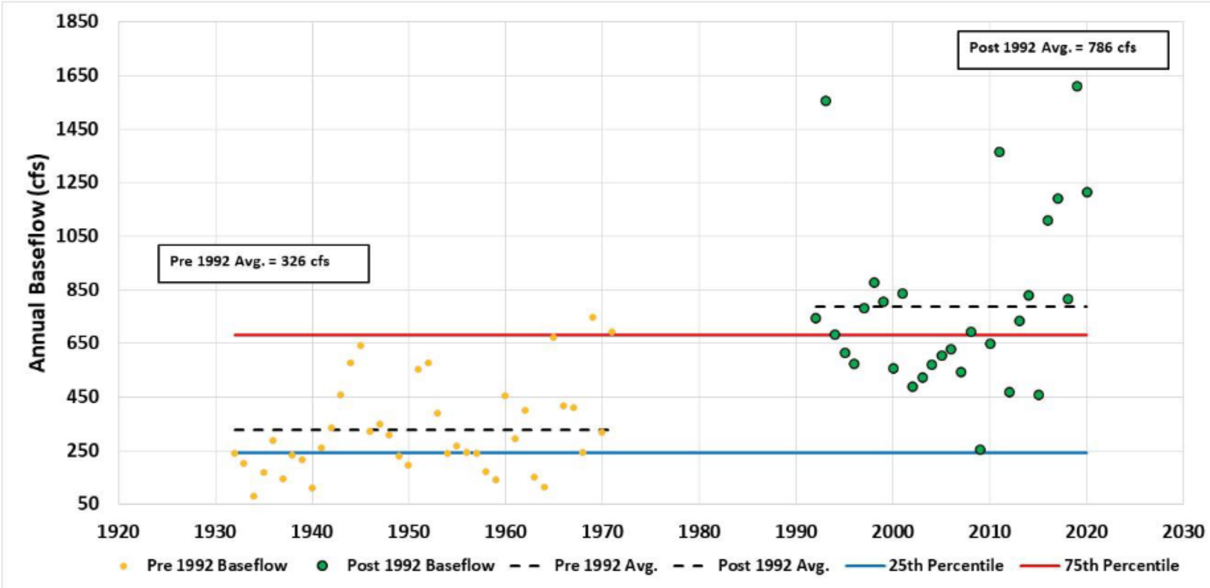
Figure 37. Annual mean discharge for the Cannon River at Welch (05355200) (USGS, 2020).



At the same time, the hydrologic regime has become flashier, with streams responding more quickly to precipitation events. Rapid rises and falls in flow reflect a system that is increasingly connected and efficient at moving water (DNR, 2023). This heightened connectivity means that pollutants generated on the landscape – whether from agricultural fields, urban areas, or legacy deposits – are more readily transported into waterways during storm events. The result is a shift toward event-driven water quality dynamics, where large pulses of sediment and nutrients are delivered during high-flow conditions.

Changes in baseflow further illustrate the evolving role of groundwater in the system. Baseflow is the portion of flow within a river or stream that does not come from overland runoff. It is key to maintaining stream channel conditions in times of little to no precipitation. Statistically significant shifts (Figure 38) in baseflow suggest alterations in recharge patterns and subsurface hydrology, likely influenced by a combination of climate trends and land use practices such as artificial drainage (DNR, 2023). Changes in baseflow volumes are often closely tied to land use. Land management practices and changes in vegetative cover can alter surface runoff dynamics and prevent water from moving downward into areas of deeper groundwater storage. These changes can increase the delivery of dissolved pollutants, particularly nitrate, to streams, reinforcing the trend toward greater overall pollutant transport.

Figure 38. Annual baseflow for the Cannon River at Welch (DNR, 2023).



Looking ahead, climate projections indicate that these patterns are likely to intensify. Modeling results suggest continued increases in peak flows and hydrologic variability through the end of the century (DNR, 2023). This implies that the processes currently driving increased sediment and nutrient loading will persist and potentially accelerate in the future.

Taken together, these hydrologic changes have direct and compounding effects on water quality. Increased runoff and peak flows enhance erosion and sediment transport, elevating TSS and degrading aquatic habitat. Nutrient loading is amplified through both surface and subsurface pathways; P is mobilized with sediment during high flows, while nitrate delivery can be increased through enhanced drainage and baseflow contributions. At the same time, the watershed's natural capacity to retain and process pollutants is diminished. Reduced residence time limits opportunities for sediment settling, plant uptake, and microbial processes such as denitrification.

The overall result is a fundamental shift in system behavior. The Cannon River Watershed is transitioning from a landscape where water and pollutants were partially stored and processed to one where they are rapidly conveyed downstream (Figure 38). This transition has important implications for water quality management. It suggests that traditional approaches focused solely on reducing pollutant sources may be insufficient if they do not also address the changing hydrologic context. As the system becomes more efficient at transporting water, greater reductions in pollutant loads may be required to achieve the same water quality outcomes.

In this way, the EHC makes a critical point: hydrologic change is not just a background condition – it is a primary driver of water quality. Effective management in the Cannon River Watershed will need to account for both the increasing magnitude of pollutant transport and the decreasing capacity of the landscape to attenuate those pollutants under a changing climate.

7. Restoration and protection

7.1 Actions taken - BMPs

The *Cannon River CWMP* was developed by the CRWJPO and approved by BWSR in 2020.

The CWMP:

- Identifies and prioritizes watershed resources and issues.
- Sets measurable goals for the priority resources and issues.
- Identifies a 10-year schedule of implementation activities and budget to achieve the goals.
- Develops plan implementation programs, administration, and coordination frameworks needed to implement the plan.

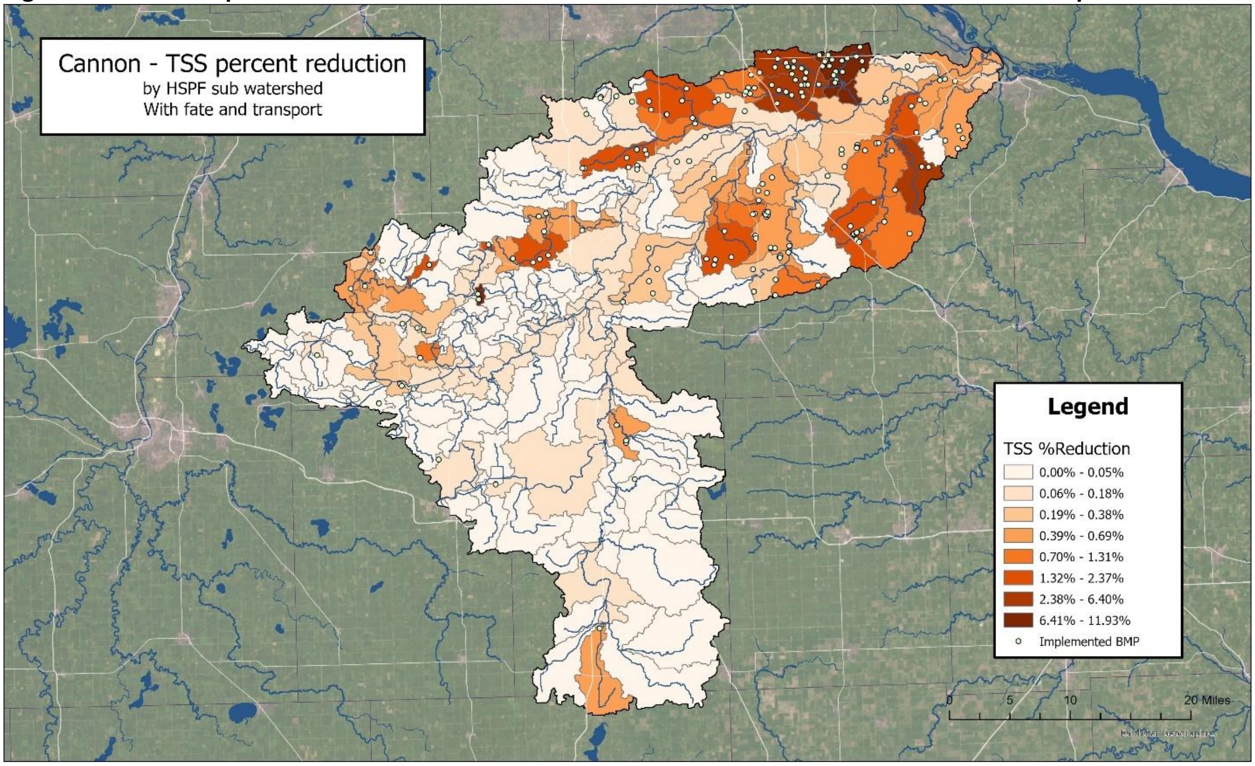
Work began in 2021, implementing structural and nonstructural BMPs, completing studies and plans, conducting outreach and engagement, and monitoring and tracking work. LGUs were surveyed and provided BMP work completed from May 2020 to June 2025, showing at least 206 BMPs have been completed in the Cannon River Watershed including reduced tillage, conservation cover perennials, grassed waterways, water and sediment control basins (WASCOBs), cover crops, and others. These BMPs treat roughly 12,644 acres or 1.4% of the watershed.

Pollutant reductions of these BMPs were estimated through modeling. The current HSPF model has a simulation period from 1996 to 2023. The HSPF-SAM was used to evaluate the impact of the BMPs on flow, TSS, TP, and total nitrogen (TN). A single scenario was created applying all recorded BMPs for the full simulation period. BMPs were summed to generate a total treated area for each BMP type within a subwatershed. Results from the BMP scenario were compared to the existing model (base scenario) outputs, which had no BMPs applied. The simulation results are reported as average annual percent load reductions.

The modeling effort, BMP reduction efficiencies, and scenario results for edge of field and at the subwatershed outlets are detailed in Appendix E. Percent load reductions are dependent on BMP type, reduction efficiencies derived from existing research and literature, and the acres treated within each subwatershed. Generally, subwatersheds with more BMPs implemented have higher modeled pollutant reductions. Some of the highest modeled pollutant reductions are in the Chub Creek, Pine Creek, Trout Brook (Miesville), Belle Creek, and Little Cannon River subwatersheds, as shown in Figure 39 through Figure 41. These results can be compared with the watershed prioritization maps in Figure 52 and Figure 53 to help guide future conservation investments and target subwatersheds where additional BMP implementation may yield substantial pollutant reductions.

The BMPs represented in the simulation significantly reduce pollutant loads but are generally not designed to reduce overall flow volume; rather, they change the timing of the hydrograph by slowing flow and reducing peak discharges. As such, the simulations did not indicate significant change in the long term annual average total flow volume. The highest estimated subwatershed outlet flow reduction was 0.51% in subwatershed 122. The outlet of subwatershed 100 represents the reductions at the outlet of the HUC-8. The estimated flow reduction at the HUC-8 outlet is 244 acre-feet per year.

Figure 39. Potential percent load reduction of TSS at the subwatershed outlet with fate and transport.



At the subwatershed outlets, the highest estimated TSS reduction of 12% is reported from subwatershed 122 (the subwatershed with darkest shading, located in northern part of the Lower Cannon River Watershed). An estimated 338 tons per year of TSS has been reduced at the HUC-8 outlet because of the reported BMPs.

Figure 40. Potential percent load reduction of TP at the subwatershed outlet with fate and transport.

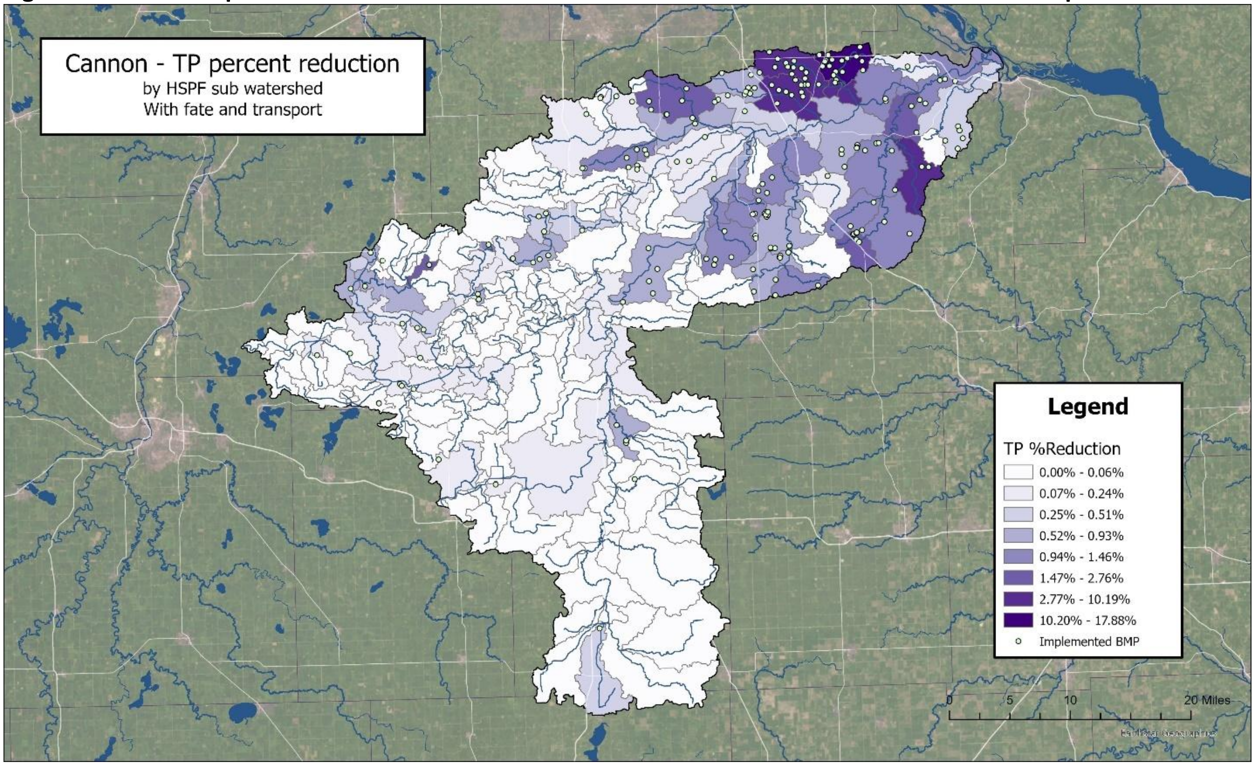
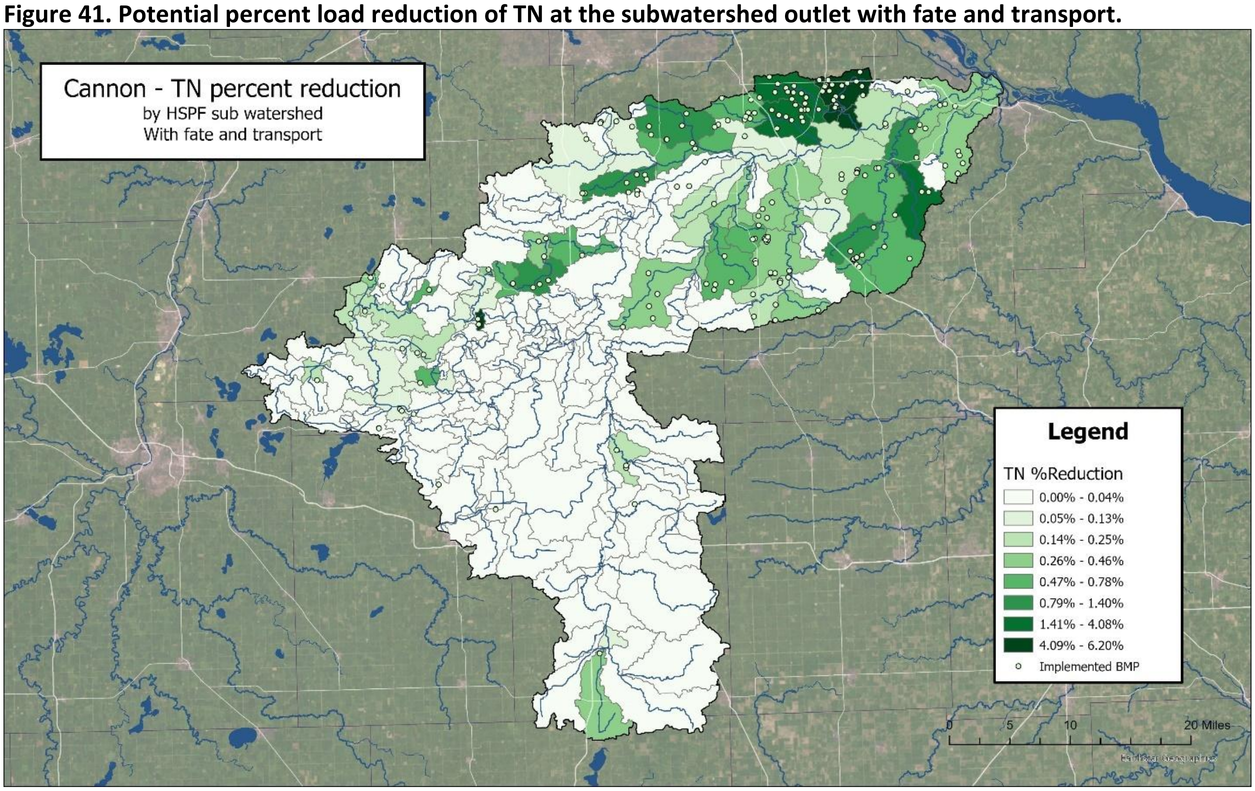


Figure 41. Potential percent load reduction of TN at the subwatershed outlet with fate and transport.



Subwatershed 122 has the highest subwatershed outlet estimated TP reductions of 17.8% and TN reductions of 6.2%. Additionally, an estimated 14,948 lbs/year of TP and 36,262 lbs/year of TN are reduced at the HUC-8 outlet from the reported BMPs.

To reiterate, this model simulation only includes BMPs installed from 2021 to 2023; therefore, it only represents approximately two years of watershed work. Prioritization and installation of BMPs have continued beyond 2023 and BMPs may be implemented by landowners and producers without cost-share and technical assistance and are not recorded or reflected in this simulation. Ultimately, this simulation represents a low estimate of the practices that have been implemented based on the best available information of pollutant reduction efficiencies and practices implemented through 2023.

7.2 Farmers protecting Rice Creek – cover crops in action

The 2016 Cannon River WRAPS documented nitrate as a primary water quality concern in the basin and described how N from cultivated acres – particularly those enhanced with subsurface tile drainage – moves rapidly to surface waters. The report emphasized the need for practices that reduce leaching during fall, winter, and spring when crops are not actively taking up N.

In response, producers in the Rice Creek Subwatershed launched the Farmers Protecting Rice Creek initiative, dramatically expanding the use of cover crops across the landscape (Figure 42). By maintaining living roots beyond the primary growing season, these producers are directly addressing the pathways identified in the WRAPS and reducing the potential for nitrate loss to downstream waters.

Rice Creek is a small subwatershed of the Cannon River located west of Dundas, Minnesota (Figure 43). It is the only trout stream in Rice County and has a self-sustaining population of brook trout. Rice Creek's watershed is roughly 4,181 acres, with around 85% of those acres used for corn and soybean production. Most of the agricultural land is drained with subsurface tiles and there are no industrial, wastewater, or urban stormwater sources of pollution. This layering of factors makes Rice Creek a good living laboratory with the potential to observe a rapid response in water quality from changes in land management practices. Rice County Soil and Water Conservation District (SWCD) partnered with Clean River Partners (formerly Cannon River Watershed Partnership) and several other organizations to work with farmers to accelerate the use of cover crops and improve the water quality of Rice Creek. The effort and investment by these partners have resulted in agricultural producers in the small watershed planting around 1,000 acres of cover crops from 2019-2025. This equates to about 30% of the tillable farmland in the Rice Creek Subwatershed. Monitoring of tile water and Rice Creek is funded by MPCA Clean Water Funds with management of the project and sampling done by Rice SWCD and Clean River Partners staff.

Figure 42. John Becker inter-seeds a six-way cover mix consisting of oats, winter triticale, crimson clover, red clover, radish, and common vetch into soybeans.

Figure 43. Location of the Rice Creek Subwatershed in relation to a nine-county area in southeast Minnesota.

Statistical analysis of tile water nitrate concentrations has been performed by Kevin Kuehner (MDA). Statistical analysis was performed with data collected from 6 fields without cover crops and 12 fields with cover crops planted between the years 2019-2024. Planting histories and approximate fertilizer applications for these fields are outlined in Table 16. A total of 984 samples typically collected between March and November were analyzed.

Table 16. Field management details of agricultural fields sampled in the Rice Creek project. Average applied N rates are approximate (K, Kuehner).

ID	Covers	Drainage Ac.	2017	2018	2019	2020	2021	2022	2023	2024	Avg N Rate (lb/ac)	Manure N
11	No	35	corn	soy	corn	soy	corn	soy	corn	corn	140	
15	No	8	corn	soy	corn	soy	corn	soy	corn	soy		
14	No	51	corn	soy	corn	soy	corn	soy/corn	corn	corn		
18	No	80						soy	corn	soy		
12	No	28	corn	soy	corn	soy	corn	soy	corn	soy	170	Dairy
13	No	40	corn	soy	corn	soy	corn	soy	corn	soy	170	Dairy
2	Yes	53		corn	corn	soy	soy	corn	soy	corn	130	
17	Mixed	33	soy	corn	soy	corn	soy	corn	soybean	corn	120	
19	Yes	80	corn	soy	corn	soy	corn	soy	corn	soy	153	
3	Mixed	110	corn+soy	corn+soy	corn+soy	corn+soy	corn+soy	soy	soy	corn+soy	140	
16	Mixed*	40						trees/grass	trees/grass	trees/grass		
6	Yes	40	corn	corn	soy	corn	soy	corn	soybean	corn	141	
9	Yes	60	corn	soy	corn	soy	corn	soy	corn	soy	153	
10	Yes	20	corn	soy	corn	soy	corn	soy	corn	soy	153	
8	Yes	33	corn	soy	corn	soy	corn	soy	corn	orn/smgrai	147	
7	Yes	31	corn	corn	soy	corn	soy	soy	corn	corn	146	
20	Yes	45						corn	soy	corn		
21	Yes	15						soy	corn	soy		
	*mixed with tree land covers											

Nitrate loads in tiled watersheds are highly sensitive to precipitation. Years with higher precipitation often lead to higher overall nitrate loads, while dry years tend to allow nitrate to accumulate in the soil, which is then released during subsequent wet periods. It is important to consider precipitation patterns when analyzing nitrate data.

During the study period of the Rice Creek project, precipitation has deviated from the 30-year normal, Figure 44. The beginning of the project period, 2019, was 59% wetter than the 30-year normal. Then 2020, 2021, and 2023 were drought years with conditions 10%, 20%, and 12% dryer than the 30-year normal, respectively. Precipitation in 2022 and 2024 were closer to the 30-year normal. An average or wet year following a prolonged dry period may result in a N flushing effect.

Figure 44. Annual precipitation departure from normal compared to the 30-year normal (34.6", 1991-2020) during the study period (year 2018 included for reference). Weather station data was obtained from the International Airport near Rochester, MN (K. Kuehner).

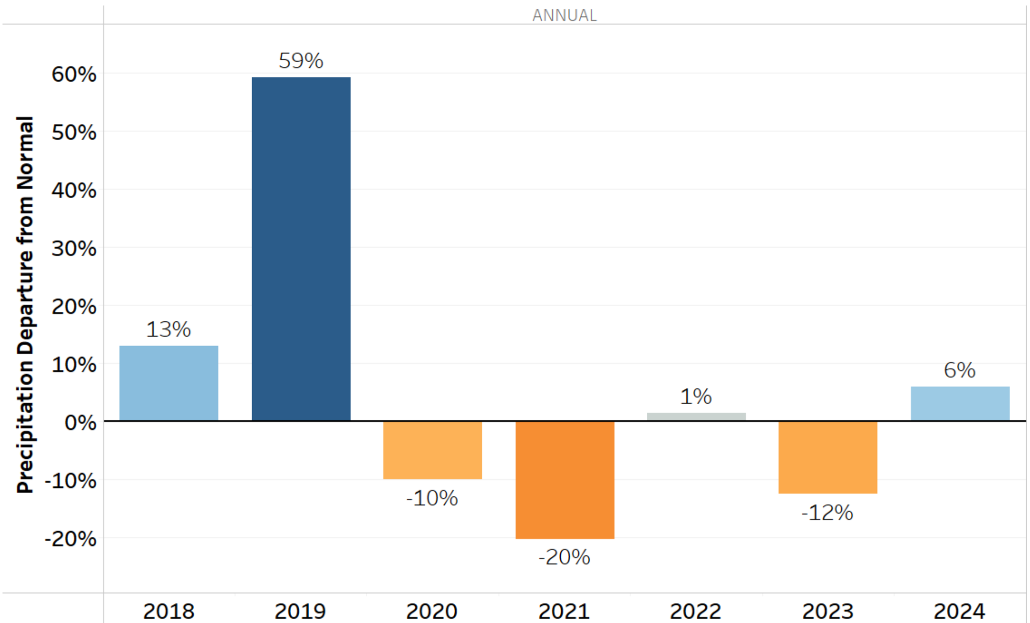


Figure 45 and Figure 46 are box plots comparing nitrate concentrations from subsurface tile samples from fields with cover crops planted and those without cover crops planted. The blue shaded box displays the upper and lower quartiles while the black horizontal line represents the median. The whiskers represent the maximum and minimum values and asterisks represent outliers. Data reflects 984 samples collected between 2019-2024 and represents six fields without cover crops planted and 12 fields with cover crops planted. Median estimated difference in Figure 46 analysis is 3.9 mg/L calculated using a nonparametric Mann-Whitney test, p=<0.001. These figures clearly show that tile water collected from the edge of fields with cover crops planted have lower nitrate concentrations than fields with no cover crops planted in Rice Creek Subwatershed. On average, fields with cover crops planted have 27% less nitrate in their tile drainage.

Figure 45. Box plot of subsurface tile nitrate concentrations from fields with and without cover crops in Rice Creek. N=984, years 2019-2024.

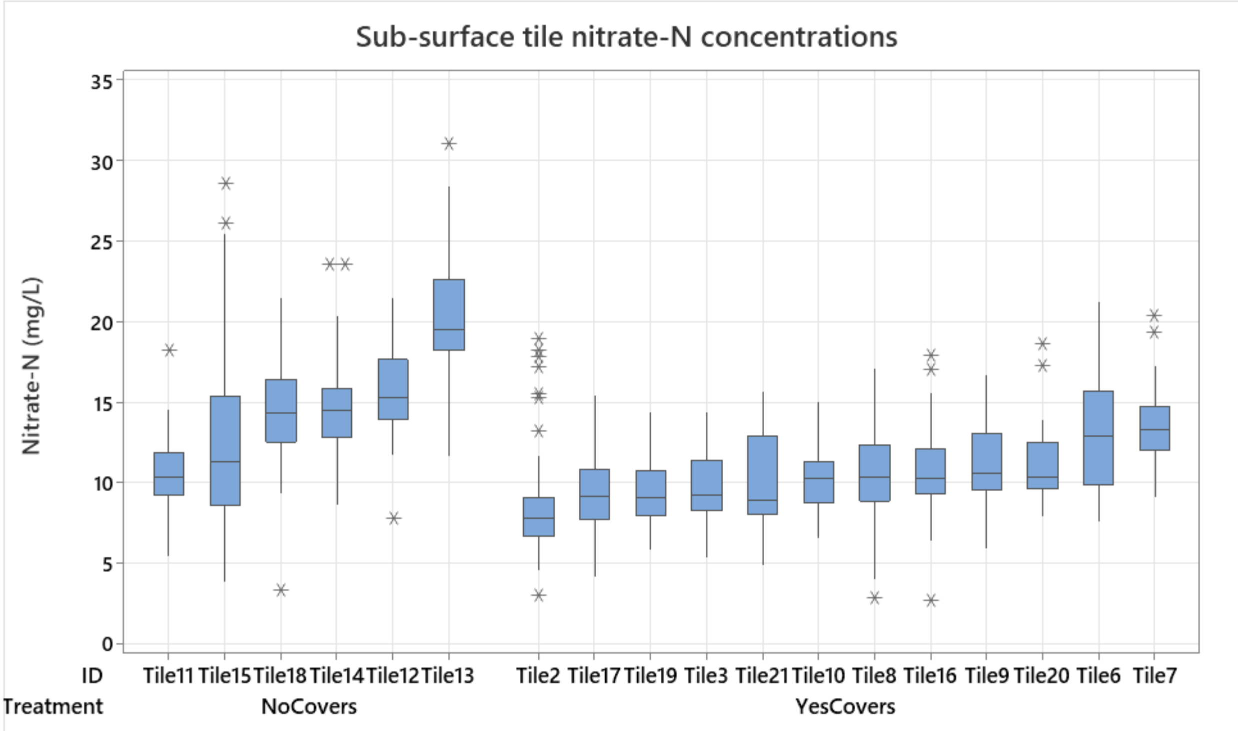
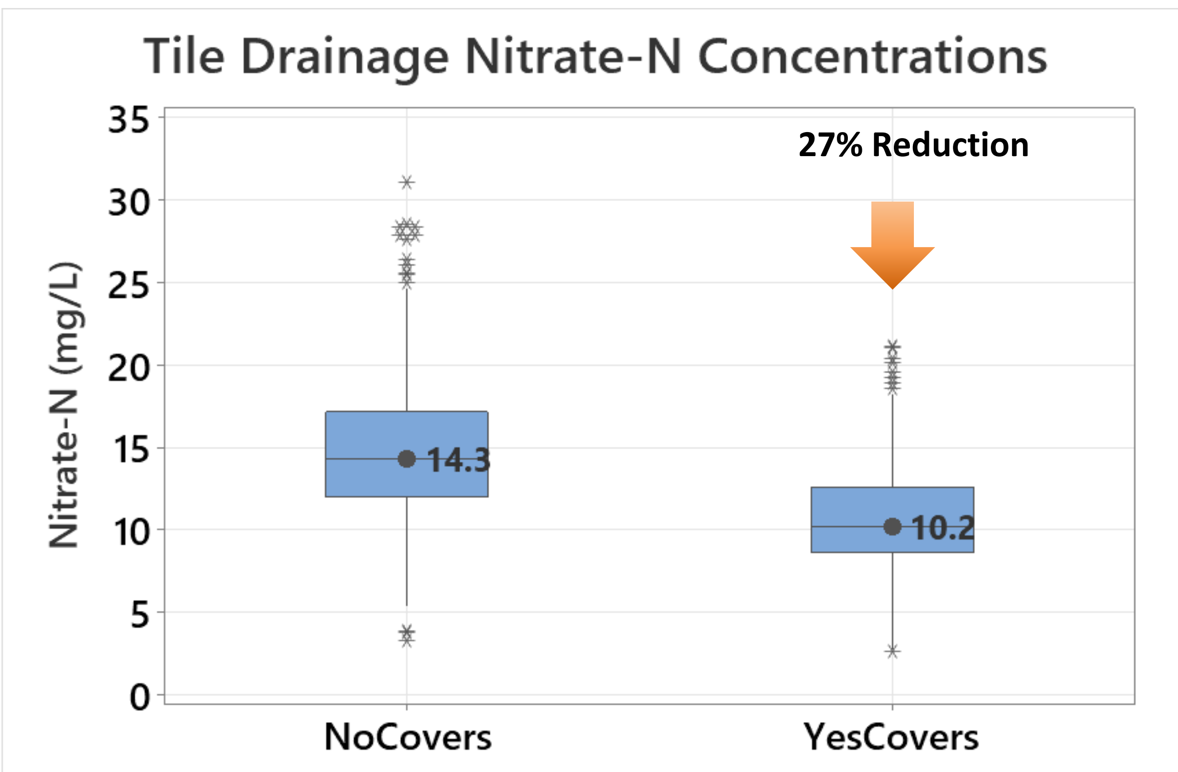


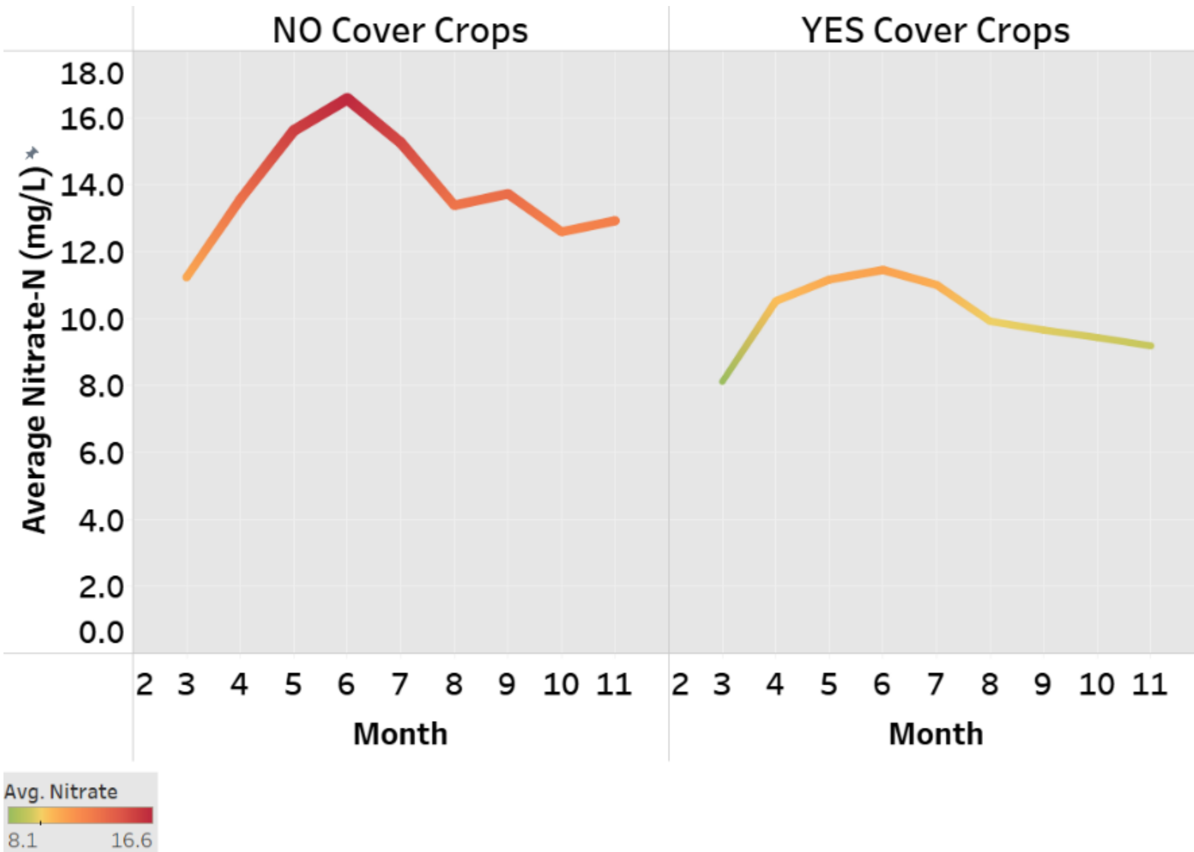
Figure 46. Box plot comparing synoptic grab sample tile nitrate concentrations collected from fields with and without cover crops planted. N=984, 2019-2025.



The monthly averages, Figure 47, further confirm that fields with cover crops planted have lower average concentrations in every month. 10 mg/L is the state and federal drinking water limit for nitrate.

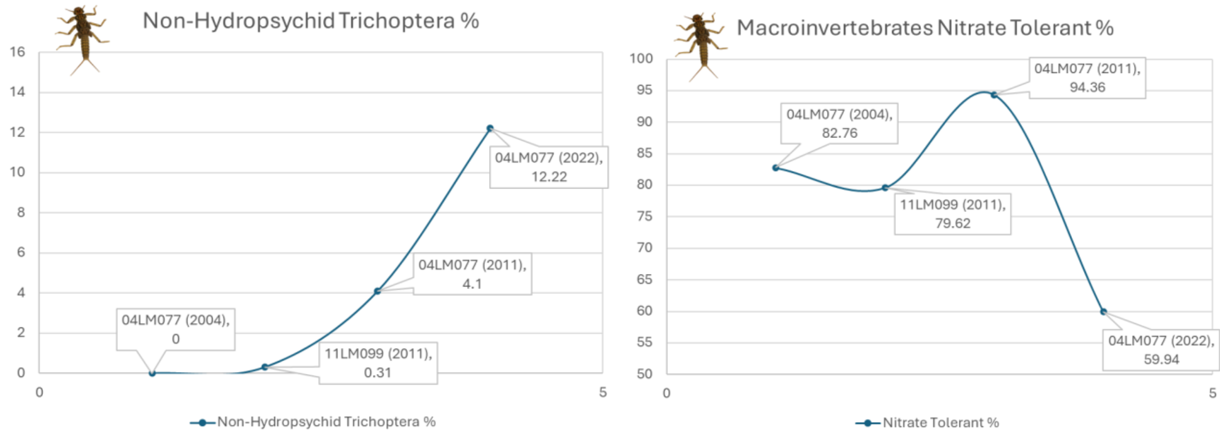
Monthly average nitrate concentrations were always above 10 mg/L for fields with no cover crops planted, with nearly all values above 12 mg/L and even reaching 17 mg/L in June during the study period examined. The monthly average nitrate concentrations in tile water from fields with cover crops planted are above 10 mg/L in April through July, with a maximum just below 12 mg/L in June. Additionally, the peak nitrate concentration occurred during the critical months of May and June, before conventional crops of corn and soybeans are typically well established. This yearly peak nitrate concentration was muted for the fields with cover crops planted showing less nutrient loss from the fields with cover crops planted.

Figure 47. Average monthly tile nitrate concentration comparing fields with and without cover crops planted (2019-2025).



This project provides a wealth of data demonstrating the benefits of planting cover crops to reduce nitrate leaving agricultural fields and protect water resources. Beyond the water chemistry aspect, 2022 DNR fish surveys estimate the number of adult Brook Trout more than doubled from their 2018 estimate (DNR, 2022). They note that the trout population in Rice Creek is healthy despite low water in recent years. MPCA's biological sampling in 2022 and 2023 show biological indicators improving as well, specifically macroinvertebrates. Figure 48 indicates increasing caddisflies, the most sensitive macroinvertebrate species, as well as decreasing percent nitrate tolerant macroinvertebrate species. Tile drainage and stream water sampling will continue in Rice Creek to further understand the impact of planting cover crops in this watershed. The commitment of local farmers and the staff at Rice SWCD and Clean River Partners are key to the success of this project.

Figure 48. Left - Percent nonhydropsychid trichoptera (caddisflies); Right - Percent nitrate tolerant macroinvertebrates.



7.3 Habitat improvement and stream restoration

While the Clean Water Fund—primarily through Watershed-Based Implementation Funding (WBIF)—provides critical support for reducing pollutant loading, it is only one part of the broader effort needed to sustain aquatic systems in the Cannon River Watershed. The Lessard-Sams Outdoor Heritage Council (LSOHC) appropriations play a complementary role by directly funding habitat restoration and enhancement. These investments target in-stream and riparian conditions that shape the physical and biological integrity of trout streams, improving habitat complexity, thermal regime, and connectivity. In doing so, LSOHC-funded work supports not just fish populations but the aquatic invertebrate communities that underpin stream health, reinforcing the ecological gains achieved through water quality improvements.

The following habitat improvement projects have been completed recently or are planned in the watershed:

- Trout Brook (Miesville Ravine County Park)
  - 2019 MNTU Habitat Improvement project (HI) Phase 1 constructed.
  - 2023 MNTU Maintenance repairs of Phase 1 HI as they begin Phase 2
  - 2023 MNTU HI Phase 2 constructed.
  - In 2024 minor repairs as the project settled, with vegetation mowing and invasive species treated. U of MN helps replant snowy campion (protected plant species mitigation)
  - In 2025 mowing and invasive species were treated. U of MN monitors replanted snowy campion.

The efforts in Trout Brook demonstrate the importance of long-term stewardship following initial construction. Habitat restoration is not a one-time activity; it requires sustained maintenance, adaptive management, and monitoring to ensure ecological function is achieved and maintained. The integration of protected species mitigation and native vegetation reestablishment highlights how habitat projects can support both aquatic and terrestrial biodiversity. Protecting the surrounding land – such as within Miesville Ravine County Park – has been critical to the success of these efforts, as intact riparian corridors reduce sediment and nutrient inputs, stabilize streambanks, and provide resilient habitat for trout and other species.

- Little Cannon River (LCR)
  - MNTU, Great River Greening, and Clean River Partners are scheduled to receive funding July 1, 2026, from their most recent LSOHC proposal. This will allow the Partners to finish the design and get permitting completed for a 4.5-mile section of the LCR for a Natural Channel Design style habitat project that will result in 5.5 miles of re-meandered trout stream.

This planned project represents a significant investment in restoring natural stream processes that have been altered by historical channelization. Re-meandering the stream will reconnect the river to its floodplain, reduce flow velocity, improve in-stream habitat complexity, and enhance water quality by reducing erosion and sediment transport. However, the long-term success of this effort depends not only on in-channel restoration but also on protection of adjacent lands. Securing conservation easements, restoring riparian buffers, and implementing compatible land use practices in the surrounding watershed are essential to prevent future degradation. Without these protections, restored channels can quickly become unstable due to upstream runoff, altered hydrology, and continued nutrient loading.

Across the watershed, these projects underscore a broader principle: habitat restoration and land protection must go hand in hand. While in-stream habitat improvements can yield immediate ecological benefits, their durability is directly tied to the condition of the surrounding landscape. Protecting sensitive areas, restoring native vegetation, and reducing external stressors such as nutrient pollution and altered hydrology are critical to sustaining coldwater fisheries and overall ecosystem health. Strategic land protection – through public ownership, conservation easements, or targeted partnerships – ensures that investments in habitat restoration provide lasting ecological, recreational, and water quality benefits.

7.4 Groundwater Protection Rule

Minnesota's Groundwater Protection Rule (GPR) became effective in 2019 and is designed to protect Minnesota's groundwater from nitrate pollution and ensure safe drinking water. It restricts N fertilizer applications during the fall and on frozen soils in areas vulnerable to contamination. The rule targets regions where public water supply wells show elevated nitrate levels and promote BMPs and alternative management tools (ATMs) to reduce nitrate levels. The rule is divided into two parts: Part 1 limits fertilizer use in areas with vulnerable groundwater or near municipal well zones, and Part 2 addresses areas where nitrate levels are already high, using a sliding scale of voluntary and regulatory actions to mitigate contamination.

Farmers in affected regions are encouraged to collaborate with local advisory teams, including agronomists and community members, to implement BMPs and other science-based practices. More information is available through the Groundwater Protection Rule webpage and the Vulnerable Groundwater areas map web page. Areas subject to fall application restrictions are posted annually on January 15. The webpage also includes details about local advisory teams and mitigation level determinations for areas impacted by elevated nitrate concentrations.

Large portions of Dakota and Goodhue counties have vulnerable groundwater and therefore restrictions on fertilizer application in the fall. Smaller portions of Rice, Steele, and Le Sueur counties also have vulnerable groundwater.

7.5 Updated Feedlot General NPDES and SDS Permit

In January 2025, the MPCA finalized updates to the National Pollutant Discharge Elimination System (NPDES) and State Disposal System (SDS) general permits for large feedlot operations. These changes aim to enhance protections for Minnesota's water resources by reducing pollutants, particularly nitrates, from manure applications. Large feedlot operations in the bedrock dominated areas of southeast Minnesota will be required (starting in 2027) to implement BMPs aimed at mitigating nitrate leaching from fields that receive manure applications. The practices vary according to time of year and include:

- Applying manure to growing perennial or row crops.
- Planting a cover crop prior to or within 14 days of application.
- N stabilizers.
- Ensuring perennial crops are included in the rotation at least two years within any five-year period (MPCA feedlots website).

8. Goals and strategies to meet water quality standards and fully supporting uses

8.1 Watershed Plans

Three main types of reports address the goals and strategies to meet water quality standards in the Cannon River Watershed. These three reports are complementary and logically sequenced: *Cannon River Watershed TMDL (2017), Cannon River WRAPS (2016)*, and *Cannon River CWMP (2020)*. Sources of pollution have not changed significantly since these reports were published; therefore, the recommendations of this WRAPS Update are similar to those provided in previous reports.

TMDL	Defines numeric pollutant reductions required – regulatory foundation
WRAPS	Identifies where and how to achieve reductions – technical targeting
CWMP	Establishes funding, governance, and 10-year implementation framework – operational implementation

The 2017 TMDL identifies widespread impairments across the basin, including 30 lakes with P impairments and 41 stream reaches impaired by bacteria, chloride, nitrate, and TSS. The highest pollutant loading occurs in agriculturally dominated southern and western subwatersheds, where row crop production, tile drainage, and streambank erosion drive significant sediment and nutrient losses. Sediment is the primary transport mechanism for P, making erosion control central to water quality improvement.

To address these impairments, the TMDL and 2016 WRAPS emphasize targeted, watershed-wide implementation of BMPs, prioritizing high-loading subwatersheds. Key strategies include stabilizing streambanks and channels, reducing field erosion through cover crops and conservation tillage, and installing edge-of-field practices like buffers and sediment basins. Nutrient reductions focus on improved fertilizer and manure management, along with tile drainage practices such as bioreactors and saturated buffers. Bacteria reductions center on livestock exclusion, septic system upgrades, and manure management improvements. These recommendations are reinforced and expanded in the CWMP, which prioritizes and integrates water quality, habitat, groundwater, and local implementation readiness into a coordinated, adaptive approach.

All three of these reports highlight the following pollutant reduction strategies:

Agricultural BMPs

- Conservation tillage
- Cover crops
- Grassed waterways and WASCOBs
- Structural erosion control

These are central to reducing sediment and P loads.

Riparian Buffers and Perennial Vegetation

Maintaining or restoring buffers to reduce sediment and nutrient runoff are emphasized.

Nutrient Management

Improved fertilizer and manure management are consistently recommended to reduce P and N contributions.

Wastewater and MS4 Compliance

The TMDL assigns WLAs to permitted facilities. WRAPS references NPDES permit implementation, and the CWMP incorporates regulatory compliance programs

Feedlot and Septic System Improvements

All three documents address bacteria and nutrient loading from feedlots and subsurface sewage treatment systems (SSTS).

Education & Outreach

Each report identifies stakeholder engagement and landowner outreach as essential to achieving load reductions.

8.2 Downstream Goals - 2025 Minnesota Nutrient Reduction Strategy

Minnesota completed its first NRS in 2014 to address excess N and P in water and updated it in 2025. The 2025 NRS evaluates 10 years of progress toward water quality goals, compiling the latest science, data, and strategies to reduce N and P. Developed with input from over 100 state, federal, and local partners and the University of Minnesota, it reflects updates in technology, land use, programs, monitoring, best practices, and knowledge of weather extremes.

The 2025 NRS reaffirms long-term, quantitative nutrient reduction goals at the state's downstream "state line" monitoring points, aligned with regional commitments such as the Gulf hypoxia goal. The core target remains a 45% reduction in both TN and TP loads relative to baseline conditions, with a target year of 2040. This applies to Minnesota's contributions to the Mississippi River system, where specific numeric load targets (e.g., ~50,088 metric tons TN and 2,544 metric tons TP annually) define the endpoint conditions at the state border. The strategy frames implementation over roughly a 15-year period (2025-2040), with ongoing monitoring used to track incremental progress toward these final load reductions (MPCA, 2026a).

To achieve these statewide targets, the strategy translates the state-line goals into "fair-share" reduction expectations for individual HUC-8 watersheds, ensuring that cumulative local actions add up to the required downstream reductions. Each HUC-8 watershed is assigned a specific load reduction target (for TN and TP) at its outlet, based on modeling of its contribution to overall basin loads. These watershed targets do not have separate fixed deadlines; instead, they are implicitly tied to the same 2040 planning horizon and are implemented through watershed-based planning cycles. The approach emphasizes phased, adaptive progress- prioritizing higher-loading watersheds first- while using tracking tools and monitoring to evaluate whether aggregated HUC-8 reductions are sufficient to meet the state-line goals by 2040 (MPCA, 2026a).

The Cannon River Watershed is assigned a 50% TN reduction (Figure 49; 2,179 metric tons) and a 32% TP reduction (Figure 50; 100 metric tons) as the "fair-share" reduction goals to help achieve the downstream commitments. These targets reflect both the watershed's relatively high nutrient contributions and its importance within the Mississippi River Basin. Achieving these goals in the Cannon River Watershed is essential for Minnesota to meet its overall nutrient reduction obligations.

Figure 49. Percent of recent average annual HUC-8 watershed TN load to be reduced to meet the final target loads of the NRS (MPCA, 2026a).

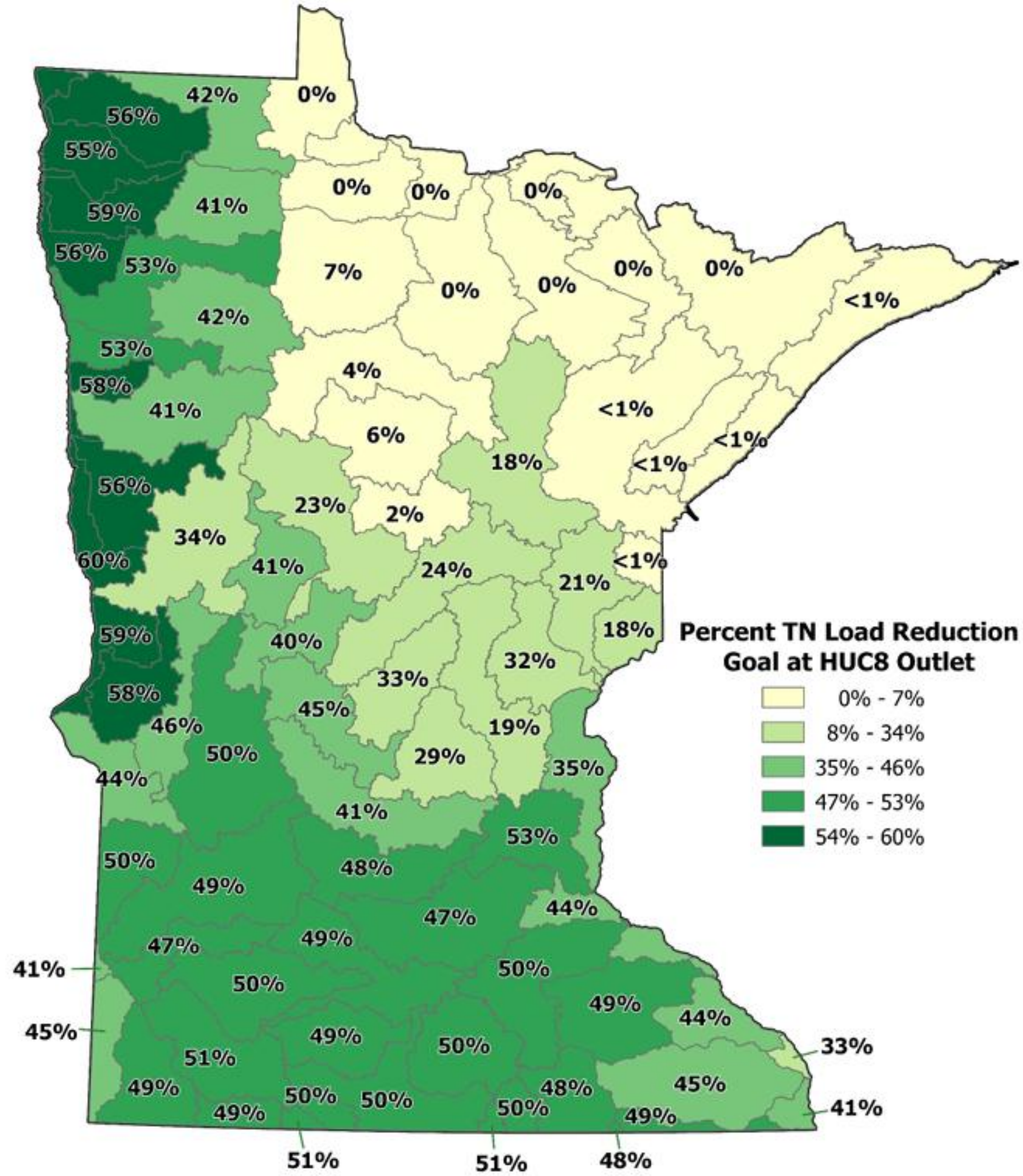
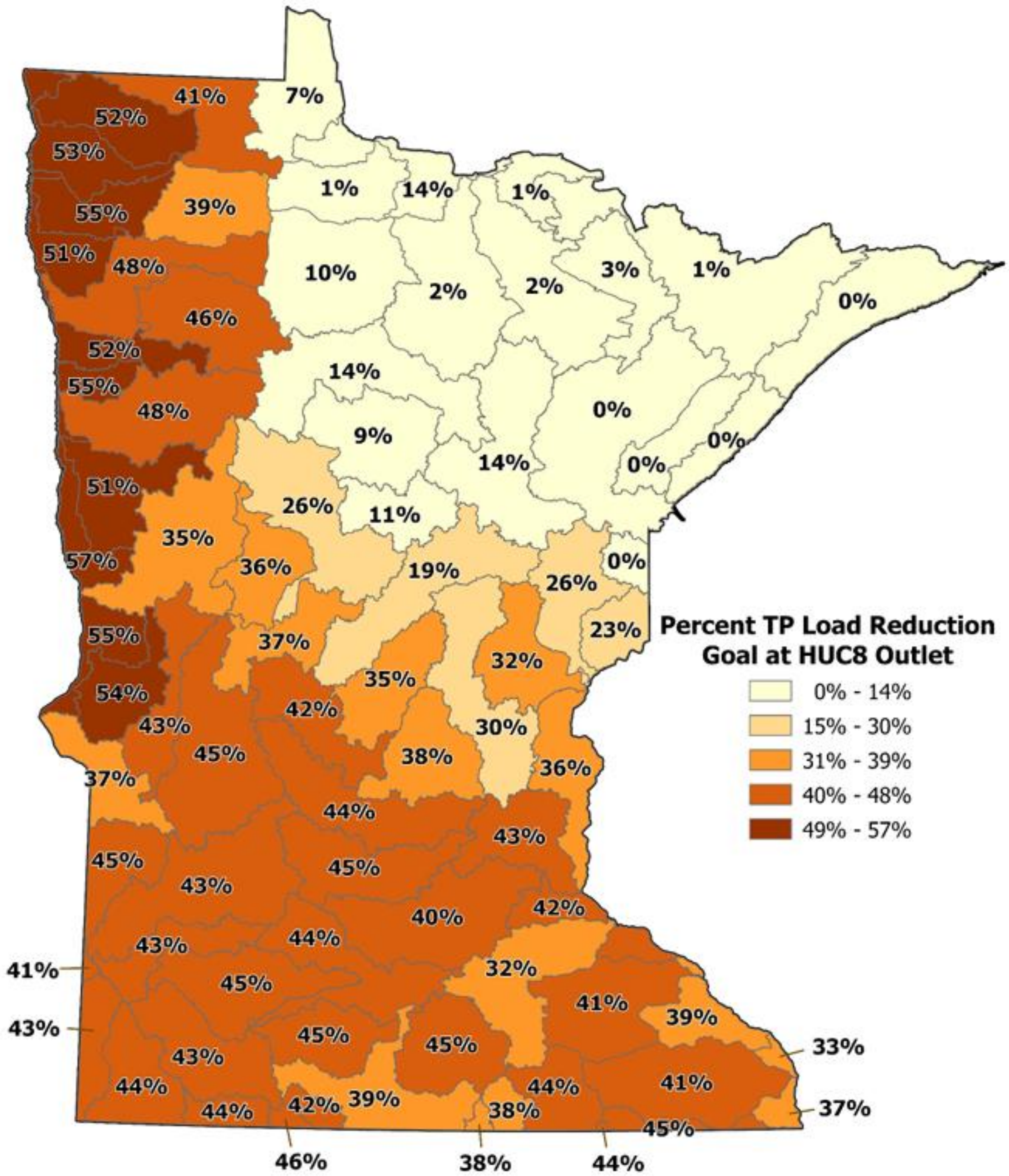


Figure 50. Percent of recent average annual HUC-8 watershed TP load to be reduced to meet the final target loads (MPCA, 2026a).



The strategy emphasizes that achieving these reductions will require widespread, targeted implementation of agricultural and land-use BMPs, since nonpoint agricultural sources dominate nutrient loading in southern Minnesota watersheds like the Cannon. Recommended actions include optimizing N fertilizer application (rate, timing, and method), expanding cover crops and perennial vegetation to reduce leaching, and converting marginal or riparian lands to buffers or perennial cover (MPCA, 2026a). These practices are intended to reduce nitrate losses through subsurface drainage while also addressing P transport via erosion and runoff.

The Cannon River's 50% TN and 32% TP reduction goals are not only numeric targets but also guideposts for coordinated, long-term changes in land management needed to meet both local water quality standards and downstream nutrient reduction commitments.

Chapter 5 in the NRS identifies a broad suite of proven cropland and landscape practices capable of significantly reducing N and P losses. Research shows that 22 practices reduce nitrate losses by 4% to 94% and 20 practices can reduce P losses by 5% to 75% or more. Achieving meaningful water quality improvements requires stacking multiple practices across the landscape.

The most effective and scalable practices for reducing nutrient pollution as presented in the NRS include:

- In-field nutrient management
    - Right rate, time, source, and placement of fertilizer and manure (4R practices)
    - Includes split applications, MRTN-based rates, and nitrification inhibitors
- Cover crops and continuous living cover (CLC)
    - Reduce nitrate leaching and improve soil health
    - Increase resilience to precipitation extremes
- Conservation crop rotations and perennial systems
    - Incorporating small grains, forage, or pasture
- Reduced tillage (e.g., strip-till)
- Water storage and treatment practices
    - Wetland restoration and construction
    - Drainage water recycling systems

These practices also provide co-benefits, including improved soil health, reduced erosion, flood mitigation, and increased farm resilience.

To meet statewide goals:

- Millions of acres must adopt nutrient-reducing practices
- One scenario estimates 17 million acres of additional implementation
- Emphasis is placed on lower-cost, scalable practices first, especially nutrient management and reduced tillage.

The Cannon River Watershed reflects many of the conditions described in the NRS, including intensive row crop agriculture, tile drainage, and increasing hydrologic connectivity, which drive both N and P loading.

1. Cropland practices (primary opportunity)
    a. The watershed is dominated by agricultural land use, making in-field nutrient management the most critical and scalable solution

    b. Cover crops, reduced tillage, and diversified rotations are especially important in:
        i. Tile-drained areas
        ii. Erosion-prone areas
2. Targeting High-Impact areas
    a. Practices should be prioritized in:
        i. High-loading subwatersheds (see updated HSPF modeling work)
        ii. Lower watershed areas with higher groundwater vulnerability
    b. Align with WRAPS prioritizes and TMDL reduction needs
3. Water storage and hydrology management
    a. Given documented increases in runoff and flashiness in the watershed:
        i. Wetland restoration, drainage water management, and floodplain reconnection are critical
    b. These practices reduce both
        i. Nutrient transport
        ii. Peak-flow driven erosion
4. Stream and channel processes
    a. Streambank erosion is a significant P source in the Cannon
    b. Priority practices include:
        i. Riparian buffers
        ii. Channel stabilization
        iii. Floodplain reconnection
5. Need for combined landscape-scale implementation
    a. No single practice will achieve TMDL or WRAPS goals
    b. Success requires:
        i. Stacking practices within fields and across watersheds
        ii. Coordinated implementation

8.3 Nitrate

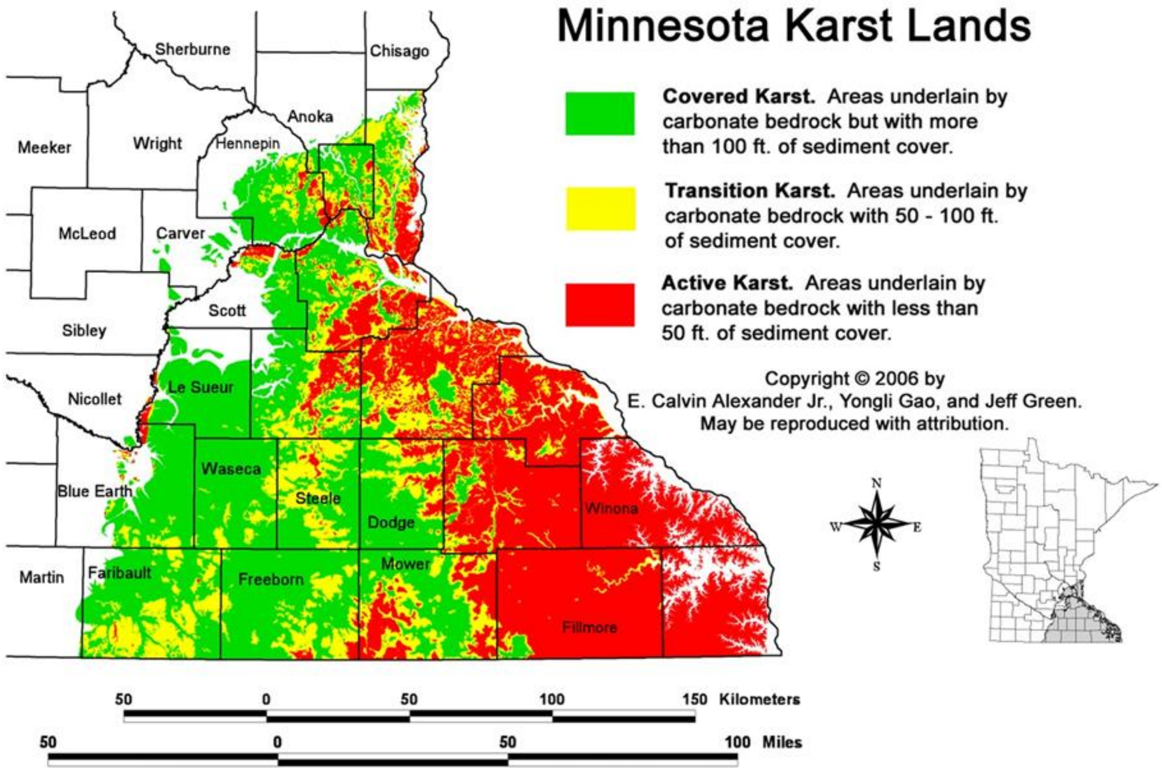
Southeast Minnesota Nitrate Strategies Collaborative Work Group

The Southeast Minnesota Nitrate Strategies Collaborative Work Group was convened by state agencies, including the MPCA, to address elevated nitrate levels in groundwater, surface water, and drinking water across the karst region of southeastern Minnesota. This region is particularly vulnerable due to shallow bedrock, sinkholes, and rapid connections between surface water and groundwater, allowing nitrate to move quickly through the system.

While much of the Cannon River Watershed is characterized by glacial till and less permeable soils (Figure 51), the southeastern and eastern portions of the watershed transition into karst-influenced terrain. These areas are generally located in:

- Lower Cannon River subwatersheds (Goodhue County)
- Areas near the Cannon River confluence with the Mississippi River
- Portions of the watershed with:
    - Thin soils over limestone bedrock
    - Increased presence of sinkholes and fractures
    - Rapid hydrologic connectivity between surface water and groundwater

Figure 51. Location of karst features in southeast Minnesota (E. Calvin Alexander, University of Minnesota).



The work group was intentionally structured as a collaborative, stakeholder-based body composed of residents and local leaders from eight southeastern Minnesota counties, supported by state agency representatives (MPCA, MDA, and MDH).

The group met monthly from July 2024 through June 2025 in day-long, in-person sessions designed to:

- Build a shared understanding of nitrate sources and impacts
- Incorporate scientific, technical, and local knowledge

- Deliberate and reach consensus on actionable strategies
- Develop recommendations for improving and accelerating nitrate reduction efforts

This structure emphasized cross-sector collaboration, bringing together agricultural, community, and environmental perspectives to develop broadly supported recommendations (Southeast Minnesota Nitrate Strategies Collaborative Work Group, 2025).

The work group recognized nitrate contamination as both a public health and environmental issue, with:

- Over 70% of nitrate originating from cropland, primarily fertilizer use
- Significant risk to private well users and community water supplies
- Ecological impacts to streams and rivers

The group emphasized that the region's karst geology makes source control critical, as nitrate readily leaches into groundwater.

The work group's recommendations focus on long-term, source-based reduction strategies, supported by improved coordination, funding, and implementation. Major strategy themes include (Southeast Minnesota Nitrate Strategies Collaborative Work Group, 2025):

1. Reduce nitrate at the source (agricultural practices) – Critical in row-crop dominated areas of the Cannon River Watershed, especially where soils are permeable of tile-drained and where groundwater connectivity is higher.
    a. Increase adoption of practices that reduce N loss, including:
        1. Improved fertilizer timing, rate, and application methods
        2. Cover crops and perennial vegetation to maintain living roots
        3. Diversified cropping systems
    b. Emphasis on keeping nutrients in the root zone and reducing leaching to groundwater
2. Expand and target conservation implementation
    a. Scale up proven practices that are currently underutilized
    b. Target implementation in highly vulnerable karst areas and priority drinking water supply zones
    c. Improve consistency and geographic coverage of conservation practices
3. Strengthening monitoring, data, and adaptive management
    a. Expand groundwater and surface water monitoring networks
    b. Utilize new tools (e.g., continuous nitrate sensors) to better understand trends and timing
    c. Improve data integration to support targeted decision-making
4. Enhance coordination, communication, and funding
    a. Improve alignment among state agencies, local governments, and partners

b. Increase funding and incentives for practice adoption

c. Strengthen outreach and engagement with landowners and communities

Groundwater vulnerability should be considered when targeting conservation practices. The 2017 MDH Cannon River GRAPS recommends prioritizing nutrient and manure management in areas with high groundwater pollution sensitivity, karst geology, and vulnerable drinking water supply areas. Incorporating these groundwater vulnerability considerations into watershed implementation can provide co-benefits for groundwater, drinking water, and surface water quality.

8.4 Modeled subwatershed loads

The 2015 Cannon River Watershed HSPF Model Development Project (LimnoTech, 2015) modeled key pollutant (TSS, TP, TN) loading in the watershed and the impact of several management scenarios. The baseline simulation represented conditions for the 1995-2012 time period. In 2026, the model was extended to include conditions through 2023, this extended model was also calibrated to provide the best representation of the watershed. The calibration was completed using three stations, one in the Lower Cannon – 103, one near the confluence of the Straight and Cannon Rivers – 802, and one in the Upper Cannon lakes area – 305. Figure 52 shows the relative modeled loading of TP and nitrate for the three calibration zones and Figure 53 shows the relative modeled loading of TP and TSS. The full model update report is available in Appendix E of this report.

The highest modeled loading catchments for both TP and nitrate (relative to each calibration zone) where nutrient reducing BMPs should be focused (Figure 52):

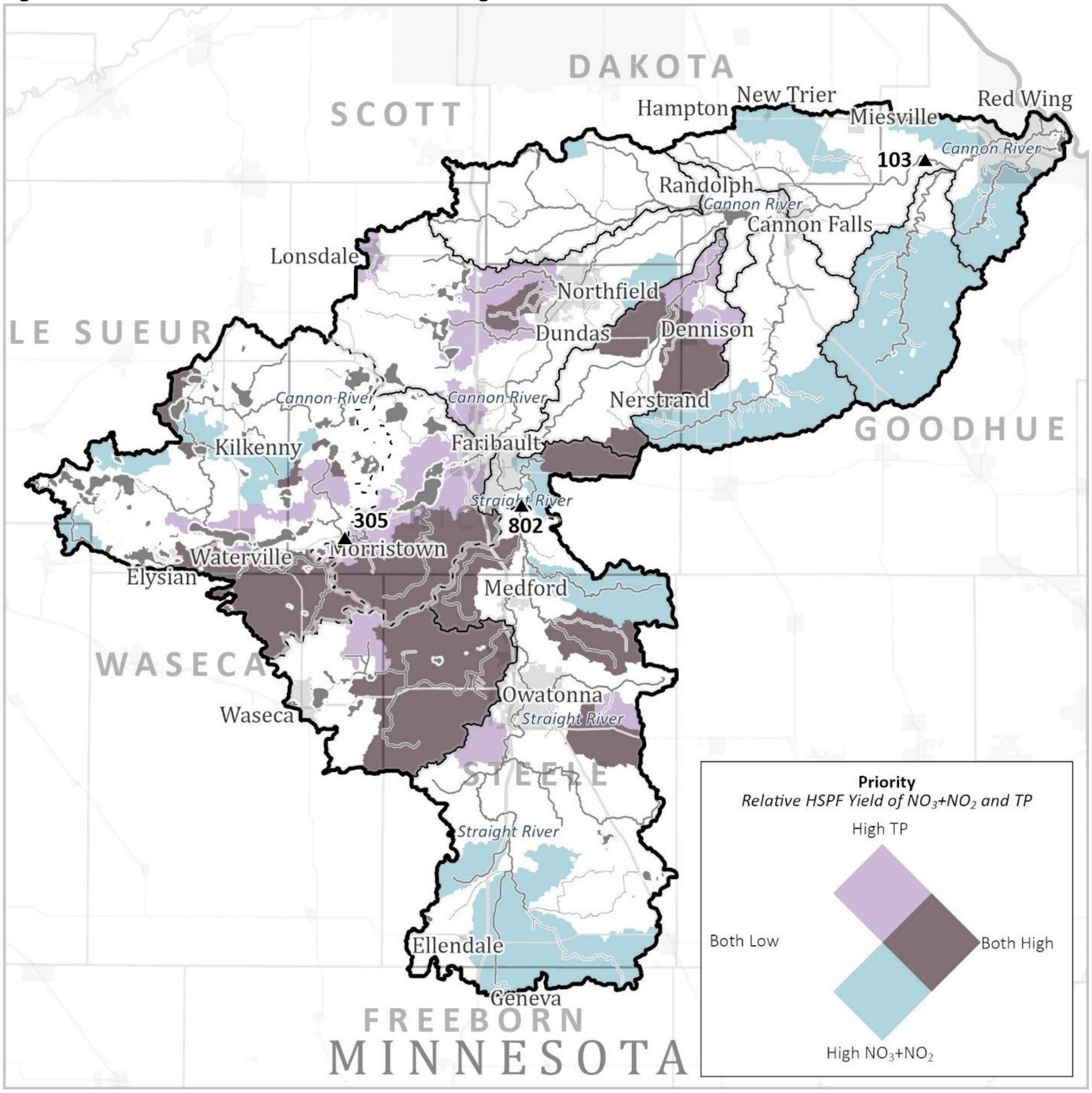
- Falls Creek
- Portions of Prairie Creek
- Rice Creek/Spring Brook
- Waterville Creek
- Mackenzie Creek
- Mud Creek
- Crane Creek
- Upper portion of Medford Creek
- Tributary to Maple Creek

Additionally, there are several catchments that are modeled to have high nitrate loading, including:

- Spring Creek
- Belle Creek
- Headwaters of Little Cannon River
- Trout Brook
- Rush Creek

- County Ditch 25
- County Ditch 64
- Headwaters of Straight River

Figure 52. Relative modeled TP and nitrate loading in three calibration zones.



The highest modeled loading catchments for both TP and TSS (relative to each calibration zone) where nutrient and sediment/erosion reducing BMPs should be focused (Figure 53):

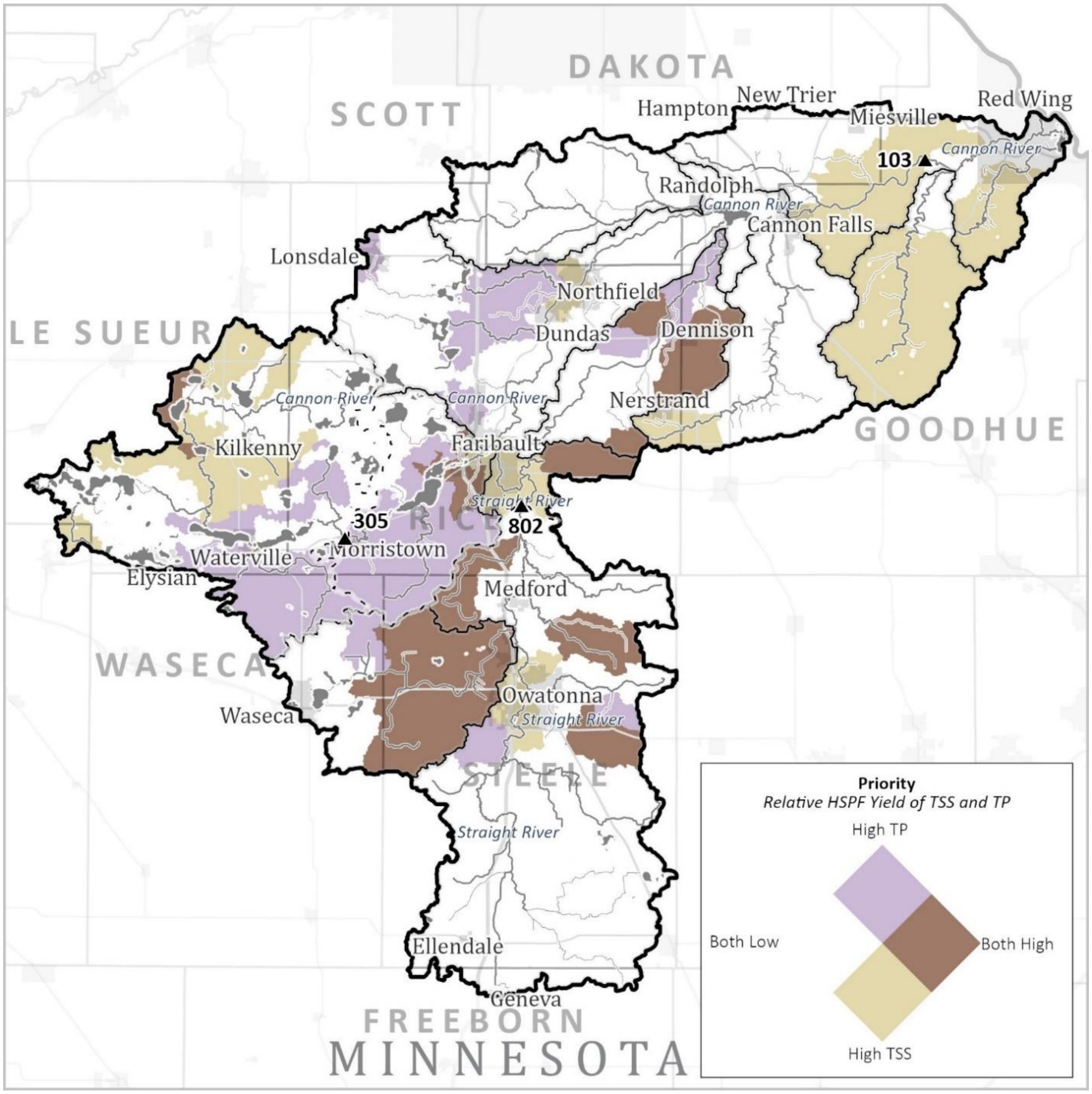
- Sections of Prairie Creek
- Falls Creek
- Mud Creek

- Crane Creek
- Upper portions of Medford Creek
- Tributary to Maple Creek

Additionally, there are a few catchments that are modeled to have high TSS loading, including:

- Spring Creek
- Belle Creek
- Trout Brook
- Lower Cannon River
- Headwaters of Little Cannon River
- Owatonna
- County Ditch 66
- Headwaters of Cannon River

Figure 53. Relative modeled TP and TSS loading in three calibration zones.



8.5 Protection

Waters fully supporting designated uses

Protecting unimpaired waters in the Cannon River Watershed is both an environmental and economic priority. Currently, 21 stream reaches and 6 lakes are fully supporting AQL and/or AQR uses, representing some of the most valuable and resilient resources in the watershed (Table 17). Maintaining these conditions is critical because once a water body becomes impaired, the cost, time, and effort required for restoration increase substantially. Restoration often involves intensive interventions – such as large-scale sediment reduction, nutrient management changes, and habitat restoration – while protection strategies can rely on more cost-effective measures like maintaining existing buffers, managing land use, and preventing new pollutant sources. In this sense, proactive protection provides a far greater return on investment than reactive restoration.

Prioritizing these high-quality waters also supports broader watershed goals by preserving ecological integrity, supporting recreation, and preventing the spread of impairments downstream. Effective protection strategies include conserving riparian corridors, enforcing shoreland regulations, protecting groundwater recharge areas, and promoting agricultural practices that minimize nutrient and sediment loss. By focusing on prevention in these 27 water bodies, partners can sustain existing beneficial uses while reducing future financial burdens and helping ensure that overall water quality goals are more achievable across the watershed.

Table 17. Cannon River Watershed water bodies fully supporting AQL and/or AQR uses.

Water body Name	Water body ID	Use(s) Fully Supported	County
Mud Creek	07040002-558	AQL	Dakota
Chub Creek, North Branch	07040002-566	AQL	Dakota
Unnamed creek (Trout Brook)	07040002-567	AQL	Dakota
Unnamed creek (Trout Brook)	07040002-580	AQR	Dakota
Cannon River	07040002-539	AQR	Goodhue
Unnamed creek	07040002-757	AQL	Goodhue
Whitewater Creek	07040002-776	AQL	Le Sueur
Rays Lake	40-0056-00	AQL	Le Sueur
Fish Lake	40-0051-00	AQL, AQR	Le Sueur
Roemhildts Lake	40-0039-00	AQL, AQR	Le Sueur
Unnamed creek (Spring Creek)	07040002-568	AQL, AQR	Rice
Falls Creek	07040002-704	AQL	Rice
Kelly Lake	66-0015-00	AQR	Rice
Dudley Lake	66-0014-00	AQL, AQR	Rice
Straight River	07040002-517	AQL	Steele
Maple Creek	07040002-519	AQL	Steele
County Ditch 64 (Straight River)	07040002-524	AQL	Steele
Unnamed Ditch	07040002-531	AQL	Steele
Straight River	07040002-535	AQL	Steele
Straight River	07040002-537	AQL	Steele
County Ditch 5	07040002-698	AQL	Steele
Unnamed creek	07040002-726	AQL	Steele
Crane Creek	07040002-744	AQL	Steele

Water body Name	Water body ID	Use(s) Fully Supported	County
Unnamed creek (Straight River)	07040002-748	AQL	Steele
Turtle Creek	07040002-771	AQL	Steele
Turtle Creek	07040002-772	AQL	Steele
Beaver Lake	74-0023-00	AQL, AQR	Steele

Groundwater dependent

Protecting groundwater-dependent water bodies is a critical extension of this broader protection strategy, particularly for the Cannon River Watershed's coldwater resources. The watershed contains six primary trout streams that depend on consistent outputs of cold, clean groundwater to sustain flow and maintain suitable habitat conditions, shown in Figure 54. These systems are especially sensitive to changes in both water quality and quantity, making them highly vulnerable to nutrient pollution, sedimentation, and hydrologic alterations. Table 18 lists these coldwater resources and their existing impairments, as well as any trends found in the water quality data. Many of these streams exhibit impairments for nitrate, turbidity, bacteria, and biological condition, underscoring the need for heightened protection efforts. Because these streams are sustained by regionally sourced groundwater, any degradation of aquifer quality or reductions in recharge can directly impact stream health, temperature regimes, and aquatic communities.

Table 18. Class 2A coldwater habitats in Cannon River Watershed.

Water body Name	Water body ID(s)	County	Impairment(s)	Trend
Unnamed Creek (Rice Creek/Spring Brook)	07040002-562, -557	Rice	*E. coli*, nitrate, turbidity, Macroinvertebrate	
Belle Creek	07040002-740, -739	Goodhue	*E. coli*, turbidity	
Little Cannon River	07040002-526, -589	Goodhue	*E. coli*, nitrate, turbidity, Macroinvertebrates, Fish	
Spring Creek	07040002-569	Goodhue	*E. coli*, turbidity	Degrading clarity
Pine Creek	07040002-520	Dakota/Goodhue	Nitrate	
Trout Brook	07040002-567	Dakota	Nitrate, Macroinvertebrates	

The importance of protecting these systems extends beyond ecological value, as the same groundwater that supports trout streams is also the primary source of drinking water and irrigation in the region. Impairments observed in these streams often reflect broader groundwater quality issues, particularly elevated nitrate concentrations. Minnesota Geological Survey Information Circular 48 emphasizes studies specific to Minnesota and the Upper Midwest showing the natural nitrate background concentration is one mg/L or less and values above one mg/L indicate groundwater quality has been impacted by human activity. As discussed in Section 5.6, nitrate can persist in groundwater for extended periods, with residence times varying based on aquifer depth and mixing. As a result, it is essential to both protect groundwater recharge areas and continue expanding implementation of BMPs that reduce nitrate leaching – such as improved nutrient management, cover crops, and perennial vegetation.

Additional groundwater dependent habitats are shown in Figure 55, including springs, calcareous fens, unique wetlands and plant communities, and groundwater dominated lakes. These sensitive habitats also require protection. Sustained and increased effort is necessary not only to prevent further degradation, but to gradually improve groundwater quality and ensure long-term viability of these sensitive, high-value ecosystems.

Figure 54. Class 2A Cold water habitats and protected Trout streams and tributaries in Cannon River Watershed.

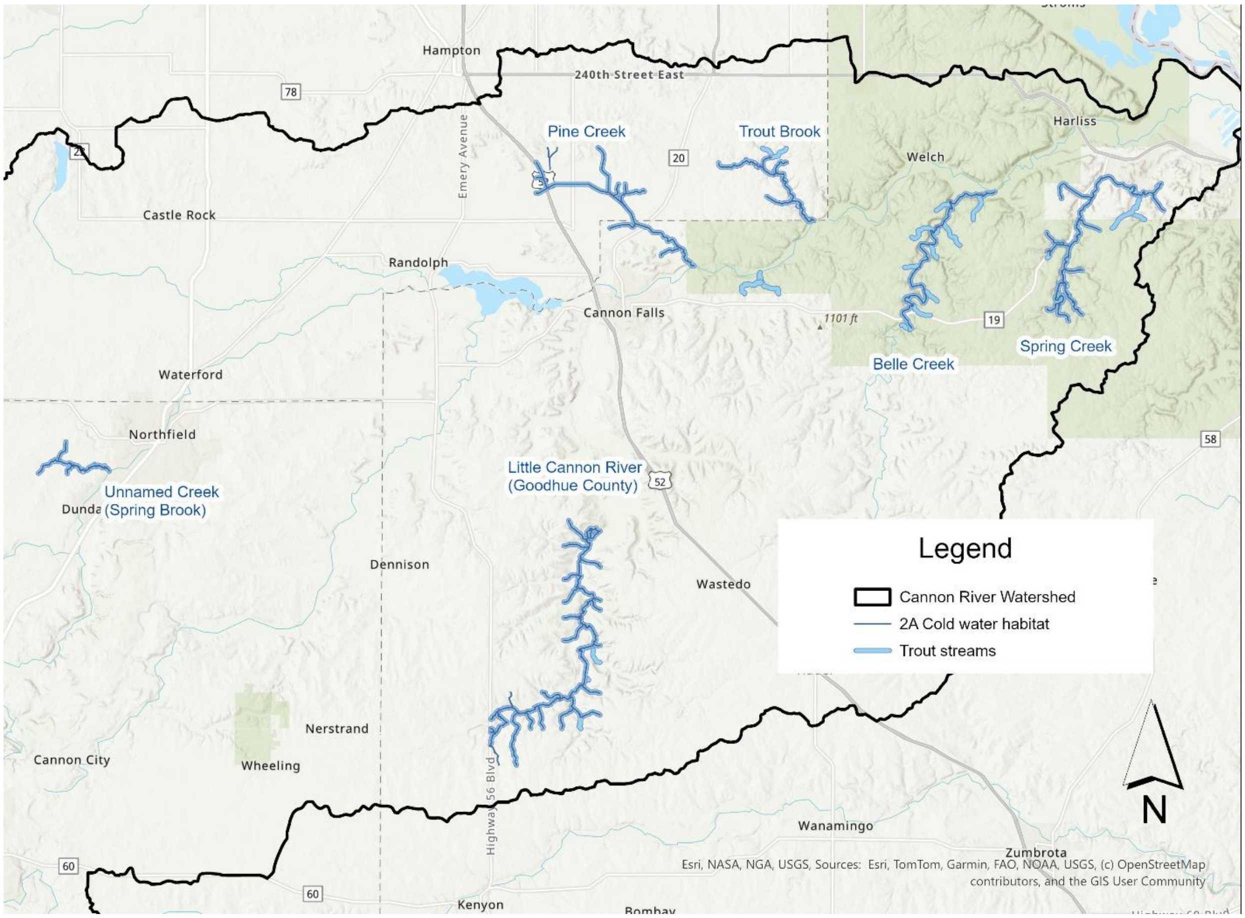


Figure 55. Groundwater dependent habitats in Cannon River Watershed.

9. Environmental justice

The MPCA is committed to environmental justice, the fair treatment and meaningful involvement of all people, regardless of race, color, national origin, or income, concerning the development, implementation, and enforcement of environmental laws, regulations, and policies. The MPCA is committed to making decisions that do not place disproportionate pollution burdens on these communities.

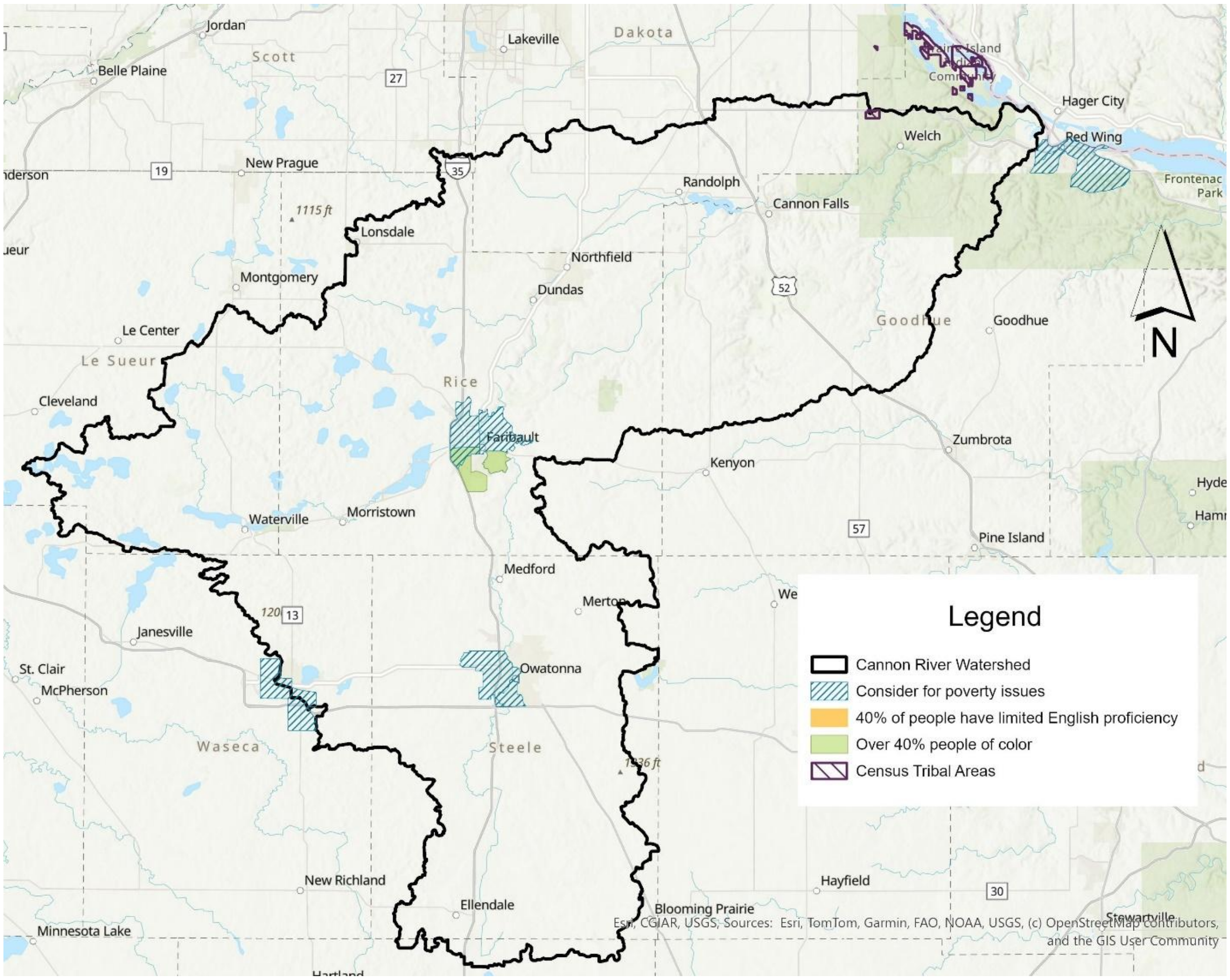
The MPCA uses environmental justice principles when reviewing and issuing grants to reduce pollution and improve air quality. Environmental justice is part of the decision-making process when writing new or renewal permits for facilities. The framework consists of strategies that integrate environmental justice into the MPCA's regulatory, monitoring, and assistance programs. It outlines the procedures, resources, and tools needed to support integration. This includes:

1. Identify areas where low-income Minnesotans, people of color, and others may be experiencing more harm or are more susceptible to environmental conditions as areas of focus for environmental justice action.
2. Modify the approach and increase work to address environmental justice issues through better understanding the sources of pollution, reducing sources through regulatory authority and influence, and providing education and public participation and engagement of people around the actions and decisions that affect them

Environmental justice areas in the Cannon River Watershed include low-income communities around the cities of Faribault, Owatonna, and Waseca as well as the Prairie Island Indian Community near Welch (Figure 56). Additionally, areas around Faribault have greater than 40% people of color. Many studies demonstrate the low-income neighborhoods and communities of color have higher potential exposures to outdoor air pollutants and have more sources of pollution. In addition, the social, economic, and health inequities that these populations face can make them more vulnerable to the effects of pollution.

These communities can experience barriers that can lead to a lack of participation in environmental restoration and protection efforts. This could be true for reasons of cost, time commitment, travel, and lack of feeling ownership of the efforts. Low-income communities often face challenges that deter their participation in environmental conservation efforts. Addressing these challenges requires a comprehensive approach that includes improving access to resources, education, and addressing systemic injustices as implementation efforts proceed. The work of connecting with and identifying the needs and desired future conditions of these communities is on-going.

Figure 56. Map of environmental justice areas in the Cannon River Watershed.



10. Public participation

Public notice for comments

An opportunity for public comment on the draft WRAPS report was provided via a public notice in the *State Register* from June 29, 2026, through July 29, 2026. There were three comments received and responded to as a result of the public comment period.

11. References

Bacigalupi, J., D. F. Staples, M. T. Treml, and D. L. Bahr. 2021. Development of fish-based indices of biological integrity for Minnesota lakes. Ecological Indicators 125:107512.

Barry, J.D., Runkel, A.C., and Tipping, R.G., 2026, Updated nitrate guidance for Minesota: Minnesota Geological Survey Information Circular IC-48

Cross, T. K., and P. C. Jacobson. 2013. Landscape factors influencing lake phosphorus concentrations across Minnesota. Lake and Reservoir Management 29:1–12.

Dakota Soil and Water Conservation District (Dakota SWCD). 2017. Trout Brook Spring Nitrate Monitoring Program.

Dakota Soil and Water Conservation District (Dakota SWCD). 2022. North Cannon River Watershed 2022 Water Monitoring Report.

Dillon, P.J., and F.H. Rigler. 1974. A test of a simple nutrient budget model predicting the phosphorus concentration in lake water. *Journal of the Fisheries Research Board of Canada* 31: 1771–1778.

Dustin, D. L., and B. Vondracek. 2017. Nearshore habitat and fish assemblages along a gradient of shoreline development. North American Journal of Fisheries Management 37:432–444.

Emmons & Oliver Resources, Inc. / Cannon River Watershed Joint Powers Board (CRWJPB). 2020. Cannon River Comprehensive Watershed Management Plan.

Engstrom, D. R., Heathcote, A. J., Burge, D. R. L. 2019. Paleolimnological Study of Phosphorus-Impaired Lakes in the Cannon River Watershed.

Groten, J.T., and Alexander, E.C. 2013. *Karst Hydrogeologic Investigation of Trout Brook, Dakota County, Minnesota*. University of Minnesota, Department of Earth Sciences, Minneapolis, Minnesota.

Jacobson, P. C., T. K. Cross, D. L. Dustin, and M. Duval. 2016. A fish habitat conservation framework for Minnesota lakes. Fisheries 41:302–317.

Kuehner, K.J., Runkel, A.C. & Barry, J.D. Informing nitrate concentration trends: estimating groundwater residence time in a karstic, multiaquifer system using anthropogenic tracers (Minnesota, USA). *Hydrogeol J* **33**, 167–192 (2025). https://doi.org/10.1007/s10040-024-02871-2

LimnoTech. 2015. Cannon River Watershed HSPF Model Development Project. https://www.pca.state.mn.us/sites/default/files/wq-ws4-23d.pdf

Metropolitan Council. 2023. Cannon River Pollutant Trend Update- 2023.

Minnesota Department of Health (MDH). 2017. *Cannon River Watershed (07040002) Groundwater Restoration and Protection Strategies Report.* https://www.health.state.mn.us/communities/environment/water/docs/cwf/grapscrwfinal.pdf

Minnesota Department of Natural Resources (DNR). 2015. *Minnesota Lake Watershed Delineation Project.* Minnesota Department of Natural Resources, Division of Ecological and Water Resources, St. Paul, Minnesota.

Minnesota Department of Natural Resources (DNR). 2019. *Score the Shore: A Citizen-Based Shoreland Habitat Assessment.* Minnesota Department of Natural Resources, St. Paul, Minnesota.

Minnesota Department of Natural Resources (DNR**).** 2021. *Lake Vulnerability to Nutrient Loading in Minnesota.* Minnesota Department of Natural Resources, St. Paul, Minnesota.

Minnesota Department of Natural Resources (DNR). 2022. Fisheries Management, Stream Survey Report: Spring Brook.

Minnesota Department of Natural Resources (DNR). 2023. Evaluation of Hydrologic Change (EHC) Technical Summary: Cannon River Watershed.

Minnesota Department of Natural Resources (DNR). 2026. Cannon River Watershed Stressor Identification Report – Lakes.

Minnesota Pollution Control Agency (MPCA). 2007. Lower Cannon River turbidity TMDL report. https://www.pca.state.mn.us/sites/default/files/wq-iw9-04e.pdf

Minnesota Pollution Control Agency (MPCA). 2009. Lower Cannon River turbidity TMDL implementation plan. https://www.pca.state.mn.us/sites/default/files/wq-iw9-04c.pdf

Minnesota Pollution Control Agency (MPCA). 2014. Cannon River Watershed Monitoring and Assessment Report. https://www.pca.state.mn.us/sites/default/files/wq-ws3-0704002b.pdf

Minnesota Pollution Control Agency (MPCA). 2014a. Jefferson-German Lake Chain TMDL report. https://www.pca.state.mn.us/sites/default/files/wq-iw9-11e.pdf

Minnesota Pollution Control Agency (MPCA). 2014b. Lake Volney TMDL report. https://www.pca.state.mn.us/sites/default/files/wq-iw9-14e.pdf

Minnesota Pollution Control Agency (MPCA). 2015. Cannon River Watershed Stressor Identification Report. https://www.pca.state.mn.us/sites/default/files/wq-ws5-07040002a.pdf

Minnesota Pollution Control Agency (MPCA). 2016. Cannon River WRAPS report. https://www.pca.state.mn.us/sites/default/files/wq-ws4-23a.pdf

Minnesota Pollution Control Agency (MPCA). 2017. Cannon River Watershed TMDL report. https://www.pca.state.mn.us/sites/default/files/wq-iw9-19e.pdf

Minnesota Pollution Control Agency (MPCA). 2024. Assessment Manual – Guidance for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report & 303(d) Impaired Waters List. https://www.pca.state.mn.us/sites/default/files/wq-iw1-04m.pdf

Minnesota Pollution Control Agency (MPCA). 2024a. Watershed nutrient loads to accomplish Minnesota's Nutrient Reduction Strategy Goals. https://www.pca.state.mn.us/sites/default/files/wq-s1-87h.pdf

Minnesota Pollution Control Agency (MPCA). 2024b. Straight River Watershed stressor identification report 2024 update. https://www.pca.state.mn.us/sites/default/files/wq-ws5-07040002b.pdf

Minnesota Pollution Control Agency (MPCA). 2025. Watershed assessment and trends update: Cannon River Watershed. https://www.pca.state.mn.us/sites/default/files/wq-ws3-0704002g.pdf

Minnesota Pollution Control Agency (MPCA). 2025a. Belle Creek Watershed stressor identification report 2025 update. https://www.pca.state.mn.us/sites/default/files/wq-ws5-07040002c.pdf

Minnesota Pollution Control Agency (MPCA). 2025b. Crane Creek Watershed stressor identification report 2025 update. https://www.pca.state.mn.us/sites/default/files/wq-ws5-07040002d.pdf

Minnesota Pollution Control Agency (MPCA). 2025c. Flowing forward: Trends in Minnesota's lakes and rivers.

Minnesota Pollution Control Agency (MPCA). 2025d. Rush Creek Watershed stressor identification report 2025 update. https://www.pca.state.mn.us/sites/default/files/wq-ws5-07040002f.pdf

Minnesota Pollution Control Agency (MPCA). 2026. Medford Creek Watershed stressor identification report 2025 update. https://www.pca.state.mn.us/sites/default/files/wq-ws5-07040002e.pdf

Minnesota Pollution Control Agency (MPCA). 2026a. 2025 Minnesota Nutrient Reduction Strategy. https://www.pca.state.mn.us/air-water-land-climate/minnesota-nutrient-reduction-strategy

Schindler, D.W. 1977. Evolution of phosphorus limitation in lakes. *Science* 195: 260–262.

Schindler, D.W. 2006. Recent advances in the understanding and management of eutrophication. *Limnology and Oceanography* 51(1, part 2): 356–363.

Soranno, P.A., K.E. Webster, J.L. Riera, T.K. Kratz, J.S. Baron, P.A. Bukaveckas, G.W. Kling, and D.S. White. 1996. Spatial variation among lakes within landscapes: Ecological organization along lake chains. *Ecosystems* 2: 395–410.

Soranno, P.A., L.A. Bacon, M.A. Beauchene, et al. 2015. Lags in the ecological response of lakes to watershed disturbance. *Ecological Applications* 25(6): 1557–1573.

Southeast Minnesota Nitrate Strategies Collaborative Work Group. 2025. Report of Recommendations https://www.pca.state.mn.us/air-water-land-climate/addressing-nitrate-in-southeastern-minnesota

Appendices

Appendix A. Lake water clarity trend analysis

A combination of customized code and the Mann-Kendall Test, Seasonal and Regional Kendall Tests Seasonal (Package “rkt”) was used to create the lake trend analysis process. The package contains the rtk function, which computes the Mann-Kendall test and the Seasonal and the Regional Kendall Tests to determine if a trend can be detected in the dataset, and then it uses the Theil-Sen’s slope estimator to draw the trend line through the data points. This analysis is based on the following:

- All data collected on or after 1971 stored in EQuIS is included in the analysis.
- In an effort to remove potentially erroneous data from being included in the analysis, all Secchi values in EQuIS with values < 0 feet and > 100 feet are thrown out.
- Trends are run by whole lake, not on individual sites on a lake. All data from all sites on a lake are combined and included in the trend analysis if they were taken on or after 1971.
- The “seasonal” component of the “Seasonal Kendall Test” blocks the data by month (i.e. Mays are compared to Mays, Junes to Junes, etc.) across years to detect potential trends. This ensures that “like data” is being compared with “like data”. Data collected in May cannot be compared over time to data taken in August because we expect fundamentally different readings during those times of year due to factors such as temperature and precipitation.
- A dataset of at least 8 years and 50 observations need to be present for a trend analysis to be run on a lake. If this criteria are not met, a result of “insufficient data” will be returned in those instances.
- Trend descriptions and strengths are associated with the following p values and slopes:

<table>
<tr><th>Trend Description and Strength</th><th>Mean p-value and Mean Slope</th></tr>
<tr><td>Evidence of improving water clarity</td><td>mean p-value <= 0.05
mean slope > 0.05</td></tr>
<tr><td>Evidence of degrading water clarity</td><td>mean p-value <= 0.05
mean slope > -0.05</td></tr>
<tr><td>Evidence of no change in water clarity</td><td>mean p-value <= 0.05
mean slope <= 0.05 & >= -0.05</td></tr>
<tr><td>No trend detected</td><td>mean p-value > 0.05</td></tr>
<tr><td>Insufficient data to run the analysis</td><td>record length < 8 |
obs < 50</td></tr>
</table>

- If a trend is detected, a rate of change over time, by year, is determined (example text: “for years 1991 to 2017 there is strong evidence of a trend for increasing water clarity on this lake, approximately 0.22 feet per year”). This is calculated by multiplying the mean slope by 10.
- A lake must experience a change greater than ½ foot/decade to be listed as having an “improving” or “degrading” water clarity trend. If a lake experiences either an improvement or reduction in water clarity that is equal to or less than ½ foot/decade, then it is identified as having “no change” in water clarity over the dataset period.

- If a lake has enough data, but the statistical result isn't significant (i.e. the p value is less than 0.05), then we will report that "no trend" was detected on the lake at this time.
- Each trend graph generated for a lake depicts all lake data (i.e. Secchi measurement results) with a trend line and 95% confidence interval. This confidence interval represents the range where the actual clarity measure will fall with 95% certainty.
- Regardless of whether a trend is detected or not, median water clarity for the most recent year of data for each lake with data in EquIS is compared to median clarity for the entire watershed.
- Median water clarity for the entire watershed is calculated by combining all lake clarity readings for the current year in each watershed and calculating the median of that total.

Appendix B. Stream water clarity trend analysis

For streams, the trend analysis is based on the following:

- Stream water clarity may vary from year to year in response to changes in rainfall amounts, watershed runoff, and other factors. To account for this year-to-year variability and detect real trends over time, the statistical trend analysis performed by the MPCA requires that a stream station has a minimum of 8 years of Secchi tube data collected between April and September, and a minimum of 50 water clarity observations, total.
- Stream stations with a majority of water clarity readings that are 100 cm or greater (50% or more) are considered too clear to run a statistical test and are not included in the analysis.
- Trend descriptions and strengths are associated with the following p values and slopes:

Trend Description and Strength	p-value and slope
Evidence of improving water clarity	p-value <= 0.05 slope > 0.2
Evidence of degrading water clarity	p-value <= 0.05 slope < -0.2
Evidence of no change in water clarity	p-value <= 0.05 slope <= 0.2 & >= -0.2
No trend detected	p-value > 0.05
Insufficient data to run the analysis	record length < 8 | obs < 50

- If a trend is detected for a stream station, a rate of change over time, by decade, is determined (example text: "for years 1998 to 2017 there is strong evidence of a trend for increasing water clarity at this stream station, approximately 5.00 cm per decade"). This is calculated by multiplying the slope by 10.
- Each trend graph generated for a stream includes a trend line and 95% confidence interval. This confidence interval represents the range where the actual clarity measure will fall with 95% certainty.
- Regardless of whether a trend is detected or not, median water clarity for the most recent year of data for each stream station with data in EquIS is compared to median clarity for the entire watershed.

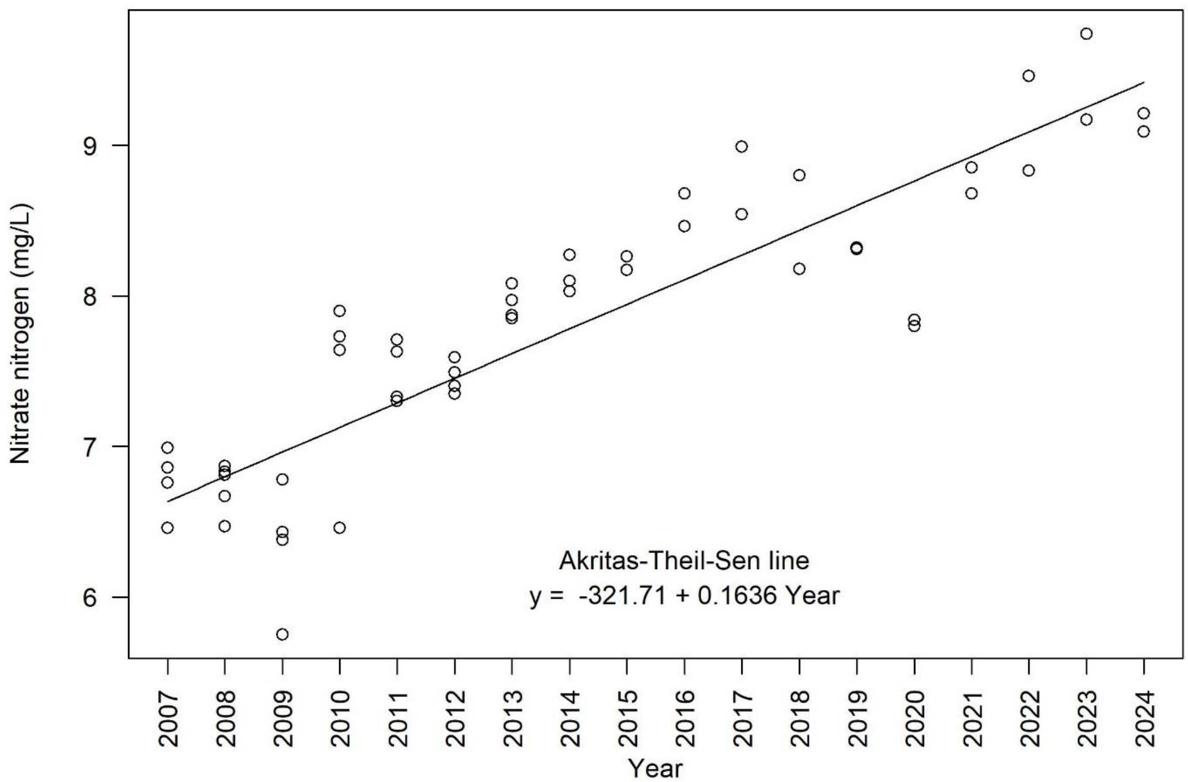
- Median water clarity for the entire watershed is calculated by combining all stream clarity readings for the current year in each watershed and calculating the median of that total.

Appendix C. Spring Creek spring trend analysis

The trend analysis in this report was performed using the seasonal Kendall test and fitting an Akritas-Theil-Sen (ATS) trend line. These are nonparametric methods commonly used to analyze monotonic (one-directional) trends in water quality. They are robust to outliers, missing values, and values less than detection limits, and can account for seasonal differences.

The results indicate a statistically significant ($p < 0.05$) increasing trend in nitrate/nitrogen over time (Figure).

Figure 57. Nitrate nitrogen trend analysis for Spring Creek spring, 2007-2024.



Relevant Sources

[Water Quality Trends for Minnesota Rivers and Streams at Milestone Sites | WRL Digital Asset Management]

Helsel, D.R., 2011. Statistics for censored environmental data using Minitab and R, 2nd ed. John Wiley & Sons, USA, N.J.

Hirsch, R.M., Slack, J.R., Smith, R.A., 1982. Techniques of Trend Analysis for Monthly Water Quality Data, Water Res. Research 18, 107-121.

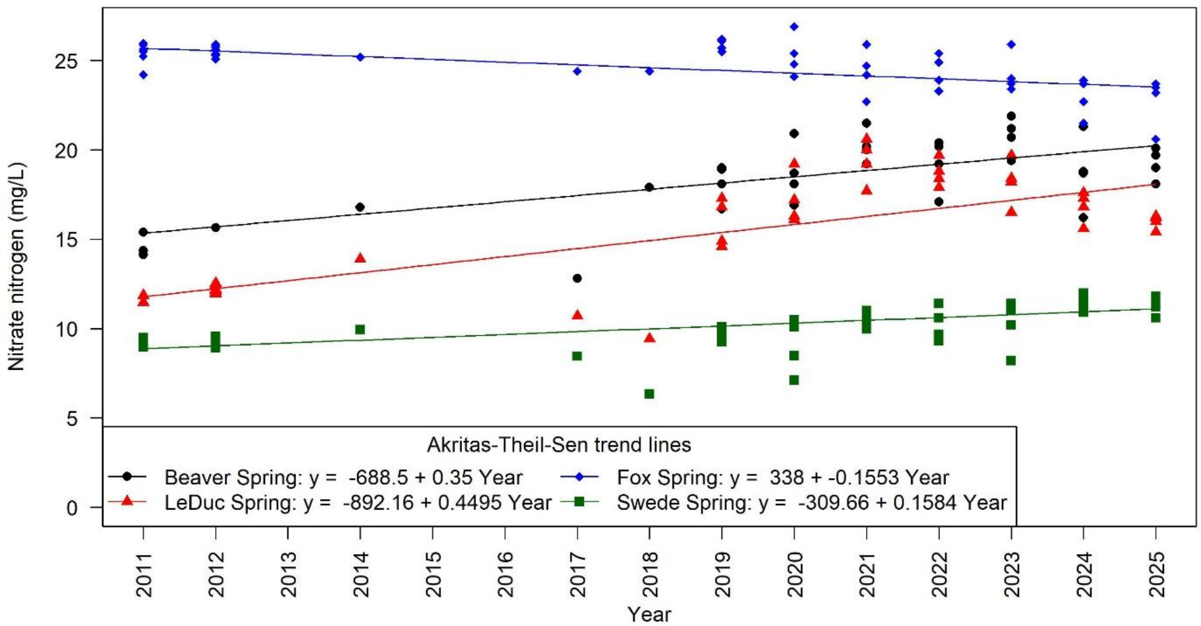
https://www.epa.gov/sites/default/files/201605/documents/tech_notes_6_dec2013_trend.pdf

Appendix D. Trout Brook springs trend analysis

The trend analysis in this report was performed using the seasonal Kendall test and fitting an ATS trend line. These are nonparametric methods commonly used to analyze monotonic (one-directional) trends in water quality. They are robust to outliers, missing values, and values less than detection limits, and can account for seasonal differences. Data collected in 2011 and later were included from analysis, and standard meteorological seasons (Mar-May, Jun-Aug, Sep-Nov, Dec-Feb) were used.

The results indicate statistically significant ($p < 0.05$) trends (increasing at Beaver, LeDuc, and Swede Springs, decreasing at Fox Spring) in nitrate nitrogen over time (Figure 58).

Figure 58. Nitrate nitrogen trend analysis in four springs, 2011 – 2025.



Relevant Sources

[Water Quality Trends for Minnesota Rivers and Streams at Milestone Sites | WRL Digital Asset Management]

Helsel, D.R., 2011. Statistics for censored environmental data using Minitab and R, 2nd ed. John Wiley & Sons, USA, N.J.

Hirsch, R.M., Slack, J.R., Smith, R.A., 1982. Techniques of Trend Analysis for Monthly Water Quality Data, Water Res. Research 18, 107-121.

https://www.epa.gov/sites/default/files/201605/documents/tech_notes_6_dec2013_trend.pdf

Appendix E. Cannon SAM BMPs Report

Use of SAM/ HSPEXP+ to estimate the impact of BMPs on water quality at Cannon River Watershed for WRAPS update

Sagor Biswas, Ian Ackman, Steven Weiss

Dated: 02/19/2026

Overview

MPCAs Southeast Watershed Unit, and local partners, requested help with defining the magnitude of water quality improvements achieved through implementation of BMPs in the Cannon River Watershed. Use of available empirical data to determine the impact of these changes is difficult for two primary reasons. First, implementation of these practices did not start at one, explicit, point in time. It occurred over a span of time with a greater intensity in the past three to five years. Second, the pre and post implementation period of record are not comparable. The pre implementation period of record might be 10 to 15 years as compared to the post implementation period which might be only 3 to 5 years. Annual summer climate variability might bias results such that meaningful comparisons are difficult to make.

As such, the MPCA Watershed Analysis and Modeling (WAM) unit used a modeling approach. The Simulation Application Manager (SAM) was used in the recently extended and calibrated Cannon River Watershed HSPF model to evaluate the impact of available BMPs on flow and three different water quality parameters (total suspended solids (TSS), total phosphorus (TP), and total nitrogen (TN)). The current HSPF model has a simulation period from 1996 to 2023. A database of implemented BMPs across the Cannon River Watershed was supplied. SAM does not allow the user to insert a BMP in a particular year, as a result, a single scenario was created applying all recorded BMPs for the full simulation period. SAM also does not have the ability to place a BMP spatially, so if multiple similar BMPs were installed within a subwatershed at different times, they were summed up to get a total treated area for that BMP within a subwatershed. Results from the BMP scenario were compared against the existing model (base scenario) outputs which had no BMPs applied.

Results are reported from the edge of the field and at each HSPF model subwatershed (smaller than HUC 12) outlets (Table 1, Fig 1). The edge of the field reductions are generally higher than at the subwatershed outlets, considering the fate and transport losses within the channel. At the edge of the field, only the non-point sources from pervious and impervious area are considered for pollutant loading. At the subwatershed outlet, point sources, atmospheric deposition, and other instream processes (bed and bank erosion) are considered. Channels are considered as a sink of nutrients (inorganic N or P) due to the consumption by benthic algae or other microorganisms, but they may be considered as a source of sediment due to bed and bank erosion.

Simulation results are reported as average annual percent load reduction in maps for TSS, TP, TN, and flow (Fig 2 to Fig 9). The estimated total load reduction between the BMP applied and the base (no BMP applied) scenarios are reported in Table 3. SAM used different load reduction efficiencies for each BMP based on the research of the NRCS documents, MN NRS, MN Stormwater manual, consultants, and expert opinions ideal for Minnesota. The table of BMP efficiencies used in this project is also provided for reference (Appendix, Table 3). The following bullet points summarize this watershed BMP simulation project.

- HUC8: 07040002
- Watershed area: 913,571 acres
- Model Simulation period: 1996-2023 (28 years)
- Scenario Comparison: Base scenario (without any BMPs) VS BMPs applied
- Total BMPs: 206 (with missing information)
- After clean-up: 172
- After aggregation of treated areas within subwatersheds: 85
    - Reduced Tillage (no-till) (1)[1]
    - Restore Tiled Wetlands (1)
    - Reduced Tillage (30%+ residue cover) (2)
    - Conservation Cover Perennials (3)
    - Bioretention (5)
    - Drainage Side Inlet Improvements (8)
    - Grassed Waterways (16)
    - Water and Sediment Control Basin (23)
    - Corn & Soybeans with Cover Crop (26)
- Total BMP acreage: 12,644 acre (1.4% of the watershed)
- Associate HSPF Subwatershed: 53

[1] Count of subwatersheds containing BMP type in parentheses.

Table 1: Available BMPs and treated area in the Cannon River Watershed

HUC12 ID	HSPF SubshedID	SAM Classification (BMP Type)	Acres Treated
70400020905	101	Corn & Soybeans with Cover Crop	125.0
70400020905	101	Drainage Side Inlet Improvements	76.9
70400020903	103	Water and Sediment Control Basin (Cropland)	3.5
70400020903	104	Drainage Side Inlet Improvements	17.0
70400020903	104	Water and Sediment Control Basin (Cropland)	26.0
70400020904	111	Corn & Soybeans with Cover Crop	95.0
70400020904	111	Grassed Waterways	40.3
70400020905	115	Drainage Side Inlet Improvements	6.1
70400020902	122	Corn & Soybeans with Cover Crop	689.4
70400020902	122	Drainage Side Inlet Improvements	1376.0
70400020902	122	Water and Sediment Control Basin (Cropland)	107.0
70400020902	123	Corn & Soybeans with Cover Crop	306.3
70400020902	124	Bioretention	5.6
70400020902	124	Corn & Soybeans with Cover Crop	927.7
70400020902	124	Grassed Waterways	552.3
70400020902	124	Water and Sediment Control Basin (Cropland)	7.8
70400020901	125	Bioretention	2.5
70400020901	125	Corn & Soybeans with Cover Crop	729.6
70400020901	125	Grassed Waterways	1545.6
70400020901	126	Corn & Soybeans with Cover Crop	123.6
70400020901	126	Water and Sediment Control Basin (Cropland)	15.1
70400020605	200	Corn & Soybeans with Cover Crop	200.9
70400020605	200	Water and Sediment Control Basin (Cropland)	12.2
70400020604	202	Bioretention	0.6
70400020604	202	Grassed Waterways	504.6
70400020605	221	Corn & Soybeans with Cover Crop	29.0
70400020602	245	Corn & Soybeans with Cover Crop	105.0
70400020602	246	Conservation Cover Perennials	9.0
70400020602	248	Corn & Soybeans with Cover Crop	111.1
70400020602	248	Water and Sediment Control Basin (Cropland)	10.0
70400020602	249	Conservation Cover Perennials	6.0
70400020104	313	Water and Sediment Control Basin (Cropland)	11.0
70400020106	348	Corn & Soybeans with Cover Crop	38.0
70400020103	365	Restore Tiled Wetlands (Cropland)	15.0
70400020104	373	Water and Sediment Control Basin (Cropland)	10.0
70400020104	374	Water and Sediment Control Basin (Cropland)	16.4

HUC12 ID	HSPF SubshedID	SAM Classification (BMP Type)	Acres Treated
70400020104	377	Water and Sediment Control Basin (Cropland)	6.0
70400020102	379	Grassed Waterways	150.0
70400020101	384	Conservation Cover Perennials	3.0
70400020101	384	Corn & Soybeans with Cover Crop	41.0
70400020101	385	Reduced Tillage (30%+ residue cover)	13.0
70400020803	400	Corn & Soybeans with Cover Crop	20.0
70400020803	401	Corn & Soybeans with Cover Crop	142.0
70400020802	403	Grassed Waterways	161.0
70400020802	403	Water and Sediment Control Basin (Cropland)	14.1
70400020801	404	Corn & Soybeans with Cover Crop	135.0
70400020801	404	Grassed Waterways	110.4
70400020801	405	Grassed Waterways	158.0
70400020803	411	Corn & Soybeans with Cover Crop	96.0
70400020803	411	Grassed Waterways	999.0
70400020802	415	Corn & Soybeans with Cover Crop	135.0
70400020802	415	Grassed Waterways	93.0
70400020703	501	Drainage Side Inlet Improvements	223.0
70400020703	501	Water and Sediment Control Basin (Cropland)	16.8
70400020702	503	Corn & Soybeans with Cover Crop	114.3
70400020702	503	Drainage Side Inlet Improvements	38.1
70400020702	503	Water and Sediment Control Basin (Cropland)	51.6
70400020702	504	Water and Sediment Control Basin (Cropland)	31.0
70400020701	505	Drainage Side Inlet Improvements	99.1
70400020701	505	Grassed Waterways	11.0
70400020701	505	Water and Sediment Control Basin (Cropland)	19.5
70400020703	511	Water and Sediment Control Basin (Cropland)	8.0
70400020702	514	Grassed Waterways	106.0
70400020501	602	Corn & Soybeans with Cover Crop	22.0
70400020501	602	Water and Sediment Control Basin (Cropland)	114.7
70400020503	606	Water and Sediment Control Basin (Cropland)	57.0
70400020502	611	Corn & Soybeans with Cover Crop	124.0
70400020502	611	Grassed Waterways	146.2
70400020502	611	Water and Sediment Control Basin (Cropland)	5.5
70400020404	700	Corn & Soybeans with Cover Crop	21.2
70400020402	701	Water and Sediment Control Basin (Cropland)	10.6
70400020402	703	Grassed Waterways	1.5
70400020403	705	Bioretention	0.3
70400020403	705	Corn & Soybeans with Cover Crop	407.4
70400020403	705	Reduced Tillage (no-till)	123.0
70400020404	710	Bioretention	1.7

HUC12 ID	HSPF SubshedID	SAM Classification (BMP Type)	Acres Treated
70400020404	710	Corn & Soybeans with Cover Crop	26.5
70400020404	711	Corn & Soybeans with Cover Crop	186.8
70400020401	715	Grassed Waterways	20.0
70400020401	715	Water and Sediment Control Basin (Cropland)	9.9
70400020303	812	Corn & Soybeans with Cover Crop	100.0
70400020308	830	Drainage Side Inlet Improvements	112.0
70400020308	830	Water and Sediment Control Basin (Cropland)	40.8
70400020203	900	Reduced Tillage (30%+ residue cover)	250.0
70400020201	915	Grassed Waterways	11.0

Among the BMPs used in the Cannon watershed, Bioretention has the highest flow reduction efficiency of 90% from developed area (Impervious). Restored Tiled Wetland has the highest flow reduction efficiency of 30% from pervious area. Conservation Cover Perennials has the highest TN reduction efficiency of 91% from all 3 flow paths (surface, interflow, and baseflow) and the highest TSS reduction efficiency of 96%. Reduced Tillage has the highest TP reduction efficiency (68%) of the BMPs simulated in this project. (Table 3 in Appendix).

The combination of tables and maps provided in this document allow one to identify the estimated pollutant load and flow reductions in specific areas and from specific BMP types. One can begin by locating subwatershed ID codes of interest in the maps. (Figures 1, 2, 3). Next, the subwatershed ID can be used to identify the documented BMPs in that area (Table 1). Finaly, the estimated percent reduction in flow volume and pollutant loading (TN, TP, and TSS) can be located at both the edge of the field and at the watershed outlet (Table 3).

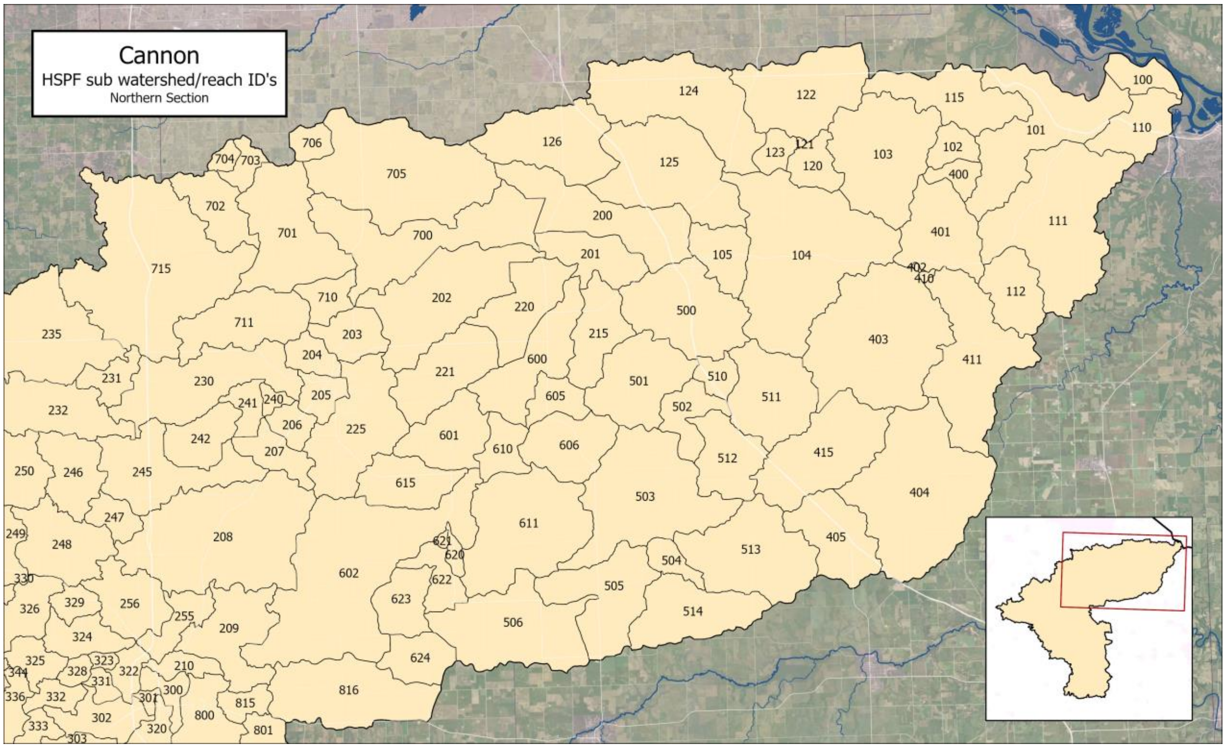


Figure 1: Cannon River Watershed HSPF model northern section subwatershed id's

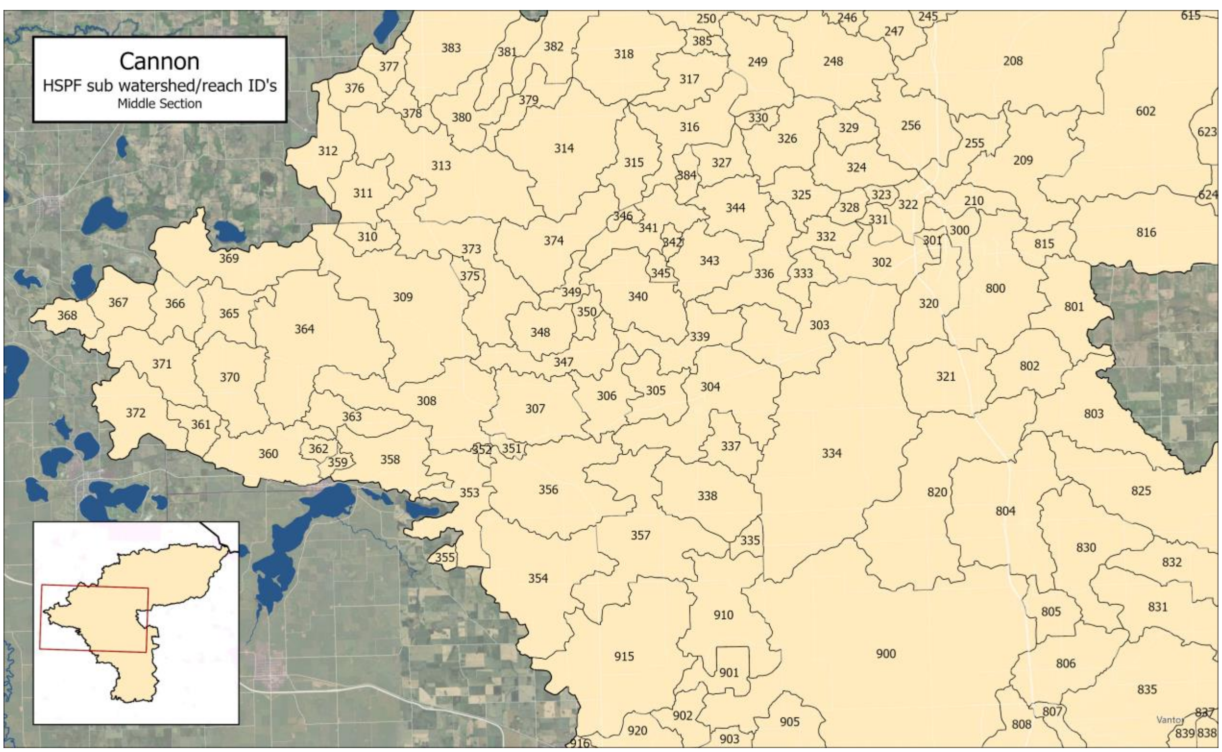


Figure 2: Cannon River Watershed HSPF model middle section subwatershed id's

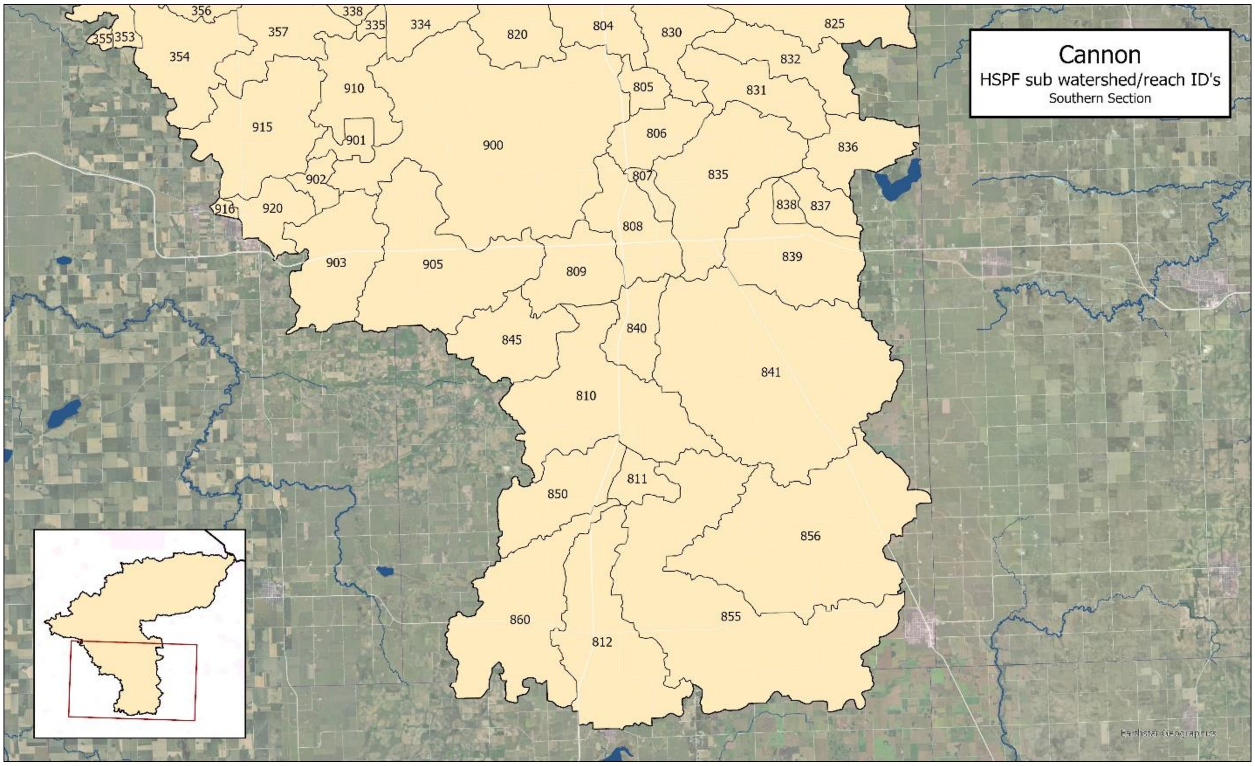


Figure 3: Cannon River Watershed HSPF model southern section subwatershed id's

Results:

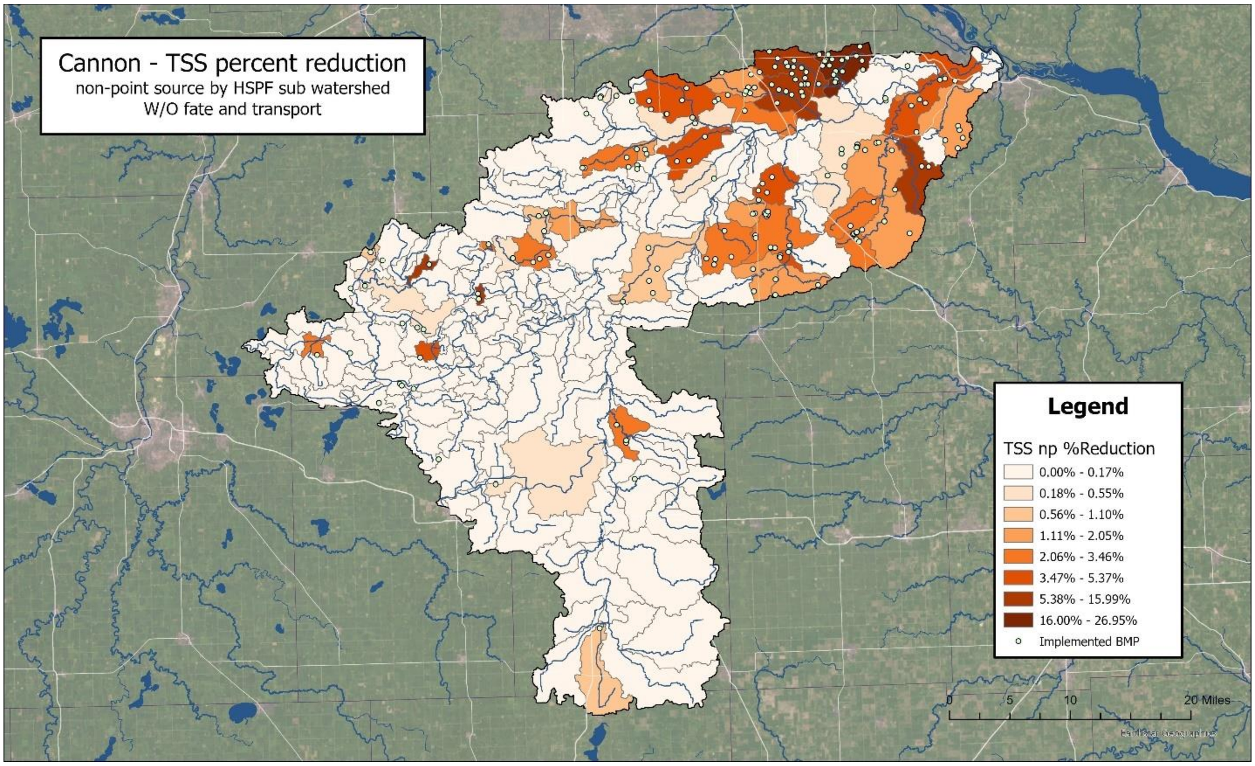


Figure 4: Potential % load reduction of TSS from the edge of the field

Considering the applied BMPs, the highest (26.9%) edge of field TSS reduction is reported from subwatershed 123 where Corn and Soybeans with Cover Crop is applied to 306 acres. The lowest edge of filed TSS reduction (0.09%) is reported from subwatershed 103 where Water and Sediment Control Basin is applied to 3.5 acres. Subwatersheds, associated BMPs, and their reduction efficiencies are reported in Tables 1 and 3.

At the subwatershed outlet, the highest TSS reduction (12%) is reported from subwatershed 122 with 3 BMPs and a total treated area of 2172.5 acres. BMPs in these watersheds include Corn and Soybeans with Cover Crop (689 acres), Drainage Side Inlet Improvements (1376 acres), and Water and Sediment Control Basin (107 acres, Table 1).

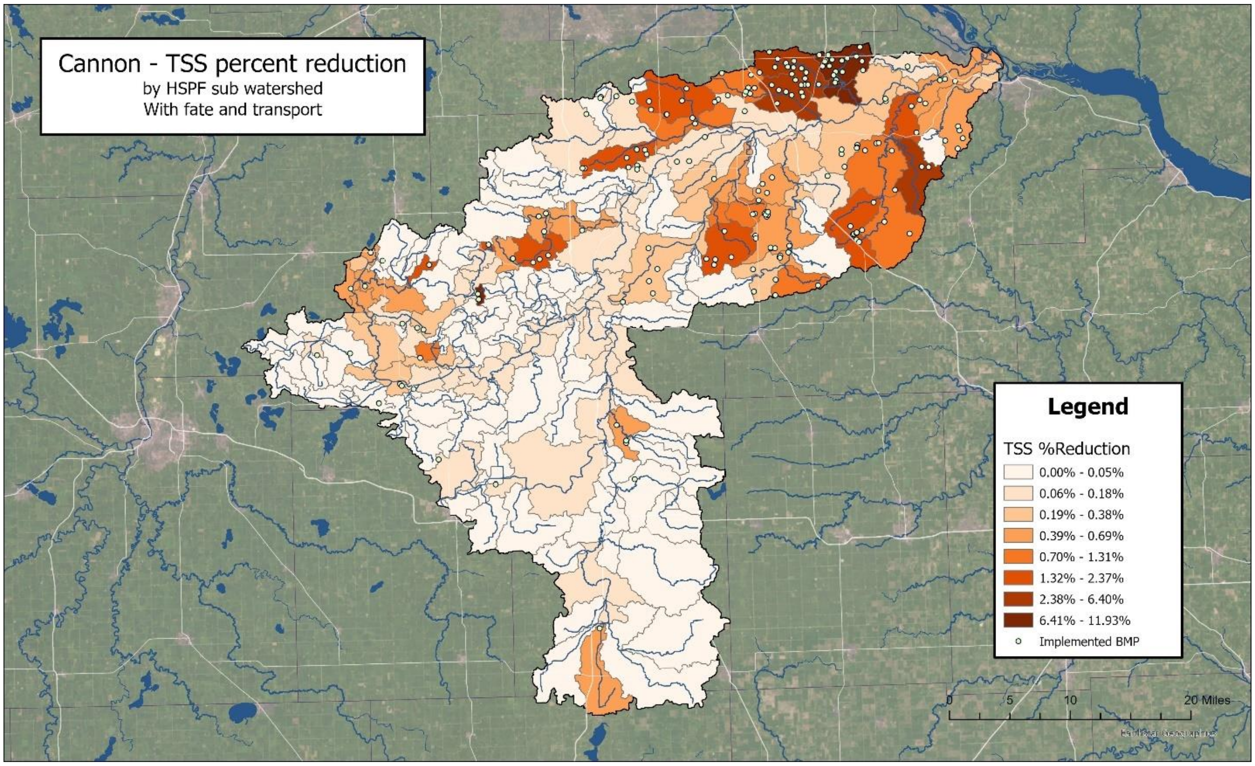


Figure 5: Potential % load reduction of TSS at the HSPF subwatershed outlet

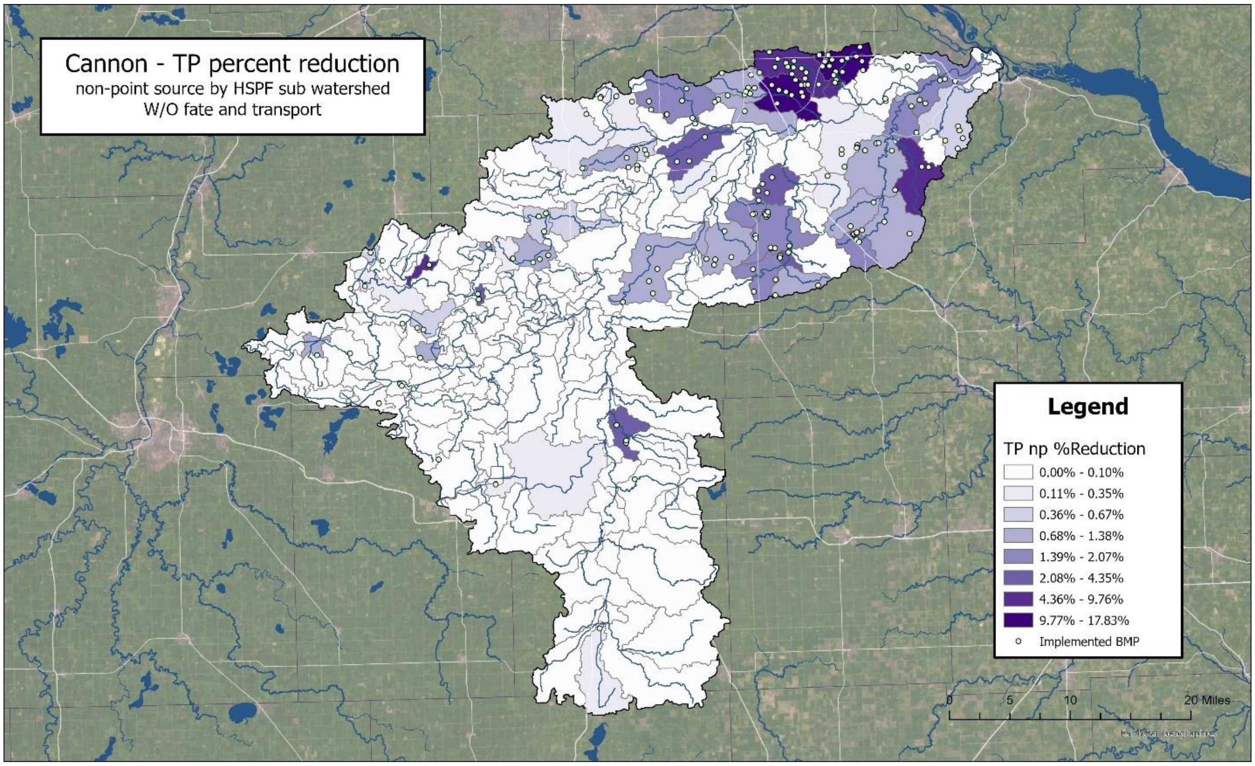


Figure 6: Potential % load reduction of TP from the edge of the field

Considering the applied BMPs, the highest edge of the field TP reduction (17.8%) is reported from subwatershed 122 with 3 BMPs- Corn and Soybeans with Cover Crop, Drainage Side Inlet Improvements and Water and Sediment Control Basin with 2172.5 acres of treated area (Table 1). The lowest (0.07%) edge of field TP reduction is coming from subwatershed 103 (Figure 6). At the subwatershed outlet, the highest TP load reduction (17.8%) is reported from subwatershed 122 (Figure 7).

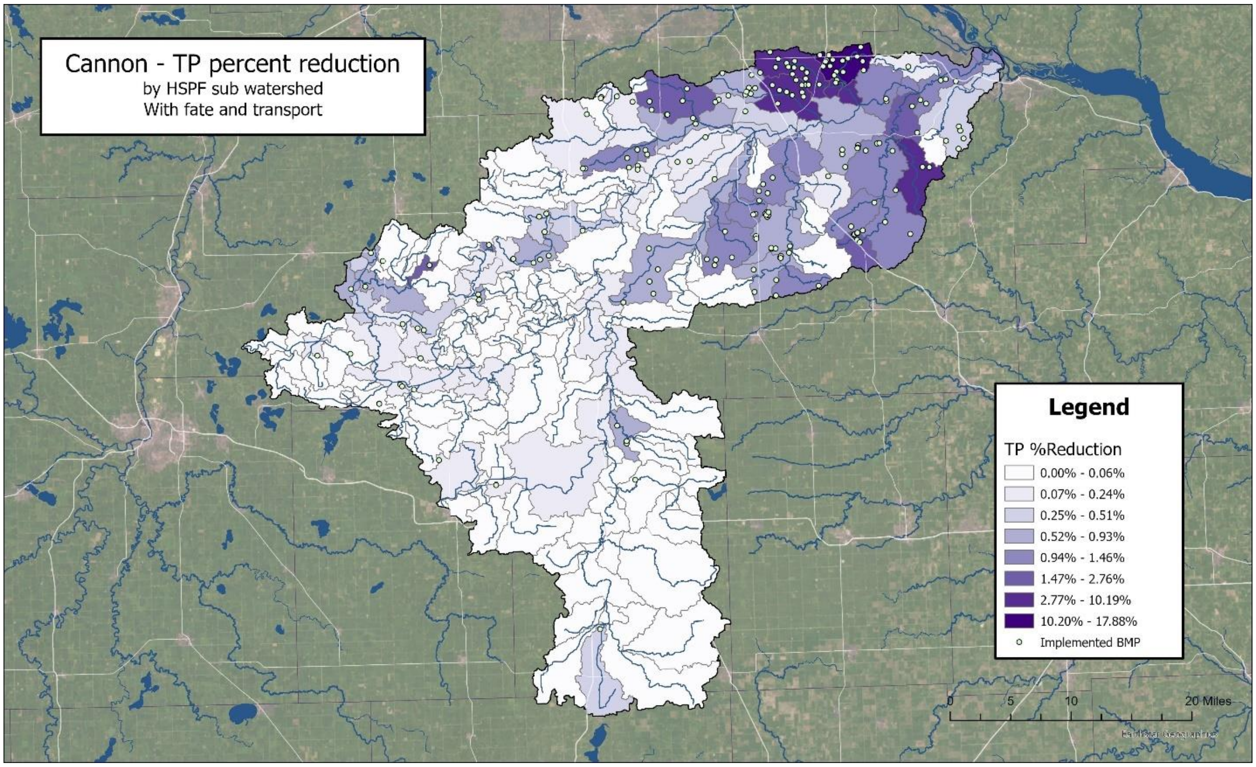


Figure 7: Potential % load reduction of TP at the HSPF subwatershed outlet

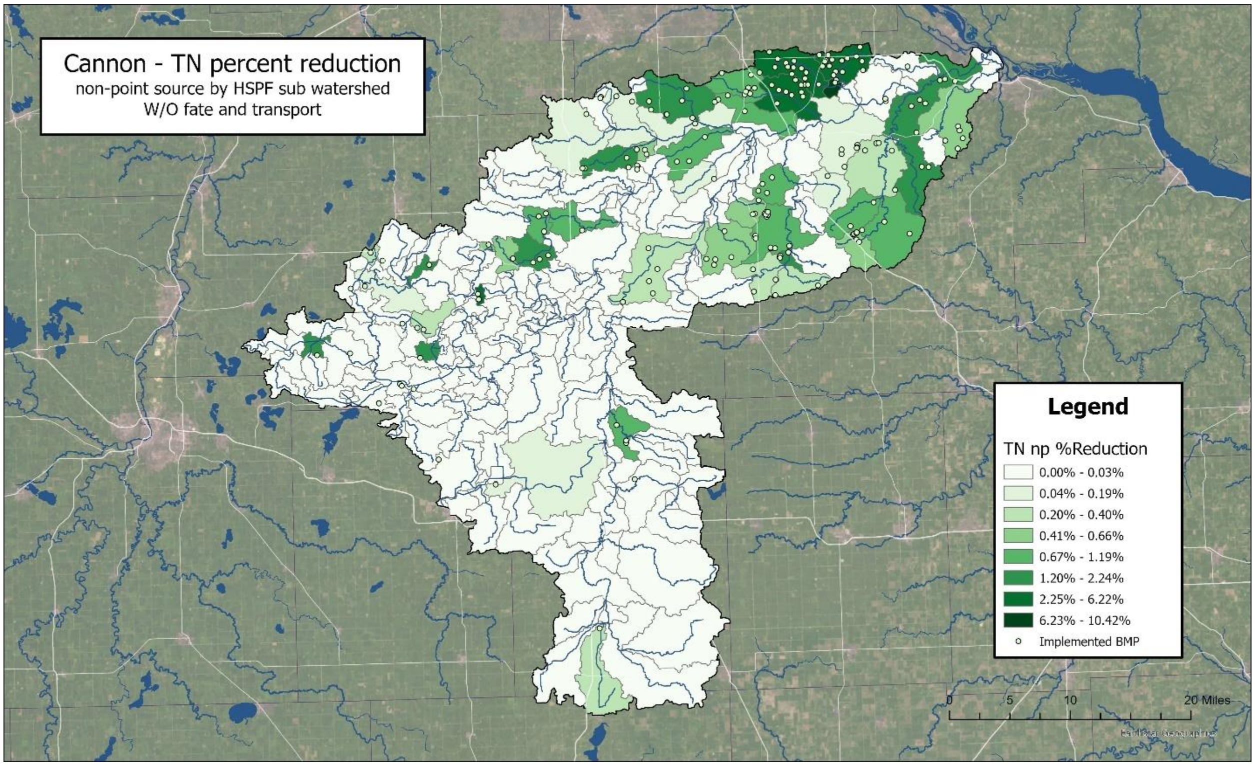


Figure 8: Potential % load reduction of TN from the edge of the field

Considering the applied BMPs, the highest (10.4%) edge of the field TN reduction is reported from subwatershed 123. The lowest (0.02%) edge of field TN reduction is coming from subwatershed 115. Subwatershed 123 contained Corn and Soybeans with Cover Crop as BMP with a total treated area of 306.3 acres (Table 1). The BMP of the subwatershed 123 is resulting in a TN load reduction of 1737.9 lbs/yr (Table 2). However, the highest edge of the field TN load reduction is coming from subwatershed 125 in Cannon River watershed and the estimated amount is 5218 lbs/yr. At the subwatershed outlet, the highest (6.2%) TN reduction is reported from subwatershed 122 (Figure 9).

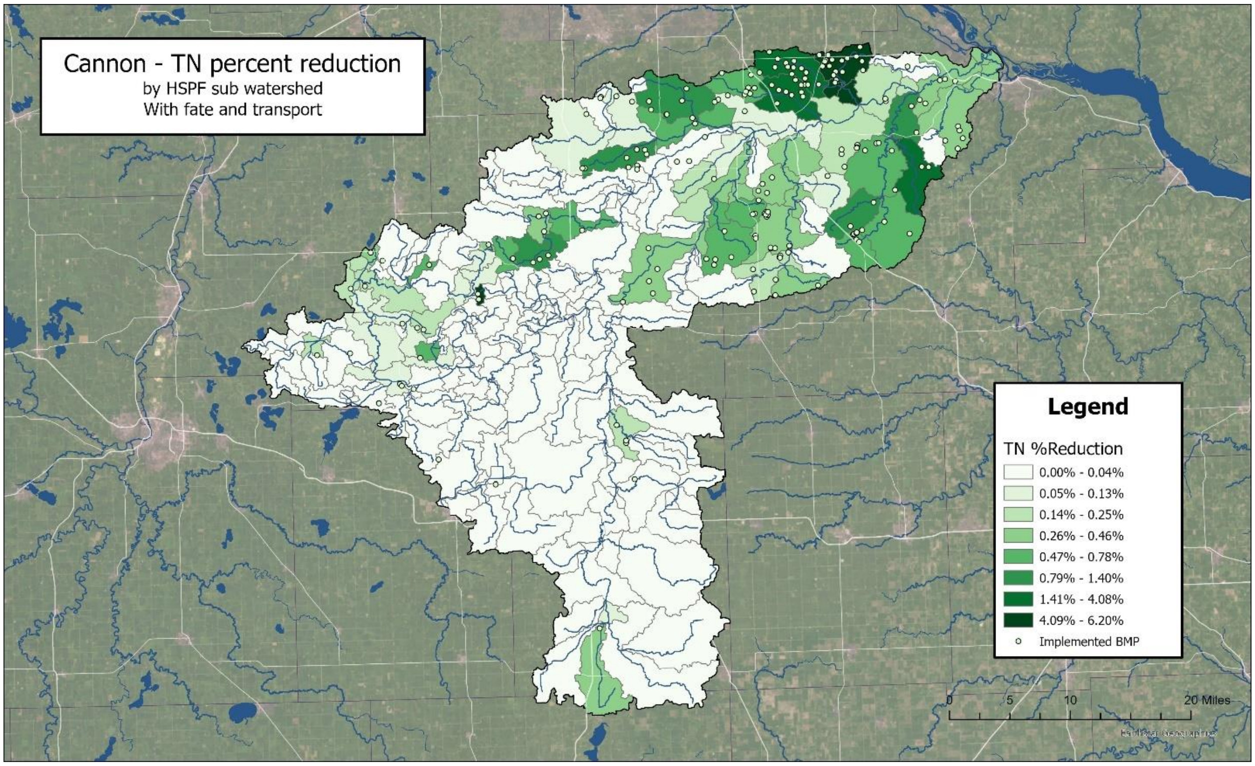


Figure 9: Potential % load reduction of TN at the HSPF subwatershed outlet

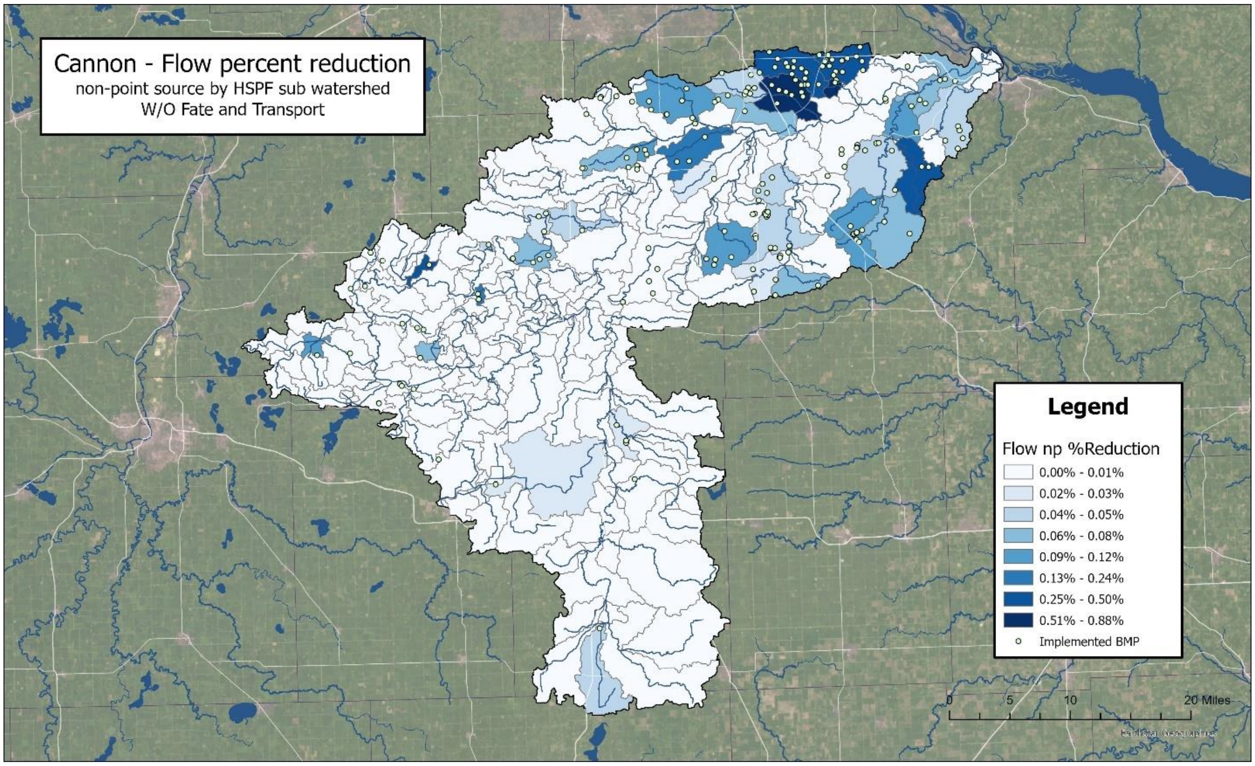


Figure 10: Potential % load reduction of flow from the edge of the field

Generally, BMPs did not result in much change in the long term annual average total flow volume. However, this study did not examine changes in monthly, high, or low flows. It is possible that some of these BMPs may result in lower high flows and increased storage, thereby resulting in higher low flows. This may be a topic of future study. Considering the applied BMPs, the highest edge of the field flow reduction is reported from subwatershed 123 (0.88%) and the lowest is reported from subwatershed 104 (0.001%, Figure 10). At the subwatershed outlet, the highest (0.51%) flow reduction is reported from subwatershed 122 outlet (Figure 11).

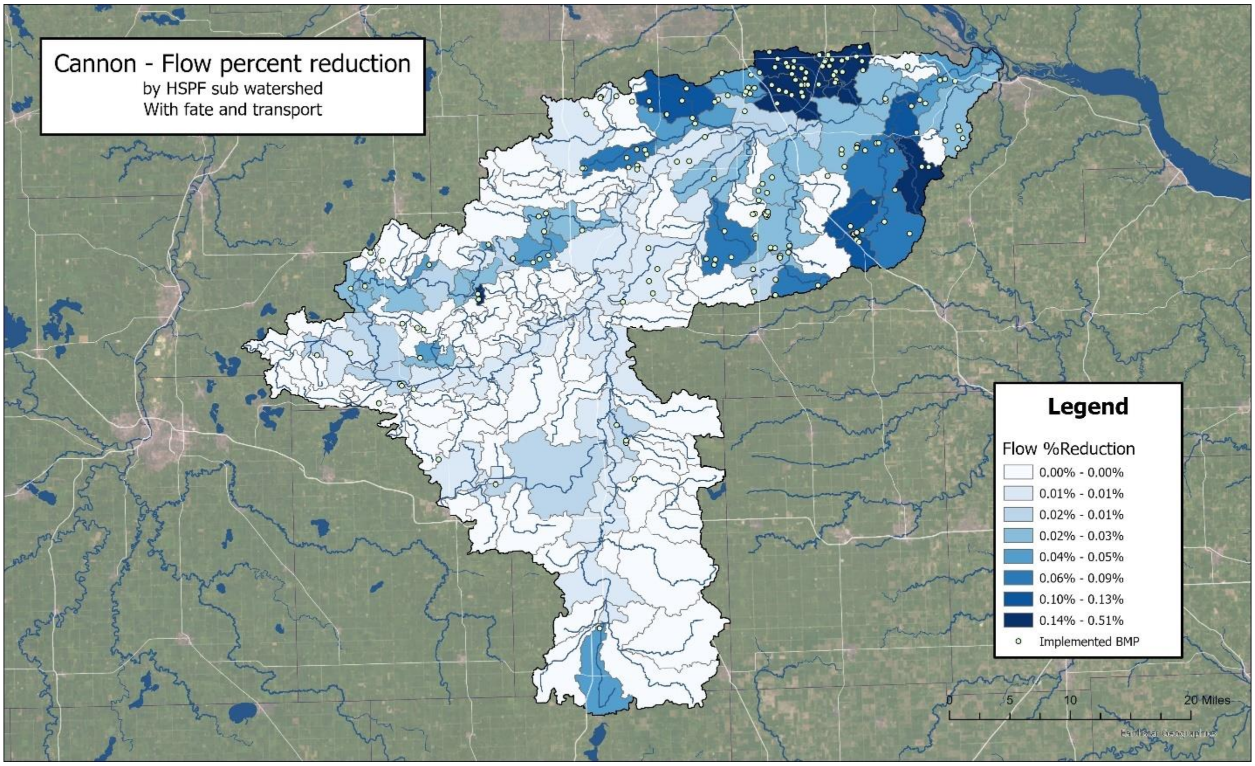


Figure 11: Potential % load reductio of flow at the subwatershed outlet

Table 2: Modeled Annual load reduction at different subwatersheds after BMP applications

Constituent	Flow (ac-ft/yr)		TN (lbs/yr)		TP (lbs/yr)		TSS (tons/yr)	
Reach ID	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**
920	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
916	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
915	0.50	0.50	41.67	39.88	5.38	5.10	0.79	0.76
910	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
905	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
903	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
902	0.00	0.49	0.00	39.75	0.00	5.01	0.00	0.76
901	0.00	0.50	0.00	39.22	0.00	4.99	0.00	0.77
900	5.38	5.87	598.10	615.88	78.03	78.93	12.47	12.36
860	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
856	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
855	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
850	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
845	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
841	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
840	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
839	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
838	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
837	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
836	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
835	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
832	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
831	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
830	1.16	1.16	744.61	727.25	88.18	84.89	11.01	9.33
825	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
820	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Constituent	Flow (ac-ft/yr)		TN (lbs/yr)		TP (lbs/yr)		TSS (tons/yr)	
Reach ID	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**
816	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
815	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
812	4.03	4.02	907.54	890.94	26.88	25.16	3.94	3.84
811	0.00	4.04	0.00	888.88	0.00	24.96	0.00	3.88
810	0.00	4.01	0.00	886.75	0.00	24.86	0.00	3.94
809	0.00	4.07	0.00	886.75	0.00	24.64	0.00	3.98
808	0.00	4.11	0.00	886.50	0.00	24.65	0.00	4.02
807	0.00	3.98	0.00	886.50	0.00	24.59	0.00	4.04
806	0.00	4.09	0.00	885.50	0.00	25.09	0.00	4.13
805	0.00	3.95	0.00	887.00	0.00	25.02	0.00	4.17
804	0.00	10.94	0.00	2224.00	0.00	186.39	0.00	25.89
803	0.00	10.94	0.00	2215.00	0.00	185.78	0.00	26.09
802	0.00	11.09	0.00	2224.50	0.00	185.47	0.00	26.11
801	0.00	11.09	0.00	2216.50	0.00	184.39	0.00	26.68
800	0.00	11.03	0.00	2207.00	0.00	182.97	0.00	26.73
715	0.36	0.36	87.67	86.42	56.37	55.98	0.30	0.35
711	3.18	3.18	820.81	811.69	158.17	156.83	1.70	2.04
710	1.04	4.21	111.48	919.66	22.09	178.46	0.78	2.88
706	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
705	10.37	10.35	1989.84	1963.13	583.91	578.98	15.18	15.31
704	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
703	0.03	0.03	2.54	0.20	2.21	1.78	0.01	0.00
702	0.00	0.02	0.00	0.99	0.00	1.89	0.00	0.00
701	0.00	0.38	69.96	156.98	34.52	92.25	0.16	0.53
700	0.45	15.36	89.49	3095.25	18.33	863.06	0.63	19.50
624	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
623	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Constituent	Flow (ac-ft/yr)		TN (lbs/yr)		TP (lbs/yr)		TSS (tons/yr)	
Reach ID	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**
622	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
621	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
620	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
615	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
611	6.41	6.39	798.49	787.84	350.71	348.10	10.10	11.15
610	0.00	6.41	0.00	785.20	0.00	346.42	0.00	10.05
606	0.00	0.00	296.18	292.39	169.27	168.13	3.02	2.63
605	0.00	0.00	0.00	291.45	0.00	167.71	0.00	2.64
602	0.49	0.49	705.79	689.36	338.32	334.73	6.29	5.82
601	0.00	0.48	0.00	686.91	0.00	334.10	0.00	5.83
600	0.00	6.88	0.00	1749.38	0.00	845.67	0.00	18.71
514	2.77	2.76	236.67	231.33	177.36	175.89	3.91	4.32
513	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
512	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
511	0.00	0.00	56.85	55.95	25.03	24.83	0.41	0.38
510	0.00	0.00	0.00	55.90	0.00	24.79	0.00	0.38
506	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
505	1.27	1.27	321.01	316.63	285.13	283.59	4.99	4.65
504	0.00	4.04	216.75	762.41	95.28	553.76	1.59	10.25
503	3.53	7.55	1064.80	1816.09	375.92	926.77	8.89	18.97
502	0.00	7.55	0.00	1814.50	0.00	926.20	0.00	19.41
501	2.23	9.79	505.13	2367.25	557.94	1506.03	9.40	28.51
500	0.00	9.76	0.00	2361.00	0.00	1504.45	0.00	29.27
415	6.16	6.15	1000.06	988.81	269.59	267.32	13.83	15.47
411	30.12	30.05	2829.26	2772.22	1642.82	1627.21	63.65	71.46
410	0.00	30.05	0.00	2769.55	0.00	1625.88	0.00	71.02
405	4.44	4.43	366.57	361.19	250.80	249.09	9.48	10.29

Constituent	Flow (ac-ft/yr)		TN (lbs/yr)		TP (lbs/yr)		TSS (tons/yr)	
Reach ID	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**
404	6.80	11.24	1459.17	1804.20	304.22	550.14	15.22	27.53
403	4.51	21.88	468.63	3240.03	295.21	1107.41	10.64	52.82
402	0.00	51.92	0.00	6007.63	0.00	2695.16	0.00	109.32
401	3.74	55.60	831.00	6816.25	130.92	2821.73	8.91	146.83
400	0.55	56.22	116.73	6926.44	18.90	2820.28	1.28	132.29
385	0.16	0.16	23.50	21.85	6.15	5.83	0.47	0.44
384	1.18	1.17	333.21	12.66	22.46	1.53	1.46	0.11
383	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
382	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
381	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
380	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
379	3.95	3.94	416.48	394.52	106.00	102.00	7.72	6.98
378	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
377	0.00	0.00	47.66	45.29	7.72	7.30	0.42	0.38
376	0.00	0.00	0.00	3.00	0.00	1.72	0.00	0.04
375	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
374	0.00	0.00	129.03	123.32	21.04	20.04	1.12	1.02
373	0.00	0.00	0.00	118.67	0.00	19.25	0.00	1.01
372	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
371	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
370	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
369	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
368	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
367	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
366	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
365	0.89	0.89	169.48	47.60	10.03	1.28	0.77	0.24
364	0.00	0.88	0.00	44.82	0.00	0.84	0.00	0.28

Constituent	Flow (ac-ft/yr)		TN (lbs/yr)		TP (lbs/yr)		TSS (tons/yr)	
Reach ID	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**
363	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
362	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
361	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
360	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
359	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
358	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
357	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
356	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
355	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
354	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
353	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
352	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
351	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
350	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
349	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
348	0.91	0.91	252.92	36.48	17.53	1.06	1.30	0.24
347	0.00	0.91	0.00	36.25	0.00	1.04	0.00	0.27
346	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
345	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
344	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
343	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
342	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
341	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
340	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
339	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
338	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
337	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Constituent	Flow (ac-ft/yr)		TN (lbs/yr)		TP (lbs/yr)		TSS (tons/yr)	
Reach ID	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**
336	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
335	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
334	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
333	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
332	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
331	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
330	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
329	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
328	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
327	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
326	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
325	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
324	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
323	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
322	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
321	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
320	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
318	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
317	0.00	0.16	0.00	2.50	0.00	1.21	0.00	0.08
316	0.00	1.33	0.00	14.60	0.00	2.65	0.00	0.22
315	0.00	1.34	0.00	10.29	0.00	3.58	0.00	0.18
314	0.00	1.33	0.00	11.28	0.00	3.72	0.00	0.25
313	0.00	5.25	88.06	458.08	14.05	114.39	0.78	8.16
312	0.00	5.27	0.00	278.73	0.00	71.83	0.00	6.15
311	0.00	5.25	0.00	274.34	0.00	71.07	0.00	6.21
310	0.00	5.25	0.00	332.97	0.00	76.80	0.00	6.49
309	0.00	6.13	0.00	367.88	0.00	76.02	0.00	6.87

Constituent	Flow (ac-ft/yr)		TN (lbs/yr)		TP (lbs/yr)		TSS (tons/yr)	
Reach ID	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**
308	0.00	6.14	0.00	232.03	0.00	46.43	0.00	4.64
307	0.00	6.14	0.00	182.13	0.00	37.57	0.00	3.89
306	0.00	7.16	0.00	197.44	0.00	35.30	0.00	3.91
305	0.00	7.11	0.00	197.81	0.00	34.38	0.00	3.82
304	0.00	7.08	0.00	199.56	0.00	34.67	0.00	3.92
303	0.00	6.95	0.00	147.19	0.00	27.20	0.00	3.28
302	0.00	7.06	0.00	130.31	0.00	25.00	0.00	3.12
301	0.00	7.23	0.00	133.25	0.00	25.38	0.00	3.23
300	0.00	7.00	0.00	130.31	0.00	24.91	0.00	3.10
256	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
255	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
250	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
249	0.18	0.18	94.59	2.87	17.39	8.38	0.26	0.02
248	2.08	2.26	586.51	582.75	139.12	146.41	3.87	3.83
247	0.00	2.26	0.00	228.21	0.00	100.62	0.00	1.47
246	0.25	2.50	139.24	196.92	25.56	102.70	0.37	1.09
245	1.93	4.43	497.12	681.68	100.69	201.71	3.23	4.31
242	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
241	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
240	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
235	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
234	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
233	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
232	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
231	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
230	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
225	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Constituent	Flow (ac-ft/yr)		TN (lbs/yr)		TP (lbs/yr)		TSS (tons/yr)	
Reach ID	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**
221	0.62	0.62	121.21	119.06	25.23	24.91	0.86	0.89
220	0.00	0.62	0.00	119.67	0.00	24.98	0.00	0.90
215	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
210	0.00	17.81	0.00	2339.00	0.00	207.38	0.00	29.77
209	0.00	17.69	0.00	2341.00	0.00	207.91	0.00	29.89
208	0.00	18.09	0.00	2352.00	0.00	208.72	0.00	30.05
207	0.00	22.72	0.00	3034.00	0.00	409.94	0.00	34.44
206	0.00	22.72	0.00	3029.00	0.00	410.59	0.00	34.68
205	0.00	22.56	0.00	3022.00	0.00	407.78	0.00	34.94
204	0.00	22.56	0.00	3035.00	0.00	408.22	0.00	35.11
203	0.00	22.50	0.00	3023.00	0.00	406.69	0.00	35.38
202	10.81	33.38	821.25	3829.00	719.83	1121.44	13.47	48.42
201	0.00	56.50	0.00	8322.00	0.00	2668.06	0.00	50.65
200	4.00	60.56	891.36	9188.00	199.66	2865.19	6.15	57.29
126	2.45	2.45	559.17	553.27	135.39	134.37	1.61	2.08
125	46.92	49.21	5218.01	5689.30	2587.80	2702.83	23.10	30.93
124	28.83	28.78	4517.21	4456.66	1458.50	1446.50	15.73	19.54
123	7.63	36.40	1737.93	6178.20	281.98	1725.78	21.56	41.76
122	25.03	24.97	4816.52	4730.68	3024.91	3001.42	22.44	27.43
121	0.00	24.97	0.00	4725.39	0.00	2997.70	0.00	26.70
120	0.00	61.38	0.00	10871.59	0.00	4717.80	0.00	69.48
115	0.06	0.06	11.00	10.79	12.48	12.39	0.41	0.38
112	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
111	3.34	3.33	628.29	621.58	148.01	146.80	9.15	9.38
110	0.00	3.34	0.00	619.72	0.00	146.33	0.00	9.48
105	0.00	69.63	0.00	11506.00	0.00	4320.50	0.00	79.73
104	0.17	119.44	212.32	17314.00	109.96	7075.31	3.53	122.86

Constituent	Flow (ac-ft/yr)		TN (lbs/yr)		TP (lbs/yr)		TSS (tons/yr)	
Reach ID	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**	**Edge of the field**	**At outlet**
103	0.00	180.94	25.77	28135.00	10.82	11790.56	0.34	187.34
102	0.00	180.56	0.00	28101.00	0.00	11748.75	0.00	191.29
101	3.81	241.00	846.14	35709.00	261.44	14813.75	13.37	328.79
100	0.00	244.00	0.00	36262.00	0.00	14947.75	0.00	338.54

Appendix

Table 3: Reduction efficiency of BMPs used in SAM

Constituents	**Flow**	**TN**			**TP**			**TSS**		
Flow Path	**Surface**	**Surface**	**Interflow**	**Baseflow**	**Surface**	**Interflow**	**Baseflow**	**Surface**	**Interflow**	**Baseflow**
Tile Line Bioreactors	0%	0%	22%	0%	0%	0%	0%	0%	0%	0%
Restore Tiled Wetlands (Cropland)	30%	52%	52%	0%	43%	43%	0%	75%	0%	0%
Controlled Tile Drainage	30%	0%	43%	0%	0%	43%	0%	0%	0%	0%
Saturated Buffer	20%	0%	45%	0%	0%	0%	0%	0%	0%	0%
Ditch Buffers, 16.5 ft wide (replacing row crops)	5%	43%	0%	35%	50%	0%	0%	74%	0%	0%
Riparian Buffers, 50 ft wide (replacing row crops)	7%	66%	0%	35%	67%	0%	0%	84%	0%	0%
Riparian Buffers, 100 ft wide (replacing row crops)	10%	79%	0%	35%	80%	0%	0%	90%	0%	0%
Riparian Buffers, 50 ft wide (Pasture)	5%	44%	0%	23%	45%	0%	0%	50%	0%	0%
Conservation Crop Rotation	10%	42%	42%	42%	30%	0%	0%	50%	0%	0%
Conservation Cover Perennials	15%	91%	93%	93%	84%	0%	0%	96%	0%	0%
Corn & Soybeans to Rotational Grazing	0%	75%	75%	75%	59%	0%	0%	75%	0%	0%
Corn & Soybeans with Cover Crop	10%	28%	28%	28%	29%	0%	0%	74%	0%	0%
Short Season Crops with Cover Crop	10%	43%	43%	43%	29%	0%	0%	74%	0%	0%
Water and Sediment Control Basin (Cropland)	0%	82%	0%	0%	85%	0%	0%	90%	0%	0%
Terrace	10%	38%	0%	0%	75%	0%	0%	87%	0%	0%
Grassed Waterways	10%	25%	0%	0%	45%	0%	0%	62%	0%	0%
Filter Strips, 50 ft wide (Cropland field edge)	2%	66%	0%	35%	67%	0%	0%	84%	0%	0%
Contour Buffer Strips	10%	50%	27%	27%	62%	0%	0%	75%	0%	0%
Contour Stripcropping	10%	37%	20%	20%	44%	0%	0%	70%	0%	0%
Feedlot Manure/Runoff Storage	90%	90%	0%	0%	90%	0%	0%	90%	0%	0%
Feedlot Runoff Reduction/Treatment	75%	75%	0%	0%	75%	0%	0%	70%	0%	0%
Nutrient Management: Precision/Variable Rate	0%	10%	26%	26%	15%	5%	0%	0%	0%	0%

Constituents	Flow	TN			TP			TSS		
Flow Path	**Surface**	**Surface**	**Interflow**	**Baseflow**	**Surface**	**Interflow**	**Baseflow**	**Surface**	**Interflow**	**Baseflow**
Nutrient Management: Improved Rates/Timing	0%	10%	13%	13%	10%	5%	0%	0%	0%	0%
Manure/Fertilizer Incorporation (no surface spreading)	0%	29%	5%	5%	35%	0%	0%	0%	0%	0%
Alternative Tile Intakes	5%	66%	0%	0%	66%	0%	0%	90%	0%	0%
Drainage Side Inlet Improvements	5%	60%	0%	0%	61%	0%	0%	65%	0%	0%
Traditional Pasture to Rotational Grazing	10%	62%	0%	10%	65%	0%	0%	60%	0%	0%
Livestock Access Control/Fencing (to waters)	10%	55%	0%	0%	65%	0%	0%	75%	0%	0%
Reduced Tillage (30%+ residue cover)	5%	33%	0%	0%	33%	0%	0%	50%	0%	0%
Reduced Tillage (no-till)	8%	79%	0%	0%	68%	0%	0%	80%	0%	0%
Forestry Erosion Control	25%	0%	0%	0%	0%	0%	0%	75%	0%	0%
Forestry Riparian Management Zones	5%	70%	0%	0%	70%	0%	0%	70%	0%	0%
Streambank/In-Channel Restoration	0%	90%	0%	0%	90%	0%	0%	90%	0%	0%
Constructed Stormwater Pond	90%	27%	0%	0%	36%	0%	0%	76%	0%	0%
Constructed Wetland	90%	27%	0%	0%	45%	0%	0%	66%	0%	0%
Infiltration Basin	90%	90%	0%	0%	90%	0%	0%	90%	0%	0%
Bioretention	90%	45%	0%	0%	40%	0%	0%	72%	0%	0%
Biofiltration	90%	45%	0%	0%	40%	0%	0%	72%	0%	0%
Permeable Pavement	90%	48%	0%	0%	45%	0%	0%	67%	0%	0%
Sand Filter	90%	28%	0%	0%	45%	0%	0%	77%	0%	0%

Appendix F. Lake water quality improvement studies

F.1. Beaver Lake water quality improvement study

Beaver Lake (74-0023-00) is located in southwest Steele County in the Straight River Subwatershed of the greater Cannon River Watershed. Recent water quality monitoring efforts for Beaver Lake suggest the lake currently meets water quality standards for AQR and therefore the lake has not been placed on the State of Minnesota's 303(d) list of impaired waters. The Cannon River Watershed local partner team has identified Bever Lake as a high priority lake for water quality protection in their 1W1P comprehensive watershed management plan (EOR 2020) and other planning documents. The local partner team requested that a water quality study be completed for Beaver Lake as part of the WRAPS update for MPCA's Cycle 2 work for the Cannon River Watershed. This technical memorandum presents the results of this work which includes the following components:

- Review of background information and data (Section F.1.1)
- Development of a lake P budget and water quality model (Section F.1.2)
- Establishment of in-lake P targets and load reductions to improve water quality (Section F.1.3)
- Potential strategies to achieve P targets and load reductions (Section F.1.4)
- Summary and considerations for future monitoring, assessments, and analyses (Section F.1.5)

F.1.1 Background information and data

Data sources and previous studies

Below is a summary of the data, studies, and models that were compiled and reviewed for this study. All items listed below are available online or were supplied by local partners. These studies and data sources are referred to throughout different sections of this study.

- *Beaver Lake - Lake Assessment Program (LAP) Report* (MPCA 1993)
- *Cannon River Watershed Management Plan* (EOR 2020)

Lake and watershed characteristics

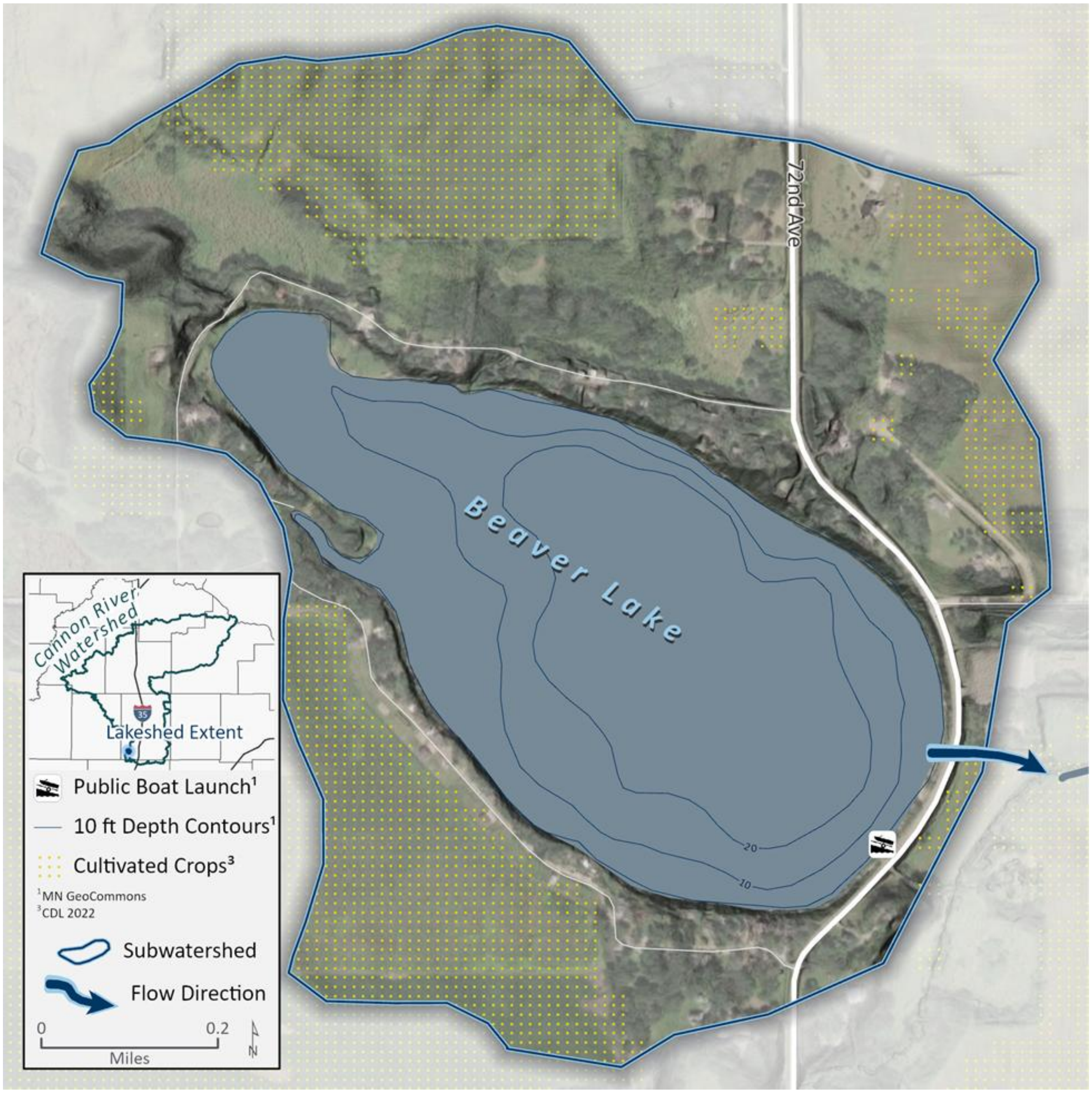
Beaver Lake is located approximately two miles northwest of Ellendale, Minnesota in the Cannon River Watershed (Figure 59). Beaver Lake was formed when an ice block which separated from the main mass of a glacier was buried in glacial till (MPCA 1993). The subsequent melting of the ice block formed the lake basin. Beaver Lake is a moderately sized lake (~98 acres) that is relatively deep for the region (27 feet max depth and 64% of lake is 10 feet or greater). An outlet structure on the west side of the lake currently regulates water levels (MPCA 1993). Outflow from Beaver Lake passes over the outlet structure and travels a short distance to an unnamed ditch which flows to the north and east approximately six miles before discharging to the Straight River. A small gate was installed in the side of a bridge culvert ¼ mile south of the lake where the unnamed ditch crosses Southwest 72nd Avenue; however, this gate has not been opened in many years (MPCA 1993).

The DNR Level 8 drainage area boundary layer shows the Beaver Lake watershed is approximately 205 acres in size (303 acres including lake surface areas). Beaver Lake is considered a headwater lake meaning there are no major streams or upstream lakes flowing to it. There is a small ditch inlet on the north side of the lake and approximately 11 drain tile outlets discharge flow and runoff from areas immediately surrounding the lake

(MPCA 1993). Beaver Lake has a very small watershed to lake area ratio (3 to 1) and an estimated hydraulic residence time of approximately four years which means the lake retains a significant amount of sediment, P, and other pollutants that enter the lake.

There is a county park on the east side of Beaver Lake that includes a concrete boat ramp as well as fishing pier and swimming beach. Much of the lake shoreline has been developed by private homeowners and the lake experiences heavy boat traffic during much of summer. There are approximately 95 seasonal and permanent dwellings located directly around the lake (DNR Lakefinder), all of which are assumed to have septic systems. There are no active registered feedlots located in the Beaver Lake drainage area. Land cover throughout Beaver Lake's 205-acre drainage area is primarily cropland (corn/soybean, 40%), followed by wetland (22%), developed/residential (21%), hay/pasture (11%), and forest and shrubland (6%) (Source: 2019 National Landcover Dataset).

Figure 59. Beaver Lake drainage area.



Water quality

Lake water quality is often evaluated using three associated parameters: TP, chlorophyll-a (chl-*a*), and Secchi depth. P is typically considered the limiting nutrient in Minnesota lakes, meaning that algal growth will increase with increases in TP. Chl-*a* is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Secchi depth is a physical measurement of water transparency. Increasing Secchi depths indicate less turbidity in the water column and increasing water quality. Conversely, rising TP and chl-*a* concentrations point to decreasing water quality and thus decreased water transparency. Measurements of these three parameters are interrelated and can be combined into an index that describes water quality.

Historic and existing water quality conditions for Beaver Lake are described using data downloaded from the MPCA's Environmental Quality Information System (EQuIS) database and the University of Minnesota's Lake Browser. EQuIS stores data collected by the MPCA, partner agencies, grantees, and volunteers. All water quality sampling data utilized for assessments, modeling, and data analysis for this study and referenced reports are stored in this database and are accessible through the [MPCA's Environmental Data Access (EDA) website](). The [University of Minnesota's Lake Browser]() provides satellite derived water quality data for over 10,000 Minnesota lakes. Data are created using an automated image processing system developed with resources from the University of Minnesota and the Environment and Natural Resources Trust Fund — Legislative and Citizens Commission on Minnesota Resources. The automated image processing system processes satellite data from Landsat 8 and Sentinel 2 and provides daily and monthly (May through October) lake clarity (i.e., Secchi depth), chl-*a*, and CDOM data for 2017 through 2021 (Page et al. 2019).

Water quality for Beaver Lake has been evaluated against Minnesota's lake eutrophication standards for class 2B lakes in the Western Corn Belt Plains (WCBP) ecoregion. Minnesota State statute defines various categories of lakes for assessment purposes, including lake, reservoir, shallow lake, and wetland (Minn. R. ch. 7050.0150). The determination between the four categories requires an analysis of basin depth, littoral area, and other characteristics in Appendix D of the *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment* (MPCA 2022a). Beaver Lake has historically been assessed by MPCA as a lake/reservoir during the water quality assessment process. Table 19 shows the current lake eutrophication water quality standards for lakes/reservoirs in the WCBP ecoregion.

Table 19. Lake eutrophication standards for class 2B lakes and reservoirs in the WCBP ecoregion.

Parameter	WCBP lakes and reservoirs
Total phosphorus (µg/L)	≤ 65
Chlorophyll-*a* (µg/L)	≤ 22
Secchi transparency (m)	≥ 0.9

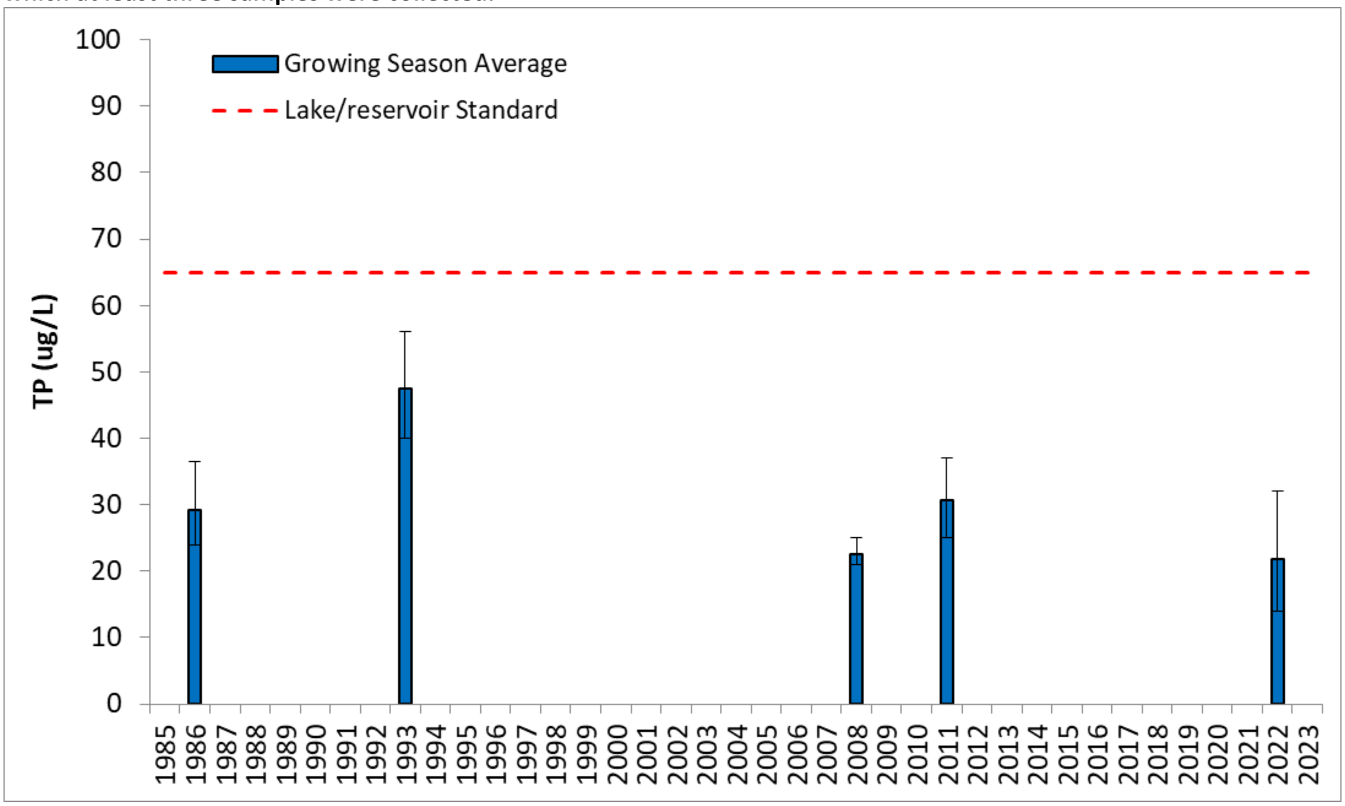
The earliest water quality data available for Beaver Lake in EQuIS are from the 1980s. Since 1986, Beaver Lake has only five years with three or more TP and chl-*a* measurements available in EQuIS during the summer growing season (i.e., June through September) and therefore lacks a consistent record for these parameters. Secchi measurements were periodically monitored during the summer growing season between 1986 and 2012 but have only been collected one year since 2012. University of Minnesota Lake Browser chl-*a* measurements are available for Beaver Lake from 2017–2021 and were combined with the field samples available in EQuIS for the analyses presented in this report. Minnesota Lake Browser Secchi depth measurements were not used in this report due to several high values that were outside the range of observed measurements reported in EQuIS.

Results of the historic TP, chl-*a*, and Secchi depth data for Beaver Lake are summarized in Table 20 and illustrated in Figure 60 through Figure 62. TP data indicate mean summer growing season concentrations have remained below the 65 µg/L WCBP lake/reservoir standard since sampling began in the 1980s. Although data is limited, Figure 60 and Table 20 show mean summer TP concentrations may have improved in the 2000s compared to the 1980s and 1990s, perhaps due to the septic system improvements around the lake in the early 2000s (see Section 4 for further discussion). Beaver Lake summer chl-*a* concentrations have been below the 22 µg/L WCBP lake/reservoir standard over the last 15 years and also may have improved over the 20+ years. Mean summer Secchi depths have also shown an improving trend since the 1980s and 1990s and have consistently met the 0.9 meter standard since monitoring began in the 1980s.

Table 20. Comparison of Bever Lake mean summer water quality during different time periods.

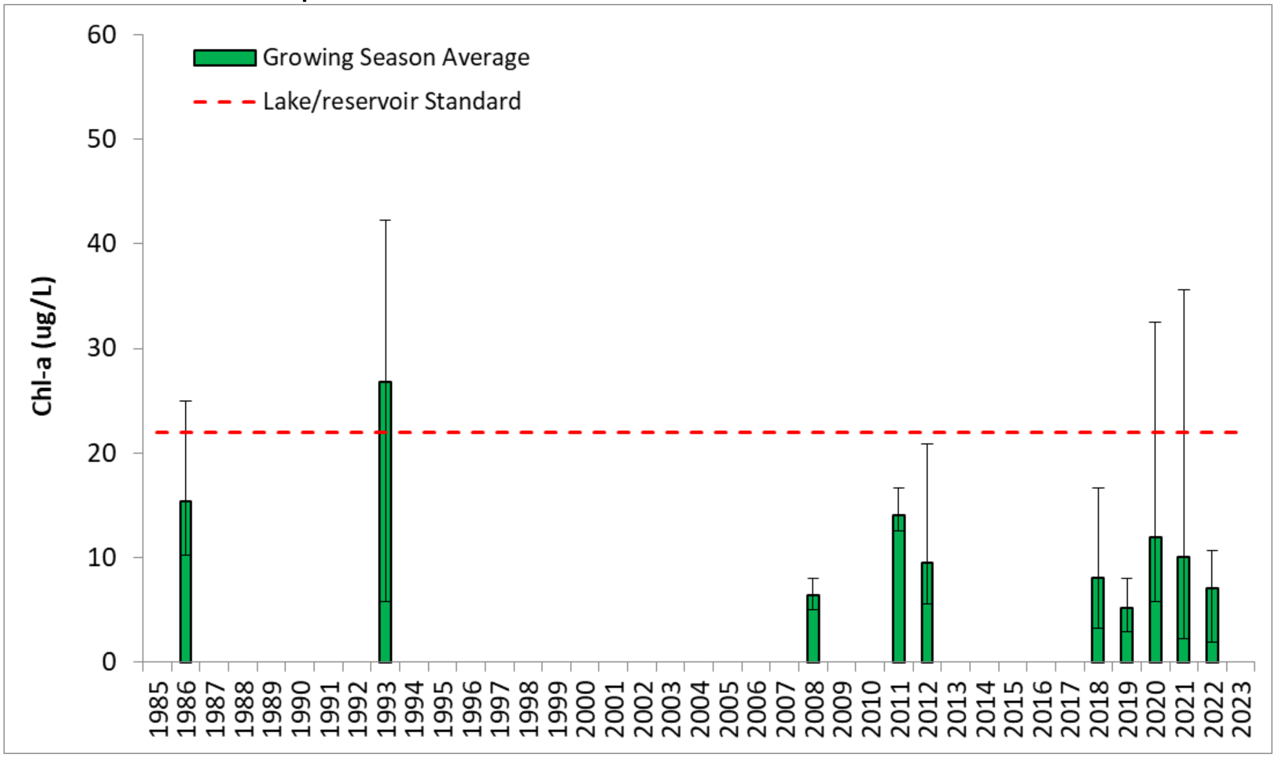
	TP (µg/L)			Chl-*a* (µg/L)			Secchi (m)		
Time period	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**
1985 through 1999	38	49	29	21	27	15	1.1	1.4	0.8
2000 through 2022	25	31	22	9	14	5	1.8	2.9	1.1
Entire record	30	49	22	11	27	5	1.4	2.9	0.8
WCBP shallow lake standards	≤65			≤22			≥ 0.9		

Figure 60. Beaver Lake summer growing season mean TP concentrations (solid bars) from 1985 through 2023 for years in which at least three samples were collected.



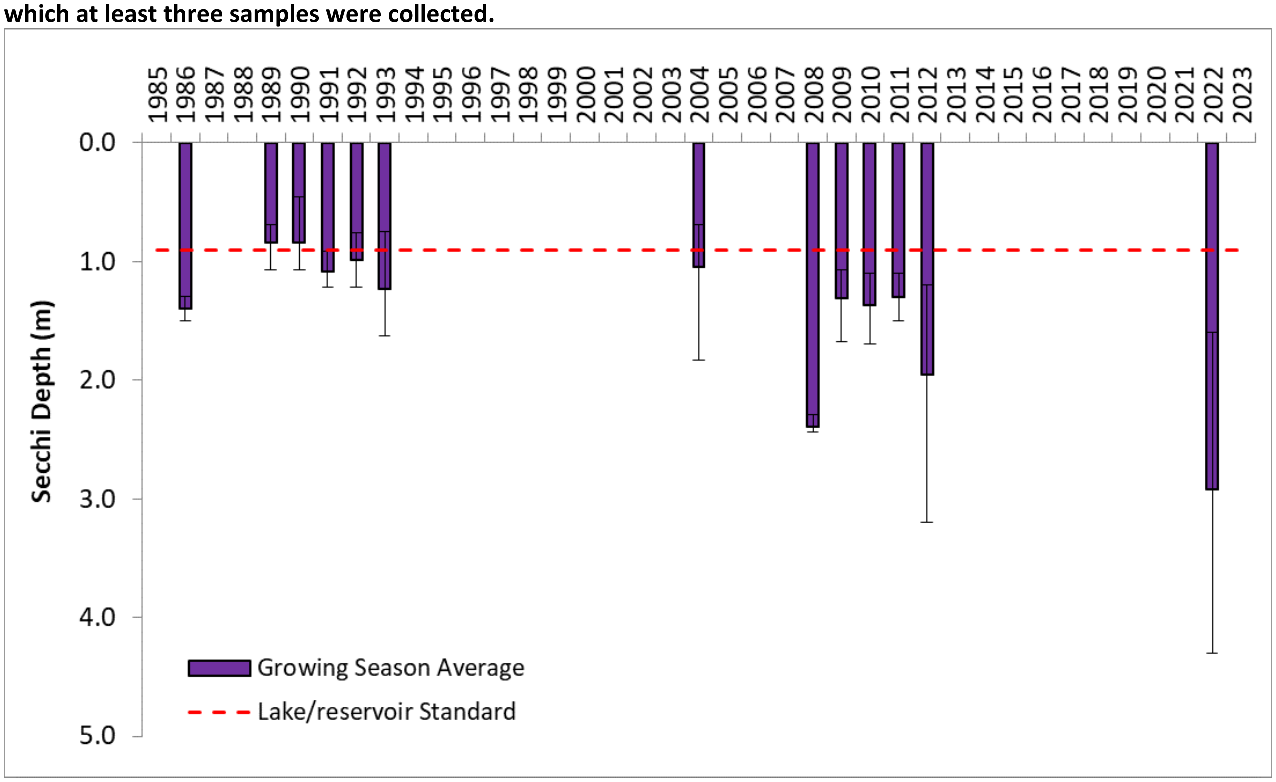
Error bars represent maximum and minimum summer growing season TP concentrations.

Figure 61. Beaver Lake summer growing season mean chl-*a* concentrations (solid bars) from 1985 through 2023 for years in which at least three samples were collected.



Error bars represent maximum and minimum summer growing season chl-*a* concentrations. Data includes discrete measurements from EQuIS (entire period) and satellite derived measurements from University of Minnesota Lake Browser (2017 through 2021).

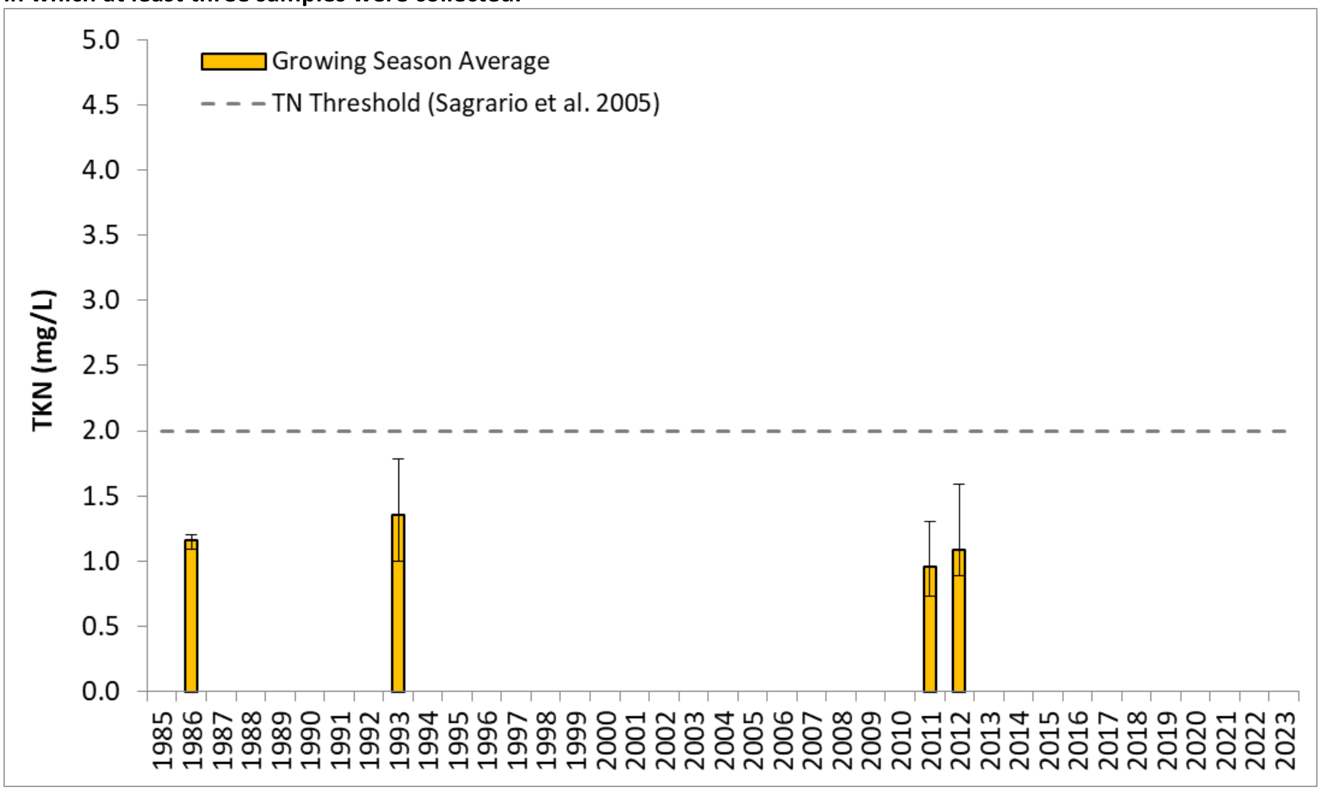
Figure 62. Beaver Lake summer growing season mean Secchi depth (solid bars) from 1985 through 2022 for years in which at least three samples were collected.



Error bars represent maximum and minimum summer growing season Secchi depth measurements. Data only includes discrete measurements available in EQuIS.

Although P is typically considered the limiting nutrient in most Minnesota lakes, N is an essential nutrient for algal and aquatic plant growth. TN (which is calculated as nitrate/nitrite + total Kjeldahl nitrogen [TKN]) has not been monitored in Beaver Lake; however, TKN (i.e., organic nitrogen + ammonia) samples have been monitored periodically and were last collected in 2012 (Figure 63). Studies have found that aquatic plant coverage and the number of plant species in lakes tend to decline when TN levels exceed ~2.0 mg/L (Sagrario et al. 2005; MPCA 2005). Results show individual samples have ranged from 0.73 to 1.78 mg/L and summer mean concentrations have ranged from 0.96 to 1.36 mg/L. Although these values are below the 2.0 mg/L threshold, more spring and summer in-lake TN measurements would be beneficial to assess N levels in Beaver Lake.

Figure 63. Beaver Lake summer growing season mean TKN concentrations (solid bars) from 1985 through 2022 for years in which at least three samples were collected.



Error bars represent maximum and minimum summer growing season TKN concentrations.

Fisheries

Beaver Lake is primarily managed by the DNR for black crappie and bluegill and secondarily for largemouth bass and walleye. During the most recent DNR fisheries surveys in 2023, black crappie catch rates were near the lowest since 1997 but were near the median of similar lakes and growth rates were greater than statewide average for age 1 and 2 fish (DNR Lakefinder). Bluegill catch rates were also near the median of similar lakes and scale and otolith analysis suggested 9-year classes were sampled indicating consistent recruitment. An abundance of smaller largemouth bass were sampled during the 2017 and 2023 surveys which is a positive influence on the bluegill population. Walleye catch rates were high in 2023 and above the upper normal range for similar lakes. Walleye management in Beaver Lake was accomplished through annual fryling stocking from 2014 through 2017 and more recently yearling stocking in 2018 and fingerling stocking in 2019 and 2022 (DNR Lakefinder). Two fish species that are often associated with poor water quality conditions, common carp and black bullhead, were both sampled well below the lower normal range during the 2023 survey. Other species sampled in Beaver Lake in 2023 included hybrid and pumpkinseed sunfish, white sucker, yellow bullhead, and yellow perch.

A common misconception is that if a lake supports a quality gamefish population (e.g., high abundance or desirable size structure of a popular gamefish species), it should be considered a healthy lake. This is not always the case because both game and nongame fish species must be considered when holistically evaluating fish community health. Oftentimes, the smaller nongame fishes serve ecologically important roles in aquatic ecosystems and are generally the most sensitive to human-induced stress. In order to better evaluate the entire fish community, the DNR uses a FIBI scoring system to assess lakes throughout the State of Minnesota. The FIBI assessments utilize fish community data collected from a combination of trap nets, gill nets, beach seines, and backpack electrofishing. From these data, an FIBI score can be calculated for a lake that provides a measure of overall fish community health based on species diversity and composition. If biological impairments are found, stressors to the fish community must be identified. More information about the sampling and assessment process can be found at the DNR Lake Biological Monitoring and Assessment website.

Beaver Lake was sampled and assessed in 2017 using the DNR's FIBI scoring system. Results of the FIBI assessment indicate Beaver Lake (FIBI score = 36) scored above the FIBI impairment threshold established for similar lakes (FIBI threshold = 24) and therefore is supportive of AQL use and is not considered impaired for AQL at this time. Due to the lake's good water quality conditions for the region and high quality fish community, it is a popular lake for fishing and recreation.

Vegetation

Submergent and emergent aquatic vegetation are critical to lakes, providing spawning and cover for fish, habitat for macroinvertebrates, refuge for prey, sediment and water column nutrient uptake, and stabilization of sediments. Declines in the abundance and diversity of aquatic vegetation can be an indication of a shifting biological community and water quality state. As disturbances increase, sensitive vegetation species are lost from the system and often replaced with less desirable species (e.g., aquatic invasive species) or no vegetation at all.

Beaver Lake is rare for lakes in the WCBP ecoregion in that it supports it supports a diverse and abundant aquatic vegetation community which provides valuable cover and spawning habitat for several fish species (DNR Lakefinder). The 2007 DNR fish survey report indicated that plant growth occurred to over 9 feet in depth. Sago and bushy pondweeds were the most commonly occurring plants observed during the 2007 fish survey. Floating leaf and emergent vegetations occurred in 20% of the vegetation transects done by DNR in 2007 and were primarily found on the south and western ends of the lake. A July 2016 point-intercept survey by DNR found 14 different floating and submerged species throughout the lake. One aquatic invasive species, CLP, has been noted by DNR as being seasonally abundant in Beaver Lake. To date, EWM has not been observed in Beaver Lake and no other invasive species have been noted on DNR's statewide infested waters list.

Lakeshore conditions

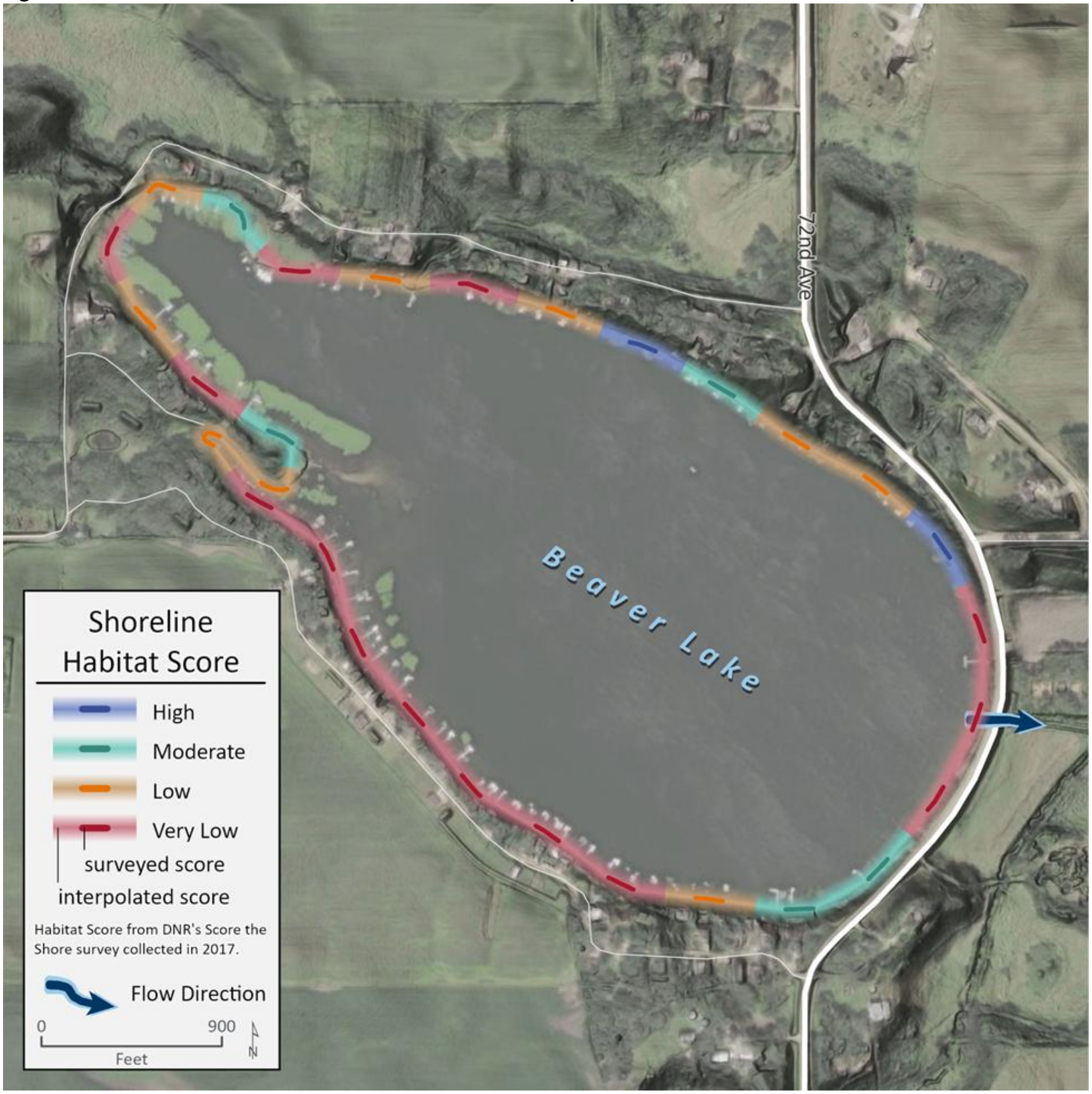
Lakeshore habitat assessments were conducted during the FIBI survey for Beaver Lake. The primary tool used in the assessments was the DNR Score the Shore (STS) Rapid Assessment (DNR 2019a) which were performed by DNR staff. STS is a protocol developed to rapidly assess the quantity and integrity of lakeshore habitat. The survey is designed to assess differences in habitat between lakes and to detect changes over time. STS surveys require visual observation of lands accessible by boat. The intent of the survey is to assess habitat, not to inspect for violations. The STS assessments consist of surveying 100-foot sections of shoreline at predefined, equally spaced survey locations along the entire shoreline of the lake. Since only 100 feet of shoreline is surveyed per location, the full assessment covers a relatively small portion of the total shoreline and results are not tied to individual properties. During the surveys, three lakeshore zones (upland/shoreland, shoreline, and aquatic) are assessed independently at each survey location. Within each zone, surveyors score specific features related to habitat, which are then summed for an overall Zone Habitat Score. Higher scores indicate a greater amount of habitat. Lower scores indicate a low percent of the site remains natural and a higher amount has been physically disturbed or altered by humans. The feature scores within each zone are summed for an overall site habitat score. This scoring process provides a simple method of ranking sites based on the percent of each site that is in a natural condition versus the percent of the site that has been altered. A lakewide score is calculated using the mean site habitat score. Scores range from 0 to 100 and lakes with a high percentage of unaltered habitat score higher than lakes that have been highly altered. More information about the methods used for the STS surveys can be found in the Minnesota Lake Plant Survey Manual (DNR 2019a).

The DNR STS assessment results for Beaver Lake are summarized in Table 21. Figure 64 illustrates the results of the overall habitat scores for the 30 STS survey locations. In this figure, the dark colored lines show the results of the individual surveyed locations (i.e., 100-foot survey sections). The lighter, thicker lines along the shoreline represent interpolated scores between the 100-foot surveyed sections. The overall score for Beaver Lake (51) is well below the mean score of all surveyed lakes in the Cannon River Watershed (mean score = 70; N = 19) and was the lowest score in the watershed. The overall score for Beaver Lake is also below the average score for lakes surveyed throughout the state of Minnesota (mean score = 74; N = 764). A low score indicates that, on average, surveyed sites have a high percentage of altered habitat. Development has had the largest effect on the shoreland and shoreline habitat components for Beaver Lake. Residential development has disturbed and altered much of Beaver Lake's shoreline, as the density of houses around the lake is high. The number of homes/cabins increased slightly since 2002. Approximately 95 dwellings were counted by the DNR in 2006 resulting in a density of 51 per shoreline mile (DNR Lakefinder). Despite this heavy development, most of the shoreline is stable, either being natural sand or cobble, and observations at vegetation transect sites indicate that less than 10% of the shoreline has been stabilized with rock riprap. Turf grass lawns maintained to the water's edge were fairly common, occurring in 40% of the vegetation transects. Coarse woody debris was limited and did not occur in any vegetation transect. Coarse woody debris is known to provide valuable fish habitat and contributes to the food chain by providing substrate for invertebrate production. It is estimated that Beaver Lake has approximately 77 docks (~42 docks per mile of shoreline) based on review of 2024 Google imagery. Dock densities exceeding 16 docks per mile can significantly affect fish communities and habitat (Jacobson et al. 2016, Dustin 2017). Based on the dock density estimate, aquatic plant removal is likely and could be contributing to physical habitat loss within the lake, which poses a threat to the Beaver Lake fish community.

Table 21. DNR STS survey results for Beaver Lake.

Category	Result
Dock density (#/mile)	42
Survey locations	30
Percent developed	100%
Shoreland zone score	18.8 low
Shoreline zone score	9.9 very low
Aquatic zone score	22.6 moderate
TOTAL SCORE	51.3 low

Figure 64. Overall site habitat STS scores for individual sample locations.



Climate

The *Climate summary for watersheds: Cannon River* (DNR 2019b) report shows that annual average temperatures in the Cannon River Watershed have increased over the last 40 years and that most years during the past two decades have been warmer than average. Monthly average temperatures in the Cannon River Watershed peak in July, and winter temperatures on average have increased over time. Annual precipitation has also shown an upward trend across the watershed since around 1940. Monthly precipitation is typically highest in June and increases in precipitation in recent years were most pronounced in April through August. The frequency of 1-inch and 3-inch rain events has increased in general in Minnesota, along with the size of the heaviest rainfall of the year. Minnesota has also experienced an increase in devastating, large-area extreme rainstorms (DNR 2022). Climate projections indicate these big rains will continue increasing into the future (DNR 2022).

Statewide lake data collected by the DNR, MPCA, and local partners shows that the climate trends described above have already impacted lakes throughout the state and region. According to MPCA's [Climate Change and Minnesota's Surface Waters Viewer](), lake surface temperatures have warmed during all seasons throughout southern Minnesota. During the summer growing season (June through September), lakes in southern Minnesota are, on average, approximately 2.7 to 4.4 degrees F warmer now than they were 50 years ago. Additionally, warmer winters have resulted in about 9 less days of ice coverage on average for lakes throughout the region since the mid-1970s.

Reduced ice coverage, higher year-around water temperatures, and more intense and frequent precipitation events can result in significant impacts to lakes and lake users, including but not limited to (MPCA 2021):

- Overall increase in flow, sediment, and nutrient loading from the lake drainage area
- Longer periods of stratification and anoxia resulting in increased internal P recycling
- Longer open water and growing season for algae and cyanobacteria blooms
- Larger fluctuations in lake level from year to year
- Potential for increased densities of aquatic invasive plants, such as CLP and EWM
- Decreases in walleye (who prefer summer water temps at 65 to 70 degrees F) in smaller, warmer lakes
- Potential for more fish kills as fish are squeezed into smaller zones to access oxygen
- Shortened season for safely recreating on ice-covered lakes

Although long-term supporting data is limited, it is likely that Beaver Lake has or is currently experiencing many of the climate impacts described above. These impacts create additional challenges to protect Beaver Lake water quality and support healthy plant and fish communities. Adaptation strategies such as improving water management practices, enhancing soil health, planting conservation perennials, and natural shoreline buffers should be considered for Beaver Lake to build resilience to these impacts and threats.

F.1.2 Lake phosphorus budget and model

An updated lake P budget and eutrophication model (BATHTUB) were set up for Beaver Lake using methods similar to the lake TMDLs in the *Cannon River Watershed Total Maximum Daily Load* Report (MPCA 2016) and other lake TMDLs throughout the State. The four primary P sources considered for the Beaver Lake model were loading from the lake's drainage area, septic systems, atmosphere, and internal recycling. Each of these sources, and how they were estimated, are discussed below in more detail.

Drainage area

Precipitation that falls within the drainage area of a lake flows across the land surface and/or through sub-surface drain tiles, and a portion of it eventually reaches the lake. P is carried with the runoff water and delivered to the lake. The primary P sources in runoff in the Beaver Lake drainage area include soils, fertilizer, vegetation, wetlands, and impervious surfaces and lawns in residential areas surrounding the lake.

Watershed runoff volumes and TP loads from the Beaver Lake drainage area were estimated using the Cannon River Watershed Hydrologic Simulation Program-Fortran (HSPF) model (2019 version). HSPF is a comprehensive, mechanistic model of watershed hydrology and water quality that allows the integrated simulation of point sources, land and soil nutrient runoff and subsurface processes, and in-stream hydraulic and sediment-chemical interactions. Model documentation contains additional details about the Cannon River HSPF model development and calibration (LimnoTech 2015). The modeling period for the Cannon River HSPF model covers 1996 through 2019. In the model, the Beaver Lake drainage area is not explicitly modeled but is included in a larger reach/subwatershed within the model (HSPF Reach 860). Table 22 presents the HSPF predicted mean annual flow and TP load by land cover type for HSPF Reach 860 that were used to represent the Beaver Lake drainage area. Based on these rates, approximately 150 lbs/year of TP is delivered to Beaver Lake and cropland (73%) represents the largest loading source to the lake.

Table 22. Model estimated flow volume and TP loading rates and annual totals for the Beaver Lake drainage area (modeled years = 2010 through 2019).

Land cover category	Area (acres)	Modeled flow rate (in/yr)	Modeled flow volume (acre-ft/yr)	Modeled TP load rate (lbs/acre/yr)	Modeled TP load (lbs/yr)
Cropland	81	14.2	96	1.35	110
Developed/residential	43	19.8	70	0.58	25
Wetland	45	8.2	31	0.15	7
Forest and shrubland	14	13.1	15	0.10	1
Hay/pasture	22	15.4	29	0.30	7
TOTAL	205	14.1	241	0.73	150

Septic systems

Flow and TP loads from septic systems were estimated using methods similar to the *Lower Minnesota River Watershed TMDL* (MPCA 2020a). The DNR estimated that there are approximately 95 residences surrounding Beaver Lake based (DNR Lakefinder). Assumptions were made regarding the number of people per household (~2.1), and the percent of homes that are occupied year around (50%) versus seasonally (50%). Estimated septic compliance rates (~84% compliant and ~16% failing or noncompliant) were assumed based on county-wide estimates for Steele County from 2010 through 2016 (MPCA county surveys) that were adjusted to account for 22 septic systems that were upgraded in the early 2000s based on information available in the Minnesota Board of Water and Soil Resources' (BWSR) eLINK database. Septic system TP removal rates for compliant systems were assumed to be approximately 80%, while removal rates of 57% were assumed for failing systems (Barr Engineering 2004). Through this analysis it was estimated that compliant septic systems currently contribute approximately 51 lbs/year of TP to Beaver Lake while noncompliant systems contribute approximately 21 lbs/year.

Atmosphere

P is bound to atmospheric particles that settle out of the atmosphere and are deposited directly onto surface water. P loading from atmospheric deposition to Beaver Lake is estimated to be approximately 38 lbs/year based on the average deposition rate across the Lower Mississippi River basin (0.39 lbs/acre-year; Barr Engineering 2007).

Internal phosphorus recycling

Internal P recycling, often referred to as "internal loading," is a common occurrence in eutrophic and hypereutrophic lakes throughout central and southern Minnesota. P contained in the sediment of lakes originates as an external P load that settles out of the water column to the lake bottom. Typically, a significant amount of the external load to the Beaver Lake is delivered during snow melt and spring and early summer runoff. During this time, low water temperatures and flushing limit the amount of algae growth and biological activity within the lake. As water temperatures increase in mid-summer (e.g., late June and July), lakes can become thermally stratified during quiescent periods and biological activity increases, which leads to higher rates of algae growth and bacterial decomposition. As this happens, DO is consumed by bacteria, and anoxic conditions (i.e., low DO) can develop at the sediment-water interface which leads to the release of P from the lake sediments. The P that is released from the sediments is in a soluble form that is readily available to algae for uptake. P that has accumulated near the sediment-water interface can be readily mixed into the surface waters during strong winds, storm events, and as stratification begins to weaken in the late summer and early fall. Internal P recycling is especially problematic in lakes during dry and hot summers, when lower flows provide less dilution for P loads recycled from lake bottom sediments. Further, algae growth rates and sediment decomposition rates are elevated during dry and hot summers due to higher water temperatures and longer hydraulic residence times (Walker 2011).

There is evidence from the available data for Beaver Lake that suggests internal P recycling occurs within the lake:

- Although temperature and DO profile data for Beaver Lake is limited, surface TP and chl-*a* concentration spikes have been observed when thermal stratification weakens or breaks down in late summer and early fall (e.g., 2004, 2018, and 2019)
- Mean surface TP and chl-*a* concentrations are highest in September and October in most years despite generally decreasing precipitation, watershed runoff, and external TP inputs during this time period, likely due to the breakdown of thermal stratification and mixing of the lake.
- Mean surface TP and chl-*a* concentrations are lower from June through August when thermal stratification is strongest and there is minimal mixing between surface and bottom waters.
- High TP concentrations ranging from 100 µg/L to over 460 µg/L have been observed in hypolimnetic (i.e., depths greater than ~12 feet) samples collected during summer stratification

At this time, there is not enough data available to explicitly quantify the amount of P that is typically recycled within Beaver Lake each year. In order to better characterize internal recycling, additional data would need to be collected such as continuous or high-frequency temperature and DO profiles, hypolimnetic P samples, and/or sediment cores. Since internal P recycling reflects recycling of loads that originally entered the lake from the lake drainage area and atmosphere, the amount of P recycling is expected to vary with external load over time.

Common carp are another potential source of internal P recycling. When present in high densities, carp can exacerbate poor water quality in lakes by destroying/uprooting aquatic vegetation and resuspending/recycling TP from lake sediments. Studies have demonstrated how adult carp can increase turbidity, TSS, TP, and negatively affect macrophyte abundance through various direct and indirect processes (Parkos et al. 2003). Research suggests that negative impacts of common carp on turbidity and vegetation begin to occur at densities of around 89 lbs/acre (Bajer et al. 2009). To our knowledge, common carp density has not been assessed in Beaver Lake. Although the gear used in the DNR trap and gill net surveys tend to underrepresent common carp abundance due to high net avoidance, these surveys can provide a relative means to track carp trends and changes over time within a lake and compare catch rates to other lakes. Based on our review of the DNR trap and gill net surveys, common carp catch rates for Beaver Lake have decreased from peak values in 2007 that were above the upper normal range for similar lakes in the region. Common carp catch rates have remained below the lower normal range during the last two DNR surveys (2017 through 2023). Negative impacts to lake habitat and water quality are likely negligible at these low levels but DNR catch rates should continue to be monitored.

CLP has also been hypothesized to contribute to internal P recycling and algae blooms in lakes after the plant dies back in midsummer. Although it can be found in a wide-range of environmental conditions, CLP is most common and abundant in alkaline (> 100 mg/L calcium carbonate alkalinity, $CaCO_3$), P-rich lakes (TP between 50 – 100 µg/L; Bolduan et al. 1994) that are dominated by urban or agricultural land use in the southern half of the state (Heiskary and Valley 2012). Based on their review of sentinel lakes throughout the state with CLP infestations, Heiskary and Valley (2012) found that some shallow lakes exhibited mid-summer TP spikes around the time of CLP senescence; however, it was difficult to determine how much of a role CLP plays compared to other internal and external sources.

Lake eutrophication model and final phosphorus budget

A spreadsheet version of the lake model BATHTUB (Walker 1987) was established for Beaver Lake to model current lake water quality conditions. BATHTUB is a steady state model that predicts eutrophication response in lakes based on empirical formulas developed for nutrient balance calculations and algal response (Walker 1987). The model was developed by the U.S. Army Corps of Engineers and has been used extensively in Minnesota and across the Midwest for lake nutrient TMDLs. Several models (subroutines) are available for use within the BATHTUB model, and the Canfield-Bachmann model was used to predict P settling/retention and the lake response to TP loads in Beaver Lake. The BATHTUB model requires flow and P loading inputs from the lake's drainage area, upstream lakes, and atmospheric deposition. Lake morphometric data are also required by the model.

Drainage area runoff volumes and P loading inputs to the Beaver Lake BATHTUB model were derived from the HSPF model (Table 22). Flow and P loading from atmospheric deposition and septic systems using the methods described above were also added to the model. With the primary external sources defined, the model predicted in-lake P concentration was compared to the 2000 through 2022 observed mean concentration (Figure 60 and Table 20). P monitoring data prior to 2000 were not used due to the septic improvements completed in the early 2000s. The model predicted in-lake TP concentration was lower than the observed concentration and therefore the P sedimentation calibration factor was adjusted (i.e., to increase sedimentation/retention) to match the monitored value.

The settling/retention model used in the Beaver Lake BATHTUB model inherently includes an average amount of P recycling. In some cases, the amount of P recycled within a lake is greater than the amount inherent in the model and the modeler may choose to add additional load to improve model calibration. Alternatively, the Canfield-Bachman P sedimentation calibration factor can be adjusted to account for internal P recycling as recommended in the BATHTUB Version 6.1 Online Documentation (Walker 2006). Although there is evidence that P recycling occurs in Beaver Lake, the BATHTUB model did not require an additional P load or any reduction to the P sedimentation calibration factor (Walker 2006). This suggests that internal recycling of P is not a major contributor to surface waters during most of the summer growing season and management of external sources is the most appropriate starting point to improve and protect in-lake water quality.

As shown in Table 23, loading from the Beaver Lake drainage area (58%) represents the largest source of P to the lake followed by septic systems (28%) and atmospheric inputs (14%). Sedimentation/retention represents the largest sink of P (93%) suggesting a significant amount of the annual load delivered to the lake is retained in the lake and its sediments.

Table 23. Beaver Lake current condition P budget (HSPF modeled years = 2010 through 2019).

Category	Annual Load (lbs/yr)	Percent of Total
Sources (+)		
Drainage area	150	58%
Atmosphere	38	14%
Septic Systems	72	28%
TOTAL	260	
Losses (-)		
Sedimentation/retention	243	93%
Outflow	17	7%
TOTAL	260	

F.1.3 Phosphorus targets and reductions

Establishing phosphorus goals to protect Beaver Lake

The primary objective of this study is to protect water quality conditions in Beaver Lake. Beaver Lake currently meets WCBP lake/reservoir standards for all three eutrophication parameters (Table 19). Therefore, an in-lake TP concentration target below the 65 µg/L standard and at or below the current mean TP concentration (25 µg/L) should be considered to protect future water quality conditions and minimize algae blooms. Here, we present two P reduction goals local partners could consider to protect Beaver Lake water quality:

- Short-term goal – reduce P loading to Beaver Lake by 5%
- Long-term goal – reduce P loading to Beaver Lake by 10%

The DNR commonly uses a 5% P load reduction goal to protect lakes that are comfortably meeting state water quality standards such as Beaver Lake. The 10% reduction goal should be viewed as a potential long-term goal after the 5% goal is achieved. The BATHTUB model and existing water quality data suggest that both goals may not lead to significant changes in algae levels or water clarity. Even if measurable improvements in chl-*a* or Secchi are not achieved, achieving these goals will help buffer the lake from future stressors such as changes in runoff patterns, temperature, and/or ecological shifts.

Load reduction goals

Table 24 presents the current TP load to Beaver Lake, the TP target load, and the load reduction required to achieve the target load. Section 4 presents example strategies and BMP options to achieve the load reductions presented in Table 24.

Table 24. TP loads and reductions to meet in-lake water quality targets.

Phosphorus goal	Current TP (µg/L)	Current TP load (lbs/yr)	TP target load (lbs/yr)	TP load reduction (lbs/yr)	TP load reduction (percent)
Short-term	25	260	247	13	5%
Long-term			234	26	10%

F.1.4 Strategies to improve Beaver Lake water quality and aquatic life

Example strategies were selected using a variety of sources, input from local stakeholders, and best professional judgement from MPCA staff. Example strategies presented in this section are intended to provide potential options to achieve the protection goals for Beaver Lake. The strategies are not required, and implementation is considered voluntary. Stakeholders should use these example practices as a path to improve water quality, but it is anticipated that implementation may change as new information is learned and data is collected. It is recommended that stakeholders incorporate other known local issues or causes when implementing practices and strive to incorporate multiple benefits into projects.

These example strategies concur with the recommendations presented for Beaver Lake in the 2016 WRAPS document:

- Maintain or increase perennial vegetation in watershed
- Protect or restore native riparian vegetation
- Avoid or mitigate for future proposed agricultural drainage improvement projects
- Require land in the shore impact zone to be established, maintained, or restored in native/perennial riparian buffer at the time of development or at the time of permit issuance
- Adhere to/increase shoreland setbacks

Cropland best management practices

MPCA developed a list of potential cropland BMP and land use change example scenarios that could be considered for Beaver Lake to improve water quality. These scenarios include:

- Implement conservation till every year on all fields currently practicing conventional till and periodic conservation till
- Implement no-till on all fields currently practicing conventional till and periodic conservation till
- Implement cover crops on all cropland fields
- Convert 25% of cropland fields to grassland
- Convert 75% of cropland fields to grassland

P reductions for each BMP scenario described above were estimated using rates derived from the defaults in HSPF– Scenario Application Manager (SAM; version 2.0) and the Watershed Pollutant Load Reduction Calculator (MPCA 2022b). Table 25 presents the potential TP load reductions for each scenario. P reductions from the example scenarios range from 15 to 64 lbs/year and therefore, depending on the scenario selected and level of adoption, could help achieve a significant amount of the annual reduction goals identified in Table 24.

Developed/residential BMPs

It is estimated that there are approximately 95 homes/residences surrounding Beaver Lake and residential areas account for 21% of the land use and 17% of the annual P load to Beaver Lake. Nearly all of the homes are on shoreline lots or other lots in close proximity to the lake. Based on investigation of air photos, most of the residential lots surrounding the lake are around 1/4 acre in size and impervious surfaces (i.e., rooftops, driveways, walkways, roads) generally cover approximately 1/2 of the lot (~0.13 acres per lot). Due to their density and close proximity to Beaver Lake, these impervious surfaces have high potential for stormwater to be delivered to the lake via surface runoff, drain tile, and/or shallow groundwater pathways.

A rain garden is one of the most efficient residential stormwater BMPs used to intercept runoff from impervious surfaces and remove pollutants before they enter surface waters. Below are three rain garden BMP example scenarios to reduce P loading from residential areas throughout the Beaver Lake drainage area.

- Low adoption scenario – 10% of residences throughout the drainage area install and maintain rain gardens to treat impervious areas (assumes 10 rain gardens treating approximately 1.3 acres of impervious area)
- Moderate adoption scenario – 25% of residences install and maintain rain gardens (24 rain gardens and 3.1 acres treated)
- High adoption scenario – 50% of residences install and maintain rain gardens (48 rain gardens and 6.2 acres treated)

P reductions from rain gardens were estimated using default rates provided in the MPCA SE model. Table 25 presents the potential TP load reductions for each scenario. Reductions range from 0.7 lbs/year for the low adoption scenario to 3.2 lbs/year for the high adoption scenario. Although the total load reductions for the raingarden scenarios are less than the cropland BMP scenarios, raingarden TP reduction efficiency is higher than many of the cropland BMPs listed in Table 25. Thus, raingardens are an effective practice in reducing P loads from developed areas in the Beaver Lake drainage area.

Lakeshore BMPs

Shoreline development for Beaver Lake is very high and has resulted in the loss of both riparian vegetation and native floating-leaf and emergent plant stands that serve as important habitat for fish and other organisms. Further, replacement of riparian vegetation with riprap and open lawns has resulted in increased nutrient inputs from fertilizer and lawn clippings, reduced buffering capacity, destabilized shoreline, and elimination of future contributions of coarse woody habitat into the lake.

Shoreland owners can significantly improve shoreline habitat by choosing to reestablish or maintain native plants along their property. Natural shorelines provide overhead cover to fish and wildlife species, contribute important coarse woody habitat into the lake, and provide a buffer for nutrient runoff from lawns and impervious surfaces. While shoreline restoration projects vary in scope and size, all can be completed in ways that are visually appealing and that maintain a view of the lake. Once completed, these projects have potential to provide many ecosystem benefits that a more traditional developed shoreline (e.g., riprap, mowed lawn, and sand beach) could not offer. The DNR maintains an interactive Restore Your Shore webpage that provides guidance for shoreland owners and professionals to use in implementing shoreland restoration projects. Protection and restoration of floating-leaf and emergent aquatic vegetation should also be prioritized, especially where aquatic habitat is limited. Shoreland owners should be aware of and adhere to current laws that regulate shoreline and aquatic plant control, riprap, sand blanket, and retaining wall installation, and other shoreline alterations.

The DNR estimates that a developed shoreline with turf grass to the water's edge allows seven to nine times more P to enter the lake than a naturally vegetated shoreline (Radomski and Van Assche 2014). While the amount of P entering the lake from shoreline lots varies due to soil, slope, and other site-specific conditions, the average pollution from 100 feet of nonbuffered shoreline has been estimated at 0.2 lbs/summer TP compared to 0.03 lbs/summer for a lot with a native vegetated shoreline buffer. Based on air photo interpretation and results of the Beaver Lake DNR STS survey (Table 21 and Figure 64), there is at least 6,500 feet of shoreline that could benefit from native shoreline buffers. Implementation of native buffers in these areas would result in TP reductions of approximately 11 lbs/year and provide several ecosystem benefits as described above and in Table 25.

Septic system improvements

At least 22 septic systems surrounding Beaver Lake were upgraded in the early 2000s based on information available in BWSR's eLINK database. These upgrades resulted in an estimated TP load reduction of 16 lbs/year according to the methods described in Section 2. It is estimated that about 15 septic systems in the Beaver Lake drainage are noncompliant at this time. If these systems were brought into compliance, TP loading to the lake would be reduced by approximately 11 lbs/year (Table 25).

Internal phosphorus recycling

As discussed in Section 2, net effects of internal P recycling were not explicitly estimated for this study. Although there is evidence that internal P recycling occurs within Beaver Lake, it is assumed that the rate of recycling will decrease as the lake and sediments equilibrate to lower external P loads. Strategies to reduce internal recycling could be considered if water quality conditions in Beaver Lake degrade in the future and/or if BMP efforts to reduce external loads fall short of the targets and goals set by the local partners. Internal recycling strategies could include, but are not limited to, water level drawdown, sediment dredging, sediment P immobilization or chemical treatment (e.g., alum and Phoslock®). The MPCA recommends feasibility studies for any lake in which major in-lake management strategies are proposed. The *Minnesota State and Regional Government Review of Internal Phosphorus Load Control* paper (MPCA 2020b) provides more information on internal load BMPs and considerations.

At this time, common carp do not appear to be significant contributor to P recycling in Beaver Lake (see Sections 1 and 2). However, efforts to limit and prevent the migration and movement of common carp from upstream/downstream water bodies could be considered as a protection strategy to prevent this threat from becoming a problem in the future. It is recommended that local partners work closely with DNR if they are interested in pursuing carp management in Beaver Lake.

As discussed in Section 2, the relationship between CLP and water quality varies substantially among lakes and clearly defining "cause and affect" can be difficult. Heiskary and Valley (2012) found little evidence supporting CLP as a driver of lake water quality conditions in Minnesota. While there are some case studies in Minnesota and Wisconsin that suggest CLP can have negative impacts on summer water quality (James et al. 2002, Welling 2010), pilot studies and published research actually demonstrate negative effects of large-scale removal of CLP on summer water quality in eutrophic lakes (Valley et al. 2006, Welling 2010). These studies concluded that a sole focus on killing CLP in lakes, especially where the plant is abundant, may carry more risks of harmful effects to water quality and fish habitat than leaving the plant unmanaged. Thus, local partners should not expect water quality enhancements by focusing exclusively on treating CLP without simultaneous, long-term measures to reduce internal and external P loads.

Nitrogen management

While the primary focus of this study is reducing P since it is typically the limiting nutrient in lakes, studies have demonstrated that N loading to lakes can affect eutrophication and should not be overlooked. As discussed in Section 1, Beaver Lake TKN concentrations have, at times, exceeded levels that may affect aquatic plants. More N monitoring data is needed to better understand N dynamics in Beaver Lake and its impact on eutrophication, aquatic plants, and other biota. Specific N targets and watershed load reduction goals for Beaver Lake could be considered in the future as more data are collected. N reductions alone may not be successful in reducing nuisance algae blooms because certain algae (e.g., blue-green algae) are able to fix atmospheric N (Wetzel 2001). However, reduction in N loading in conjunction with the P load reductions is likely the best approach for reducing algal growth and nuisance algal blooms (MPCA 2005). Table 25 presents TN reductions rates/efficiencies for most of the cropland BMPs discussed in this report.

Table 25. Beaver Lake BMP example scenarios and associated TP load reductions and other benefits.

Strategy type	BMP	BMP example scenario	Current level of adoption	BMP TP reduction rate/efficiency	TP load reduction (lbs/yr)	Other water quality and habitat benefits
Cropland BMPs	Conservation till	Conservation till on all cropland fields currently practicing conventional till (81 ac)	none	0.21 lbs/ac/yr[a]	17	sediment (reduction = 160 lbs/ac/yr[a]), nitrogen (reduction = 1.18 lbs/ac/yr[a]), improved soil health
	No till	No-till on all cropland fields practicing conventional till (81 ac)	none	0.43 lbs/ac/yr[a]	35	sediment (reduction = 260 lbs/ac/yr[a]), nitrogen (reduction = 2.82 lbs/ac/yr[a]), improved soil health
	Cover crops	Cover crops on all cropland fields (234 ac)	none	0.18 lbs/ac/yr[a]	15	sediment (reduction = 240 lbs/ac/yr[a]), nitrogen (reduction = 5.23 lbs/ac/yr[a]), improved soil health
	Cropland to grassland	Convert 25% of cropland fields to grassland (20 ac)	none	1.05 lbs/ac/yr[b]	21	sediment (reduction = 300 lbs/ac/yr[a]), nitrogen (reduction = 17.34 lbs/ac/yr[a])
		Convert 75% of cropland fields to grassland (61 ac)	none	1.05 lbs/ac/yr[b]	64	
Developed/ Residential BMPs	Rain gardens	Low adoption: 10 residences install raingardens to treat 1.3 acres	unknown	0.52 lbs/ac/yr[c]	0.7	sediment (reduction = 123 lbs/ac/yr[c]), water retention, groundwater recharge
		Moderate adoption: 24 residences install raingardens to treat 3.1 acres	unknown	0.52 lbs/ac/yr[c]	1.6	
		High adoption: 48 residences install raingardens to treat 6.2 acres	unknown	0.52 lbs/ac/yr[c]	3.2	
Shoreline BMPs	Native shoreline buffers	Implement native shoreline buffers on 6,500 feet of developed, nonbuffered shoreline	unknown	0.17 lbs/100-ft of shoreline[d]	11	filtering of sediment and other pollutants, reduced erosion, shoreline stabilization, habitat for insects, fish, birds, amphibians, decreased maintenance cost

Strategy type	BMP	BMP example scenario	Current level of adoption	BMP TP reduction rate/efficiency	TP load reduction (lbs/yr)	Other water quality and habitat benefits
Septic system improvements	Septic system upgrade	Upgrade all failing septic systems in watershed (~15 systems)	84% (~80 systems)	0.73 lbs/system/yr[e]	11	nitrogen and fecal coliform reductions (not quantified)

[a] Source: Watershed Pollutant Load Reduction Calculator (MPCA 2022b)

[b] Source: Le Sueur River HSPF–SAM (version 2.0)

[c] Source: MPCA Simple Estimator model

[d] Source: Radomski and Van Assche 2014

[e] Source: MPCA 2020a and Barr Engineering 2004

F.1.5 Summary and future monitoring and analyses

This study identifies two water quality improvement goals for Beaver Lake that local partners can use to help guide protection efforts. The short-term goal is intended to reduce P loading by 5% or approximately 13 lbs/year (Table 24). Short-term goal could be achieved through a moderate level of adoption of the BMP scenarios identified in Section 4 and Table 25. The long-term goal, which calls for P load reduction of 10% (26 lbs/year; Table 24), could be met through high level adoption of the BMP scenarios presented in Section 4. Implementation of cropland BMPs such as conservation till, no-till, and cover crops will be critical to meet both of the protection goals presented in this study. Septic system upgrades and rain gardens on residential properties surrounding Beaver Lake should also be targeted as these are pollutant sources with direct pathways to the lake. Finally, due to the high density of residential development surrounding Beaver Lake, native shoreline buffers will be a critical strategy to reduce nutrient inputs and restore and protect fish habitat. Recent shoreline surveys scores for Beaver were the lowest of all lakes in the Cannon River Watershed and well below the mean statewide score.

The following list of monitoring activities and analyses would be beneficial over the course of the implementation period. These items will help refine and update the watershed and lake models, assist in prioritizing and targeting BMPs, and track response to BMPs as they are implemented using an adaptive management approach.

- Collect surface water quality samples (i.e., TP, chl-*a*, Secchi depth) at least one time per month from April/May through October. Although the lake standards require June through September sampling, spring and fall data would be beneficial to better understand nutrient dynamics and eutrophication response over the entire open water season.
- Consider adding TN (i.e., TKN and nitrate/nitrite) to the list of surface water monitoring parameters to investigate if/how N may be affecting eutrophication and biological communities.
- Continue monitoring nonnative species (e.g., common carp, CLP, EWM) where they are present to ensure they do not reach densities that could substantially alter water quality and physical habitat in the future.
- Continue mapping and surveying native submerged and emergent vegetation communities to document baseline conditions and track changes as management occurs.
- Encourage individual lakeshore residents and lake association members to participate in the Minnesota Lake Steward Program and the Score Your Shore Survey to educate about sustainable land management, self-assess habitat conditions along their shorelines, and identify potential improvements.
- Utilize lidar-based terrain analysis products (e.g., PTMApp) to identify and target locations (both cropland and residential) with higher rates of soil loss and sediment delivery throughout the Beaver Lake drainage area.
- Periodically update the watershed model, lake model, and other models and tools as new data is collected and BMPs are implemented

F.2. Cedar Lakes water quality improvement study

Cedar Lake (66-0052-00) is located in southwest Rice County in the Upper Cannon Subwatershed of the greater Cannon River Watershed. Historic water quality monitoring (1999-2008) for Cedar Lake showed the lake did not meet water quality standards for AQR and the lake was placed on the State of Minnesota's 303(d) list of impaired waters in 2010. A TMDL study was completed for the Cannon River Watershed in 2016, which included P load targets and reduction goals for Cedar Lake. Recent water quality monitoring efforts (2016-2023) suggest that in-lake water quality has not changed significantly since the impairment listing and the TMDL study and the lake is still impaired for AQR.

The Cannon River Watershed local partner team has identified Cedar Lake as a high priority lake for water quality improvement in their 1W1P comprehensive watershed management plan (EOR 2020) and other planning documents. The local partner team requested that a water quality study be completed for Cedar Lake as part of the WRAPS Update for MPCA's Cycle 2 work for the Cannon River Watershed. This technical memorandum presents the results of this work which includes the following components:

- Review of background information and data (Section F.2.1)
- Development of a lake P budget and water quality model (Section F.2.2)
- Establishment of in-lake P targets and load reductions to improve water quality (Section F.2.3)
- Potential strategies to achieve P targets and load reductions (Section F.2.4)
- Summary and considerations for future monitoring, assessments, and analyses (Section F.2.5)

F.2.1 Background information and data

Data sources and previous studies

Below is a summary of the data, studies, and models that were compiled and reviewed for this study. All items listed below are available online or were supplied by local partners. These studies and data sources are referred to throughout different sections of this study.

- *Status and Trend Monitoring Summary for Rice County, Minnesota Lakes: Cannon, Wells, Kelly, Dudley, Circle, Cedar, and Roberds* (MPCA 2000)
- *Cannon River Watershed Total Maximum Daily Load* (MPCA 2016)
- *Paleolimnological Study of Phosphorus-Impaired Lakes in the Cannon River Watershed* (Engstrom et al. 2019)
- *Cannon River Watershed Management Plan* (EOR 2020)
- *Cedar Lake Phosphorus Budget* (Limnopro 2020)

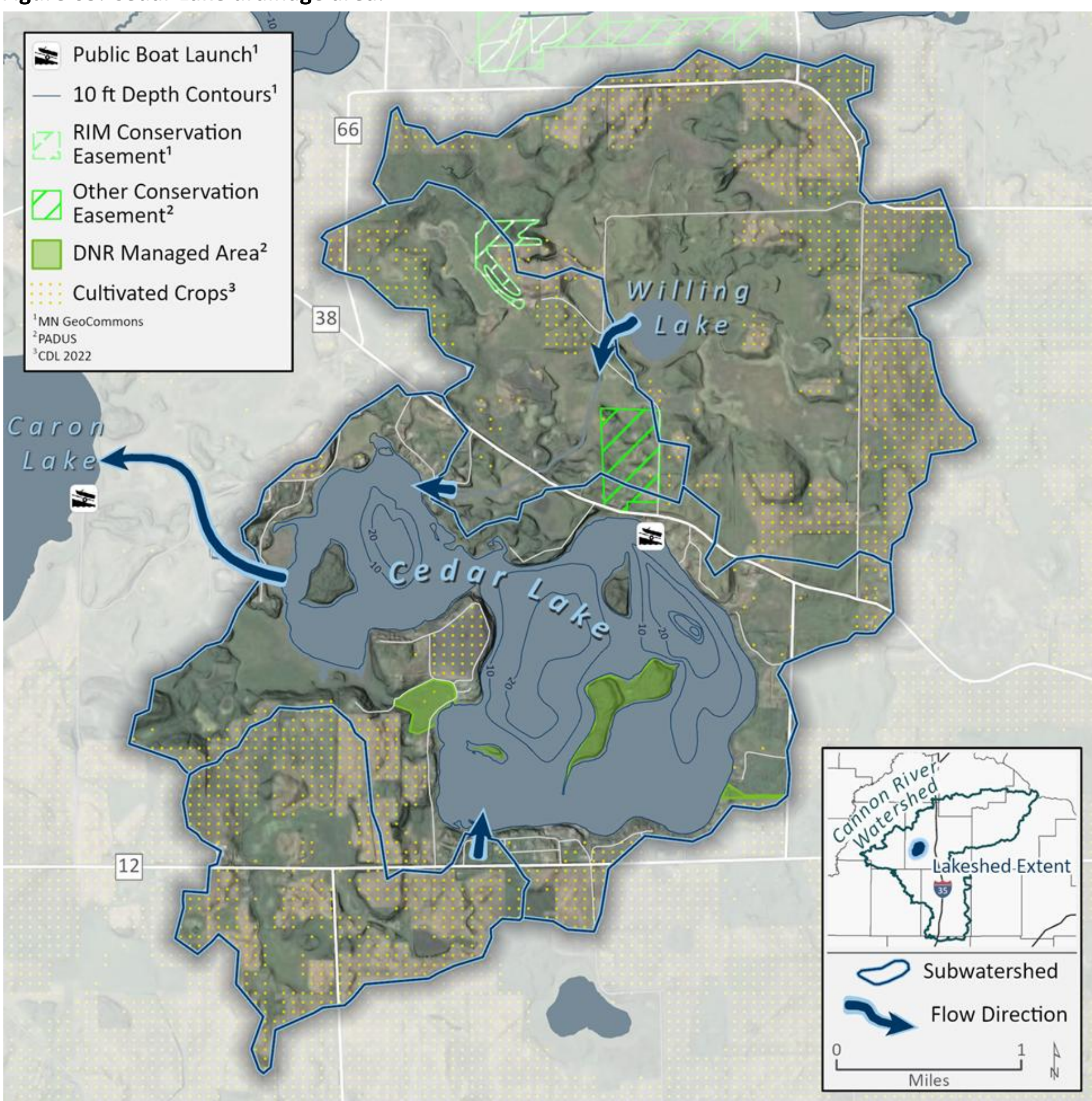
Lake and watershed characteristics

Cedar Lake is located approximately six miles west of Faribault, Minnesota in the Cannon River Watershed (Figure 65). Cedar Lake is a relatively large (~902 acres) and deep lake for the region (42 feet max depth). The lake has a relatively complex shoreline with four islands, two of which are designated as Aquatic Management and Scientific and Natural Areas by the DNR. There is a natural outlet on the northwest side of the lake that flows through underneath Ivanhoe Court and then to a small wetland before flowing into Caron Lake.

The DNR Level 8 drainage area boundary layer shows the Cedar Lake watershed is approximately 3,840 acres in size (4,742 acres including lake surface areas). Cedar Lake is considered a headwater lake meaning there are no major streams or upstream lakes flowing to it. The lake receives flow and runoff from areas immediately surrounding the lake (~937 acres) and three small tributary inlets as described in Limnopro 2020: Willing Inlet (Inlet N; drainage area = 2,142 acres), Hennepin Inlet (Inlet S1; drainage area = 611 acres), and Geneva Ct. Inlet (Inlet S2B; drainage area = 130 acres). Cedar Lake has a relatively small watershed to lake area ratio (5.2 to 1) and an estimated hydraulic residence time of approximately 1.5 years.

There are approximately 217 seasonal and permanent homes located directly around Cedar Lake, all of which potentially have septic systems (Limnopro 2020). At this time there are only four active feedlots with registered animals located in the Cedar Lake drainage area. The registered feedlots include an elk farm (~194 animal units), one beef cattle operation (~40 animal units) and two small horse farms near the lake with less than seven horses. Land cover throughout Cedar Lake's 3,820-acre drainage area consists of hay/pasture (33%), cropland (corn/soybean 24%), forest and shrubland (23%), wetland (14%), and developed/residential (5%).

Figure 65. Cedar Lake drainage area.



Lake water quality

Lake water quality is often evaluated using three associated parameters: TP, chl-*a*, and Secchi depth. P is typically considered the limiting nutrient in Minnesota lakes, meaning that algal growth will increase with increases in TP. Chl-*a* is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Secchi depth is a physical measurement of water transparency. Increasing Secchi depths indicate less turbidity in the water column and increasing water quality. Conversely, rising TP and chl-*a* concentrations point to decreasing water quality and thus decreased water transparency. Measurements of these three parameters are interrelated and can be combined into an index that describes water quality.

Historic and existing water quality conditions for Cedar Lake are described using data downloaded from the MPCA's EQuIS database and the University of Minnesota's Lake Browser. EQuIS stores data collected by the MPCA, partner agencies, grantees, and volunteers. All water quality sampling data utilized for assessments, modeling, and data analysis for this study and referenced reports are stored in this database and are accessible through the MPCA's Environmental Data Access (EDA) website. The University of Minnesota's Lake Browser provides satellite derived water quality data for over 10,000 Minnesota lakes. Data are created using an automated image processing system developed with resources from the University of Minnesota and the Environment and Natural Resources Trust Fund — Legislative and Citizens Commission on Minnesota Resources. The automated image processing system processes satellite data from Landsat 8 and Sentinel 2 and provides daily and monthly (May through October) lake clarity (i.e., Secchi depth), chl-*a*, and colored dissolved organic matter (CDOM) data for 2017 through 2021 (Page et al. 2019).

Water quality for Cedar Lake has been evaluated against Minnesota's lake eutrophication standards for class 2B lakes in the North Central Hardwood Forest (NCHF) ecoregion. Minnesota State statute defines various categories of lakes for assessment purposes, including lake, reservoir, shallow lake, and wetland (Minn. R. ch. 7050.0150). The determination between the four categories requires an analysis of basin depth, littoral area, and other characteristics in Appendix D of the *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment* (MPCA 2022a). Although Cedar Lake has a fairly large littoral area (~75% of lake area), it is assessed by MPCA as a lake/reservoir during the water quality assessment process. Table 26 shows the current lake eutrophication water quality standards for lakes/reservoirs in the NCHF ecoregion.

Table 26. Lake eutrophication standards for class 2B lakes and reservoirs in the NCHF ecoregion.

Parameter	NCHF lakes and reservoirs
Total phosphorus (µg/L)	≤ 40
Chlorophyll-a (µg/L)	≤ 14
Secchi transparency (m)	≥ 1.4

The earliest TP and chl-*a* data available for Cedar Lake in EQuIS are from the early 1980s. Since 2000, Cedar Lake has had seven years with three or more TP and chl-*a* measurements during the summer growing season (i.e., June through September) and therefore lacks a consistent record for these parameters. Secchi measurements have been routinely monitored dating back to 1974 and have a more complete record. University of Minnesota Lake Browser chl-*a* data are available for Cedar Lake from 2017–2021 and were combined with the field samples available in EQuIS for the analyses presented in this report.

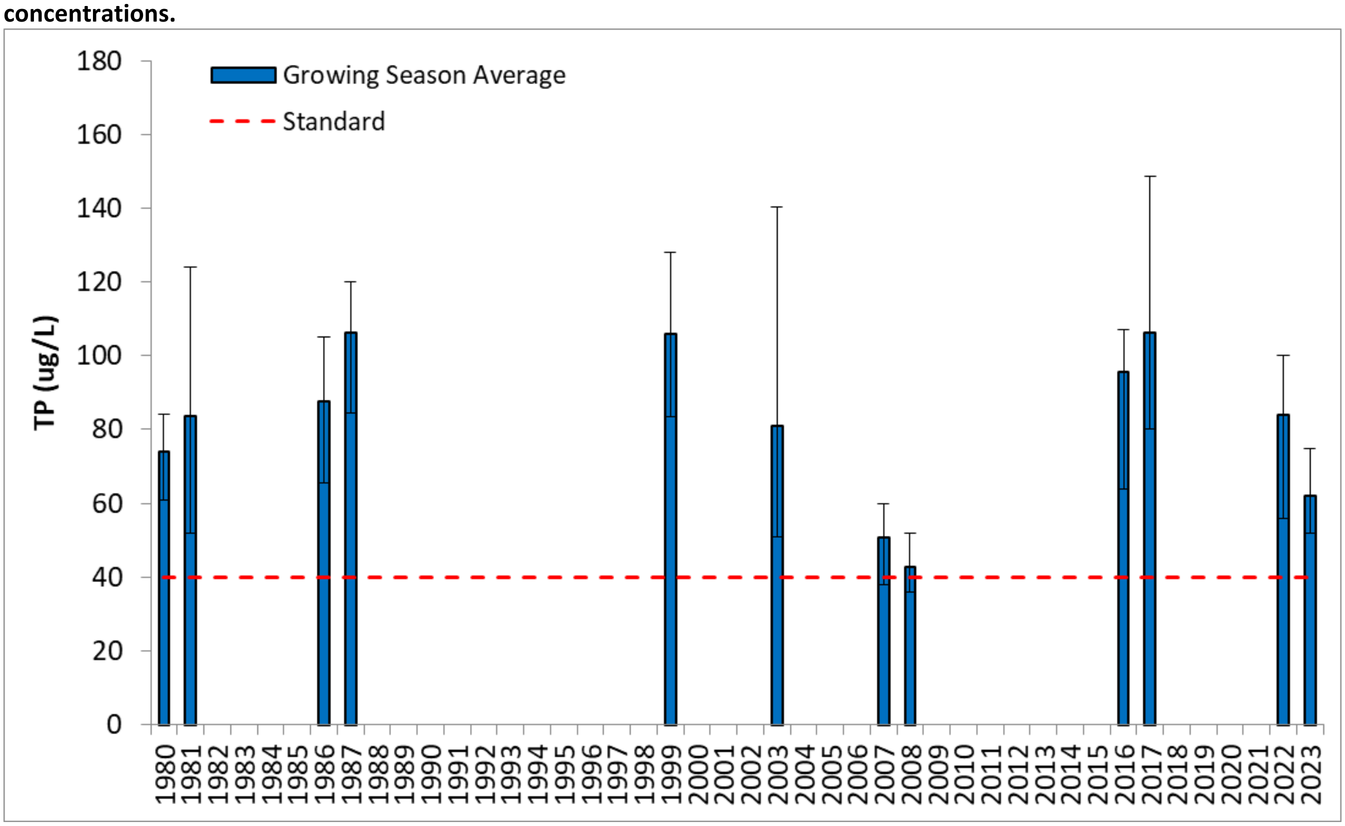
Results of the TP, chl-*a*, and Secchi depth data for Cedar Lake are summarized in Table 27 and illustrated in Figure 66 through Figure 68. TP data indicate mean summer growing season concentrations have exceeded the

40 µg/L NCHF lake/reservoir standard every year since the early 1980s. Aside from 2007 and 2008, mean summer TP concentrations have typically fluctuated between 60 µg/L and 100 µg/L and show no clear trends over the last 40 years. Cedar Lake summer chl-*a* concentrations also show no clear trends and have consistently exceeded the 14 µg/L NCHF lake/reservoir standard since 1980. Mean summer Secchi depths, on the other hand, improved from around 0.5 meter in the 1980s to close to 1.0 meter in the early 1990s through 2023. However, Secchi depths have failed to meet the NCHF lake/reservoir standard every year since 1980.

Table 27. Comparison of Cedar Lake mean summer water quality during different time periods.

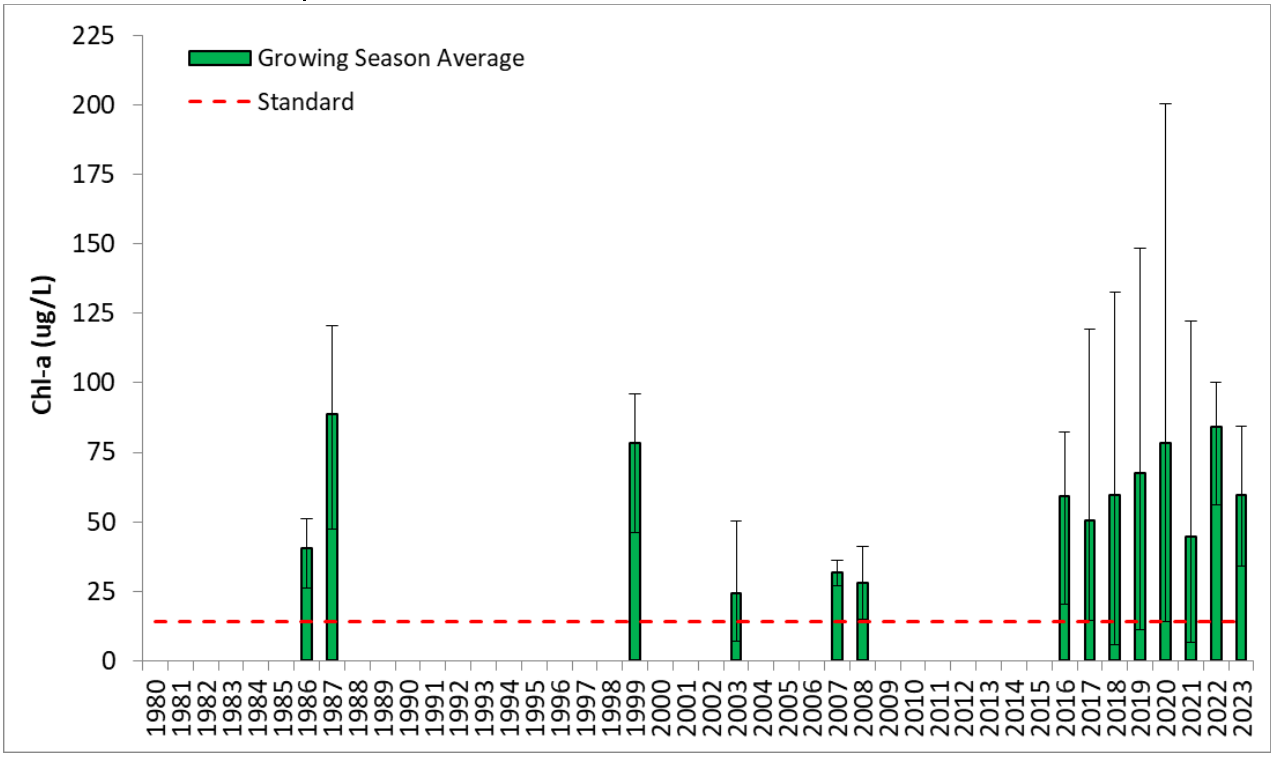
	TP (µg/L)			Chl-*a* (µg/L)			Secchi (m)		
Time period	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**
1980 through 1999	91	106	74	69	89	40	0.8	1.3	0.4
2000 through 2023	75	106	43	53	84	24	0.9	1.2	0.6
2010 through 2023	87	106	62	63	84	45	0.8	1.2	0.6
Entire record	82	106	43	57	89	24	0.8	1.3	0.4
NCHF lake and reservoir standards	≤40			≤14			≥ 1.4		

Figure 66. Cedar Lake summer growing season mean TP concentrations (solid bars) from 1980 through 2023 for years in which at least three samples were collected. Error bars represent maximum and minimum summer growing season TP concentrations.



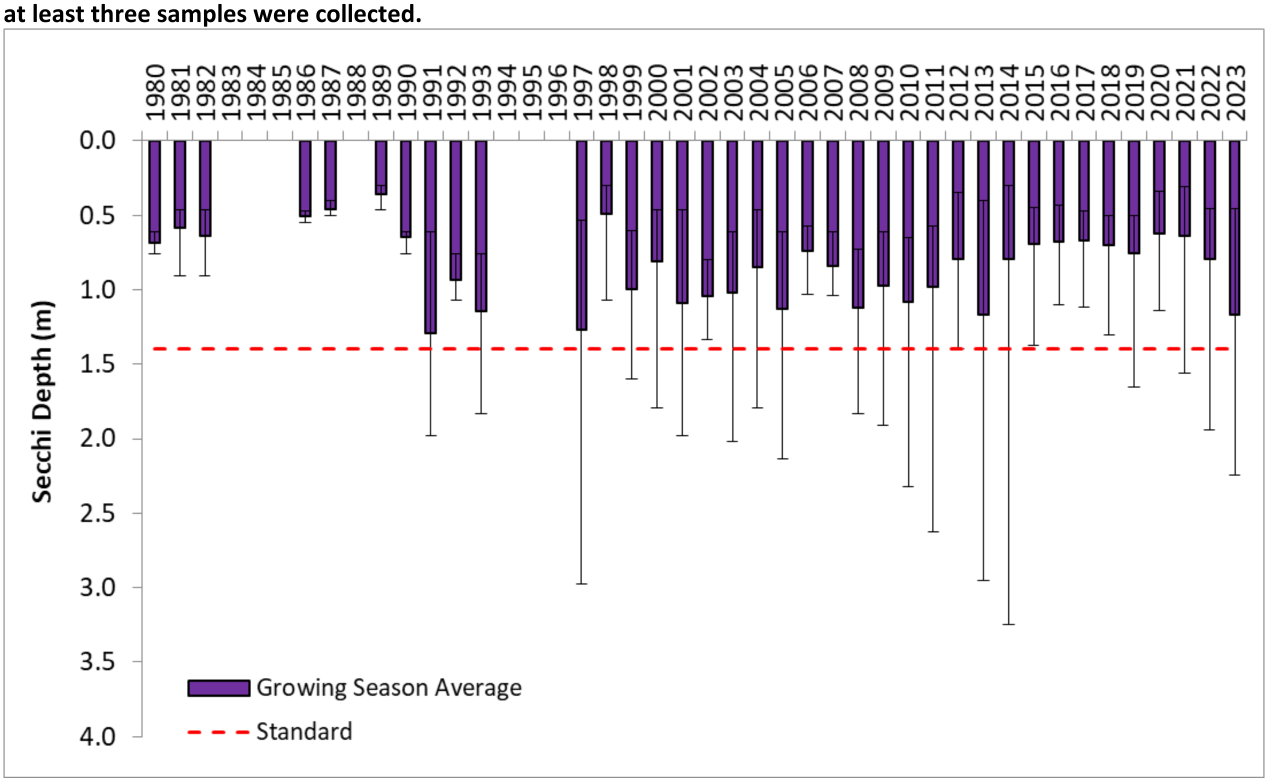
Error bars represent maximum and minimum summer growing season TP concentrations.

Figure 67. Cedar Lake summer growing season mean chl-*a* concentrations (solid bars) from 1980 through 2023 for years in which at least three samples were collected.



Error bars represent maximum and minimum summer growing season chl-*a* concentrations. Data includes discrete measurements from EQuIS (entire period) and satellite derived measurements from University of Minnesota Lake Browser (2017 through 2021).

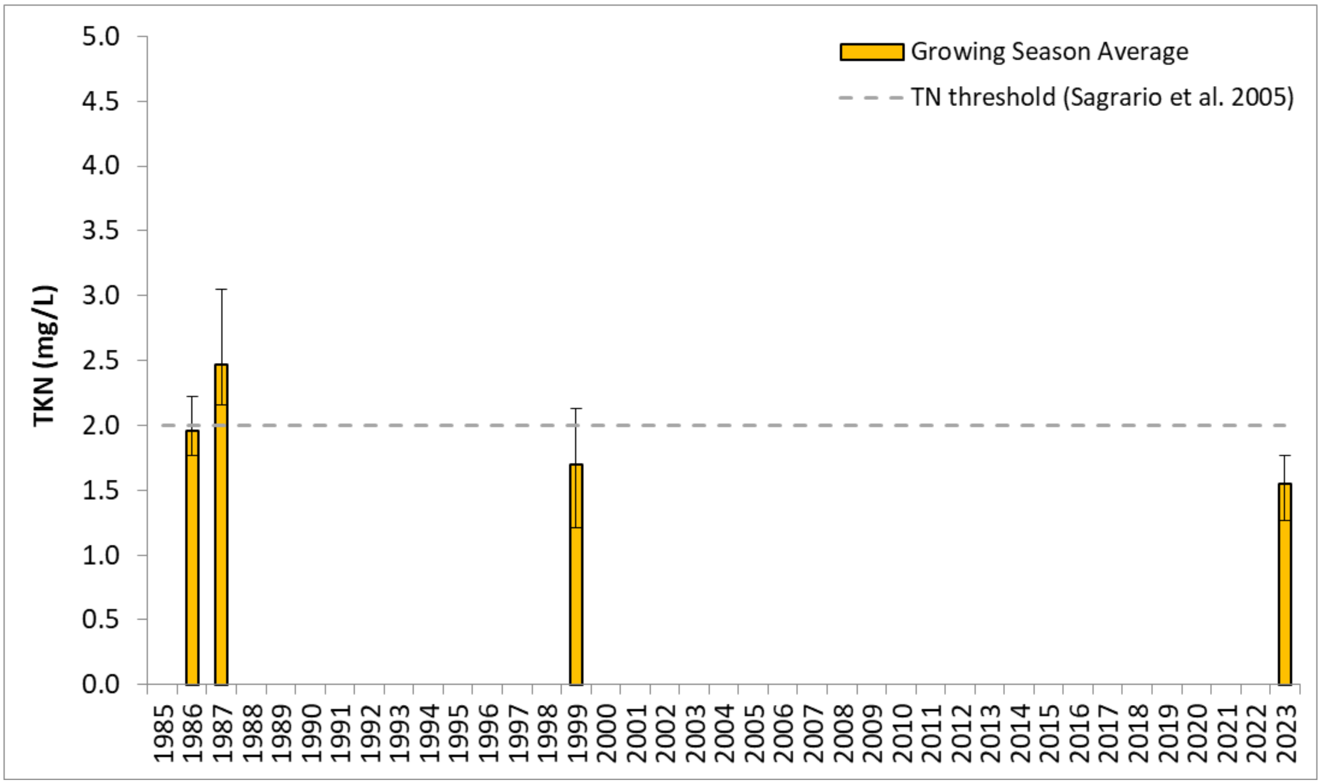
Figure 68. Cedar Lake summer growing season mean Secchi depth (solid bars) from 1980 through 2023 for years in which at least three samples were collected.



Error bars represent maximum and minimum summer growing season Secchi depth measurements. Data includes only discrete measurements from EQuIS.

Although P is typically considered the limiting nutrient in most Minnesota lakes, N is an essential nutrient for algal and aquatic plant growth. TN (which is calculated as nitrate/nitrite + total Kjeldahl nitrogen [TKN]) has not been monitored in Cedar Lake; however, TKN (i.e., organic N + ammonia) samples have been monitored periodically and were last collected in 2023 (Figure 69). Results show individual samples have ranged from 1.92 to 3.05 mg/L and summer mean concentrations have ranged from 1.55 to 2.47 mg/L. Studies have found that aquatic plant coverage and the number of plant species in lakes tend to decline when TN levels exceed ~2.0 mg/L (Sagrario et al. 2005; MPCA 2005a). More spring and summer in-lake TN measurements are needed in Cedar Lake to better understand if/how N levels are impacting eutrophication (i.e., algae growth), aquatic plants, and other biota.

Figure 69. Cedar Lake summer growing season mean TKN concentrations (solid bars) from 1980 through 2023 for years in which at least three samples were collected. Error bars represent maximum and minimum summer growing season TKN concentrations.



Tributary water quality

TP and flow measurements were monitored at three inlet points (Figure 70) to Cedar Lake on seven occasions in 2019 (Limnopro 2020). Results of the 2019 monitoring efforts are summarized in Table 28. Inlet TP concentrations were high at all sites in 2019, particularly during the summer growing season (i.e., June through September). All three sampling locations are located downstream of flow-through wetland complexes that, based on review of air photos, have been hydrologically altered by ditching and receive inputs from adjacent agricultural fields (Figure 71 through Figure 73). Wetlands often go anoxic (i.e., very low oxygen levels) during the warm summer months which can lead to release of soluble P from the wetland sediment and through breakdown of wetland plants and organic matter. Particulate P can also be exported from wetlands during high flow conditions through suspension and transport of fine organic material within the wetland and ditch network.

Willing Lake (66-0051-00) is a small lake (~25 acres) surrounded by wetlands that drain a significant portion (~74%) of the area flowing to Cedar Lake via Inlet N (Figure 71). There is currently no water quality data available for Willing Lake in MPCA's EQuIS database. There are 74 chl-*a* and Secchi depth measurements from 2017 through 2021 available through the UMN Lake Browser. These data suggest Willing Lake does not experience significant planktonic algae blooms (mean summer chl-*a* = 10 µg/L) and has very good water clarity (mean Secchi depth = 2.2 m) despite high TP levels measured downstream at Inlet N in 2019. More inlet monitoring data is needed to better understand P dynamics in Willing Lake and the wetland complexes upstream of Cedar Lake.

Figure 70. Cedar lake inlet monitoring locations.

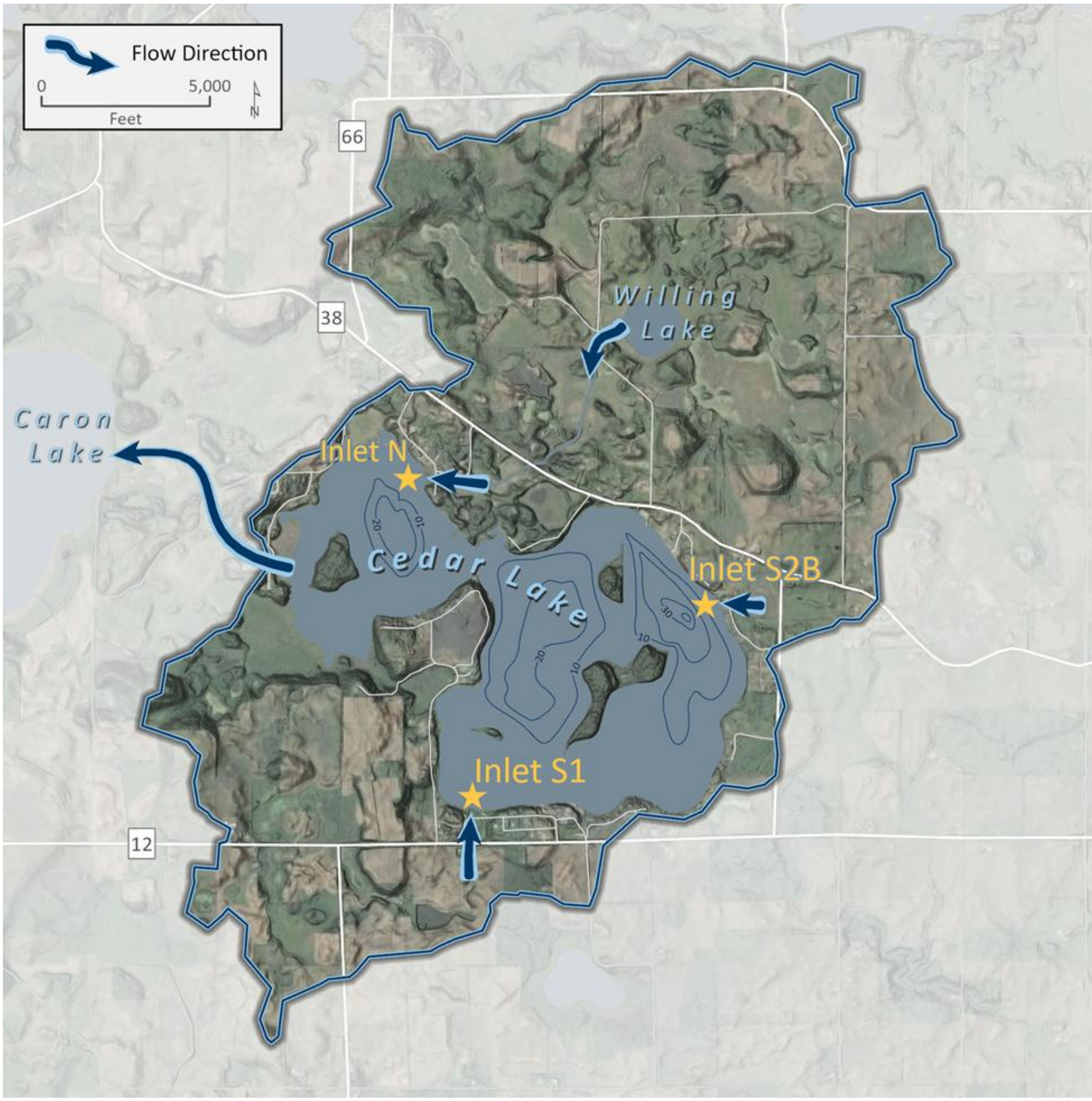


Figure 71. Inlet N drainage area which includes Willing Lake.

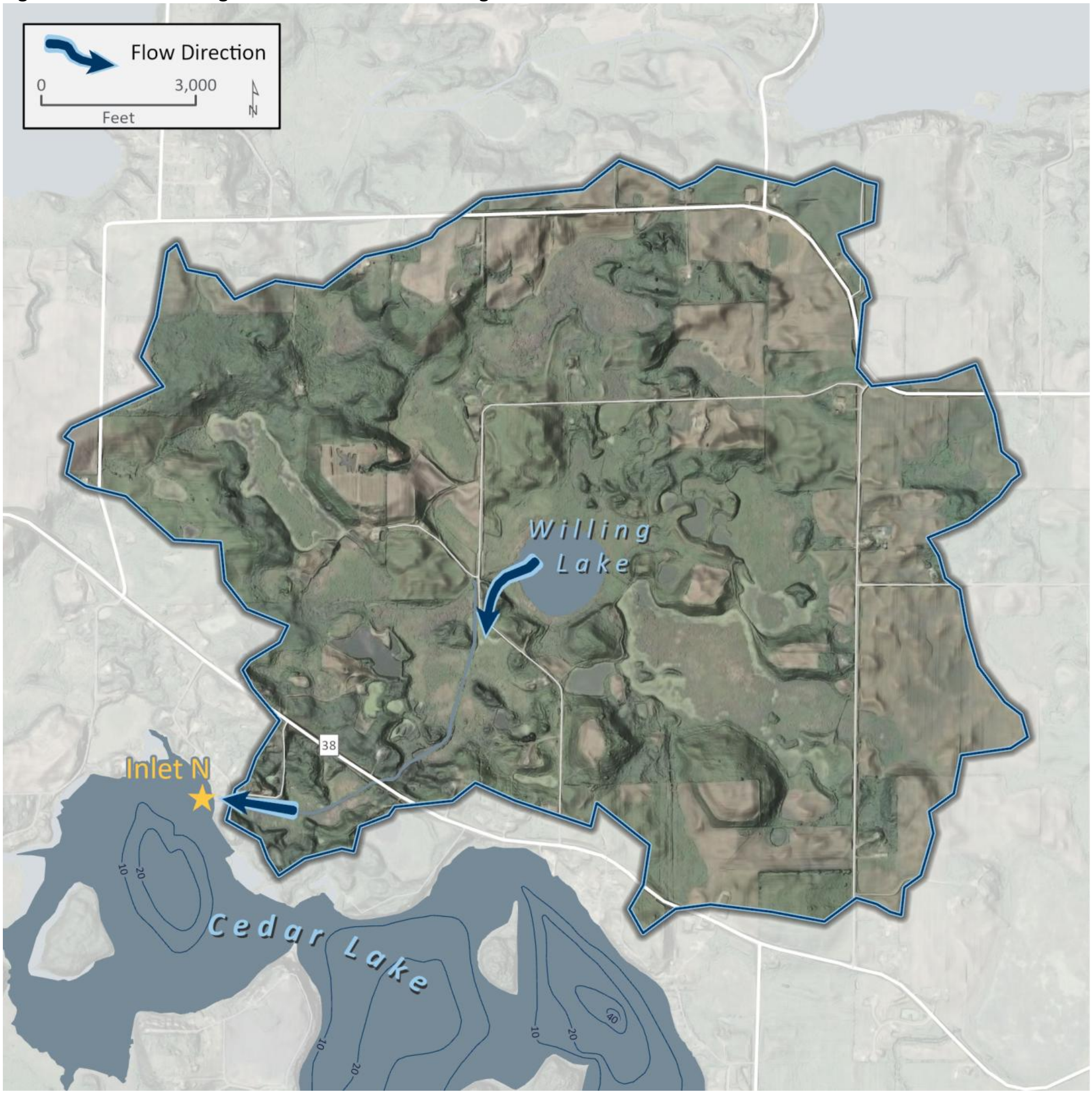


Figure 72. Inlet S1 drainage area.

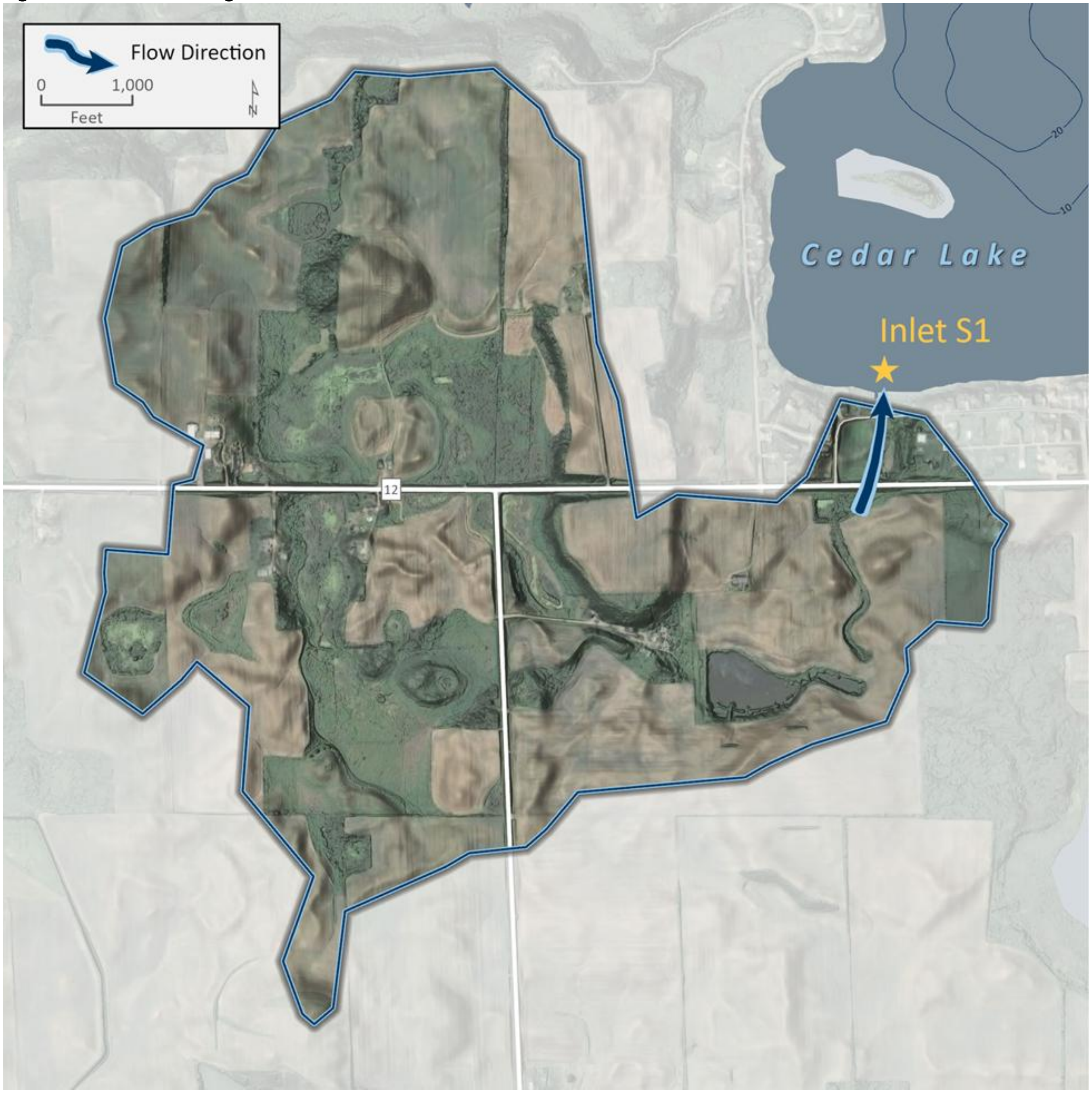


Figure 73. Inlet S2B drainage area.

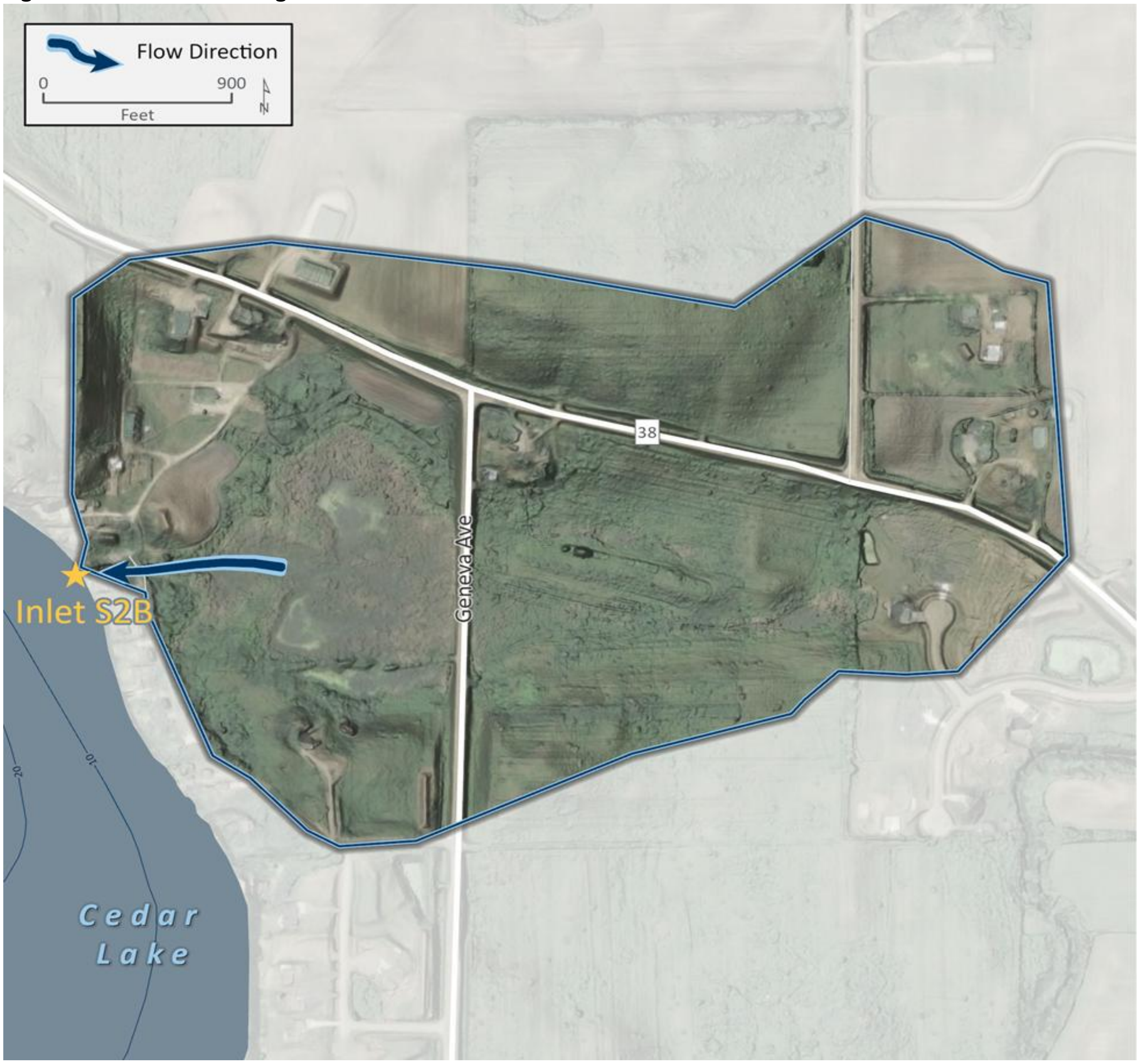


Table 28. Cedar Lake 2019 inlet monitoring results (source: Limnopro 2020).

	Inlet N (Willing)		Inlet S2B (Geneva Ct.)		S1 (Hennepin)	
Date	**Flow (cfs)**	**TP (µg/L)**	**Flow (cfs)**	**TP (µg/L)**	**Flow (cfs)**	**TP (µg/L)**
5/24/2019	3.93	92	0.20	182	1.45	230
6/24/2019	1.03	418	0.06	1,220	0.56	915
7/25/2019	9.94	350	0.15	720	1.86	545
8/23/2019	0.80	365	0.01	600	0.09	195
9/12/2019	19.4	365	5.32	260	7.10	555
9/24/2019	4.90	260	0.38	630	1.27	340
10/14/2019	10.2	84	0.41	267	2.42	111
Median	4.90	350	0.20	600	1.45	340
Mean	7.17	276	0.93	554	2.11	413
Flow-weighted mean	--	274	--	300	--	442

Fisheries

Cedar Lake is currently managed by the DNR for black crappie, bluegill, and largemouth bass and secondarily for northern pike and walleye. The fisheries management plan for Cedar Lake calls for stocking 100,000 Northern Pike fry in odd years and 673,000 Walleye fry in even years (DNR Lakefinder). Cedar Lake is designated as a Tier-1 Lake and is therefore surveyed as part of a regularly scheduled monitoring program at a frequency of every three years. During the most recent DNR fisheries surveys in 2022, black crappie catch rates were above normal ranges for similar lakes while average size was at the lower end of the normal range. Similarly, bluegill catch rates were near the upper normal range for similar lakes, but average size was slightly below the normal range. In general, Cedar Lake currently exhibits strong panfish numbers, however growth and size structure could be improved upon. Cedar Lake currently supports a strong largemouth bass fishery with catch rates and average size at or near the upper normal range during the 2022 survey. Two fish species that are often associated with poor water quality conditions, common carp and black bullhead, were both sampled at or below the lower normal range during the 2022 survey. Other species sampled in Cedar Lake in 2022 included bigmouth buffalo, bowfin, brown and yellow bullhead, freshwater drum, golden shiner, northern pike, walleye, white bass, white crappie, and yellow perch.

A common misconception is that if a lake supports a quality gamefish population (e.g., high abundance or desirable size structure of a popular gamefish species), it should be considered a healthy lake. This is not necessarily true because both game and nongame fish species must be considered when holistically evaluating fish community health. Oftentimes, the smaller nongame fishes serve ecologically important roles in aquatic ecosystems and are generally the most sensitive to human-induced stress. In order to better evaluate the entire fish community, the DNR uses a FIBI scoring system to assess lakes throughout the State of Minnesota. The FIBI assessments utilize fish community data collected from a combination of trap nets, gill nets, beach seines, and backpack electrofishing. From these data, an FIBI score can be calculated for a lake that provides a measure of overall fish community health based on species diversity and composition. If biological impairments are found, stressors to the fish community must be identified. More information about the sampling and assessment process can be found at the DNR Lake Biological Monitoring and Assessment website.

Cedar Lake was sampled and assessed in 2019 using the DNR's FIBI scoring system. Results of the FIBI assessment indicate Cedar Lake (FIBI score = 17) scored well below the FIBI impairment threshold established for similar lakes (FIBI threshold = 45) and therefore does not support AQL use and is considered impaired for AQL. Individual metric scores indicate the overall FIBI score was most negatively influenced by the absence of intolerant species and low number of vegetative dwelling species captured in the survey. A SID Report is currently being developed for Cedar Lake to identify the primary stressors to the fish communities and to provide general strategies to help address the stressors. Preliminary results of the SID assessment have identified eutrophication and physical habitat alteration as the probable causes of stress to AQL in Cedar Lake. Physical habitat alteration was determined to contribute to the impaired fish community based on review of information reflecting riparian disturbance, aquatic plant community condition, nonnative species introduction, and connectivity. The final SID Report is expected to be completed in 2026.

Vegetation

Submergent and emergent aquatic vegetation are critical to lakes, providing spawning and cover for fish, habitat for macroinvertebrates, refuge for prey, sediment and water column nutrient uptake, and stabilization of sediments. Declines in the abundance and diversity of aquatic vegetation can be an indication of a shifting biological community and water quality state. As disturbances increase, sensitive vegetation species are lost from the system and often replaced with less desirable species (e.g., aquatic invasive species) or no vegetation at all.

Cedar Lake is rare in that it supports a relatively diverse and abundant aquatic vegetation community which provides valuable cover and spawning habitat for a number of fish species (DNR Lakefinder). July 2014 and August 2018 point intercept surveys by DNR found a total of 14 and 19 submerged and floating plant species, respectively. White-stem pondweed was observed by DNR during a largemouth bass electrofishing survey and appeared to be abundant. White-stem pondweed is a native vegetation that provides valuable habitat for several species of fish. EWM, an invasive species, was first discovered in Cedar Lake in 2001. EWM can limit recreational activities by forming dense mats on the water surface and disrupt aquatic ecosystems by competing with and displacing native plants. Another invasive species, CLP, is common in Cedar Lake and has been actively managed by the Cedar Lake Association since 2018. Management of CLP has consisted of surface application of herbicide (Aquathol K) at three to five treatment areas from 2018 through 2024. Total area treated by herbicide has ranged from 25 acres in 2018 through 2021 to approximately 50 acres in 2023 and 2024 (Cedar Lake Association website).

Lakeshore conditions

Lakeshore habitat assessments were conducted during the FIBI and SID process for Cedar Lake. The primary tool used in the assessments was the DNR STS Rapid Assessment (DNR 2019a), which was performed by DNR staff. STS is a protocol developed to rapidly assess the quantity and integrity of lakeshore habitat. The survey is designed to assess differences in habitat between lakes and to detect changes over time. STS surveys require visual observation of lands accessible by boat. The intent of the survey is to assess habitat, not to inspect for violations. The STS assessments consist of surveying 100-foot sections of shoreline at predefined, equally spaced survey locations along the entire shoreline of the lake. Since only 100 feet of shoreline is surveyed per location, the full assessment covers a relatively small portion of the total shoreline and results are not tied to individual properties. During the surveys, three lakeshore zones (upland/shoreland, shoreline, and aquatic) are assessed independently at each survey location. Within each zone, surveyors score specific features related to habitat, which are then summed for an overall Zone Habitat Score. Higher scores indicate a greater amount of habitat. Lower scores indicate a low percent of the site remains natural and a higher amount has been physically disturbed or altered by humans. The feature scores within each zone are summed for an overall site habitat score. This scoring process provides a simple method of ranking sites based on the percent of each site that is in a natural condition versus the percent of the site that has been altered. A lakewide score is calculated using the mean site habitat score. Scores range from 0 to 100 and lakes with a high percentage of unaltered habitat score higher than lakes that have been highly altered. More information about the methods used for the STS surveys can be found in the Minnesota Lake Plant Survey Manual (DNR 2019a).

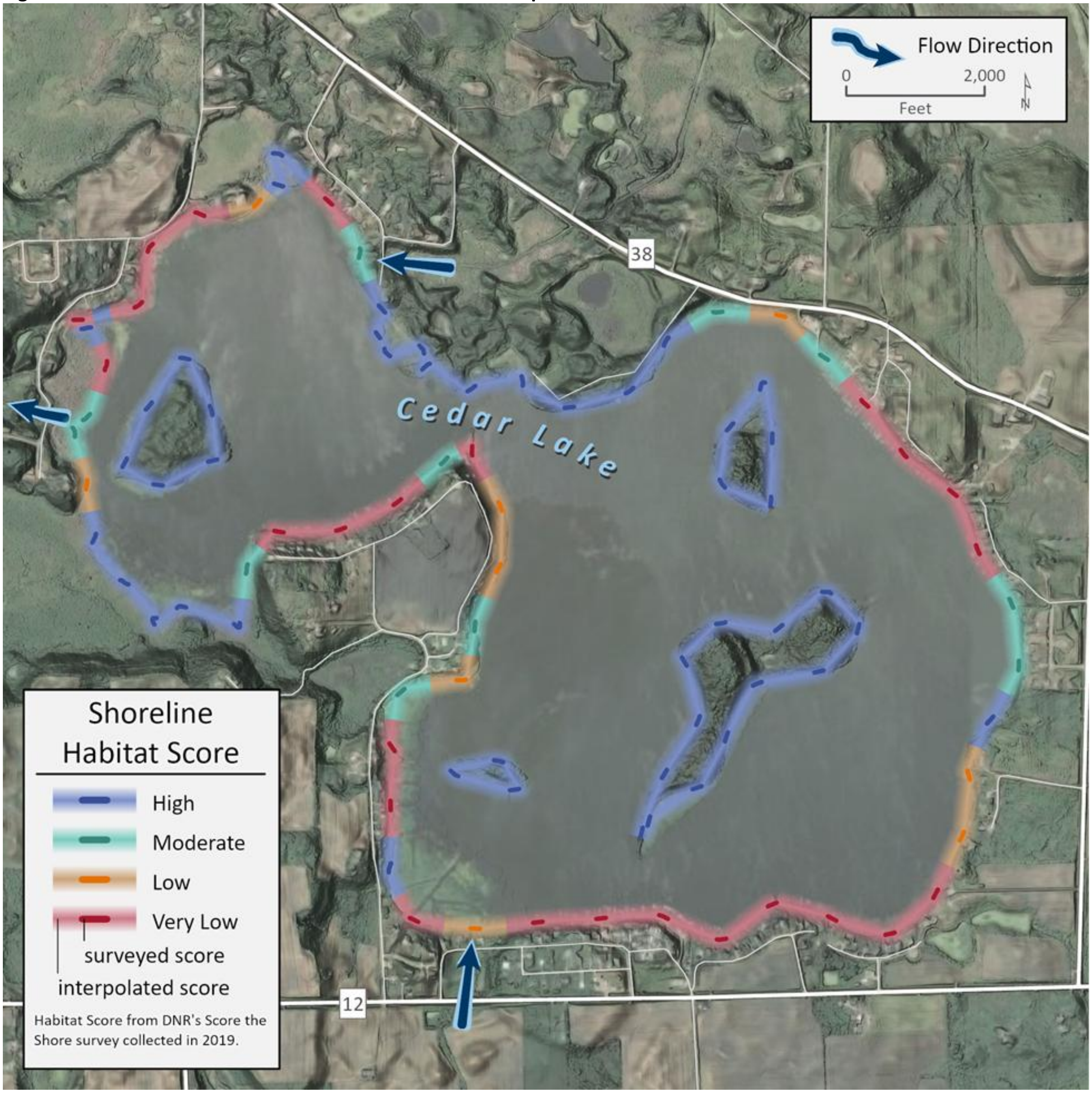
The DNR STS assessment results for Cedar Lake are summarized in Table 29. Figure 74 illustrates the results of the overall habitat scores for the 92 STS survey locations. In this figure, the dark colored lines show the results of the individual surveyed locations (i.e., 100-foot survey sections). The lighter, thicker lines along the shoreline represent interpolated scores between the 100-foot surveyed sections. The overall score for Cedar Lake (71) is considered moderate and is close to the mean score of other lakes in the Cannon River Watershed (mean score = 70; N = 19) and lakes throughout the state of Minnesota (mean score = 74; N = 764). A moderate score indicates that, on average, surveyed sites have a high percentage of unaltered habitat but that at least one zone (i.e., shoreland, shoreline, or aquatic) has lower habitat quality than a high scoring site. Development has had the largest effect on the shoreland and shoreline habitat components for Cedar Lake. Developed sites generally scored much lower, with a mean score of 48.8 (very low), while undeveloped sites had a mean score of 96.2 (high). In many of the developed shoreline areas, lawns are maintained to the water's edge and shorelines are altered with rock riprap or sand blankets, thereby disrupting the natural riparian buffer (DNR Lakefinder). Cedar Lake still has a significant amount of undeveloped shoreline (~52%) and in these areas the lake offers quality fish habitat, including diverse aquatic vegetation, woody debris, and overhanging limbs.

The DNR estimates that Cedar Lake has approximately 206 docks (18.2 docks per mile of shoreline) based on review of 2023 Google imagery. Dock densities exceeding 16 docks per mile can significantly affect fish communities and habitat (Jacobson et al. 2016, Dustin 2017). Based on the dock density estimate, aquatic plant removal has likely contributed to some physical habitat loss within the lake, which could result in changes to the fish community as evaluated by the FIBI.

Table 29. DNR STS survey results for Cedar Lake.

Category	Result
Dock density (#/mile)	18.2
Survey locations	92
Percent developed	52%
Shoreland zone score	21.8 low
Shoreline zone score	24.0 moderate
Aquatic zone score	25.7 moderate
TOTAL SCORE	71.4 moderate

Figure 74. Overall site habitat STS scores for individual sample locations.



Climate

The *Climate summary for watersheds: Cannon River* (DNR 2019b) report shows that annual average temperatures in the Cannon River Watershed have increased over the last 40 years and that most years during the past two decades have been warmer than average. Monthly average temperatures in the Cannon River Watershed peak in July, and winter temperatures on average have increased over time. Annual precipitation has also shown an upward trend across the watershed since around 1940. Monthly precipitation is typically highest in June and increases in precipitation in recent years were most pronounced in April through August. The frequency of 1-inch and 3-inch rain events has increased in general in Minnesota, along with the size of the heaviest rainfall of the year. Minnesota has also experienced an increase in devastating, large-area extreme rainstorms (DNR 2022). Climate projections indicate these big rains will continue increasing into the future (DNR 2022).

Statewide lake data collected by the DNR, MPCA, and local partners shows that the climate trends described above have already impacted lakes throughout the state and region. According to MPCA's [Workbook: Climate change and Minnesota's surface waters](), lake surface temperatures have warmed during all seasons throughout southern Minnesota. During the summer growing season (June through September), lakes in southern Minnesota are, on average, approximately 2.7 to 4.4˚F warmer now than they were 50 years ago. Additionally, warmer winters have resulted in about nine less days of ice coverage on average for lakes throughout the region since the mid-1970s.

Reduced ice coverage, higher year-around water temperatures, and more intense and frequent precipitation events can result in significant impacts to lakes and lake users, including but not limited to (MPCA 2021):

- Overall increase in flow, sediment, and nutrient loading from the lake drainage area
- Longer periods of stratification and anoxia resulting in increased internal P recycling
- Longer open water and growing season for algae and cyanobacteria blooms
- Larger fluctuations in lake level from year to year
- Potential for increased densities of aquatic invasive plants, such as CLP and EWM
- Decreases in walleye (who prefer summer water temps at 65˚F to 70˚F) in smaller, warmer lakes
- Potential for more fish kills as fish are squeezed into smaller zones to access oxygen
- Shortened season for safely recreating on ice-covered lakes

Although long-term supporting data is limited, it is likely that Cedar Lake has or is currently experiencing many of the climate impacts described above. These impacts create additional challenges to effectively manage Cedar Lake water quality and support healthy plant and fish communities. Adaptation strategies such as improving water management practices, enhancing soil health, planting conservation perennials, and natural shoreline buffers should be considered for Cedar Lake to build resilience to these impacts and threats.

F.2.2 Lake phosphorus budget and model

An updated lake P budget and eutrophication model (BATHTUB) were set up for Cedar Lake using methods similar to the lake TMDLs in the *Cannon River Watershed Total Maximum Daily Load* report (MPCA, 2016) and other lake TMDLs throughout the State. The four primary P sources considered for the Cedar Lake model were loading from the Cedar Lake drainage area, septic systems, atmosphere, and internal recycling. Each of these sources, and how they were estimated, are discussed below in more detail.

Drainage area

Precipitation that falls within the drainage area of a lake flows across the land surface and/or through sub-surface drain tiles, and a portion of it eventually reaches the lake. P is carried with the runoff water and delivered to the lake. The primary P sources in runoff in the Cedar Lake drainage area include soils, fertilizer, vegetation, wetlands, and impervious surfaces and lawns in residential areas surrounding the lake.

Watershed runoff volumes and TP loads from the Cedar Lake drainage area were estimated using the Cannon River Watershed HSPF model (2019 version). HSPF is a comprehensive, mechanistic model of watershed hydrology and water quality that allows the integrated simulation of point sources, land and soil nutrient runoff and subsurface processes, and in-stream hydraulic and sediment-chemical interactions. Model documentation contains additional details about the Cannon River HSPF model development and calibration (LimnoTech 2015).

The modeling period for the Cannon River HSPF model covers 1996 through 2019. In the model, the Cedar Lake drainage area is represented as two separate reaches/subwatersheds: 1) Willing inlet to the north (HSPF Reach 344); and 2) Cedar Lake direct drainage area (HSPF Reach 343). The 2019 flow and TP measurements for Inlet N (Table 28) were compared to HSPF predicted values during the same time period. Model predicted flows aligned well with the measured data. In general, the HSPF model accurately predicted the 2019 observed TP concentrations in May and October but underpredicted TP from June through September, likely due to the upstream wetland influences discussed in Section 1. To account for this, June through September TP rates were increased in HSPF until model predicted TP concentrations matched the observed values. After these adjustments were made, average annual flow and TP loading rates (model years 2010 through 2019) for each land cover category used in the model were extracted to estimate average annual flow volumes and P loads delivered to Cedar Lake (Table 30).

Table 30. Model estimated flow volume and TP loading rates and annual totals for the Cedar Lake drainage area (modeled years = 2010 through 2019).

Land cover category	Area (acres)	Modeled flow rate (in/yr)	Modeled flow volume (acre-ft/yr)	Modeled TP load rate (lbs/acre/yr)	Modeled TP load (lbs/yr)
Cropland	908	15.3	1,158	1.33	1,205
Developed/residential	220	21.3	391	1.00	220
Wetland	552	7.86	361	0.18	99
Forest	640	13.6	724	0.21	134
Hay/pasture/grassland	1,520	16.9	2,139	0.73	1,105
TOTAL	3,840	14.9	4,773	0.72	2,763

Septic systems

Flow and TP loads from septic systems were estimated using methods similar to the *Lower Minnesota River Watershed TMDL* (MPCA 2020a). The Limnopro 2020 study estimated that there are approximately 217 septic systems in the Cedar Lake drainage area based on interpretation of satellite photographs. Assumptions were made regarding the number of people per household (~2.1), and the percent of homes that are occupied year around (50%) versus seasonally (50%). Estimated septic compliance rates (~50% compliant and ~50% failing or noncompliant) were assumed based on estimates supplied by the county (Rice SWCD personal communication). Septic system TP removal rates for compliant systems was assumed to be approximately 80%, while removal rates of 57% were assumed for failing systems (Barr Engineering 2004). Through this analysis it was estimated that compliant septic systems currently contribute approximately 69 lbs/year of TP to Cedar Lake while noncompliant systems contribute approximately 149 lbs/year.

Atmosphere

P is bound to atmospheric particles that settle out of the atmosphere and are deposited directly onto surface water. P loading from atmospheric deposition to Cedar Lake is estimated to be approximately 348 lbs/year based on the average deposition rate across the Lower Mississippi River Basin (0.39 lbs/acre-year; Barr Engineering 2007).

Internal phosphorus recycling

Internal P recycling, often referred to as "internal loading," is a common occurrence in eutrophic and hypereutrophic shallow lakes throughout central and southern Minnesota. P contained in the sediment of lakes originates as an external P load that settles out of the water column to the lake bottom. Typically, a significant amount of the external load to Cedar Lake is delivered during snow melt and spring and early summer runoff. During this time, low water temperatures and flushing limit the amount of algae growth and biological activity within the lake. As water temperatures increase in mid-summer (e.g., late June and July), lakes can become thermally stratified during quiescent periods and biological activity increases, which leads to higher rates of algae growth and bacterial decomposition. As this happens, DO is consumed by bacteria, and noxic conditions (i.e., low DO) can develop at the sediment-water interface which leads to the release of P from the lake sediments. The P that is released from the sediments is in a soluble form that is readily available to algae for uptake. In shallower areas, P that has accumulated near the sediment-water interface can be readily mixed into the surface waters during strong winds and storm events, and in deeper areas as stratification begins to weaken in the late summer. Internal P recycling is especially problematic in shallow and moderately deep lakes during dry and hot summers, when lower flows provide less dilution for P loads recycled from lake bottom sediments. Further, algae growth rates and sediment decomposition rates are elevated during dry and hot summers due to higher water temperatures and longer hydraulic residence times (Walker 2011).

There are multiple lines of evidence from the available data that suggest internal P recycling occurs within Cedar Lake:

- Mean surface TP and chl-*a* concentrations increase from May through July and remain high in August, September, and into October most years despite generally decreasing precipitation, watershed runoff, and external TP inputs during this time period
- Although temperature and DO profile data for Cedar Lake is rather limited, surface TP and chl-*a* concentration spikes have been observed when thermal stratification weakens or breaks down late in the summer and following water column mixing events (e.g., 2019, 2022, and 2023)
- High TP concentrations ranging from 150 µg/L to over 600 µg/L are commonly observed in hypolimnetic (i.e., depths greater than ~15 feet) samples collected during summer stratification

At this time, there is not enough data available to explicitly quantify the amount of P that is typically recycled within Cedar Lake each year. In order to better characterize internal recycling, specific data would need to be collected such as continuous or high-frequency temperature and DO profiles, additional hypolimnetic P samples, and/or sediment cores. Since internal P recycling reflects recycling of loads that originally entered the lake from the lake drainage area and atmosphere, the amount of P recycling is expected to vary with external load over time.

Common carp are another potential source of internal P recycling. When present in high densities, carp can exacerbate poor water quality in lakes by destroying/uprooting aquatic vegetation and resuspending/recycling TP from lake sediments. Studies have demonstrated how adult carp can increase turbidity, TSS, TP, and negatively affect macrophyte abundance through various direct and indirect processes (Parkos et al. 2003). Research suggests that negative impacts of common carp on turbidity and vegetation begin to occur at densities of around 89 lbs/acre (Bajer et al. 2009). To our knowledge, common carp density has not been assessed in Cedar Lake. Although the gear used in the DNR trap and gill net surveys tend to underrepresent common carp abundance due to high net avoidance, these surveys can provide a relative means to track carp trends and changes over time within a lake and compare catch rates to other lakes. Based on our review of the DNR trap and gill net surveys, common carp catch rates for Cedar Lake have decreased from peak values in 1981 and 2001 that were above the upper normal range for similar lakes in the region. Common carp catch rates have remained at or below the lower normal range during the last five DNR surveys (2018 through 2022). Negative impacts to lake habitat and water quality are likely negligible at these low levels but their presence remains a concern (DNR Lakefinder).

CLP has also been hypothesized to contribute to internal P recycling and algae blooms in lakes after the plant dies back in midsummer. Although it can be found in a wide-range of environmental conditions, CLP is most common and abundant in alkaline (> 100 mg/L calcium carbonate alkalinity, $CaCO_3$), P-rich lakes (TP between 50 – 100 µg/L; Bolduan et al. 1994) that are dominated by urban or agricultural land use in the southern half of the state (Heiskary and Valley 2012). Based on their review of sentinel lakes throughout the state with CLP infestations, Heiskary and Valley (2012) suggest that there is no evidence that CLP has a significant influence on the trophic status or seasonal water quality dynamics for deep lakes in Minnesota. Some of the shallow lakes in their study exhibited mid-summer TP spikes around the time of CLP senescence, however it is difficult to determine how much of a role CLP plays compared to other internal and external sources.

Lake eutrophication model and final phosphorus budget

A spreadsheet version of the lake model BATHTUB (Walker 1987) was established for Cedar Lake to model current lake water quality conditions. BATHTUB is a steady state model that predicts eutrophication response in lakes based on empirical formulas developed for nutrient balance calculations and algal response (Walker 1987). The model was developed by the U.S. Army Corps of Engineers and has been used extensively in Minnesota and across the Midwest for lake nutrient TMDLs. Several models (subroutines) are available for use within the BATHTUB model, and the Vollenweider (1976) Northern Lakes model was used to predict P settling/retention and the lake response to TP loads in Cedar Lake. The BATHTUB model requires flow and P loading inputs from the lake's drainage area, upstream lakes, and atmospheric deposition. Lake morphometric data are also required by the model.

Drainage area runoff volumes and P loading inputs to the Cedar Lake BATHTUB model were derived from the HSPF model (Table 30). Flow and P loading from atmospheric deposition and septic systems using the methods described above were also added to the model. With the primary external sources defined, the model predicted in-lake P concentration was compared to the 2010 through 2023 observed mean TP concentration (87 µg/L; Table 27). The model predicted in-lake TP concentration was slightly higher than the observed concentration and therefore the P sedimentation calibration factor was adjusted upward to match the monitored value.

The settling/retention model used in the Cedar Lake BATHTUB model inherently includes an average amount of P recycling. In some cases, the amount of P recycled within a lake is greater than the amount inherent in the model and the modeler may choose to add additional load to improve model calibration. Alternatively, the Canfield-Bachman P sedimentation calibration factor can be adjusted to account for internal P recycling as recommended in the BATHTUB Version 6.1 Online Documentation (Walker 2006). Although there is evidence that P recycling occurs in Cedar Lake, the BATHTUB model did not require an additional P load or significant reductions to the P sedimentation calibration factor (Walker 2006). This is consistent with the original BATHTUB model developed for the Cedar Lake TMDL (MPCA 2015 and 2016) and the sediment core analyses, and mass-balance calculations done for Cedar Lake as part of the Cannon River Watershed paleolimnological study (Engstrom et al. 2019). This suggests that internal recycling of P and external inputs are in equilibrium and management of external sources is the most appropriate starting point to achieve sustained, long-term improvements to in-lake water quality.

As shown in Table 31, loading from the Cedar Lake drainage area (83%) represents the largest source of P to the lake followed by atmospheric inputs (10%) and septic systems (7%). Sedimentation/retention represents the largest sink of P (66%) suggesting a significant amount of the annual load delivered to the lake is retained in the lake and its sediments.

The P budget numbers presented in Table 31 are slightly different than those estimated in previous studies. The Cedar Lake TMDL study used literature-based land use loading rates and BATHTUB to estimate a mean annual TP load to Cedar Lake of approximately 2,474 lbs/year (MPCA 2015 and 2016). While this is about 25% lower than the total load estimated in this study, the TMDL models covered a different time period (2007 through 2010) in which both mean in-lake TP concentration (50 µg/L compared to 87 µg/L) and mean annual rainfall (30 in/yr compared to 40 in/yr) were significantly lower. The Cedar Lake Phosphorus Budget Study (Limnopro 2020), which focused exclusively on model year 2019, estimated P loading for that year to be approximately 5,924 lbs. This value is significantly higher than the mean value presented in Table 31 (3,329 lbs/yr), which is not surprising given that the mean summer in-lake TP concentration for 2019 (104 µg/L) was higher than the 2010 through 2023 summer mean (87 µg/L) used to calibrate the BATHTUB model for this study. Further, 2019 precipitation (49 in) was higher than the 2010 through 2023 mean (40 in/yr). In summary, the P budget developed for this report utilizes up-to-date models and data that cover the most recent 10-year period and therefore should provide an accurate representation of current water quality conditions for Cedar Lake.

Table 31. Cedar Lake current condition phosphorus budget (HSPF modeled years = 2010 through 2019).

Category	Annual Load (lbs/yr)	Percent of Total
Sources (+)		
Drainage area	2,763	83%
Atmosphere	348	10%
Septic Systems	218	7%
TOTAL	3,329	
Losses (-)		
Sedimentation/retention	2,195	66%
Outflow	1,134	34%
TOTAL	3,329	

F.2.3 Phosphorus targets and reductions

Establishing phosphorus targets to improve water quality

The primary objective of this study is to improve water quality conditions in Cedar Lake. Cedar Lake currently exceeds the 40 µg/L NCHF lake/reservoir TP standard and the 14 µg/L chl-*a* standard based on data collected since 2000 (Table 27). Therefore, an in-lake TP concentration target below the 40 µg/L standard should be the ultimate goal for Cedar Lake to reduce summer chl-*a* concentrations and nuisance algae blooms. Since current TP levels are more than twice the standard, it may be helpful to set an interim TP target for Cedar Lake to help guide early implementation efforts to improve water quality. Here, we present two water quality targets local partners could consider for Cedar Lake:

- Interim target – decrease mean summer TP concentrations from 87 µg/L to 60 µg/L to kickstart restoration efforts and the adaptive management process
- Ultimate target – decrease mean summer TP concentrations to 40 µg/L to meet the NCHF lake and reservoir standard

It is recommended that the local partners continue collecting TP and chl-*a* data during the summer growing season to track progress toward these targets, inform future management, and better understand nutrient and algae dynamics in Cedar Lake.

Load reduction goals

With the proposed TP targets defined, the Cedar Lake BATHTUB model was used to estimate the annual TP loads and reductions that will be needed to meet the in-lake TP concentration targets. Table 32 presents the current TP load to Cedar Lake, the model-predicted TP load needed to meet each target condition, and the load reductions required to meet the targets. Section 4 presents example strategies and BMP options to achieve the load reductions presented in Table 32.

Table 32. TP loads and reductions to meet in-lake water quality targets.

Water quality target	TP target (µg/L)	Current TP[1] (µg/L)	Current TP load (lbs/yr)	TP target load (lbs/yr)	TP load reduction (lbs/yr)	TP load reduction (percent)
Interim	60	87	3,329	2,295	1,034	31%
Ultimate	40			1,530	1,799	54%

1 Mean of 2010 through 2023 monitored data

F.2.4 Strategies to improve Cedar Lake water quality and aquatic life

Example strategies were selected using a variety of sources, input from local stakeholders, and best professional judgement from MPCA staff. Example strategies presented in this section are intended to provide potential options to achieve the water quality targets and loading goals for Cedar Lake presented in Section 3. The strategies are not required, and implementation is considered voluntary. Stakeholders should use these example practices as a path to improve water quality, but it is anticipated that implementation may change as new information is learned and data is collected. It is recommended that stakeholders incorporate other known local issues or causes when implementing practices and strive to incorporate multiple benefits into projects.

Cropland best management practices

The MPCA consulted with local partner staff (Rice SWCD personal communication) to develop a list of potential cropland BMP and land use change example scenarios that could be considered for Cedar Lake to improve water quality. These scenarios include:

- Implement conservation till on all fields currently practicing conventional till
- Implement no-till on all fields currently practicing conventional till
- Implement cover crops on all cropland fields
- Convert 25% of cropland fields to grassland
- Convert 75% of cropland fields to grassland

P reductions for each BMP scenario described above were estimated using rates derived from the defaults in HSPF–SAM (version 2.0) and the [Watershed Pollutant Load Reduction Calculator](#) (MPCA 2022b). Table 33 presents the potential TP load reductions for each scenario. P reductions from the example scenarios range from 216 to 819 lbs/year and therefore, depending on the scenario selected and level of adoption, could help achieve a significant amount of the annual reduction goals identified in Table 32.

Upstream shallow lake and wetland assessments

As discussed in Sections 1 and 2, each of the main tributary inlets to Cedar Lake flow through shallow lake and wetland systems that receive runoff from adjacent agricultural fields. These wetlands have the potential to become overloaded over time which can lead to flooding and water level fluctuations, increased sedimentation, low DO, P release from the sediment, and degraded habitat. It is recommended that more data be collected on these systems and a process be established to assess their hydrology, habitat conditions, and downstream water quality impacts. If it is determined that these wetlands exhibit degraded conditions, then potential projects to restore and/or improve these systems should be evaluated. Regardless of their current condition, sediment and nutrient reduction BMPs should be prioritized and targeted on the developed land and agricultural fields upstream of these systems.

Developed/residential BMPs

It is estimated that there are approximately 217 homes/residences (Limnopro 2020) throughout the Cedar Lake drainage area and residential areas account for about 6% of the land use and 8% of the annual P load to Cedar Lake. Most of the homes are on shoreline lots or other lots in close proximity to the lake. Based on investigation of air photos, most of the residential lots surrounding the lake are around 0.5 acre in size and impervious surfaces (i.e., rooftops, driveways, walkways, roads) generally cover approximately half of the lot (~0.25 acres per lot). Due to their close proximity to Cedar Lake, these impervious surfaces have high potential for stormwater to be delivered to the lake via surface runoff, drain tile, and/or shallow groundwater pathways.

A rain garden is one of the most efficient residential stormwater BMPs used to intercept runoff from impervious surfaces and remove pollutants before they enter surface waters. Below are three rain garden BMP example scenarios to reduce P loading from residential areas throughout the Cedar Lake drainage area.

- Low adoption scenario – 10% of residences throughout the drainage area install and maintain rain gardens to treat impervious areas (assumes 22 rain gardens treating approximately 6 acres of impervious area)
- Moderate adoption scenario – 25% of residences install and maintain rain gardens (55 rain gardens and 14 acres treated)
- High adoption scenario – 50% of residences install and maintain rain gardens (109 rain gardens and 28 acres treated)

P reductions from rain gardens were estimated using default rates provided in the MPCA Simple Estimator (SE) model. The SE model is an Excel-based tool that is commonly used by municipalities in Minnesota to estimate flow, P loads, and BMP load reductions in urban and residential areas (link to Minnesota Stormwater Manual SE page). Table 33 presents the potential TP load reductions for each scenario. Reductions range from 5 lbs/year for the low adoption scenario to 25 lbs/year for the high adoption scenario. Although the total load reductions for the raingarden scenarios are less than the cropland BMP scenarios, raingarden TP reduction efficiency is higher than many of the cropland BMPs listed in Table 33. Thus, raingardens are an effective practice in reducing P loads from developed areas in the Cedar Lake drainage area.

Lakeshore BMPs

The DNR Lake SID Report (DNR 2026) indicates that physical habitat alteration is likely occurring at a level that would contribute to an impaired fish community in Cedar Lake based on review of information reflecting riparian lakeshore development. Shoreline development for Cedar Lake is relatively high and has resulted in the loss of both riparian vegetation and native floating-leaf and emergent plant stands that serve as important habitat for fish and other organisms. Further, replacement of riparian vegetation with riprap and open lawns has resulted in increased nutrient inputs from fertilizer and lawn clippings, reduced buffering capacity, destabilized shoreline, and elimination of future contributions of coarse woody habitat into the lake.

Shoreland owners can significantly improve shoreline habitat by choosing to reestablish or maintain native plants along their property. Natural shorelines provide overhead cover to fish and wildlife species, contribute important coarse woody habitat into the lake, and provide a buffer for nutrient runoff from lawns and impervious surfaces. While shoreline restoration projects vary in scope and size, all can be completed in ways that are visually appealing and that maintain a view of the lake. Once completed, these projects have potential to provide many ecosystem benefits that a more traditional developed shoreline (e.g., riprap, mowed lawn, and sand beach) could not offer. The DNR maintains an interactive Restore Your Shore webpage that provides guidance for shoreland owners and professionals to use in implementing shoreland restoration projects. Protection and restoration of floating-leaf and emergent aquatic vegetation should also be prioritized, especially where aquatic habitat is limited. Shoreland owners should be aware of and adhere to current laws that regulate shoreline and aquatic plant control, riprap, sand blanket, and retaining wall installation, and other shoreline alterations.

The DNR estimates that a developed shoreline with turf grass to the water's edge allows seven to nine times more P to enter the lake than a naturally vegetated shoreline (Radomski and Van Assche 2014). While the amount of P entering the lake from shoreline lots varies due to soil, slope, and other site-specific conditions, the average pollution from 100 feet of nonbuffered shoreline has been estimated at 0.2 lbs/summer of TP compared to 0.03 lbs/summer for a lot with a native vegetated shoreline buffer. Based on air photo interpretation and results of the Cedar Lake DNR STS survey (Table 29 and Figure 74), there is at least 17,500 feet of shoreline that could benefit from native shoreline buffers. Implementation of native buffers in these areas would result in TP reductions of approximately 30 lbs/year and provide several ecosystem benefits as described above and in Table 33.

Septic system improvements

It is estimated that about 50% of the septic systems (~109 systems) in the Cedar Lake drainage are noncompliant at this time (Rice SWCD personal communication). If these systems were brought into compliance, TP loading to the lake would be reduced by approximately 80 lbs/year (Table 33).

Internal phosphorus recycling

As discussed in Section 2, net effects of internal P recycling were not explicitly estimated for this study. Although there is evidence that internal P recycling occurs within Cedar Lake, it is assumed that the rate of recycling will decrease as the lake and sediments equilibrate to lower external P loads. Implementation strategies to decrease internal P recycling could be considered if in-lake TP and eutrophication response variables do not improve, or are slow to improve, as watershed reductions are achieved. Strategies to reduce internal recycling could also be pursued if BMP efforts to reduce external loads fall short of the targets and goals set by the local partners. Internal recycling strategies could include, but are not limited to, water level drawdown, sediment dredging, sediment P immobilization or chemical treatment (e.g., alum and Phoslock®). The MPCA recommends feasibility studies for any lake in which major in-lake management strategies are proposed. The *Minnesota State and Regional Government Review of Internal Phosphorus Load Control* paper (MPCA 2020b) provides more information on internal load BMPs and considerations.

At this time, common carp do not appear to be significant contributor to P recycling in Cedar Lake (see Sections 1 and 2). However, efforts to limit and prevent the migration and movement of common carp from upstream/downstream water bodies could be considered as a protection strategy to prevent this threat from becoming a problem in the future. It is recommended that local partners work closely with DNR if they are interested in pursuing carp management in Cedar Lake.

As discussed in Section 2, the relationship between CLP and water quality varies substantially among lakes and clearly defining "cause and affect" can be difficult. Heiskary and Valley (2012) found little evidence supporting CLP as a driver of lake water quality conditions in Minnesota. While there are some case studies in Minnesota and Wisconsin that suggest CLP can have negative impacts on summer water quality (James et al. 2002, Welling 2010), pilot studies and published research actually demonstrate negative effects of large-scale removal of CLP on summer water quality in eutrophic lakes (Valley et al. 2006, Welling 2010). These studies concluded that a sole focus on killing CLP in lakes, especially where the plant is abundant, may carry more risks of harmful effects to water quality and fish habitat than leaving the plant unmanaged. Thus, local partners should not expect water quality enhancements by focusing exclusively on treating CLP without simultaneous, long-term measures to reduce internal and external P loads.

Nitrogen management

While the primary focus of this study is reducing P since it is typically the limiting nutrient in lakes, studies have demonstrated that N loading to lakes can affect eutrophication and should not be overlooked. As discussed in Section 1, Cedar Lake TKN concentrations have, at times, exceeded levels that may affect aquatic plants. More N monitoring data is needed to better understand N dynamics in Cedar Lake and its impact on eutrophication, aquatic plants, and other biota. Specific N targets and watershed load reduction goals for Cedar Lake could be considered in the future as more data are collected. N reductions alone may not be successful in reducing nuisance algae blooms because certain algae (e.g., blue-green algae) are able to fix atmospheric N (Wetzel 2001). However, reduction in N loading in conjunction with the P load reductions is likely the best approach for reducing algal growth and nuisance algal blooms (MPCA 2005). Table 33 presents TN reductions rates/efficiencies for most of the cropland BMPs discussed in this report.

Table 33. Cedar Lake BMP example scenarios and associated TP load reductions and other benefits.

Strategy type	BMP	BMP example scenario	Current level of adoption	BMP TP reduction rate/efficiency	TP load reduction (lbs/yr)	Other water quality and habitat benefits
Cropland BMPs	Conservation till	Conservation till on all cropland fields currently practicing conventional till (908 ac)	none	33% removal efficiency[b]	398	sediment (reduction = 60 lbs/ac/yr[a]), nitrogen (reduction = 1.22 lbs/ac/yr[a]), improved soil health
	No till	No-till on all cropland fields practicing conventional till (908 ac)	none	68% removal efficiency[b]	819	sediment (reduction = 100 lbs/ac/yr[a]), nitrogen (reduction = 2.92 lbs/ac/yr[a]), improved soil health
	Cover crops	Cover crops on all cropland fields (908 ac)	none	29% removal efficiency[b]	263	sediment (reduction = 100 lbs/ac/yr[a]), nitrogen (reduction = 5.39 lbs/ac/yr[a]), improved soil health
	Cropland to grassland	Convert 25% of cropland fields to grassland (227 ac)	none	0.95 lbs/ac/yr[b]	216	sediment (reduction = 120 lbs/ac/yr[a]), nitrogen (reduction = 20 lbs/ac/yr[a])
		Convert 75% of cropland fields to grassland (681 ac)	none	0.95 lbs/ac/yr[b]	647	
Developed/ Residential BMPs	Rain gardens	Low adoption: 22 residences install raingardens to treat 6 acres	unknown	0.90 lbs/ac/yr[c]	5.4	sediment (reduction = 165 lbs/ac/yr[c]), water retention, groundwater recharge
		Moderate adoption: 55 residences install raingardens to treat 14 acres	unknown	0.90 lbs/ac/yr[c]	13	
		High adoption: 109 residences install raingardens to treat 28 acres	unknown	0.90 lbs/ac/yr[c]	25	
Shoreline BMPs	Native shoreline buffers	Implement native shoreline buffers on 17,500 feet of developed, nonbuffered shoreline	unknown	0.17 lbs/100-ft of shoreline[d]	30	filtering of sediment and other pollutants, reduced erosion, shoreline stabilization, habitat for insects, fish, birds, amphibians, decreased maintenance cost
Septic system improvements	Septic system upgrade	Upgrade all failing septic systems in watershed (~109 systems)	50% (~109 systems)	0.73 lbs/system/yr[e]	80	nitrogen and fecal coliform reductions (not quantified)

[a] Source: Watershed Pollutant Load Reduction Calculator (MPCA 2022b)

[b] Source: Le Sueur River HSPF–SAM (version 2.0)

[c] Source: MPCA Simple Estimator model

[d] Source: Radomski and Van Assche 2014

[e] Source: MPCA 2020a and Barr Engineering 2004

F.2.5 Summary and future monitoring, assessments, and analyses

This study identifies two water quality improvement goals for Cedar Lake that local partners can use to help guide implementation efforts. The interim goal is intended to reduce mean summer TP concentrations from 87 µg/L to 60 µg/L and requires TP load reductions of approximately 1,034 lbs/year (~31% reduction; Table 32). The interim goal could be achieved through a high level of adoption of the BMP scenarios identified in Section 4 and Table 33. The ultimate goal, which calls for an in-lake TP concentration of 40 µg/L and TP load reductions of 1,799 per year (54%), will be difficult to meet based on the BMP scenario reduction estimates presented in Section 4. To achieve this goal, drastic changes in land use/cover (e.g., conversion of cropland and residential to grass land or wetland) or engineered solutions such as wetland alterations and in-lake treatments to decrease internal P recycling may be needed. The MPCA recommends feasibility studies be performed prior to pursuing wetland and in-lake management projects and these strategies should be paired with watershed BMPs to improve project longevity.

Implementation of cropland BMPs such as conservation till, no-till, and cover crops will be critical to meet both of the water quality goals presented in this study. Septic system upgrades and rain gardens on residential properties surrounding Cedar Lake should also be targeted as these are pollutant sources with direct pathways to the lake. Although P load reduction benefits are lower than some of the other BMPs presented in Section 4, native shoreline buffers will be an important strategy to restore and protect fish habitat. Cedar Lake was recently listed as impaired for AQL (fish community), and a lack of native shoreline vegetation was identified as one of the primary stressors.

Finally, the following list of monitoring activities and analyses would be beneficial over the course of the implementation period. These items will help refine and update the watershed and lake models, assist in prioritizing and targeting BMPs, and track response to BMPs as they are implemented using an adaptive management approach.

- Collect surface water quality samples (i.e., TP, chl-*a*, Secchi depth) at least one time per month from April/May through October. Although the lake standards require June through September sampling, spring and fall data would be beneficial to better understand nutrient dynamics and eutrophication response over the entire open water season.
- Consider adding TN (i.e., TKN and nitrate/nitrite) to the list of surface water monitoring parameters to investigate if/how N may be affecting eutrophication and biological communities.
- Continue collecting water quality samples (P, N, sediment) at primary inlet points to Cedar Lake to help validate and/or refine the models developed for this report and to track reductions as BMPs are implemented.
- Assess and monitor the shallow lake and wetland systems upstream of Cedar Lake to better understand their hydrology, water quality, habitat conditions, and other ecosystem services.
- Consider collecting sediment cores (i.e., laboratory incubations for sediment P release) and additional water column profiles (i.e., temperature and DO) to evaluate how stratification, water column mixing, and internal P recycling are affecting seasonal water quality patterns and trends.

- Continue monitoring nonnative species (e.g., common carp, CLP, EWM) where they are present to ensure they do not reach densities that could substantially alter water quality and physical habitat in the future.
- Continue mapping and surveying native submerged and emergent vegetation communities to document baseline conditions and track changes as management occurs.
- Encourage individual lakeshore residents and lake association members to participate in the Lake Steward – Minnesota Lakes & Rivers Advocates and the Score Your Shore Survey to educate about sustainable land management, self-assess habitat conditions along their shorelines, and identify potential improvements.
- Utilize lidar-based terrain analysis products (e.g., PTMApp) to identify and target locations (both cropland and residential) with higher rates of soil loss and sediment delivery throughout the Cedar Lake drainage area.
- Periodically update the watershed model, lake model, and other models and tools as new data is collected and BMPs are implemented

F.3 Fish Lake Water Quality Improvement Study

Fish Lake (40-0051-00) is located in southern Le Sueur County in the Upper Cannon River Subwatershed of the greater Cannon River Watershed. Recent water quality monitoring efforts for Fish Lake suggest the lake currently meets water quality standards for AQR and therefore the lake has not been placed on the State of Minnesota's 303(d) list of impaired waters. The Cannon River Watershed local partner team has identified Fish Lake as a high priority lake for water quality protection in their 1W1P comprehensive watershed management plan (EOR 2020) and other planning documents. The local partner team requested that a water quality study be completed for Fish Lake as part of the WRAPS Update for MPCA's Cycle 2 work for the Cannon River Watershed. This technical memorandum presents the results of this work which includes the following components:

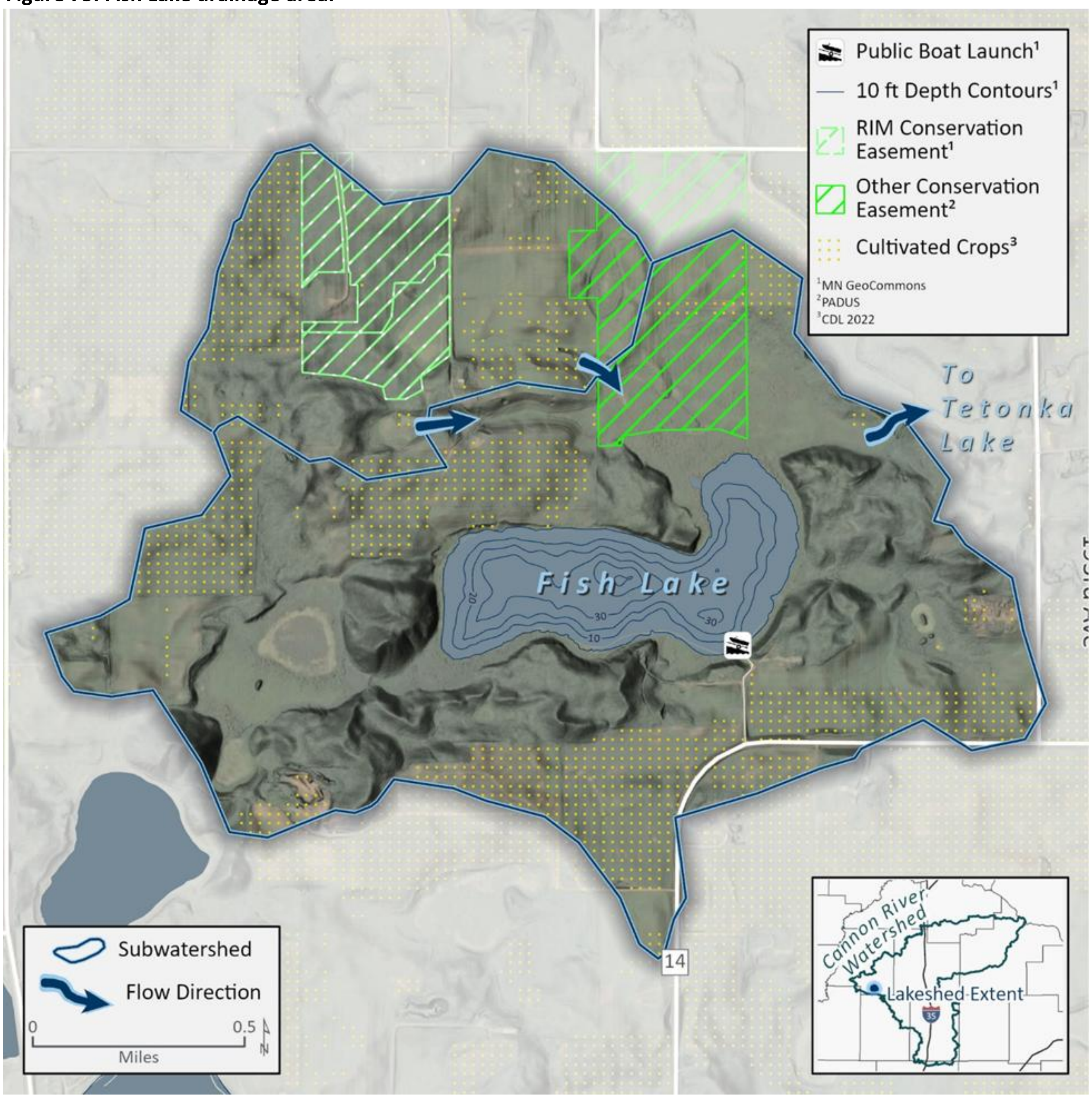
- Review of background information and data (Section F.3.1)
- Development of a lake P budget and water quality model (Section F.3.2)
- Establishment of in-lake P targets and load reductions to improve water quality (Section F.3.3)
- Potential strategies to achieve P targets and load reductions (Section F.3.4)
- Summary and considerations for future monitoring, assessments, and analyses (Section F.3.5)

F.3.1 Background information and data

Lake and watershed characteristics

Fish Lake is a relatively small (~77 acres) and deep lake (55 feet max depth and 18 feet average depth) located approximately two miles north of Elysian, Minnesota in the Cannon River Watershed (Figure 75). The DNR Level 9 drainage area boundary layer shows the Fish Lake watershed is approximately 756 acres in size (833 acres including lake surface areas). Fish Lake is considered a headwater lake meaning there are no major streams or upstream lakes flowing to it and it receives runoff from shoreline areas and fields surrounding the lake. Fish Lake has a relatively small watershed to lake area ratio (~11 to 1) and an estimated hydraulic residence time of approximately 1.5 years which suggests the lake retains a significant amount of sediment, P, and other pollutants that enter the lake. Fish Lake outlets to a wetland on the northeast side of the lake, which then outlets to an unnamed stream that flows a short distance to Tetonka Lake. There is a DNR public access on the southeast corner of Fish Lake and most of the lake's shoreline is undeveloped with only a few private residences surrounding the lake. At this time there are two active feedlots with 237 registered animals (all beef cattle) located in the Fish Lake drainage area. Land cover throughout Fish Lake's 755-acre drainage area consists of hay/pasture (32%), forest and shrubland (32%), cropland (corn/soybean, 22%), wetland (12%), and developed/residential (2%) (Source: 2019 National Landcover Dataset). There are two conservation easements in the Fish Lake drainage area. A Reinvest In Minnesota (RIM) conservation easement of 49.8 acres was established in 2013 and another 78.15 acre conservation easement that is managed as part of the Le Sueur County Waterfowl Production Area. This easement represents nearly 17% of the Fish Lake drainage area. Having this protection of the drainage area is integral to the protection of water quality in Fish Lake. See Section 2 for additional information on Fish Lake land cover and model assumptions.

Figure 75. Fish Lake drainage area.



Water quality

Lake water quality is often evaluated using three associated parameters: TP, chl-*a*, and Secchi depth. P is typically considered the limiting nutrient in Minnesota lakes, meaning that algal growth will increase with increases in TP. Chl-*a* is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Secchi depth is a physical measurement of water transparency. Increasing Secchi depths indicate less turbidity in the water column and increasing water quality. Conversely, rising TP and chl-*a* concentrations point to decreasing water quality and thus decreased water transparency. Measurements of these three parameters are interrelated and can be combined into an index that describes water quality.

Historic and existing water quality conditions for Fish Lake are described using data downloaded from the MPCA's EQuIS database and the University of Minnesota's Lake Browser. EQuIS stores data collected by the MPCA, partner agencies, grantees, and volunteers. All water quality sampling data utilized for assessments, modeling, and data analysis for this study and referenced reports are stored in this database and are accessible through the MPCA's Environmental Data Access (EDA) website. The University of Minnesota's Lake Browser provides satellite derived water quality data for over 10,000 Minnesota lakes. Data are created using an automated image processing system developed with resources from the University of Minnesota and the Environment and Natural Resources Trust Fund — Legislative and Citizens Commission on Minnesota Resources. The automated image processing system processes satellite data from Landsat 8 and Sentinel 2 and provides daily and monthly (May through October) lake clarity (i.e., Secchi depth), chl-*a*, and CDOM data for 2017 through 2021 (Page et al. 2019).

Water quality for Fish Lake has been evaluated against Minnesota's lake eutrophication standards for class 2B lakes in the NCHF ecoregion. Minnesota State statute defines various categories of lakes for assessment purposes, including lake, reservoir, shallow lake, and wetland (Minn. R. ch. 7050.0150). The determination between the four categories requires an analysis of basin depth, littoral area, and other characteristics in Appendix D of the *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment* (MPCA 2022a). Fish Lake, due to its depth and morphology, has historically been assessed by MPCA as a lake/reservoir during the water quality assessment process. Table 34 shows the current lake eutrophication water quality standards for lakes/reservoirs in the NCHF ecoregion.

Table 34. Lake eutrophication standards for class 2B lakes and reservoirs in the NCHF ecoregion.

Parameter	NCHF lakes and reservoirs
Total phosphorus (µg/L)	≤ 40
Chlorophyll-*a* (µg/L)	≤ 14
Secchi transparency (m)	≥ 1.4

The earliest TP and chl-*a* data available for Fish Lake in EQuIS are from 2007. Since 2007, Fish Lake has had only three years with three or more TP, chl-*a*, and Secchi measurements available in EQuIS during the summer growing season (i.e., June through September) and therefore lacks a consistent record for these parameters. Secchi measurements have been routinely monitored dating back to 1997 and have a more complete record. University of Minnesota Lake Browser chl-*a* measurements are available for Fish Lake from 2017–2021 and were combined with the field samples available in EQuIS for the analyses presented in this report. Minnesota Lake

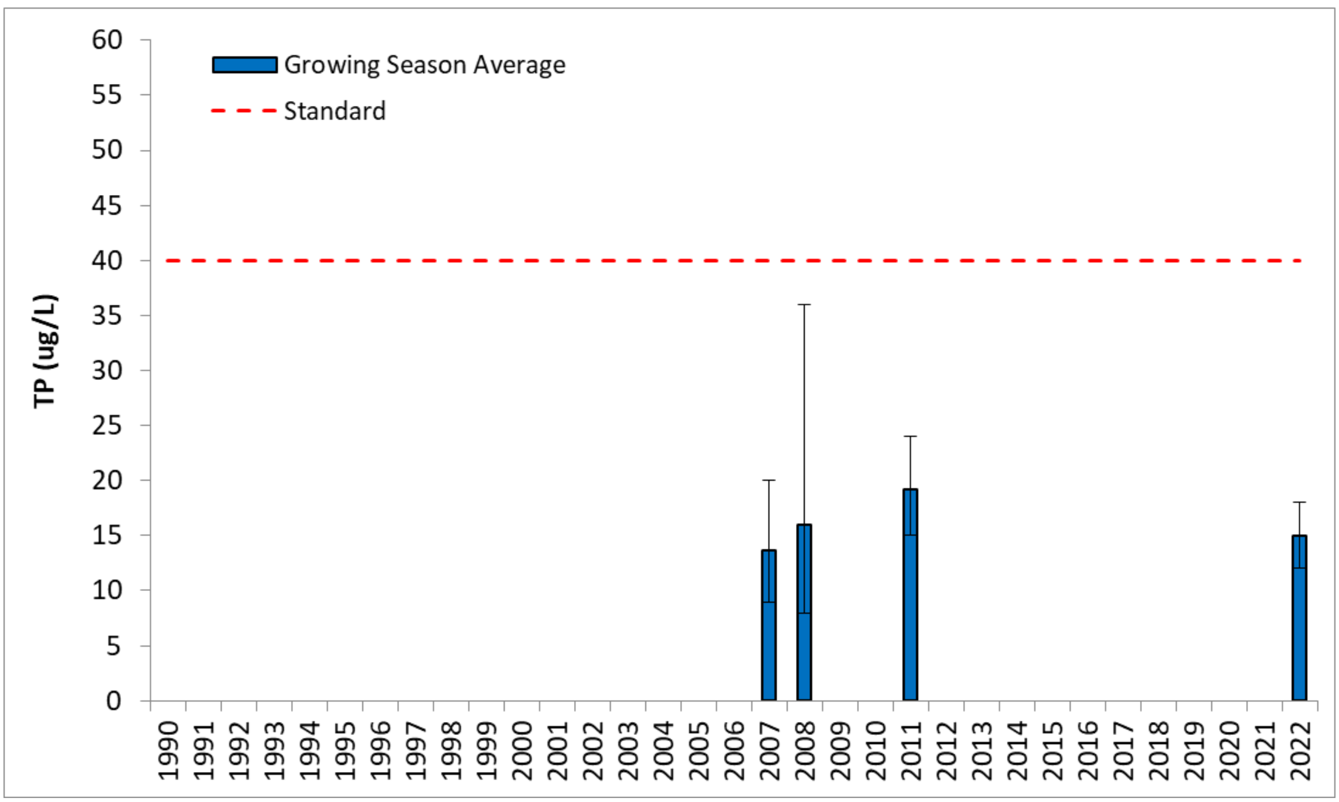
Browser Secchi depth measurements were not used in this report due to several high values that were outside the range of observed measurements reported in EQuIS.

Results of the historic TP, chl-*a*, and Secchi depth data for Fish Lake are summarized in Table 35 and illustrated in Figure 76 through Figure 78. TP data indicate mean summer growing season concentrations have remained below the 40 µg/L NCHF lake/reservoir standard since sampling began in 2007. Fish Lake summer chl-*a* concentrations have also remained below the 14 µg/L NCHF lake/reservoir standard over the last 15 years. Mean summer Secchi depths have also consistently met the 1.4 meter standard since monitoring began in 1997. However, the Secchi depth data suggests there may be a slight declining trend over the last 25 years that began around 2005 Table 35 and Figure 78.

Table 35. Summary of Fish Lake mean summer water quality compared to state standards.

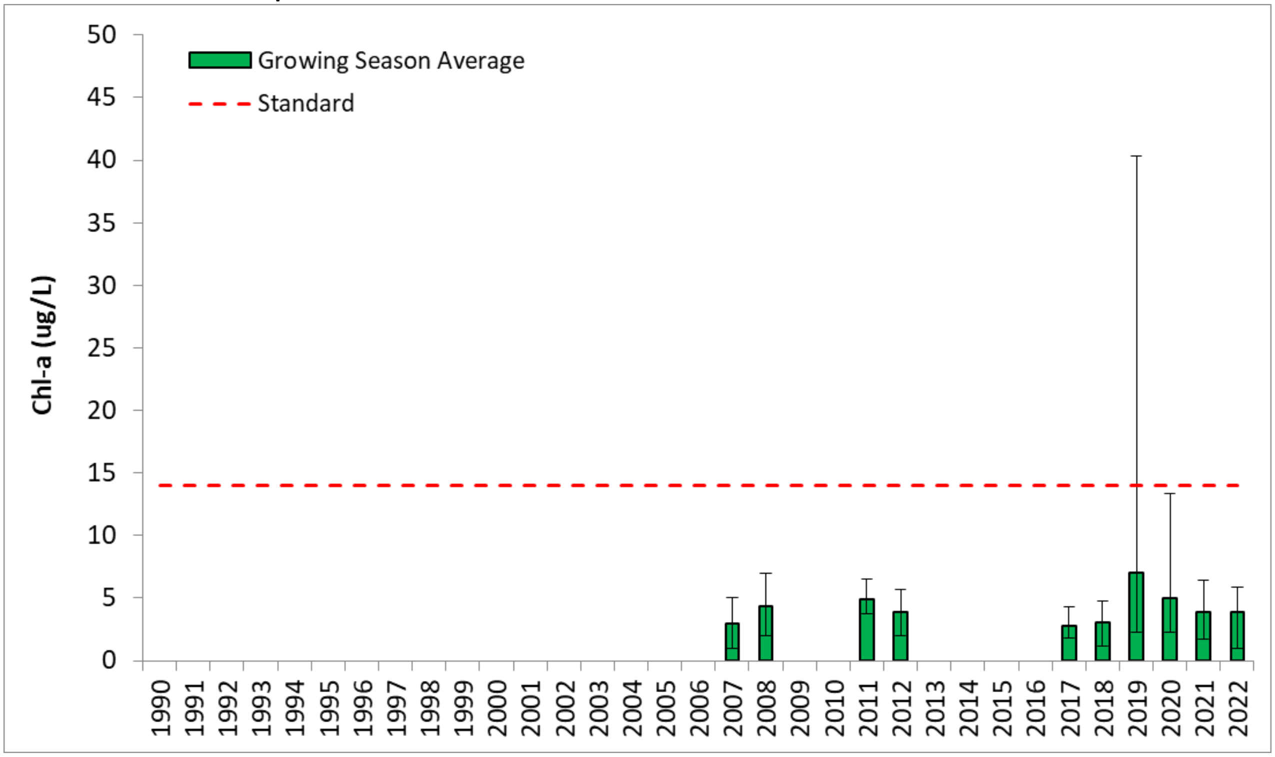
	TP (µg/L)			Chl-*a* (µg/L)			Secchi (m)		
Time period	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**
1990 through 2006	--	--	--	--	--	--	3.9	4.7	2.9
2007 through 2022	16	19	14	4	7	3	3.5	4.4	2.9
Entire record (1990-2022)	16	19	14	4	7	3	3.7	4.7	2.9
NCHF lake standards	≤40			≤14			≥ 1.4		

Figure 76. Fish Lake summer growing season mean TP concentrations (solid bars) from 1990 through 2022 for years in which at least three samples were collected. Error bars represent maximum and minimum summer growing season TP concentrations.



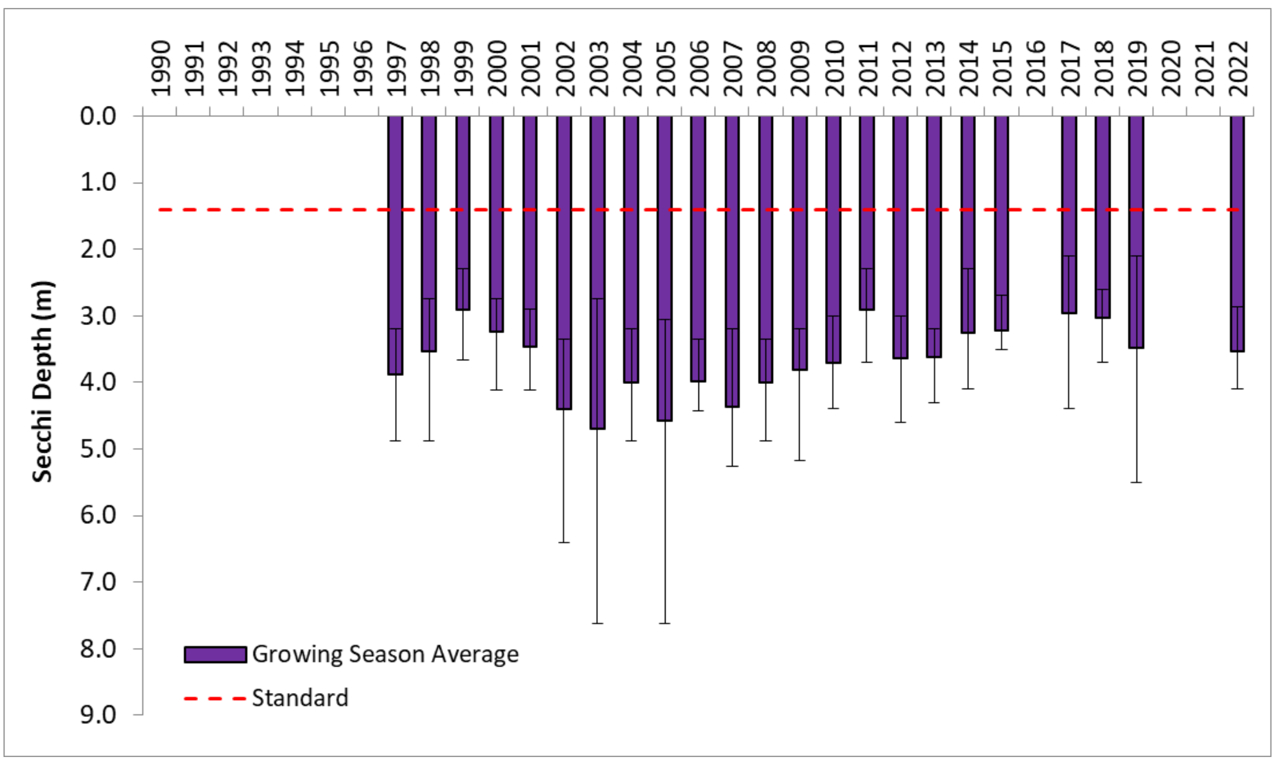
Error bars represent maximum and minimum summer growing season TP concentrations.

Figure 77. Fish Lake summer growing season mean chl-*a* concentrations (solid bars) from 1990 through 2022 for years in which at least three samples were collected.



Error bars represent maximum and minimum summer growing season chl-*a* concentrations. Data includes discrete measurements from EQuIS (entire period) and satellite derived measurements from University of Minnesota Lake Browser (2017 through 2021).

Figure 78. Fish Lake summer growing season mean Secchi depth (solid bars) from 1985 through 2022 for years in which at least three samples were collected.



Error bars represent maximum and minimum summer growing season Secchi depth measurements. Data only includes discrete measurements available in EQuIS.

Fisheries

Fish Lake is primarily managed by the DNR for bluegill, largemouth bass, and northern pike. No stocking plan exists for Fish Lake, so the fish community persists exclusively from natural recruitment. During the most recent DNR fisheries surveys in 2019, black crappie catch rates were low and below the lower normal range compared to similar lakes (DNR Lakefinder). Bluegill and largemouth bass catch rates were high compared to previous surveys. Bluegills and largemouth bass do well in Fish Lake due to its clear water and healthy and abundant aquatic vegetation community. Northern pike numbers were lower than previous surveys, but mean size was high compared to similar lakes. Catch rates for two fish species that are often associated with poor water quality conditions, common carp and black bullhead, were very low in 2019 and have generally been low since sampling began in 1979. Other species sampled in Fish Lake in 2019 include black crappie, bowfin, brown bullhead, hybrid sunfish, pumpkinseed sunfish, white sucker, and yellow bullhead.

A common misconception is that if a lake supports a quality gamefish population (e.g., high abundance or desirable size structure of a popular gamefish species), it should be considered a healthy lake. This is not always the case because both game and nongame fish species must be considered when holistically evaluating fish community health. Oftentimes, the smaller nongame fishes serve ecologically important roles in aquatic ecosystems and are generally the most sensitive to human-induced stress. In order to better evaluate the entire fish community, the DNR uses a FIBI scoring system to assess lakes throughout the State of Minnesota. The FIBI assessments utilize fish community data collected from a combination of trap nets, gill nets, beach seines, and backpack electrofishing. From these data, an FIBI score can be calculated for a lake that provides a measure of overall fish community health based on species diversity and composition. If biological impairments are found, stressors to the fish community must be identified. More information about the sampling and assessment process can be found at the DNR Lake Biological Monitoring and Assessment website.

Fish Lake was sampled and assessed in 2019 using the DNR's FIBI scoring system. Results of the FIBI assessment indicate Fish Lake (FIBI score = 57) scored above the FIBI impairment threshold established for similar lakes (FIBI threshold = 38) and therefore the fish community is in good health, and near exceptional health at this time.

Vegetation

Submergent and emergent aquatic vegetation are critical to lakes, providing spawning and cover for fish, habitat for macroinvertebrates, refuge for prey, sediment and water column nutrient uptake, and stabilization of sediments. Declines in the abundance and diversity of aquatic vegetation can be an indication of a shifting biological community and water quality state. As disturbances increase, sensitive vegetation species are lost from the system and often replaced with less desirable species (e.g., aquatic invasive species) or no vegetation at all.

Fish Lake is rare for lakes in southern Minnesota in that it is a clear lake that supports a diverse and abundant aquatic vegetation community. At total of 25 submerged and floating plant species were sampled in a 1998 survey performed by the DNR (DNR Lakefinder). There are several emergent plant species in the littoral zone of Fish Lake, including wild rice, which provide important habitat for fish and aquatic insects. Only one invasive species (AIS) was noted during the 1998 survey - CLP.

Lakeshore conditions

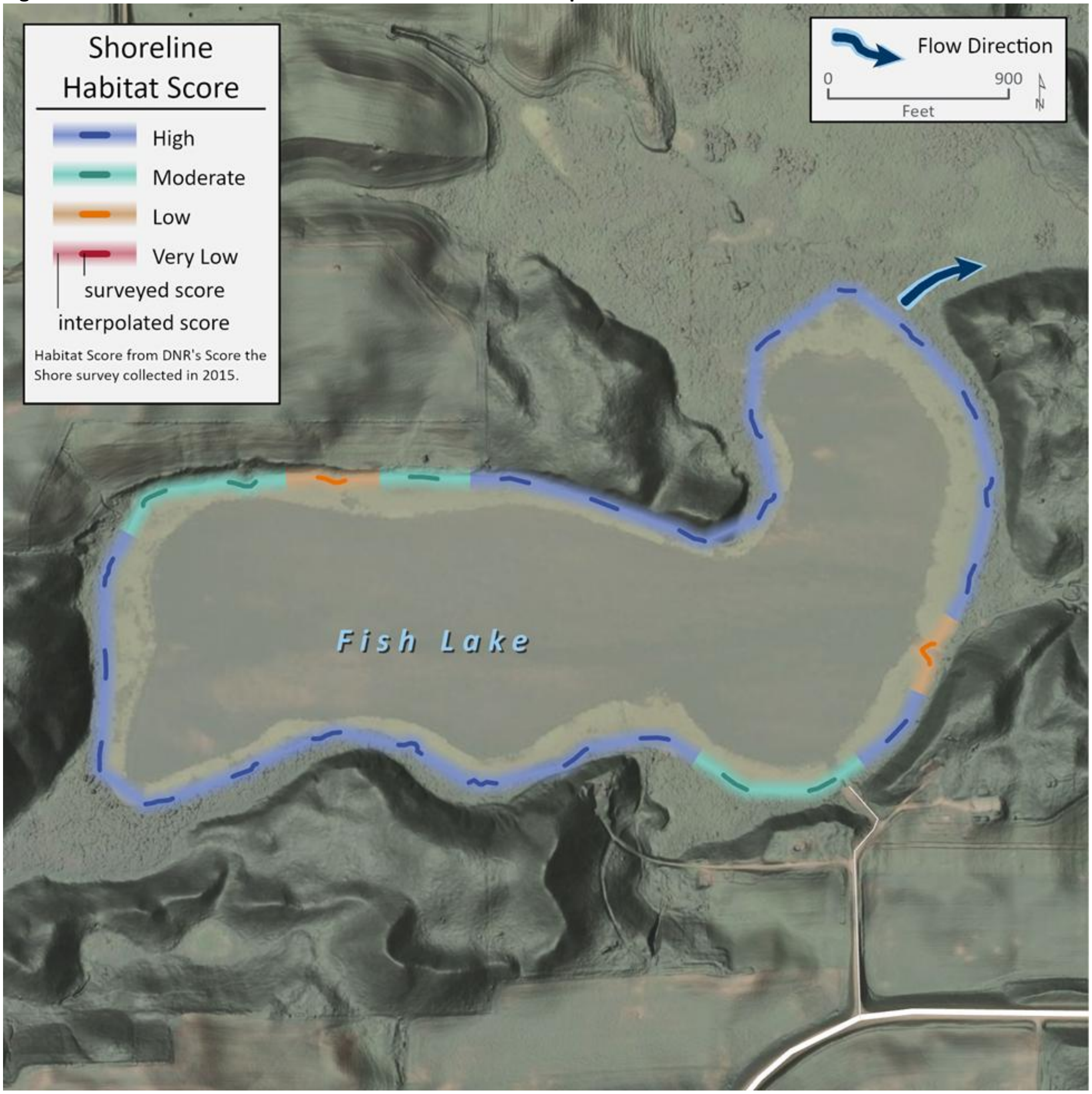
Lakeshore habitat assessments were conducted during the 2019 FIBI survey for Fish Lake. The primary tool used in the assessments was the DNR STS Rapid Assessment (DNR 2019a) which were performed by DNR staff. STS is a protocol developed to rapidly assess the quantity and integrity of lakeshore habitat. The survey is designed to assess differences in habitat between lakes and to detect changes over time. STS surveys require visual observation of lands accessible by boat. The intent of the survey is to assess habitat, not to inspect for violations. The STS assessments consist of surveying 100-foot sections of shoreline at predefined, equally spaced survey locations along the entire shoreline of the lake. Since only 100 feet of shoreline is surveyed per location, the full assessment covers a relatively small portion of the total shoreline and results are not tied to individual properties. During the surveys, three lakeshore zones (upland/shoreland, shoreline, and aquatic) are assessed independently at each survey location. Within each zone, surveyors score specific features related to habitat, which are then summed for an overall Zone Habitat Score. Higher scores indicate a greater amount of habitat. Lower scores indicate a low percent of the site remains natural and a higher amount has been physically disturbed or altered by humans. The feature scores within each zone are summed for an overall site habitat score. This scoring process provides a simple method of ranking sites based on the percent of each site that is in a natural condition versus the percent of the site that has been altered. A lakewide score is calculated using the mean site habitat score. Scores range from 0 to 100 and lakes with a high percentage of unaltered habitat score higher than lakes that have been highly altered. More information about the methods used for the STS surveys can be found in the Minnesota Lake Plant Survey Manual (DNR 2019a).

The DNR STS assessment results for Fish Lake are summarized in Table 36. Figure 79 illustrates the results of the overall habitat scores for the 29 STS survey locations. In this figure, the dark colored lines show the results of the individual surveyed locations (i.e., 100-foot survey sections). The lighter, thicker lines along the shoreline represent interpolated scores between the 100-foot surveyed sections. The overall score for Fish Lake (88.6) is considered high and exceeds the mean score of all surveyed lakes in the Cannon River Watershed (mean score = 70; N = 19). The overall score for Fish Lake also exceeds the average score for lakes surveyed throughout the state of Minnesota (mean score = 74; N = 764). A high score indicates that the lake has a low percentage of unaltered habitat. Fish Lake is one of the least developed lakes in the Waterville area and has very little residential development. Most of the riparian zone is wooded and intact which provides diverse and high-quality habitat and a riparian buffer from the surrounding agricultural fields. It is estimated that Fish Lake has approximately two docks (~1.1 docks per mile of shoreline) based on review of 2023 Google imagery. Dock densities exceeding 16 docks per mile can significantly affect fish communities and habitat (Jacobson et al. 2016, Dustin 2017).

Table 36. DNR STS survey results for Fish Lake.

Category	Result
Dock density (#/mile)	1.1
Survey locations	29
Percent developed	21%
Shoreland zone score	30.1 high
Shoreline zone score	30.1 high
Aquatic zone score	28.4 high
TOTAL SCORE	88.6 high

Figure 79. Overall site habitat STS scores for individual sample locations.



Climate

The *Climate summary for watersheds: Cannon River* (DNR 2019b) report shows that annual average temperatures in the Cannon River Watershed have increased over the last 40 years and that most years during the past two decades have been warmer than average. Monthly average temperatures in the Cannon River Watershed peak in July, and winter temperatures on average have increased over time. Annual precipitation has also shown an upward trend across the watershed since around 1940. Monthly precipitation is typically highest in June and increases in precipitation in recent years were most pronounced in April through August. The frequency of one inch and three-inch rain events has increased in general in Minnesota, along with the size of the heaviest rainfall of the year. Minnesota has also experienced an increase in devastating, large-area extreme rainstorms (DNR 2022). Climate projections indicate these big rains will continue increasing into the future (DNR 2022).

Statewide lake data collected by the DNR, MPCA, and local partners shows that the climate trends described above have already impacted lakes throughout the state and region. According to MPCA's Climate Change and Minnesota's Surface Waters Viewer, lake surface temperatures have warmed during all seasons throughout southern Minnesota. During the summer growing season (June through September), lakes in southern Minnesota are, on average, approximately 2.7˚F to 4.4˚F warmer now than they were 50 years ago. Additionally, warmer winters have resulted in about 9 less days of ice coverage on average for lakes throughout the region since the mid-1970s.

Reduced ice coverage, higher year-around water temperatures, and more intense and frequent precipitation events can result in significant impacts to lakes and lake users, including but not limited to (MPCA 2021):

- Overall increase in flow, sediment, and nutrient loading from the lake drainage area
- Longer periods of stratification and anoxia resulting in increased internal P recycling
- Longer open water and growing season for algae and cyanobacteria blooms
- Larger fluctuations in lake level from year to year
- Potential for increased densities of aquatic invasive plants, such as CLP and EWM
- Decreases in walleye (who prefer summer water temps at 65˚F to 70˚F) in smaller, warmer lakes
- Potential for more fish kills as fish are squeezed into smaller zones to access oxygen
- Shortened season for safely recreating on ice-covered lakes

Although long-term supporting data is limited, it is likely that Fish Lake has or is currently experiencing many of the climate impacts described above. These impacts create additional challenges to protect Fish Lake water quality and support healthy plant and fish communities. Adaptation strategies such as improving water management practices, enhancing soil health, planting conservation perennials, and natural shoreline buffers should be considered for Fish Lake to build resilience to these impacts and threats.

F.3.2 Lake phosphorus budget and model

A P budget and eutrophication model (BATHTUB) were established for Fish Lake using methods similar to the lake TMDLs in the *Cannon River Watershed Total Maximum Daily Load Report* (MPCA 2016) and other lake TMDLs throughout the State. The four primary P sources considered for the Fish Lake model were loading from the lake's drainage area, septic systems, atmosphere, and internal recycling. Each of these sources, and how they were estimated, are discussed below in more detail.

Drainage area

Precipitation that falls within the drainage area of a lake flows across the land surface and/or through sub-surface drain tiles, and a portion of it eventually reaches the lake. P is carried with the runoff water and delivered to the lake. The primary P sources in runoff in the Fish Lake drainage area include soils, fertilizer, vegetation, wetlands, and impervious surfaces and lawns in residential areas surrounding the lake.

Watershed runoff volumes and TP loads from the Fish Lake drainage area were estimated using the Cannon River Watershed HSPF model (2019 version). HSPF is a comprehensive, mechanistic model of watershed hydrology and water quality that allows the integrated simulation of point sources, land and soil nutrient runoff and subsurface processes, and in-stream hydraulic and sediment-chemical interactions. Model documentation contains additional details about the Cannon River HSPF model development and calibration (LimnoTech 2015).

The modeling period for the Cannon River HSPF model covers 1996 through 2019. In the model, the Fish Lake drainage area is not explicitly modeled but is included in a larger reach/subwatershed within the model (HSPF Reach 363). Table 37 presents the HSPF predicted mean annual flow and TP load by land cover type for HSPF Reach 363 that were used to represent the Fish Lake drainage area. Based on these rates, approximately 195 lbs of TP is delivered to Fish Lake each year and cropland (54%) represents the largest loading source to the lake.

Table 37. Model estimated flow volume and TP loading rates and annual totals for the Fish Lake drainage area (modeled years = 2010 through 2019).

Land cover category	Area (acres)	Modeled flow rate (in/yr)	Modeled flow volume (acre-ft/yr)	Modeled TP load rate (lbs/acre/yr)	Modeled TP load (lbs/yr)
Cropland	165	15.6	214	0.65	106
Developed/residential	19	21.0	34	0.52	10
Wetland	90	7.9	59	0.09	8
Forest and shrubland	239	13.7	273	0.07	16
Hay/pasture	243	17.2	348	0.23	55
TOTAL	756	14.7	928	0.26	195

Septic systems

Flow and TP loads from septic systems were estimated using methods similar to the *Lower Minnesota River Watershed TMDL* (MPCA 2020a). It is estimated that there are approximately five residences surrounding Fish Lake based on review of 2023 Google imagery. Assumptions were made regarding the number of people per household (~2.1), and the percent of homes that are occupied year around (100%) versus seasonally (0%). Estimated septic compliance rates (~50% compliant and ~50% failing or noncompliant) were assumed based on estimates supplied by the county (Le Sueur County Environmental Services personal communication). Septic system TP removal rates for compliant systems was assumed to be approximately 80%, while removal rates of 57% were assumed for failing systems (Barr Engineering 2004). Through this analysis it was estimated that compliant septic systems currently contribute approximately two lbs/year of TP to Fish Lake while noncompliant systems contribute approximately five lbs/year.

Atmosphere

P is bound to atmospheric particles that settle out of the atmosphere and are deposited directly onto surface water. P loading from atmospheric deposition to Fish Lake is estimated to be approximately 30 lbs/year based on the average deposition rate across the Lower Mississippi River basin (0.38 lbs/acre-year; Barr Engineering 2007).

Internal phosphorus recycling

Internal P recycling, often referred to as “internal loading,” is a common occurrence in eutrophic and hypereutrophic lakes throughout central and southern Minnesota. P contained in the sediment of lakes originates as an external P load that settles out of the water column to the lake bottom. Typically, a significant amount of the external load to the Fish Lake is delivered during snow melt and spring and early summer runoff. During this time, low water temperatures and flushing limit the amount of algae growth and biological activity within the lake. As water temperatures increase in mid-summer (e.g., late June and July), lakes can become thermally stratified during quiescent periods and biological activity increases, which leads to higher rates of algae growth and bacterial decomposition. As this happens, DO is consumed by bacteria, and anoxic conditions (i.e., low DO) can develop at the sediment-water interface which leads to the release of P from the lake sediments. The P that is released from the sediments is in a soluble form that is readily available to algae for uptake. P that has accumulated near the sediment-water interface can be readily mixed into the surface waters during strong winds, storm events, and as stratification begins to weaken in the late summer and early fall. Internal P recycling is especially problematic in lakes during dry and hot summers, when lower flows provide less dilution for P loads recycled from lake bottom sediments. Further, algae growth rates and sediment decomposition rates are elevated during dry and hot summers due to higher water temperatures and longer hydraulic residence times (Walker 2011).

There is evidence from the available data for Fish Lake that suggests internal P recycling occurs within the lake:

- Mean surface chl-*a* concentrations are highest in September and October in most years despite generally decreasing precipitation, temperature, watershed runoff, and external TP inputs during this time period
- Mean surface chl-*a* concentrations are lower from June through August when thermal stratification is strongest and there is minimal mixing between surface and bottom waters.
- High TP concentrations ranging from 450 µg/L to over 1,800 µg/L were observed in hypolimnion (i.e., depths greater than ~10 meters) samples collected during late summer and early fall (August, September, and October) in 2011 and 2022 when the lake was stratified.

At this time, there is not enough data available to explicitly quantify the amount of P that is typically recycled within Fish Lake each year. Since the lake maintains a stratified water column into October, it does not appear that a significant amount of the P that is released from the lake sediments during the summer mixes with surfaces until after the growing season index period (i.e., October or November). In order to better characterize internal recycling, additional data would need to be collected such as continuous or high-frequency temperature and DO profiles, hypolimnetic P samples, and/or sediment cores. Since internal P recycling reflects recycling of loads that originally entered the lake from the lake drainage area and atmosphere, the amount of P recycling is expected to vary with external load over time.

Common carp are another potential source of internal P recycling. When present in high densities, carp can exacerbate poor water quality in lakes by destroying/uprooting aquatic vegetation and resuspending/recycling TP from lake sediments. Studies have demonstrated how adult carp can increase turbidity, TSS, TP, and negatively affect macrophyte abundance through various direct and indirect processes (Parkos et al. 2003). Research suggests that negative impacts of common carp on turbidity and vegetation begin to occur at densities of around 89 lbs/acre (Bajer et al. 2009). To our knowledge, common carp density has not been assessed in Fish Lake. Although the gear used in the DNR trap and gill net surveys tend to underrepresent common carp abundance due to high net avoidance, these surveys can provide a relative means to track carp trends and changes over time within a lake and compare catch rates to other lakes. Based on our review of the DNR trap and gill net surveys, common carp catch rates for Fish Lake have remained well below the lower normal range of similar lakes since the late 1970s. Negative impacts to lake habitat and water quality are likely negligible at these low levels but DNR catch rates should continue to be monitored.

CLP has also been hypothesized to contribute to internal P recycling and algae blooms in lakes after the plant dies back in midsummer. Although it can be found in a wide-range of environmental conditions, CLP is most common and abundant in alkaline (> 100 mg/L calcium carbonate alkalinity, CaCO3), P-rich lakes (TP between 50 – 100 µg/L; Bolduan et al. 1994) that are dominated by urban or agricultural land use in the southern half of the state (Heiskary and Valley 2012). Based on their review of sentinel lakes throughout the state with CLP infestations, Heiskary and Valley (2012) found that some shallow lakes exhibited mid-summer TP spikes around the time of CLP senescence, however it was difficult to determine how much of a role CLP plays compared to other internal and external sources.

Lake eutrophication model and final phosphorus budget

A spreadsheet version of the lake model BATHTUB (Walker 1987) was established for Fish Lake to model current lake water quality conditions. BATHTUB is a steady state model that predicts eutrophication response in lakes based on empirical formulas developed for nutrient balance calculations and algal response (Walker 1987). The model was developed by the U.S. Army Corps of Engineers and has been used extensively in Minnesota and across the Midwest for lake nutrient TMDLs. Several models (subroutines) are available for use within the BATHTUB model, and the Canfield-Bachmann model was used to predict P settling/retention and the lake response to TP loads in Fish Lake. The BATHTUB model requires flow and P loading inputs from the lake's drainage area, upstream lakes, and atmospheric deposition. Lake morphometric data are also required by the model.

Drainage area runoff volumes and P loading inputs to the Fish Lake BATHTUB model were derived from the HSPF model (Table 37). Flow and P loading from atmospheric deposition and septic systems using the methods described above were also added to the model. With the primary external sources defined, the model predicted in-lake P concentration was compared to the 2007 through 2022 observed mean concentration (Figure 76 and Table 35). The model predicted in-lake TP concentration was higher than the observed concentration and therefore the P sedimentation calibration factor was adjusted (i.e., to increase sedimentation/retention) to match the monitored value.

The settling/retention model used in the Fish Lake BATHTUB model inherently includes an average amount of internal P recycling. In some cases, the amount of P recycled within a lake is greater than the amount inherent in the model and the modeler may choose to add additional load to improve model calibration. Alternatively, the Canfield-Bachman P sedimentation calibration factor can be adjusted to account for internal P recycling as recommended in the BATHTUB Version 6.1 Online Documentation (Walker 2006). Although there is evidence that P recycling occurs in Fish Lake, the BATHTUB model did not require an additional P load or any reduction to the P sedimentation calibration factor (Walker 2006). This suggests that internal recycling of P is not a major contributor to surface waters during most of the summer growing season and management of external sources is the most appropriate starting point to improve and protect in-lake water quality.

As shown in Table 38, loading from the Fish Lake drainage area (84%) represents the largest source of P to the lake followed by atmospheric inputs (13%) and septic systems (3%). Sedimentation/retention represents the largest sink of P (82%) suggesting a significant amount of the annual load delivered to the lake is retained in the lake and its sediments.

Table 38. Fish Lake current condition P budget (HSPF modeled years = 2010 through 2019).

Category	Annual Load (lbs/yr)	Percent of Total
Sources (+)		
Drainage area	195	84%
Atmosphere	30	13%
Septic Systems	7	3%
TOTAL	232	
Losses (-)		
Sedimentation/retention	191	82%
Outflow	41	18%
TOTAL	232	

F.3.3 Phosphorus targets and reductions

Establishing phosphorus goals to protect Fish Lake

The primary objective of this study is to protect water quality conditions in Fish Lake. Fish Lake currently meets NCHF lake/reservoir standards for all three eutrophication parameters (Table 34). Therefore, an in-lake TP concentration target below the 40 µg/L standard and at or below the current mean TP concentration (16 µg/L) should be considered to protect future water quality conditions and minimize algae blooms. Here, we present two P reduction goals local partners could consider protecting Fish Lake water quality:

- Short-term goal – reduce P loading to Fish Lake by 5%
- Long-term goal – reduce P loading to Fish Lake by 10%

The DNR commonly uses a 5% P load reduction goal to protect lakes that are comfortably meeting state water quality standards such as Fish Lake. The 10% reduction goal should be viewed as a potential long-term goal after the 5% goal is achieved. The BATHTUB model and existing water quality data suggest that both goals may not lead to significant changes in algae levels or water clarity. Even if measurable improvements in chl-*a* or Secchi are not achieved, achieving these goals will help buffer the lake from future stressors such as changes in runoff patterns, temperature, and/or ecological shifts.

Load reduction goals

Table 39 presents the current TP load to Fish Lake, the TP target load, and the load reduction required to achieve the target load. Section 4 presents example strategies and BMP options to achieve the load reductions presented in Table 39.

Table 39. TP loads and reductions to meet in-lake water quality targets.

Phosphorus goal	Current TP (µg/L)	Current TP load (lbs/yr)	TP target load (lbs/yr)	TP load reduction (lbs/yr)	TP load reduction (percent)
Short-term	16	232	220	12	5%
Long-term			209	23	10%

F.3.4 Strategies to improve Fish Lake water quality and aquatic life

Example strategies were selected using a variety of sources, input from local stakeholders, and best professional judgement from MPCA staff. Example strategies presented in this section are intended to provide potential options to achieve the protection goals for Fish Lake. The strategies are not required, and implementation is considered voluntary. Stakeholders should use these example practices as a path to improve water quality, but it is anticipated that implementation may change as new information is learned and data is collected. It is recommended that stakeholders incorporate other known local issues or causes when implementing practices and strive to incorporate multiple benefits into projects.

Cropland best management practices

The MPCA developed a list of potential cropland BMP and land use change example scenarios that could be considered for Fish Lake to improve water quality. These scenarios include:

- Implement conservation till every year on all fields currently practicing conventional till and periodic conservation till
- Implement no-till on all fields currently practicing conventional till and periodic conservation till
- Implement cover crops on all cropland fields
- Convert 25% of cropland fields to grassland
- Convert 75% of cropland fields to grassland

P reductions for each BMP scenario described above were estimated using rates derived from the defaults in HSPF–SAM (version 2.0) and the Watershed Pollutant Load Reduction Calculator (MPCA 2022b). Table 40 presents the potential TP load reductions for each scenario. P reductions from the example scenarios range from 17 to 54 lbs/year and therefore, depending on the scenario selected and level of adoption, would achieve the reduction goals identified in Table 39.

Developed/residential BMPs

It is estimated that there are only five homes/residences surrounding Fish Lake and residential areas account for 3% of the land use and 5% of the annual P load to Fish Lake. Nearly all of the homes are in fairly close proximity to the lake. Based on investigation of air photos, most of the residential lots have about one-third acre of impervious surfaces (i.e., rooftops, driveways, walkways, roads). Due to their close proximity to Fish Lake, these impervious surfaces have high potential for stormwater to be delivered to the lake via surface runoff, drain tile, and/or shallow groundwater pathways.

A rain garden is one of the most efficient residential stormwater BMPs used to intercept runoff from impervious surfaces and remove pollutants before they enter surface waters. Below are three rain garden BMP example scenarios to reduce P loading from residential areas throughout the Fish Lake drainage area.

- Low adoption scenario – One residence (20%) installs and maintains a rain garden to treat impervious areas (assumes 0.3 acres of impervious area is treated by rain garden)
- Moderate adoption scenario – Three residences install and maintain rain gardens (1.0 acres treated)
- High adoption scenario – Five residences install and maintain rain gardens (1.7acres treated)

P reductions from rain gardens were estimated using default rates provided in the MPCA SE model. Table 40 presents the potential TP load reductions for each scenario. Reductions range from 0.1 lbs/year for the low adoption scenario to 0.7 lbs/year for the high adoption scenario. Although the total load reductions for the raingarden scenarios are less than the cropland BMP scenarios, raingarden TP reduction efficiency is higher than many of the cropland BMPs listed in Table 40.

Lakeshore BMPs

Shoreline development for Fish Lake is low at this time but has the potential to impact both riparian vegetation and native floating-leaf and emergent plant stands that serve as important habitat for fish and other organisms. Further, allowing cattle access to the lake and riparian areas can result in increased nutrient inputs, reduced buffering capacity, destabilized shoreline, and elimination of future contributions of coarse woody habitat into the lake.

Shoreland owners can significantly improve shoreline habitat by choosing to reestablish or maintain native plants along their property. Natural shorelines provide overhead cover to fish and wildlife species, contribute important coarse woody habitat into the lake, and provide a buffer for nutrient runoff from lawns and impervious surfaces. While shoreline restoration projects vary in scope and size, all can be completed in ways that are visually appealing and that maintain a view of the lake. Once completed, these projects have potential to provide many ecosystem benefits that a more traditional developed shoreline (e.g., riprap, mowed lawn, and sand beach) could not offer. The DNR maintains an interactive Restore Your Shore webpage that provides guidance for shoreland owners and professionals to use in implementing shoreland restoration projects. Protection and restoration of floating-leaf and emergent aquatic vegetation should also be prioritized, especially where aquatic habitat is limited. Shoreland owners should be aware of and adhere to current laws that regulate shoreline and aquatic plant control, riprap, sand blanket, and retaining wall installation, and other shoreline alterations.

The DNR estimates that a developed shoreline with turf grass to the water's edge allows seven to nine times more P to enter the lake than a naturally vegetated shoreline (Radomski and Van Assche 2014). While the amount of P entering the lake from shoreline lots varies due to soil, slope, and other site-specific conditions, the average pollution from 100 feet of nonbuffered shoreline has been estimated at 0.2 lbs/summer TP compared to 0.03 lbs/summer for a lot with a native vegetated shoreline buffer. Based on air photo interpretation and results of the Fish Lake DNR STS survey (Table 36 and Figure 79), there is approximately 600 feet of shoreline that could benefit from native shoreline buffers. Implementation of native buffers in these areas would result in TP reductions of approximately one pound per year and provide several ecosystem benefits as described above and in Table 40. Since Fish shoreline is relatively undeveloped at this time, protecting and maintaining the lake's high-quality shoreline and habitat features will be a key protection strategy for the lake.

Septic system improvements

It is estimated that about 50% of the septic systems (~2.5 systems) in the Fish Lake drainage are noncompliant at this time (Le Sueur County Environmental Services personal communication). If these systems were brought into compliance, TP loading to the lake would be reduced by approximately three lbs/year (Table 40).

Internal phosphorus recycling

As discussed in Section 2, net effects of internal P recycling were not explicitly estimated for this study. Although there is evidence that internal P recycling occurs within Fish Lake, it is assumed that the rate of recycling will decrease as the lake and sediments equilibrate to lower external P loads. Strategies to reduce internal recycling could be considered if water quality conditions in Fish Lake degrade in the future and/or if BMP efforts to reduce external loads fall short of the targets and goals set by the local partners. Internal recycling strategies could include, but are not limited to, water level drawdown, sediment dredging, sediment P immobilization or chemical treatment (e.g., alum and Phoslock®). The MPCA recommends feasibility studies for any lake that major in-lake management strategies are proposed. The *Minnesota State and Regional Government Review of Internal Phosphorus Load Control* paper (MPCA 2020b) provides more information on internal load BMPs and considerations.

At this time, common carp do not appear to be significant contributor to P recycling in Fish Lake (see Sections 1 and 2). However, efforts to limit and prevent the migration and movement of common carp from upstream/downstream water bodies could be considered as a protection strategy to prevent this threat from becoming a problem in the future. It is recommended that local partners work closely with DNR if they are interested in pursuing carp management in Fish Lake.

As discussed in Section 2, the relationship between CLP and water quality varies substantially among lakes and clearly defining “cause and affect” can be difficult. Heiskary and Valley (2012) found little evidence supporting CLP as a driver of lake water quality conditions in Minnesota. While there are some case studies in Minnesota and Wisconsin that suggest CLP can have negative impacts on summer water quality (James et al. 2002, Welling 2010), pilot studies and published research actually demonstrate negative effects of large-scale removal of CLP on summer water quality in eutrophic lakes (Valley et al. 2006, Welling 2010). These studies concluded that a sole focus on killing CLP in lakes, especially where the plant is abundant, may carry more risks of harmful effects to water quality and fish habitat than leaving the plant unmanaged. Thus, local partners should not expect water quality enhancements by focusing exclusively on treating CLP without simultaneous, long-term measures to reduce internal and external P loads.

Table 40. Fish Lake BMP example scenarios and associated TP load reductions and other benefits.

Strategy type	BMP	BMP example scenario	Current level of adoption	BMP TP reduction rate/efficiency	TP load reduction (lbs/yr)	Other water quality and habitat benefits
Cropland BMPs	Conservation till	Conservation till on all cropland fields currently practicing conventional till (165 ac)	none	0.16 lbs/ac/yr[a]	26	sediment (reduction = 120 lbs/ac/yr[a]), nitrogen (reduction = 1.13 lbs/ac/yr[a]), improved soil health
	No till	No-till on all cropland fields practicing conventional till (165 ac)	none	0.33 lbs/ac/yr[a]	54	sediment (reduction = 180 lbs/ac/yr[a]), nitrogen (reduction = 2.70 lbs/ac/yr[a]), improved soil health
	Cover crops	Cover crops on all cropland fields (165 ac)	none	0.14 lbs/ac/yr[a]	23	sediment (reduction = 160 lbs/ac/yr[a]), nitrogen (reduction = 4.93 lbs/ac/yr[a]), improved soil health
	Cropland to grassland	Convert 25% of cropland fields to grassland (41 ac)	none	0.41 lbs/ac/yr[b]	17	sediment (reduction = 220 lbs/ac/yr[a]), nitrogen (reduction = 16.32 lbs/ac/yr[a])
		Convert 75% of cropland fields to grassland (124 ac)	none	0.41 lbs/ac/yr[b]	51	
Developed/ Residential BMPs	Rain gardens	Low adoption: 1 residence installs raingarden to treat 0.3 acres	unknown	0.42 lbs/ac/yr[c]	0.1	sediment (reduction = 123 lbs/ac/yr[c]), water retention, groundwater recharge
		Moderate adoption: 3 residences install raingardens to treat 1.0 acres	unknown	0.42 lbs/ac/yr[c]	0.4	
		High adoption: 5 residences install raingardens to treat 1.7 acres	unknown	0.42 lbs/ac/yr[c]	0.7	
Shoreline BMPs	Native shoreline buffers	Implement native shoreline buffers on 600 feet of developed, nonbuffered shoreline	unknown	0.17 lbs/100-ft of shoreline[d]	1.0	filtering of sediment and other pollutants, reduced erosion, shoreline stabilization, habitat for insects, fish, birds, amphibians, decreased maintenance cost
Septic system improvements	Septic system upgrade	Upgrade all failing septic systems in watershed (~2.5 systems)	50% (~2.5 systems)	1.1 lbs/system/yr[e]	2.8	nitrogen and fecal coliform reductions (not quantified)

[a] Source: Watershed Pollutant Load Reduction Calculator (MPCA 2022b)

[b] Source: Le Sueur River HSPF–SAM (version 2.0)

[c] Source: [MPCA Simple Estimator model]

[d] Source: Radomski and Van Assche 2014

[e] Source: MPCA 2020a and Barr Engineering 2004

F.3.5 Summary and future monitoring and analyses

This study identifies two water quality protection goals for Fish Lake that local partners can use to help guide protection efforts. The short-term goal is intended to reduce P loading by 5% or approximately 12 lbs/year (Table 39). The short-term goal could be achieved through low to moderate level of adoption of the BMP scenarios identified in Section 4 and Table 40. The long-term goal, which calls for P load reduction of 10% (23 lbs/year; Table 39), could be met through moderate to high level adoption of the BMP scenarios presented in Section 4. Implementation of cropland BMPs such as conservation till, no-till, and cover crops will be critical to meet both of the protection goals presented in this study. Septic system upgrades and rain gardens on residential properties surrounding Fish Lake should also be targeted as these are pollutant sources with direct pathways to the lake. Finally, although Fish Lake currently has a low level of shoreline development, limiting cattle access to riparian areas and ensuring native shoreline buffers remain in place will be an important strategy to protect fish and the lake's high-quality fish habitat.

The following list of monitoring activities and analyses would be beneficial over the course of the implementation period. These items will help refine and update the watershed and lake models, assist in prioritizing and targeting BMPs, and track response to BMPs as they are implemented using an adaptive management approach.

- Collect surface water quality samples (i.e., TP, chl-*a*, Secchi depth) at least one time per month from April/May through October. Although the lake standards require June through September sampling, spring and fall data would be beneficial to better understand nutrient dynamics and eutrophication response over the entire open water season.
- Consider adding TN (i.e., TKN and nitrate/nitrite) to the list of surface water monitoring parameters to investigate if/how N may be affecting eutrophication and biological communities.
- Continue monitoring nonnative species (e.g., common carp, CLP, EWM) where they are present to ensure they do not reach densities that could substantially alter water quality and physical habitat in the future.
- Continue mapping and surveying native submerged and emergent vegetation communities to document baseline conditions and track changes as management and protection efforts occur.
- Encourage individual lakeshore residents and lake association members to participate in the Lake Steward – Minnesota Lakes & Rivers Advocates and the Score Your Shore Survey to educate about sustainable land management, self-assess habitat conditions along their shorelines, and identify potential improvements.
- Utilize lidar-based terrain analysis products (e.g., PTMApp) to identify and target locations (both cropland and residential) with higher rates of soil loss and sediment delivery throughout the Fish Lake drainage area.
- Periodically update the watershed model, lake model, and other models and tools as new data is collected and BMPs are implemented.

F.4 Hunt Lake Water Quality Improvement Study

Hunt Lake (66-0047-00) is located in western Rice County in the Upper Cannon Subwatershed of the greater Cannon River Watershed. Historic water quality monitoring (2007-2008) for Hunt Lake showed the lake did not meet water quality standards for AQR and the lake was placed on the State of Minnesota's 303(d) list of impaired waters in 2010. A TMDL study was completed for the Cannon River Watershed in 2016 which included P load targets and reduction goals for Hunt Lake. Recent water quality monitoring efforts (2017-2023) suggest that in-lake water quality has not changed significantly since the impairment listing and the TMDL study and the lake is still impaired for AQR.

The Cannon River Watershed local partner team has identified Hunt Lake as a high priority lake for water quality improvement in their 1W1P comprehensive watershed management plan (EOR 2020) and other planning documents. The local partner team requested that a water quality study be completed for Hunt Lake as part of the WRAPS Update for MPCA's Cycle 2 work for the Cannon River Watershed. This technical memorandum presents the results of this work, which includes the following components:

- Review of background information and data (Section F.4.1)
- Development of a lake P budget and water quality model (Section F.4.2)
- Establishment of in-lake P targets and load reductions to improve water quality (Section F.4.3)
- Potential strategies to achieve P targets and load reductions (Section F.4.4)
- Summary and considerations for future monitoring, assessments, and analyses (Section F.4.5)

F.4.1 Background information and data

Data sources and previous studies

Below is a summary of the data, studies, and models that were compiled and reviewed for this study. All items listed below are available online or were supplied by local partners. These studies and data sources are referred to throughout different sections of this memo.

- *BATHTUB Modeling to Support Watershed Protection and Restoration Strategy Development: Lakes of the Upper Cannon River Watershed – Working Paper* (MPCA 2015)
- *Cannon River Watershed Total Maximum Daily Load* (MPCA 2016)
- *Cannon River Watershed Management Plan* (EOR 2020)

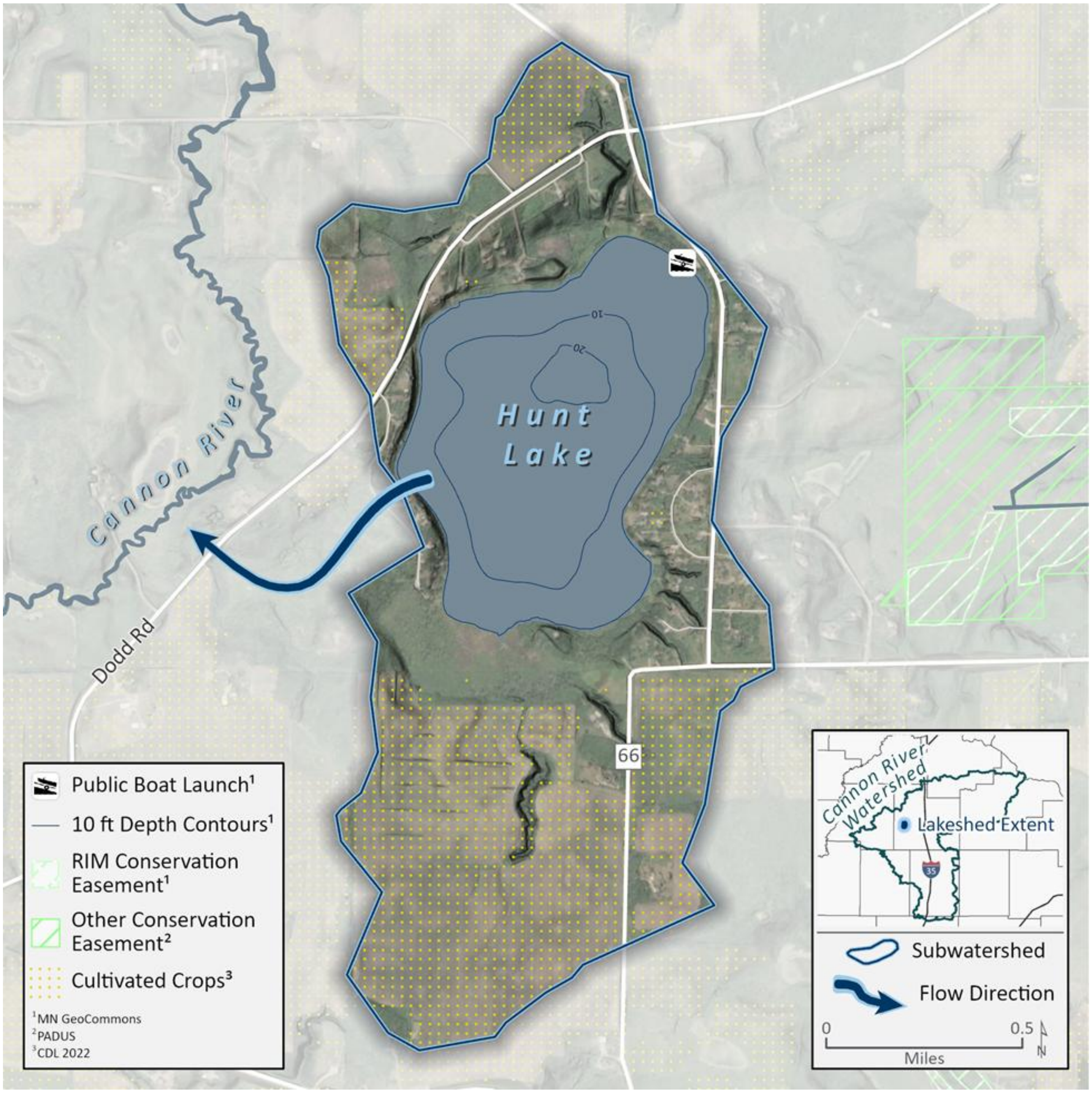
Lake and watershed characteristics

Hunt Lake is located approximately eight miles northwest of Faribault, Minnesota in the Cannon River Watershed (Figure 80). Hunt Lake is a relatively small (~176 acres) lake with maximum and mean depths of 27 feet and 10 feet, respectively, and therefore exhibits both shallow and deeper lake characteristics. A concrete weir structure on the west side of the lake controls the lake outlet which flows to an unnamed stream, which crosses beneath Isabella Trail and Dodd Road and before discharging to the Cannon River.

The DNR Level 8 drainage area boundary layer shows the Hunt Lake watershed is approximately 469 acres in size (645 acres including lake surface areas). Hunt Lake is considered a headwater lake meaning there are no major streams or upstream lakes flowing to it. The lake receives flow and runoff from areas immediately surrounding the lake and has a very small watershed to lake area ratio (3.7 to 1). Hunt Lake has an estimated hydraulic residence time of approximately three years and therefore retains a significant amount of sediment, P, and other pollutants that enter the lake.

There are approximately 50 seasonal and permanent homes located around Hunt Lake, all of which potentially have septic systems. At this time there are no active feedlots with registered animals located in the Hunt Lake drainage area, however there are several small feedlots that are not required to register located just outside the drainage area boundary. Land cover throughout Hunt Lake's 469-acre drainage area consists of cropland (corn/soybean 50%), forest and shrubland (19%), developed/residential (13%), hay/pasture (12%), and wetland (6%) (Source: 2019 National Landcover Dataset).

Figure 80. Hunt Lake drainage area.



Lake water quality

Lake water quality is often evaluated using three associated parameters: TP, chl-*a*, and Secchi depth. P is typically considered the limiting nutrient in Minnesota lakes, meaning that algal growth will increase with increases in TP. Chl-*a* is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Secchi depth is a physical measurement of water transparency. Increasing Secchi depths indicate less turbidity in the water column and increasing water quality. Conversely, rising TP and chl-*a* concentrations point to decreasing water quality and thus decreased water transparency. Measurements of these three parameters are interrelated and can be combined into an index that describes water quality.

Historic and existing water quality conditions for Hunt Lake are described using data downloaded from the MPCA's EQuIS database and the University of Minnesota's Lake Browser. EQuIS stores data collected by the MPCA, partner agencies, grantees, and volunteers. All water quality sampling data utilized for assessments, modeling, and data analysis for this study and referenced reports are stored in this database and are accessible through the MPCA's Environmental Data Access (EDA) website. The University of Minnesota's Lake Browser provides satellite derived water quality data for over 10,000 Minnesota lakes. Data are created using an automated image processing system developed with resources from the University of Minnesota and the Environment and Natural Resources Trust Fund — Legislative and Citizens Commission on Minnesota Resources. The automated image processing system processes satellite data from Landsat 8 and Sentinel 2 and provides daily and monthly (May through October) lake clarity (i.e., Secchi depth), chl-*a*, and CDOM data for 2017 through 2021 (Page et al. 2019).

Water quality for Hunt Lake has been evaluated against Minnesota's lake eutrophication standards for class 2B lakes in the NCHF ecoregion. Minnesota State statute defines various categories of lakes for assessment purposes, including lake, reservoir, shallow lake, and wetland (Minn. R. ch. 7050.0150). The determination between the four categories requires an analysis of basin depth, littoral area, and other characteristics in Appendix D of the *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment* (MPCA 2022a). Although Hunt Lake has a maximum depth of 25 feet, it has historically been assessed by MPCA as a shallow lake during the water quality assessment process. Table 41 shows the current lake eutrophication water quality standards for shallow lakes in the NCHF ecoregion.

Table 41. Lake eutrophication standards for class 2B shallow lakes in the NCHF ecoregion.

Parameter	NCHF lakes and reservoirs
Total phosphorus (µg/L)	≤ 60
Chlorophyll-a (µg/L)	≤ 20
Secchi transparency (m)	≥ 1.0

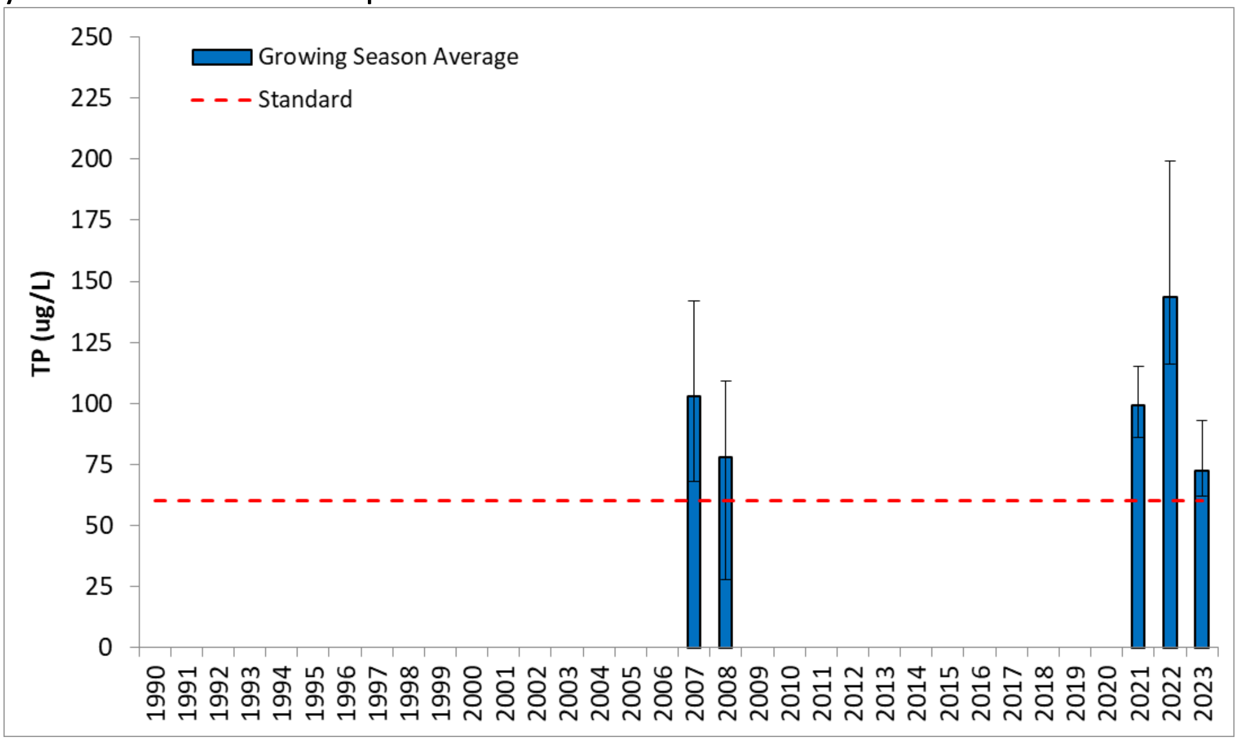
The earliest TP and chl-*a* data available for Hunt Lake in EQuIS are from 2007 and 2008. Since 2007, Hunt Lake has five years with three or more TP and chl-*a* field measurements during the summer growing season (i.e., June through September) and therefore lacks a consistent record for these parameters. Secchi measurements have been monitored occasionally dating back to the mid-1970s. University of Minnesota Lake Browser chl-*a* data are available for Hunt Lake from 2017–2021 and were combined with the field samples available in EQuIS for the analyses presented in this report.

Results of the TP, chl-*a*, and Secchi depth data for Hunt Lake are summarized in Table 42 and illustrated in Figure 81 through Figure 83. TP data indicate mean summer growing season concentrations have exceeded the 60 µg/L NCHF shallow lake standard every year since 2007. Mean summer TP concentrations have typically fluctuated between 70 µg/L and 150 µg/L and show no clear trends. Hunt Lake summer chl-*a* concentrations also show no clear trends and have consistently exceeded the 20 µg/L NCHF shallow lake standard every year. Mean summer Secchi depths, on the other hand, have met or exceeded the 1.0 meter shallow lake standard in 11 of 13 summers since 1996.

Table 42. Comparison of Hunt Lake mean summer water quality during different time periods.

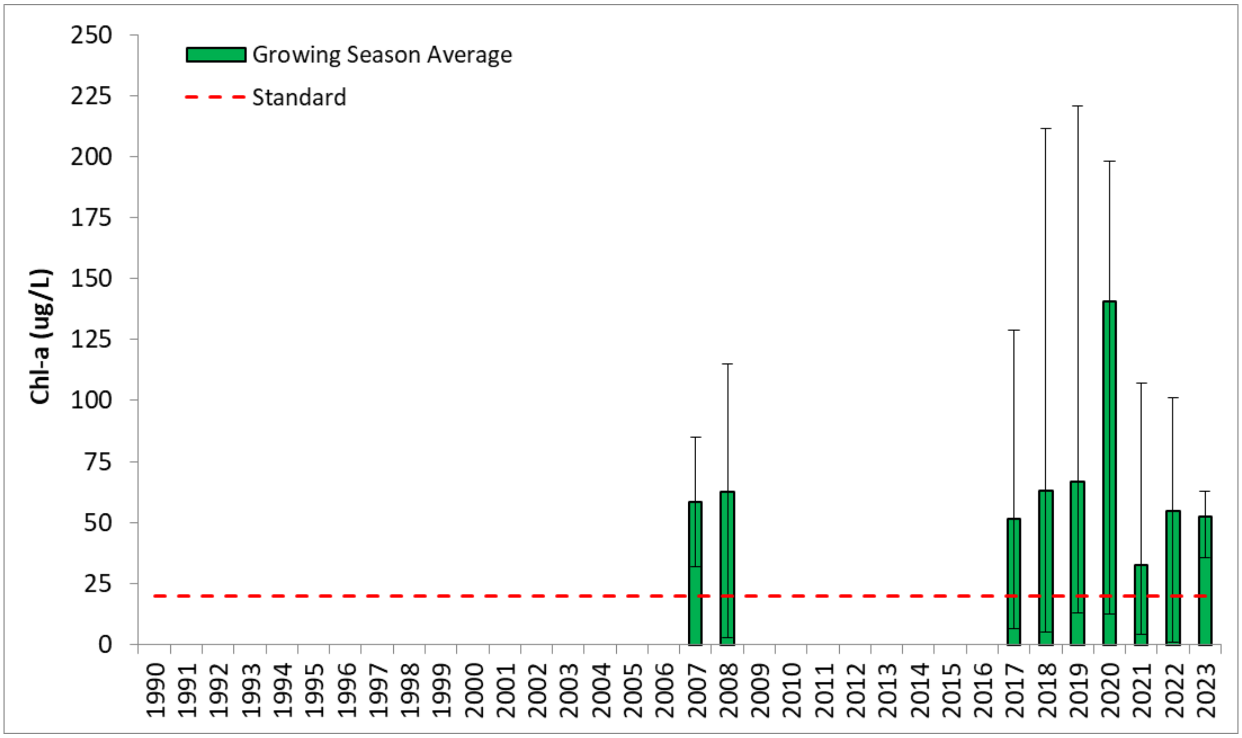
Time period	TP (µg/L)			Chl-*a* (µg/L)			Secchi (m)		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
2000 through 2009	91	103	78	61	63	58	0.98	1.20	0.58
2010 through 2023	105	144	72	66	141	33	1.24	1.63	0.83
2000 through 2023	99	144	72	65	141	33	1.15	1.63	0.58
NCHF shallow lake standards	≤60			≤20			≥ 1.0		

Figure 81. Hunt Lake summer growing season mean TP concentrations (solid bars) from 1990 through 2023 for years in which at least three samples were collected.



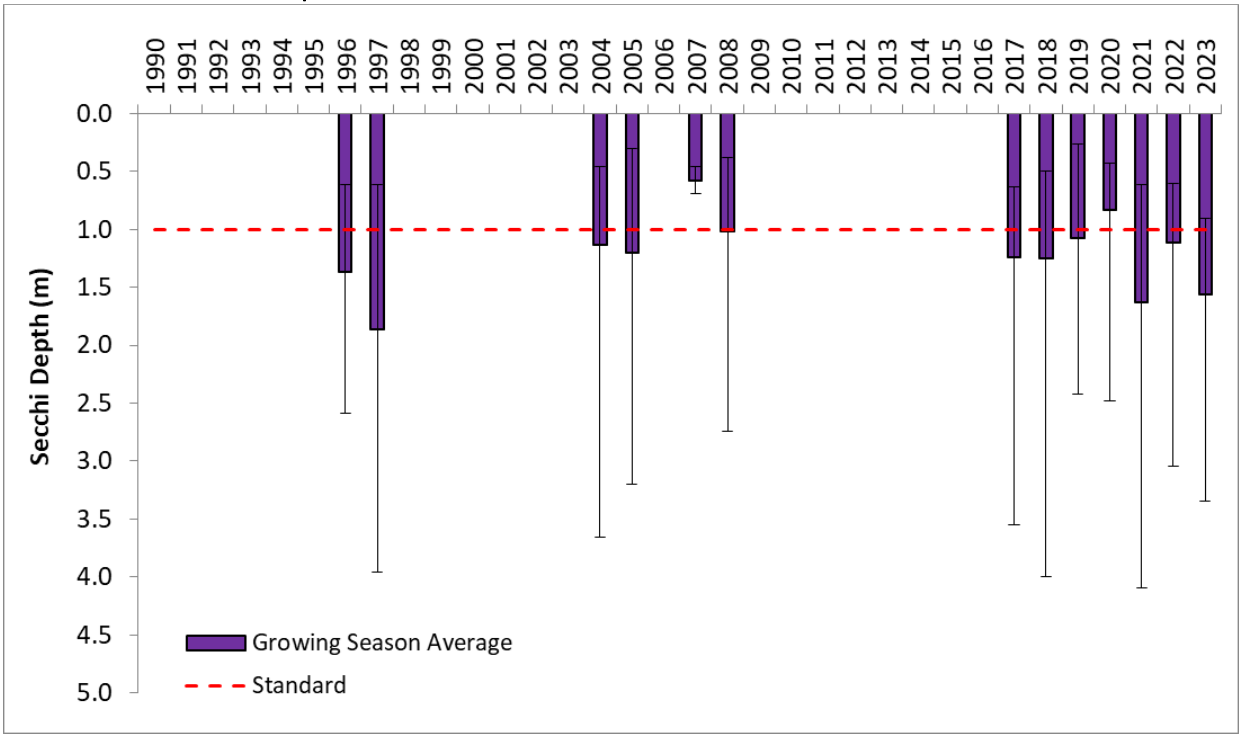
Error bars represent maximum and minimum summer growing season TP concentrations.

Figure 82. Hunt Lake summer growing season mean chl-*a* concentrations (solid bars) from 1990 through 2023 for years in which at least three samples were collected.



Error bars represent maximum and minimum summer growing season chl-*a* concentrations. Data includes discrete measurements from EQuIS (entire period) and satellite derived measurements from University of Minnesota Lake Browser (2017 through 2021).

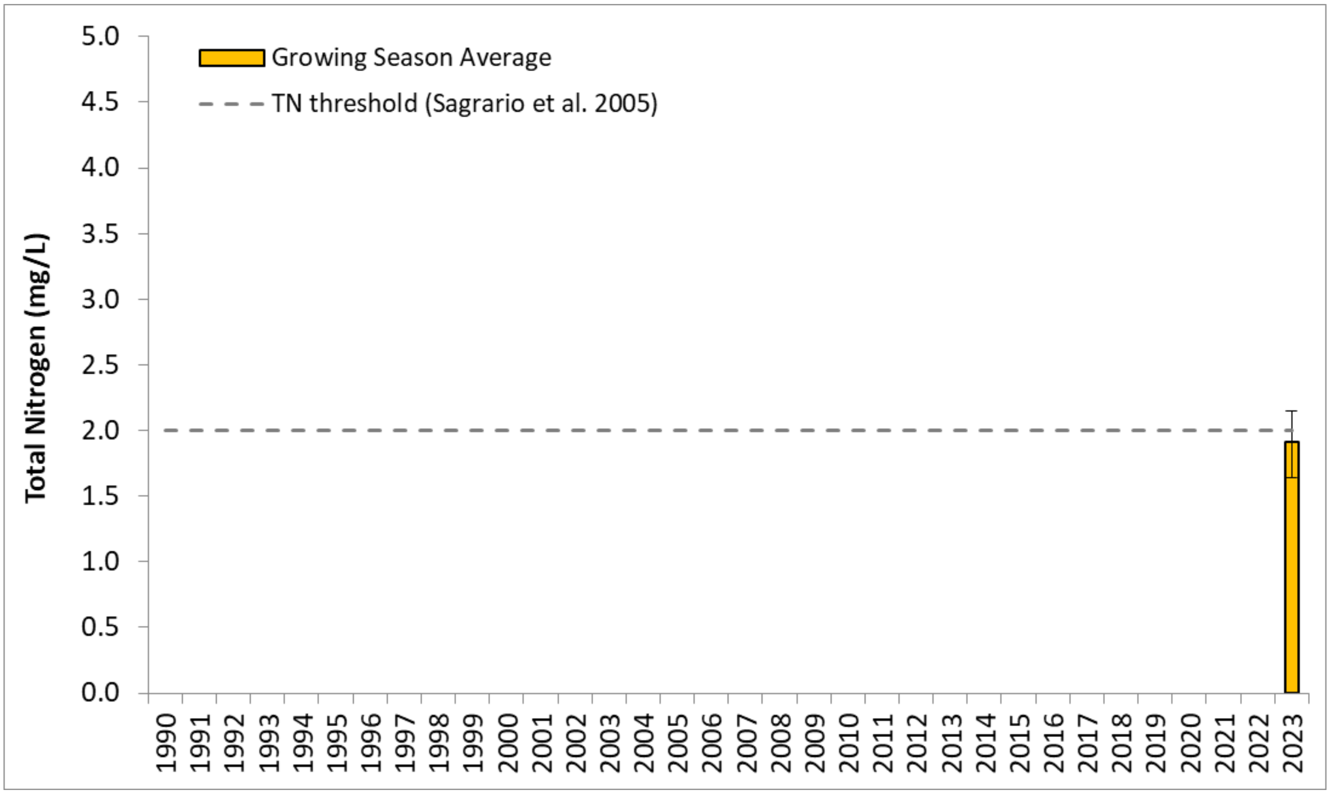
Figure 83. Hunt Lake summer growing season mean Secchi depth (solid bars) from 1990 through 2023 for years in which at least three samples were collected.



Error bars represent maximum and minimum summer growing season Secchi depth measurements. Data includes discrete measurements from EQuIS (entire period) and satellite derived measurements from University of Minnesota Lake Browser (2017 through 2021).

Although P is typically considered the limiting nutrient in most Minnesota lakes, N is an essential nutrient for algal and aquatic plant growth. TN (which is calculated as nitrate/nitrite + total Kjeldahl nitrogen [TKN]) samples were collected by the MPCA in 2023 (Figure 84). Results show individual samples ranged from 1.92 to 3.05 mg/L and summer mean concentrations have ranged from 1.50 to 2.15 mg/L. Studies have found that aquatic plant coverage and the number of plant species in lakes tend to decline when TN levels exceed ~2.0 mg/L (Sagrario et al. 2005; MPCA 2005). More spring and summer in-lake TN measurements are needed in Hunt Lake to better understand if/how N levels are impacting eutrophication (i.e., algae growth), aquatic plants, and other biota.

Figure 84. Hunt Lake summer growing season mean TN concentrations (solid bars) from 1990 through 2023 for years in which at least three samples were collected.



Error bars represent maximum and minimum summer growing season TN concentrations.

Fisheries

Hunt Lake is currently managed by the DNR for black crappie, bluegill, and largemouth bass and secondarily for northern pike and walleye. The management plan calls for stocking winter rescue adult northern pike when available. The latest stocking events include northern pike adults in 2019 and walleye fry in 2023. Hunt Lake has a history of winterkill and instability due to its shallow depth and high nutrient levels. The most recent winterkill event was the winter of 2022-2023 (DNR Lakefinder). Various dead fish were observed; however, many gamefish species were sampled the following spring suggesting it was not a complete winterkill event.

During the most recent DNR fisheries surveys in 2023, black crappie catch rates were near the median of similar lakes while average size was above the upper normal range. Bluegill catch rates were also near the median of similar lakes, but average size was near the lower normal range. In general, Hunt Lake currently exhibits strong panfish numbers and growth, and size structure should improve over time. Although not sampled in high numbers, there appeared to be a healthy largemouth bass population in Hunt Lake in 2023 and the length frequency distribution indicated consistent natural reproduction and recruitment (DNR Lakefinder). Two fish species that are often associated with poor water quality conditions, common carp and black bullhead, were both sampled at or below the lower normal range during the 2023 survey. Other species sampled in Hunt Lake in 2023 included bigmouth buffalo, freshwater drum, golden shiner, hybrid sunfish, northern pike, white crappie, yellow bullhead, and yellow perch.

A common misconception is that if a lake supports a quality gamefish population (e.g., high abundance or desirable size structure of a popular gamefish species), it should be considered a healthy lake. This is not necessarily true because both game and nongame fish species must be considered when holistically evaluating fish community health. Oftentimes, the smaller nongame fishes serve ecologically important roles in aquatic ecosystems and are generally the most sensitive to human-induced stress. In order to better evaluate the entire fish community, the DNR uses a FIBI scoring system to assess lakes throughout the State of Minnesota. The FIBI assessments utilize fish community data collected from a combination of trap nets, gill nets, beach seines, and backpack electrofishing. From these data, an FIBI score can be calculated for a lake that provides a measure of overall fish community health based on species diversity and composition. If biological impairments are found, stressors to the fish community must be identified. More information about the sampling and assessment process can be found at the DNR Lake Biological Monitoring and Assessment website.

Hunt Lake was sampled and assessed in 2017 using the DNR's FIBI scoring system. Results of the FIBI assessment indicate Hunt Lake (FIBI score = 22) scored below the FIBI impairment threshold established for similar lakes (FIBI threshold = 36) and therefore does not support AQL use and is considered impaired for AQL. Individual metric scores indicate the overall FIBI score was most negatively influenced by the absence of vegetative dwelling species in nearshore sampling and the relatively low proportion of biomass in trap nets from insectivore species (2%). A SID Report is currently being developed for Hunt Lake to identify the primary stressors to the fish communities and to provide general strategies to help address the stressors. Preliminary results of the SID assessment have identified eutrophication and physical habitat alteration as the probable cause of stress to AQL in Hunt Lake. Physical habitat alteration is occurring at a level that would contribute to the impaired fish community based on a review of information reflecting riparian disturbance, aquatic plant community condition, nonnative species introduction, and connectivity. The final SID Report is expected to be completed in 2026.

Vegetation

Submergent and emergent aquatic vegetation are critical to lakes, providing spawning and cover for fish, habitat for macroinvertebrates, refuge for prey, sediment and water column nutrient uptake, and stabilization of sediments. Declines in the abundance and diversity of aquatic vegetation can be an indication of a shifting biological community and water quality state. As disturbances increase, sensitive vegetation species are lost from the system and often replaced with less desirable species (e.g., aquatic invasive species) or no vegetation at all.

The most recent aquatic plant survey for Hunt Lake was in July 2022 and the DNR sampled 14 native submersed and floating leaf plant species. There were also two nonnative invasive plant species: CLP and EWM. The DNR uses a metric called FQI to assess the quality of plant communities in Minnesota lakes. The FQI score considers both the total number of plant species as well as likelihood of species in the community to inhabit areas closest to their natural state. High FQI scores are indicative of a plant community composed of a diverse array of species including many that are intolerant of anthropogenic stressors. The most recent FQI score for Hunt Lake (20.5) exceeds (i.e., meets) DNR's FQI minimum standard threshold (18.6) to support AQL. However, anecdotal information from DNR fisheries and lakeshore homeowners suggests CLP may be outcompeting native plants and has grown to nuisance levels in recent years. The Hunt Lake Association has been actively managing CLP since 2021. Management of CLP has consisted of surface application of Aquathol K or Flumioxazin from 2021 through 2025. Total area treated by herbicide has ranged from 13.8 to approximately 20 acres (J. Flory, personal communication, 2026).

Lakeshore conditions

Lakeshore habitat assessments were conducted during the FIBI and SID process for Hunt Lake. The primary tool used in the assessments was the DNR STS Rapid Assessment (DNR 2019a), which was performed by DNR staff. STS is a protocol developed to rapidly assess the quantity and integrity of lakeshore habitat. The survey is designed to assess differences in habitat between lakes and to detect changes over time. STS surveys require visual observation of lands accessible by boat. The intent of the survey is to assess habitat, not to inspect for violations. The STS assessments consist of surveying 100-foot sections of shoreline at predefined, equally spaced survey locations along the entire shoreline of the lake. Since only 100 feet of shoreline is surveyed per location, the full assessment covers a relatively small portion of the total shoreline and results are not tied to individual properties. During the surveys, three lakeshore zones (upland/shoreland, shoreline, and aquatic) are assessed independently at each survey location. Within each zone, surveyors score specific features related to habitat, which are then summed for an overall Zone Habitat Score. Higher scores indicate a greater amount of habitat. Lower scores indicate a low percent of the site remains natural and a higher amount has been physically disturbed or altered by humans. The feature scores within each zone are summed for an overall site habitat score. This scoring process provides a simple method of ranking sites based on the percent of each site that is in a natural condition versus the percent of the site that has been altered. A lakewide score is calculated using the mean site habitat score. Scores range from 0 to 100 and lakes with a high percentage of unaltered habitat score higher than lakes that have been highly altered. More information about the methods used for the STS surveys can be found in the Minnesota Lake Plant Survey Manual (DNR 2019a).

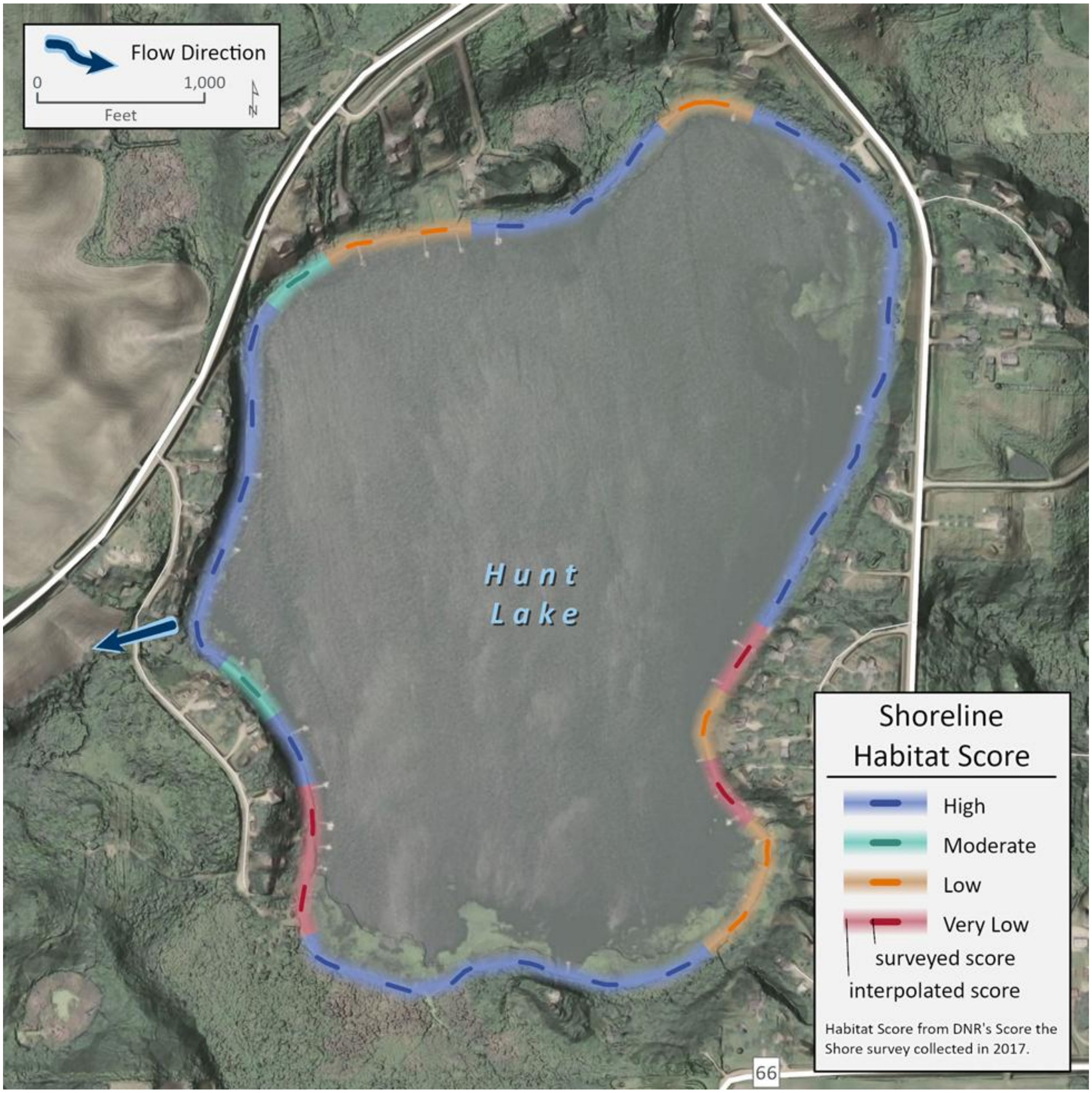
The DNR STS assessment results for Hunt Lake are summarized in Table 43. Figure 85 illustrates the results of the overall habitat scores for the 36 STS survey locations. In this figure, the dark colored lines show the results of the individual surveyed locations (i.e., 100-foot survey sections). The lighter, thicker lines along the shoreline represent interpolated scores between the 100-foot surveyed sections. The overall score for Hunt Lake (80) is considered moderate and is above the mean score of other lakes in the Cannon River Watershed (mean score = 70; N = 19) and lakes throughout the state of Minnesota (mean score = 74; N = 764). A moderate score indicates that, on average, surveyed sites have a high percentage of unaltered habitat but that at least one zone (i.e., shoreland, shoreline, or aquatic) has lower habitat quality than a high scoring site. Development has had the largest effect on the shoreland and shoreline habitat components for Hunt Lake. Developed sites generally scored lower, with a mean score of 75, while undeveloped sites had a mean score of 95. In many of the developed shoreline areas, lawns are typically maintained to the shores edge, thereby disrupting the natural riparian buffer (DNR Lakefinder).

The DNR estimates that Hunt Lake has approximately 48 docks (22 docks per mile of shoreline) based on review of 2023 Google imagery. Dock densities exceeding 16 docks per mile can significantly affect fish communities and habitat (Jacobson et al. 2016, Dustin 2017).

Table 43. DNR STS survey results for Hunt Lake.

Category	Result
Dock density (#/mile)	22
Survey locations	36
Percent developed	75%
Shoreland zone score	24.7 moderate
Shoreline zone score	27.4 moderate
Aquatic zone score	28.0 high
TOTAL SCORE	80.0 moderate

Figure 85. Overall site habitat STS scores for individual sample locations.



Climate

The *Climate summary for watersheds: Cannon River* (DNR 2019b) report shows that annual average temperatures in the Cannon River Watershed have increased over the last 40 years and that most years during the past two decades have been warmer than average. Monthly average temperatures in the Cannon River Watershed peak in July, and winter temperatures on average have increased over time. Annual precipitation has also shown an upward trend across the watershed since around 1940. Monthly precipitation is typically highest in June and increases in precipitation in recent years were most pronounced in April through August. The frequency of 1-inch and 3-inch rain events has increased in general in Minnesota, along with the size of the heaviest rainfall of the year. Minnesota has also experienced an increase in devastating, large-area extreme rainstorms (DNR 2022). Climate projections indicate these big rains will continue increasing into the future (DNR 2022).

Statewide lake data collected by the DNR, MPCA, and local partners shows that the climate trends described above have already impacted lakes throughout the state and region. According to MPCA's [Climate Change and Minnesota's Surface Waters Viewer](), lake surface temperatures have warmed during all seasons throughout southern Minnesota. During the summer growing season (June through September), lakes in southern Minnesota are, on average, approximately 2.7˚F to 4.4˚F warmer now than they were 50 years ago. Additionally, warmer winters have resulted in about 9 less days of ice coverage on average for lakes throughout the region since the mid-1970s.

Reduced ice coverage, higher year-around water temperatures, and more intense and frequent precipitation events can result in significant impacts to lakes and lake users, including but not limited to (MPCA 2021):

- Overall increase in flow, sediment, and nutrient loading from the lake drainage area
- Longer periods of stratification and anoxia resulting in increased internal P recycling
- Longer open water and growing season for algae and cyanobacteria blooms
- Larger fluctuations in lake level from year to year
- Potential for increased densities of aquatic invasive plants, such as CLP and EWM
- Decreases in walleye (who prefer summer water temps at 65˚F to 70˚F) in smaller, warmer lakes
- Potential for more fish kills as fish are squeezed into smaller zones to access oxygen
- Shortened season for safely recreating on ice-covered lakes

Although long-term supporting data is limited, it is likely that Hunt Lake has or is currently experiencing many of the climate impacts described above. These impacts create additional challenges to effectively manage Hunt Lake water quality and support healthy plant and fish communities. Adaptation strategies such as improving water management practices, enhancing soil health, planting conservation perennials, and natural shoreline buffers should be considered for Hunt Lake to build resilience to these impacts and threats.

F.4.2. Lake phosphorus budget and model

An updated lake P budget and eutrophication model (BATHTUB) were set up for Hunt Lake using methods similar to the lake TMDLs in the *Cannon River Watershed Total Maximum Daily Load Report* (MPCA, 2016) and other lake TMDLs throughout the State. The four primary P sources considered for the Hunt Lake model were loading from the lake's drainage area, septic systems, atmosphere, and internal recycling. Each of these sources, and how they were estimated, are discussed below in more detail.

Drainage area

Precipitation that falls within the drainage area of a lake flows across the land surface and/or through subsurface drain tiles, and a portion of it eventually reaches the lake. P is carried with the runoff water and delivered to the lake. The primary P sources in runoff in the Hunt Lake drainage area include soils, fertilizer, vegetation, wetlands, and impervious surfaces and lawns in residential areas surrounding the lake.

Watershed runoff volumes and TP loads from the Hunt Lake drainage area were estimated using the Cannon River Watershed HSPF model (2019 version). HSPF is a comprehensive, mechanistic model of watershed hydrology and water quality that allows the integrated simulation of point sources, land and soil nutrient runoff and subsurface processes, and in-stream hydraulic and sediment-chemical interactions. Model documentation contains additional details about the Cannon River HSPF model development and calibration (LimnoTech 2015). The modeling period for the Cannon River HSPF model covers 1996 through 2019. In the model, the Hunt Lake drainage area is represented as one reach/subwatershed (HSPF Reach 384). Table 44 presents the HSPF predicted mean annual flow and TP load by land cover type in the Hunt Lake drainage. The model predicts that, on average, approximately 204 lbs of TP are delivered to Hunt Lake each year and that cropland (75%) represents the largest loading source to the lake.

Table 44. Model estimated flow volume and TP loading rates and annual totals for the Hunt Lake drainage area (modeled years = 2010 through 2019).

Land cover category	Area (acres)	Modeled flow rate (in/yr)	Modeled flow volume (acre-ft/yr)	Modeled TP load rate (lbs/acre/yr)	Modeled TP load (lbs/yr)
Cropland	234	16	306	0.65	152
Developed/residential	62	21	107	0.51	31
Wetland	30	8	20	0.06	2
Forest	89	14	105	0.07	6
Hay/pasture/grassland	54	17	78	0.24	13
TOTAL	469	16	616	0.44	204

Septic systems

Flow and TP loads from septic systems were estimated using methods similar to the *Lower Minnesota River Watershed TMDL* (MPCA 2020a). We estimate that there are approximately 50 septic systems in the Hunt Lake drainage area based on interpretation of satellite photographs. Assumptions were made regarding the number of people per household (~2.1), and the percent of homes that are occupied year around (50%) versus seasonally (50%). Assumptions were made regarding the number of people per household (~2.1), and the percent of homes that are occupied year around (50%) versus seasonally (50%). Estimated septic compliance rates (~50% compliant and ~50% failing or noncompliant) were assumed based on estimates supplied by the county (Rice SWCD personal communication). Septic system TP removal rates for compliant systems was assumed to be approximately 80%, while removal rates of 57% were assumed for failing systems (Barr Engineering 2004). Through this analysis it was estimated that compliant septic systems currently contribute approximately 16 lbs/year of TP to Hunt Lake while noncompliant systems contribute approximately 34 lbs/year.

Atmosphere

P is bound to atmospheric particles that settle out of the atmosphere and are deposited directly onto surface water. P loading from atmospheric deposition to Hunt Lake is estimated to be approximately 68 lbs/year based on the average deposition rate across the Lower Mississippi River basin (0.39 lbs/acre-year; Barr Engineering 2007).

Internal phosphorus recycling

Internal P recycling, often referred to as "internal loading," is a common occurrence in eutrophic and hypereutrophic shallow lakes throughout central and southern Minnesota. P contained in the sediment of lakes originates as an external P load that settles out of the water column to the lake bottom. Typically, a significant amount of the external load to Hunt Lake is delivered during snow melt and spring and early summer runoff. During this time, low water temperatures and flushing limit the amount of algae growth and biological activity within the lake. As water temperatures increase in mid-summer (e.g., late June and July), lakes can become thermally stratified during quiescent periods and biological activity increases, which leads to higher rates of algae growth and bacterial decomposition. As this happens, DO is consumed by bacteria, and anoxic conditions (i.e., low DO) can develop at the sediment-water interface which leads to the release of P from the lake sediments. The P that is released from the sediments is in a soluble form that is readily available to algae for uptake. In shallower areas, P that has accumulated near the sediment-water interface can be readily mixed into the surface waters during strong winds and storm events, and in deeper areas as stratification begins to weaken in the late summer. Internal P recycling is especially problematic in shallow lakes during dry and hot summers, when lower flows provide less dilution for P loads recycled from lake bottom sediments. Further, algae growth rates and sediment decomposition rates are elevated during dry and hot summers due to higher water temperatures and longer hydraulic residence times (Walker 2011).

There are multiple lines of evidence from the available data that suggest internal P recycling occurs within Hunt Lake:

- Mean surface TP and chl-*a* concentrations increase from May through July and remain high in August and September most years despite generally decreasing precipitation, watershed runoff, and external TP inputs during this time period
- Although temperature and DO profile data for Hunt Lake is rather limited, surface TP and chl-*a* concentration spikes have been observed when thermal stratification weakens or breaks down late in the summer and following water column mixing events (e.g., 2022 and 2023)
- High TP concentrations ranging from 100 µg/L to over 1,260 µg/L have been observed in hypolimnetic (i.e., depths greater than ~12 feet) samples collected during summer stratification
- P settling/retention in the Hunt Lake BATHTUB model (see next section) had to be reduced from default values to calibrate to observed mean summer TP levels

At this time, there is not enough data available to explicitly quantify the amount of P that is typically recycled within Hunt Lake each year. In order to better characterize internal recycling, specific data would need to be collected such as continuous or high-frequency temperature and DO profiles, additional hypolimnetic P samples, and/or sediment cores. Since internal P recycling reflects recycling of loads that originally entered the lake from the lake drainage area and atmosphere, the amount of P recycling is expected to vary with external load over time.

Common carp are another potential source of internal P recycling. When present in high densities, carp can exacerbate poor water quality in lakes by destroying/uprooting aquatic vegetation and resuspending/recycling TP from lake sediments. Studies have demonstrated how adult carp can increase turbidity, TSS, TP, and negatively affect macrophyte abundance through various direct and indirect processes (Parkos et al. 2003). Research suggests that negative impacts of common carp on turbidity and vegetation begin to occur at densities of around 89 lbs/acre (Bajer et al. 2009). To our knowledge, common carp density has not been assessed in Hunt Lake. Although the gear used in the DNR trap and gill net surveys tend to underrepresent common carp abundance due to high net avoidance, these surveys can provide a relative means to track carp trends and changes over time within a lake and compare catch rates to other lakes. Based on our review of the DNR trap and gill net surveys, common carp catch rates for Hunt Lake have decreased from peak values in 1993 that were near the upper normal range for similar lakes in the region. Common carp catch rates have remained at or below the lower normal range during the last two DNR surveys (2017 through 2023). Negative impacts to lake habitat and water quality are likely negligible at these low levels but catch rates should continue to be monitored. The DNR has indicated that common carp numbers in Hunt Lake are likely limited by a lack of connectivity to suitable spawning habitat (DNR Lakefinder).

CLP has also been hypothesized to contribute to internal P recycling and algae blooms in lakes after the plant dies back in midsummer. Although it can be found in a wide-range of environmental conditions, CLP is most common and abundant in alkaline (> 100 mg/L calcium carbonate alkalinity, CaCO3), P-rich lakes (TP between 50 – 100 µg/L; Bolduan et al. 1994) that are dominated by urban or agricultural land use in the southern half of the state (Heiskary and Valley 2012). Based on their review of sentinel lakes throughout the state with CLP infestations, Heiskary and Valley (2012) found that some shallow lakes exhibited mid-summer TP spikes around the time of CLP senescence, however, it was difficult to determine how much of a role CLP plays compared to other internal and external sources.

Lake eutrophication model and final phosphorus budget

A spreadsheet version of the lake model BATHTUB (Walker 1987) was established for Hunt Lake to model current lake water quality conditions. BATHTUB is a steady state model that predicts eutrophication response in lakes based on empirical formulas developed for nutrient balance calculations and algal response (Walker 1987). The model was developed by the U.S. Army Corps of Engineers and has been used extensively in Minnesota and across the Midwest for lake nutrient TMDLs. Several models (subroutines) are available for use within the BATHTUB model, and the Vollenweider (1976) Northern Lakes model was used to predict P settling/retention and the lake response to TP loads in Hunt Lake. The BATHTUB model requires flow and P loading inputs from the lake's drainage area, upstream lakes, and atmospheric deposition. Lake morphometric data are also required by the model.

Drainage area runoff volumes and P loading inputs to the Hunt Lake BATHTUB model were derived from the HSPF model (Table 44). Flow and P loading from atmospheric deposition and septic systems using the methods described above were also added to the model. With the primary external sources defined, the model predicted in-lake P concentration was compared to the long-term observed mean TP concentration (99 µg/L; Table 42). The model predicted in-lake TP concentration was lower than the observed concentration and therefore the P sedimentation calibration factor was adjusted downward until the monitored value is achieved as recommended in the BATHTUB Version 6.1 Online Documentation (Walker 2006).

Although there is evidence that P recycling occurs in Hunt Lake, this source was not explicitly included in our modeling analysis since it is difficult to quantify, and it reflects recycling of P that originally entered the lake from external sources. In long-term steady-state models such as BATHTUB, including internal P recycling as a separate loading source in the model could produce a model that is less reliable for evaluating response to future changes in external load (Walker 2006). Instead, internal P recycling is implicitly accounted for in the Hunt Lake BATHTUB model by adjusting P sedimentation to match monitored TP levels.

As shown in Table 45, loading from the Hunt Lake drainage area (63%) represents the largest source of P to the lake followed by atmospheric inputs (21%) and septic systems (16%). Lake outflow (52%) and sedimentation/retention (48%) are the primary sinks of P for Hunt Lake.

The P budget numbers estimated in the Hunt Lake TMDL study (~900 lbs/yr; MPCA 2016) are significantly higher than those presented in this study (~300 lbs/yr). The TMDL's individual estimates of drainage area load (~250 lbs/yr), atmospheric deposition (~47 lbs/yr), and septic inputs (31 lbs/yr) to Hunt Lake (MPCA 2015) are very close to the values estimated in this study. The primary difference between the TMDL study and this study is the approach used to calibrate the BATHUB model. No adjustments were made to the sedimentation calibration factor in the original TMDL model during the calibration process. Instead, default sedimentation rates were applied, and incremental P loads were added to the model until modeled TP concentrations matched observed values. This method of calibration, often referred to as the model residual approach, is commonly used in TMDLs throughout Minnesota. For the Hunt Lake TMDL, the additional load needed to calibrate the model was approximately 572 lbs/year. The TMDL study suggests that the source of the additional load is unknown and could be the result of several factors including excessive internal P recycling, sediment resuspension from fish and wind, or other sources (e.g., watershed loads) that could not be quantified with the available data. This study uses a different approach to calibrate the updated BATHTUB model for Hunt Lake (i.e., adjusting the sedimentation calibration factor as described above) in which internal P recycling and/or other unknown sources are implicit in the model. This approach provides a more effective tool for evaluating lake water quality response to changes in external load (Walker 2006), which is a primary objective of this study. In the future, the Hunt Lake BATHTUB model could be updated to explicitly model and account for internal P recycling if/when more monitoring data is collected to accurately quantify its contribution.

Table 45. Hunt Lake current condition P budget (HSPF modeled years = 2010 through 2019; long-term lake TP concentration = 99 µg/L).

Category	Annual Load (lbs/yr)	Percent of Total
Sources (+)		
Drainage area	204	63%
Atmosphere	68	21%
Septic Systems	50	16%
TOTAL	322	
Losses (-)		
Sedimentation/retention	155	48%
Outflow	167	52%
TOTAL	322	

F.4.3. Phosphorus targets and reductions

Establishing phosphorus targets to improve water quality

The primary objective of this study is to improve water quality conditions in Hunt Lake. Hunt Lake currently exceeds the 60 µg/L NCHF shallow lake TP standard and the 20 µg/L chl-*a* standard based on data collected since 2000 (Table 42). Therefore, an in-lake TP concentration target at or below the 60 µg/L standard should be the ultimate goal for Hunt Lake to reduce summer chl-*a* concentrations and nuisance algae blooms. Since current TP levels are significantly above the standard, it may be helpful to set an interim TP target for Hunt Lake to help guide early implementation efforts to improve water quality. Here, we present two water quality targets local partners could consider for Hunt Lake:

- Interim target – decrease mean summer TP concentrations from 99 µg/L to 80 µg/L to kickstart restoration efforts and the adaptive management process
- Ultimate target – decrease mean summer TP concentrations to 60 µg/L to meet the NCHF lake and reservoir standard

It is recommended that the local partners continue collecting TP and chl-*a* data during the summer growing season to track progress toward these targets, inform future management, and better understand nutrient and algae dynamics in Hunt Lake.

Load reduction goals

With the proposed TP targets defined, the Hunt Lake BATHTUB model was used to estimate the annual TP loads and reductions that will be needed to meet the in-lake TP concentration targets. Table 46 presents the current TP load to Hunt Lake, the model-predicted TP load needed to meet each target condition, and the load reductions required to meet the targets. Section 4 presents example strategies and BMP options to achieve the load reductions presented in Table 46.

Table 46. TP loads and reductions to meet in-lake water quality targets.

Water quality target	TP target (µg/L)	Current TP[1] (µg/L)	Current TP load (lbs/yr)	TP target load (lbs/yr)	TP load reduction (lbs/yr)	TP load reduction (percent)
Interim	80	99	322	260	62	19%
Ultimate	60			195	127	39%

1 Long-term summer mean (2000 through 2023)

F.4.4 Strategies to improve Hunt Lake water quality and aquatic life

Example strategies were selected using a variety of sources, input from local stakeholders, and best professional judgement from MPCA staff. Example strategies presented in this section are intended to provide potential options to achieve the water quality targets and loading goals for Hunt Lake presented in Section 3. The strategies are not required, and implementation is considered voluntary. Stakeholders should use these example practices as a path to improve water quality, but it is anticipated that implementation may change as new information is learned and data is collected. It is recommended that stakeholders incorporate other known local issues or causes when implementing practices and strive to incorporate multiple benefits into projects.

Cropland best management practices

There are currently various cropland BMPs in place in the Hunt Lake drainage. Based on discussion with Rice SWCD staff, the cropland fields to the south of Hunt Lake have implemented several WASCOBs, terraces, and grad stabilization. These BMPs are potentially reducing annual P loading to Hunt Lake by as much as 53 lbs/year based on our review of air photos and P reduction rates and assumptions derived from the defaults in HSPF–SAM (version 2.0) and the Watershed Pollutant Load Reduction Calculator (MPCA 2022b).

The MPCA consulted with local partner staff (Rice SWCD personal communication) to develop a list of additional cropland BMPs and land use change example scenarios that could be considered for cropland fields in the Hunt Lake drainage area that are not currently practicing BMPs (~102 acres). These scenarios include:

- Implement conservation till every year on all fields currently practicing conventional till
- Implement no-till on all fields currently practicing conventional till
- Implement cover crops on all cropland fields
- Convert 25% of cropland fields to grassland
- Convert 75% of cropland fields to grassland

P reductions for each BMP scenario described above were estimated using rates derived from the defaults in HSPF–SAM (version 2.0) and the Watershed Pollutant Load Reduction Calculator (MPCA 2022b).

Table 47 presents the potential TP load reductions for each scenario. P reductions from the example scenarios range from 9 to 31 lbs/year and therefore, depending on the scenario selected and level of adoption, could help achieve some of the annual reduction goals identified in Table 46.

Developed/residential BMPs

It is estimated that there are approximately 50 homes/residences throughout the Hunt Lake drainage area and residential areas account for about 13% of the land use and 15% of the annual P load to Hunt Lake. Most of the homes are on shoreline lots or other lots in close proximity to the lake. Based on investigation of air photos, most of the residential lots surrounding the lake are around one acre in size and impervious surfaces (i.e., rooftops, driveways, walkways, roads) generally cover approximately one-third of the lot (~0.33 acres per lot). Due to their close proximity to Hunt Lake, these impervious surfaces have high potential for stormwater to be delivered to the lake via surface runoff, drain tile, and/or shallow groundwater pathways.

A rain garden is one of the most efficient residential stormwater BMPs used to intercept runoff from impervious surfaces and remove pollutants before they enter surface waters. Below are three rain garden BMP example scenarios to reduce P loading from residential areas throughout the Hunt Lake drainage area.

- Low adoption scenario – 10% of residences throughout the drainage area install and maintain rain gardens to treat impervious areas (assumes 5 rain gardens treating approximately 2 acres of impervious area)
- Moderate adoption scenario – 25% of residences install and maintain rain gardens (13 rain gardens and 4 acres treated)
- High adoption scenario – 50% of residences install and maintain rain gardens (25 rain gardens and 8 acres treated)

P reductions from rain gardens were estimated using default rates provided in the MPCA Simple Estimator (SE) model. The SE model is an Excel-based tool that is commonly used by municipalities in Minnesota to estimate flow, P loads, and BMP load reductions in urban and residential areas (link to Minnesota Stormwater Manual SE page). Table 47 presents the potential TP load reductions for each scenario. Reductions range from 0.9 lbs/year for the low adoption scenario to 3.7 lbs/year for the high adoption scenario. Although the total load reductions for the raingarden scenarios are less than the cropland BMP scenarios, raingarden TP reduction efficiency is higher than many of the cropland BMPs listed in Table 47. Thus, raingardens are an effective practice in reducing P loads from developed areas in the Hunt Lake drainage area. Rice SWCD indicated that some of the agricultural land on the west and northwest side of the lake is currently being developed into low density, large lot housing units. This development has the potential to reduce TP loading to Hunt Lake, especially if stormwater raingardens and/or other BMPs are incorporated to treat runoff from impervious surfaces.

Lakeshore BMPs

The DNR Lake SID Report (DNR 2026) indicates that physical habitat alteration is likely occurring at a level that would contribute to an impaired fish community in Hunt Lake based on review of information reflecting riparian lakeshore development. Shoreline development for Hunt Lake is relatively high and has resulted in the loss of both riparian vegetation and native floating-leaf and emergent plant stands that serve as important habitat for fish and other organisms. Further, replacement of riparian vegetation with riprap and open lawns has resulted in increased nutrient inputs from fertilizer and lawn clippings, reduced buffering capacity, destabilized shoreline, and elimination of future contributions of coarse woody habitat into the lake.

Shoreland owners can significantly improve shoreline habitat by choosing to reestablish or maintain native plants along their property. Natural shorelines provide overhead cover to fish and wildlife species, contribute important coarse woody habitat into the lake, and provide a buffer for nutrient runoff from lawns and impervious surfaces. While shoreline restoration projects vary in scope and size, all can be completed in ways that are visually appealing and that maintain a view of the lake. Once completed, these projects have potential to provide many ecosystem benefits that a more traditional developed shoreline (e.g., riprap, mowed lawn, and sand beach) could not offer. The DNR maintains an interactive Restore Your Shore webpage that provides guidance for shoreland owners and professionals to use in implementing shoreland restoration projects. Protection and restoration of floating-leaf and emergent aquatic vegetation should also be prioritized, especially where aquatic habitat is limited. Shoreland owners should be aware of and adhere to current laws that regulate shoreline and aquatic plant control, riprap, sand blanket, and retaining wall installation, and other shoreline alterations.

The DNR estimates that a developed shoreline with turf grass to the water's edge allows seven to nine times more P to enter the lake than a naturally vegetated shoreline (Radomski and Van Assche 2014). While the amount of P entering the lake from shoreline lots varies due to soil, slope, and other site-specific conditions, the average pollution from 100 feet of nonbuffered shoreline has been estimated at 0.2 lbs/summer TP compared to 0.03 lbs/summer for a lot with a native vegetated shoreline buffer. Based on air photo interpretation and results of the Hunt Lake DNR STS survey (Table 43 and Figure 85), there is at least 2,400 feet of shoreline that could benefit from native shoreline buffers. Implementation of native buffers in these areas would result in TP reductions of approximately 4 lbs/year and provide several ecosystem benefits as described above and in Table 47

Septic system improvements

It is estimated that about 50% of the septic systems (~25 systems) in the Hunt Lake drainage are noncompliant at this time (Rice SWCD personal communication). If these systems were brought into compliance, TP loading to the lake would be reduced by approximately 18 lbs/year (Table 47).

Internal phosphorus recycling

As discussed in Section 2, net effects of internal P recycling were not explicitly estimated for this study. Although there is evidence that internal P recycling occurs within Hunt Lake, it is assumed that the rate of recycling will decrease as the lake and sediments equilibrate to lower external P loads. Implementation strategies to decrease internal P recycling could be considered if in-lake TP and eutrophication response variables do not improve, or are slow to improve, as watershed reductions are achieved. Strategies to reduce internal recycling could also be pursued if BMP efforts to reduce external loads fall short of the targets and goals set by the local partners. Internal recycling strategies could include, but are not limited to, water level drawdown, sediment dredging, sediment P immobilization or chemical treatment (e.g., alum and Phoslock®). The MPCA recommends feasibility studies for any lake in which major in-lake management strategies are proposed. The *Minnesota State and Regional*

Government Review of Internal Phosphorus Load Control paper (MPCA 2020b) provides more information on internal load BMPs and considerations.

At this time, common carp do not appear to be significant contributor to P recycling in Hunt Lake (see Sections 1 and 2). However, efforts to limit and prevent the migration and movement of common carp from upstream/downstream water bodies could be considered as a protection strategy to prevent this threat from becoming a problem in the future. It is recommended that local partners work closely with DNR if they are interested in pursuing carp management in Hunt Lake.

As discussed in Section 2, the relationship between CLP and water quality varies substantially among lakes and clearly defining “cause and affect” can be difficult. Heiskary and Valley (2012) found little evidence supporting CLP as a driver of lake water quality conditions in Minnesota. While there are some case studies in Minnesota and Wisconsin that suggest CLP can have negative impacts on summer water quality (James et al. 2002, Welling 2010), pilot studies and published research actually demonstrate negative effects of large-scale removal of CLP on summer water quality in eutrophic lakes (Valley et al. 2006, Welling 2010). These studies concluded that a sole focus on killing CLP in lakes, especially where the plant is abundant, may carry more risks of harmful effects to water quality and fish habitat than leaving the plant unmanaged. Thus, local partners should not expect water quality enhancements by focusing exclusively on treating CLP without simultaneous, long-term measures to reduce internal and external P loads.

Nitrogen management

While the primary focus of this study is reducing P since it is typically the limiting nutrient in lakes, studies have demonstrated that N loading to lakes can affect eutrophication and should not be overlooked. As discussed in Section 1, Hunt Lake TKN concentrations have, at times, exceeded levels that may affect aquatic plants. More N monitoring data is needed to better understand N dynamics in Hunt Lake and its impact on eutrophication, aquatic plants, and other biota. Specific N targets and watershed load reduction goals for Hunt Lake could be considered in the future as more data are collected. N reductions alone may not be successful in reducing nuisance algae blooms because certain algae (e.g., blue-green algae) are able to fix atmospheric N (Wetzel 2001). However, reduction in N loading in conjunction with the P load reductions is likely the best approach for reducing algal growth and nuisance algal blooms (MPCA 2005). Table 47 presents TN reductions rates/efficiencies for most of the cropland BMPs discussed in this report.

Table 47. Hunt Lake BMP example scenarios and associated TP load reductions and other benefits.

Strategy type	BMP	BMP example scenario	Current level of adoption	BMP TP reduction rate/efficiency	TP load reduction (lbs/yr)	Other water quality and habitat benefits
Cropland BMPs	Conservation till	Conservation till on all cropland fields currently practicing conventional till and no other BMPs (102 ac)	none	0.14 lbs/ac/yr[a]	14	sediment (reduction = 80 lbs/ac/yr[a]), nitrogen (reduction = 1.3 lbs/ac/yr[a]), improved soil health
	No till	No-till on all cropland fields practicing conventional till and no other BMPs (102 ac)	none	0.30 lbs/ac/yr[a]	31	sediment (reduction = 120 lbs/ac/yr[a]), nitrogen (reduction = 3.1 lbs/ac/yr[a]), improved soil health
	Cover crops	Cover crops on all cropland fields (102 ac)	none	0.13 lbs/ac/yr[a]	13	sediment (reduction = 120 lbs/ac/yr[a]), nitrogen (reduction = 5.83 lbs/ac/yr[a]), improved soil health
	Cropland to grassland	Convert 25% of cropland fields with no BMPs to grassland (26 ac)	none	0.36 lbs/ac/yr[c]	9	sediment (reduction = 160 lbs/ac/yr[a]), nitrogen (reduction = 19.29 lbs/ac/yr[a])
		Convert 75% of cropland fields with no BMPs to grassland (77 ac)	none	0.36 lbs/ac/yr[c]	28	
Developed/ Residential BMPs	Rain gardens	Low adoption: 5 residences install raingardens to treat 2 acres	unknown	0.46 lbs/ac/yr[c]	0.9	sediment (reduction = 123 lbs/ac/yr[c]), water retention, groundwater recharge
		Moderate adoption: 13 residences install raingardens to treat 4 acres	unknown	0.46 lbs/ac/yr[c]	1.8	
		High adoption: 25 residences install raingardens to treat 8 acres	unknown	0.46 lbs/ac/yr[c]	3.7	
Shoreline BMPs	Native shoreline buffers	Implement native shoreline buffers on 2,400	unknown	0.17 lbs/100-ft of shoreline[d]	4.1	filtering of sediment and other pollutants, reduced erosion, shoreline stabilization,

Strategy type	BMP	BMP example scenario	Current level of adoption	BMP TP reduction rate/efficiency	TP load reduction (lbs/yr)	Other water quality and habitat benefits
		feet of developed, nonbuffered shoreline				habitat for insects, fish, birds, amphibians, decreased maintenance cost
Septic system improvements	Septic system upgrade	Upgrade all failing septic systems in watershed (~25 systems)	50% (~25 systems)	0.73 lbs/system/yr[e]	18	nitrogen and fecal coliform reductions (not quantified)

[a] Source: Watershed Pollutant Load Reduction Calculator (MPCA 2022b)

[b] Source: Le Sueur River HSPF–SAM (version 2.0)

[c] Source: MPCA Simple Estimator model

[d] Source: Radomski and Van Assche 2014

[e] Source: MPCA 2020a and Barr Engineering 2004

F.4.5 Summary and future monitoring, assessments, and analyses

This study identifies two water quality improvement goals for Hunt Lake that local partners can use to help guide implementation efforts. The interim goal is intended to reduce mean summer TP concentrations from 99 µg/L to 80 µg/L and require TP load reductions of approximately 62 lbs/year (~19% reduction; Table 46). Local landowners could potentially achieve the interim goal through a high level of adoption of the BMP scenarios identified in Section 4 and Table 47. The ultimate goal, which calls for an in-lake TP concentration of 60 µg/L and TP load reductions of 127 per year (39%), will be difficult to meet based on the BMP scenario reduction estimates presented in Section 4. To achieve this goal, drastic changes in land use/cover (e.g., conversion of cropland and residential to grass land or wetland) or engineered solutions such as in-lake treatments to decrease internal P recycling may be needed. The MPCA recommends feasibility studies be performed prior to pursuing wetland and in-lake management projects and these strategies should be paired with watershed BMPs to improve project longevity.

Implementation of cropland BMPs such as conservation till, no-till, and cover crops will be critical to meet and maintain both of the water quality goals presented in this study. Septic system upgrades and rain gardens on residential properties surrounding Hunt Lake should also be targeted as these are pollutant sources with direct pathways to the lake. Although P load reduction benefits are lower than some of the other BMPs presented in Section 4, native shoreline buffers will be an important strategy to restore and protect fish habitat. Hunt Lake was recently listed as impaired for AQL (fish community), and a lack of native shoreline vegetation was identified as one of the primary stressors.

Finally, the following list of monitoring activities and analyses would be beneficial over the course of the implementation period. These items will help refine and update the watershed and lake models, assist in prioritizing and targeting BMPs, and track response to BMPs as they are implemented using an adaptive management approach.

- Collect surface water quality samples (i.e., TP, chl-*a*, Secchi depth) at least one time per month from April/May through October. Although the lake standards require June through September sampling, spring and fall data would be beneficial to better understand nutrient dynamics and eutrophication response over the entire open water season.
- Consider adding TN (i.e., TKN and nitrate/nitrite) to the list of surface water monitoring parameters to investigate if/how N may be affecting eutrophication and biological communities.
- Collect water quality samples (P, N, sediment) at primary inlet points (e.g., channel on south end of lake) to Hunt Lake to help validate and/or refine the models developed for this report and to track reductions as BMPs are implemented.
- Consider collecting sediment cores (i.e., laboratory incubations for sediment P release) and additional water column profiles (i.e., temperature and DO) to evaluate how stratification, water column mixing, and internal P recycling are affecting seasonal water quality patterns and trends.
- Continue monitoring nonnative species (e.g., common carp, CLP, EWM) where they are present to ensure they do not reach densities that could substantially alter water quality and physical habitat in the future.

- Continue mapping and surveying native submerged and emergent vegetation communities to document baseline conditions and track changes as management occurs.
- Encourage individual lakeshore residents and lake association members to participate in the Lake Steward – Minnesota Lakes & Rivers Advocates and the Score Your Shore Survey to educate about sustainable land management, self-assess habitat conditions along their shorelines, and identify potential improvements.
- Utilize lidar-based terrain analysis products (e.g., PTMApp) to identify and target locations (both cropland and residential) with higher rates of soil loss and sediment delivery throughout the Hunt Lake drainage area.
- Periodically update the watershed model, lake model, and other models and tools as new data is collected and BMPs are implemented.

F.5 Kelly and Dudley Lakes water quality improvement study

Kelly Lake (66-0015-00) and Dudley Lake (66-0014-00) are located in central Rice County in the Upper Cannon River Subwatershed of the greater Cannon River Watershed. Recent water quality monitoring efforts for both lakes suggest the lake currently meets water quality standards for AQR and therefore the lakes have not been placed on the State of Minnesota's 303(d) list of impaired waters. The Cannon River Watershed local partner team has identified Kelly and Dudley lakes as high priority lakes for water quality protection in their 1W1P comprehensive watershed management plan (EOR 2020) and other planning documents. The local partner team requested that a water quality study be completed for both lakes as part of the WRAPS Update for MPCA's Cycle 2 work for the Cannon River Watershed. This technical memorandum presents the results of this work which includes the following components:

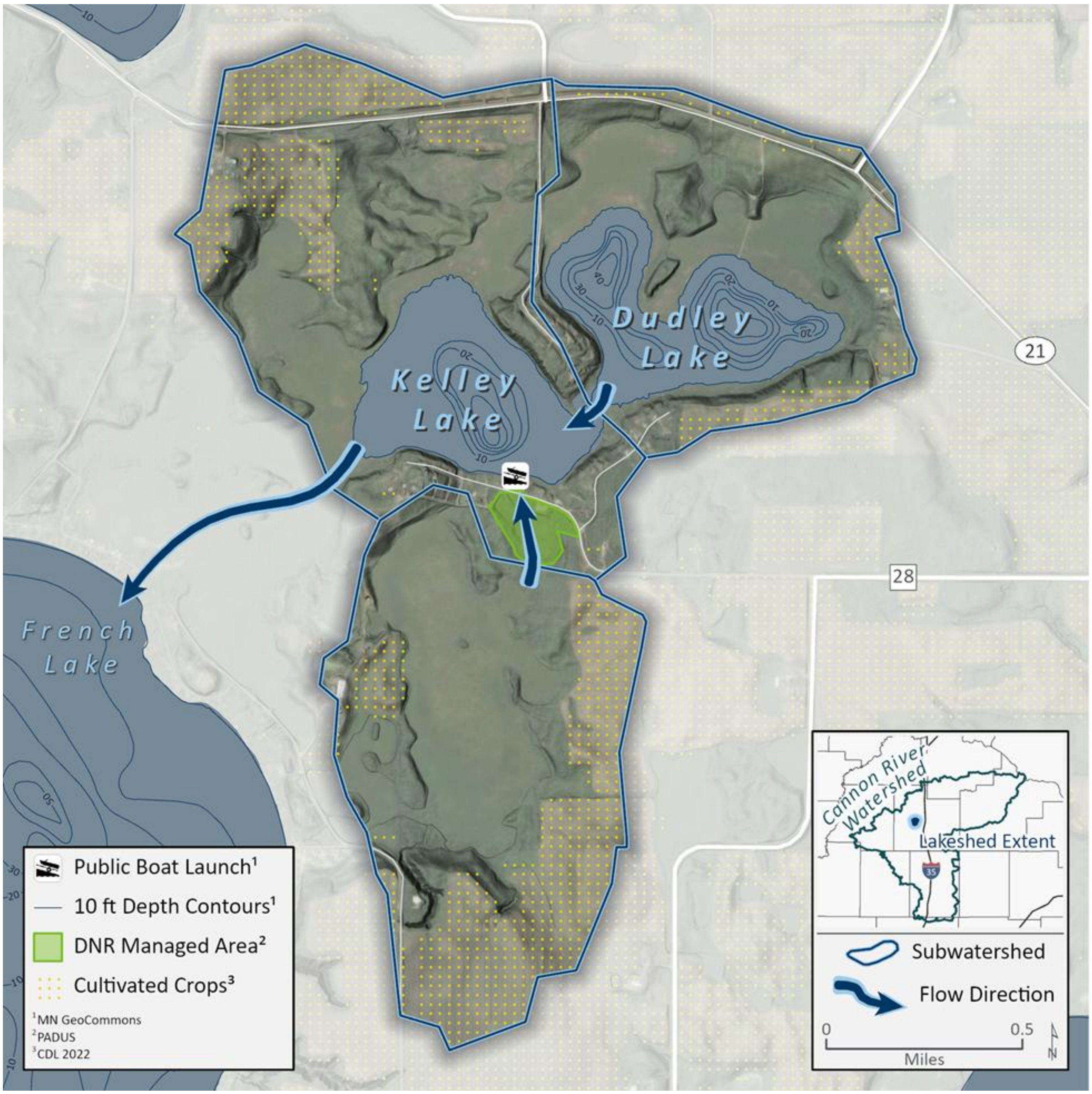
- Review of background information and data (Section F.5.1)
- Development of lake P budgets and water quality models (Section F.5.2)
- Establishment of in-lake P targets and load reductions to improve water quality (Section F.5.3)
- Potential strategies to achieve P targets and load reductions (Section F.5.4)
- Summary and considerations for future monitoring, assessments, and analyses (Section F.5.5)

F.5.1 Background information and data

Lake and watershed characteristics

Kelly and Dudley lakes are located approximately five miles northwest of Faribault, Minnesota in the Cannon River Watershed (Figure 86). Dudley Lake is located upstream (east) of Kelly Lake, and the two lakes are connected by a small channel located on the southwest side of Dudley Lake. Kelly (~63 acres) and Dudley (~62 acres) are small lakes that are deep for the region (50 feet and 60 feet maximum depth, respectively). The DNR Level 9 drainage area boundary layer shows the Dudley Lake watershed is approximately 162 acres in size (226 acres including lake surface area). The Kelly Lake watershed, not including the area draining to Dudley Lake, is approximately 512 acres (576 including lake surface area). Both lakes are considered a headwater lakes meaning there are no major streams flowing to them and they receive their runoff from shoreline areas and fields surrounding the lakes. Dudley Lake has a very small watershed to lake area ratio (3.5 to 1) and long hydraulic residence time (5 years), which means the lake retains a significant amount of sediment, P, and other pollutants that are delivered to it. Kelly Lake has a larger watershed to lake area ratio (9 to 1) and shorter hydraulic residence time (0.7 years); therefore, flushes more often and generally retain less sediment and nutrients than Dudley. Kelly Lake outlets to a wetland on the southwest side of the lake which flows to French Lake. There is a DNR public access on the south side of Kelly Lake and the lake's shoreline is moderately developed with approximately 30 seasonal and permanent homes located around both lakes, all of which potentially have septic systems. At this time there are no active feedlots with registered animals located in the Kelly Lake or Dudley Lake drainage areas, however there may be small farms with livestock that are not required to register. Land cover throughout Kelly and Dudley lakes' 674-acre drainage area is a mixture of wetland (25%), forest and shrubland (23%), cropland (corn/soybean, 22%), hay/pasture (21%), and developed/residential (9%) (Source: 2019 National Landcover Dataset).

Figure 86. Kelly and Dudley lakes drainage area.



Water quality

Lake water quality is often evaluated using three associated parameters: TP, chl-*a*, and Secchi depth. P is typically considered the limiting nutrient in Minnesota lakes, meaning that algal growth will increase with increases in TP. Chl-*a* is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Secchi depth is a physical measurement of water transparency. Increasing Secchi depths indicate less turbidity in the water column and increasing water quality. Conversely, rising TP and chl-*a* concentrations point to decreasing water quality and thus decreased water transparency. Measurements of these three parameters are interrelated and can be combined into an index that describes water quality.

Historic and existing water quality conditions for Kelly and Dudley lakes are described using data downloaded from the MPCA's EQuIS database and the University of Minnesota's Lake Browser. EQuIS stores data collected by the MPCA, partner agencies, grantees, and volunteers. All water quality sampling data utilized for assessments, modeling, and data analysis for this study and referenced reports are stored in this database and are accessible through the MPCA's Environmental Data Access (EDA) website. The University of Minnesota's Lake Browser provides satellite derived water quality data for over 10,000 Minnesota lakes. Data are created using an automated image processing system developed with resources from the University of Minnesota and the Environment and Natural Resources Trust Fund — Legislative and Citizens Commission on Minnesota Resources. The automated image processing system processes satellite data from Landsat 8 and Sentinel 2 and provides daily and monthly (May through October) lake clarity (i.e., Secchi depth), chl-*a*, and CDOM data for 2017 through 2021 (Page et al. 2019).

Water quality for Kelly and Dudley lakes has been evaluated against Minnesota's lake eutrophication standards for class 2B lakes in the NCHF ecoregion. Minnesota State statute defines various categories of lakes for assessment purposes, including lake, reservoir, shallow lake, and wetland (Minn. R. ch. 7050.0150). The determination between the four categories requires an analysis of basin depth, littoral area, and other characteristics in Appendix D of the *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment* (MPCA 2022a). Kelly and Dudley lakes, due to their depth and morphology, have historically been assessed by MPCA as a lake/reservoir during the water quality assessment process. Table 48 shows the current lake eutrophication water quality standards for lakes/reservoirs in the NCHF ecoregion.

Table 48. Lake eutrophication standards for class 2B lakes and reservoirs in the NCHF ecoregion.

Parameter	NCHF lakes and reservoirs
Total phosphorus (µg/L)	≤ 40
Chlorophyll-a (µg/L)	≤ 14
Secchi transparency (m)	≥ 1.4

Since 1990, Kelly and Dudley lakes have had only six years with three or more TP and chl-*a* measurements available in EQuIS during the summer growing season (i.e., June through September) and therefore lack a consistent record for these parameters. Secchi depth measurements for Kelly (collected 16 years since 1990) and Dudley (collected 19 years since 1990) lakes have more complete records due to volunteer monitoring efforts. University of Minnesota Lake Browser chl-*a* measurements are available for both lakes from 2017–2021 and were combined with the field samples available in EQuIS for the analyses presented in this report.

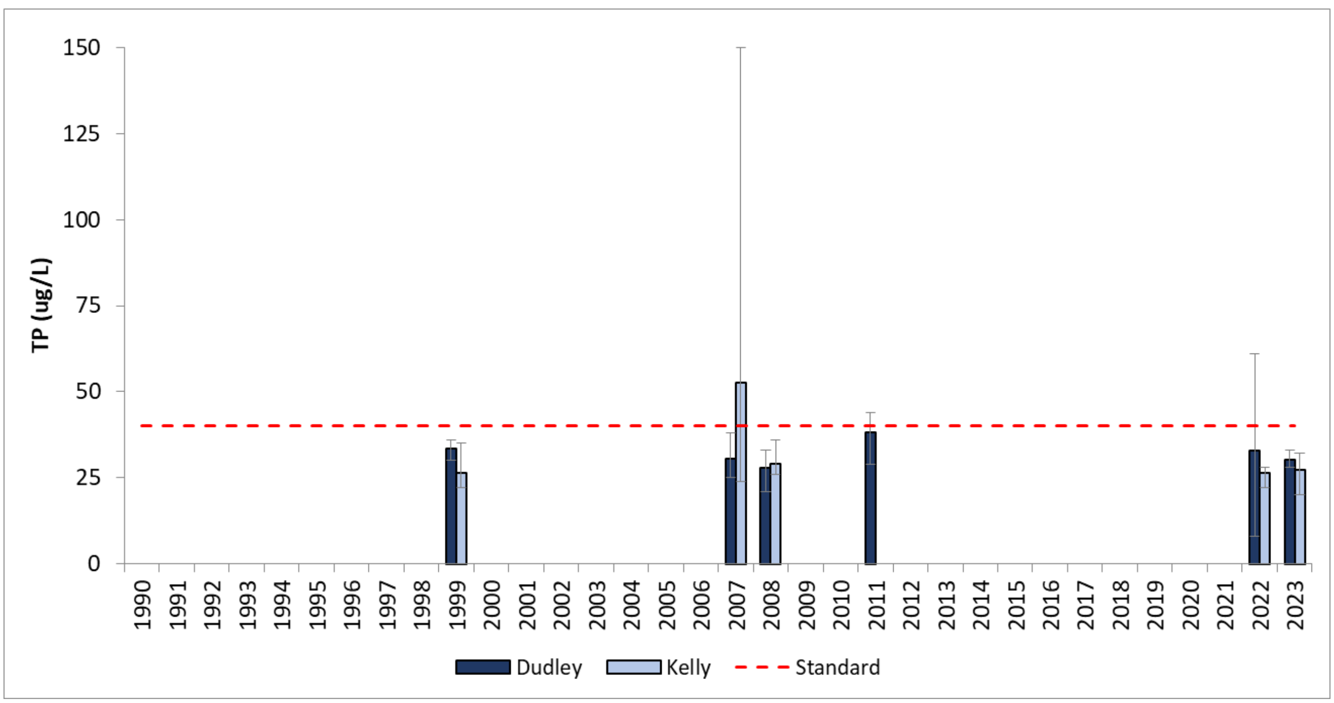
Minnesota Lake Browser Secchi depth measurements were not used in this report due to several high values that were outside the range of observed measurements reported in EQuIS.

Results of the historic TP, chl-*a*, and Secchi depth data for Kelly and Dudley lakes are shown in Figure 87 through Figure 89. TP data for Kelly and Dudley lakes indicate mean summer growing season concentrations have been below the 40 µg/L NCHF lake most years since 1990. Figure 87 shows mean summer TP concentrations have consistently remained around 30 µg/L in both lakes throughout the entire monitoring period. Kelly and Dudley lakes' chl-*a* measurements have also generally remained below the 14 µg/L NCHF lake standard since 1990; however, there are a few years in which the standard was exceeded in both lakes. Mean summer chl-*a* concentrations in both lakes are closer to the standard compared to TP indicating occasional nuisance algae blooms do occur. Mean summer Secchi depths for Kelly and Dudley lakes have consistently met the 1.4 meter NCHF lake standard since 1990. Secchi depth may have shown a slight declining trend from 2004 to 2019 but improved during the most recent sampling in 2022. Continued Secchi depth monitoring is recommended in both lakes to track trends and changes in the future.

Table 49. Summary of Dudley and Kelly lakes mean summer water quality compared to state standards.

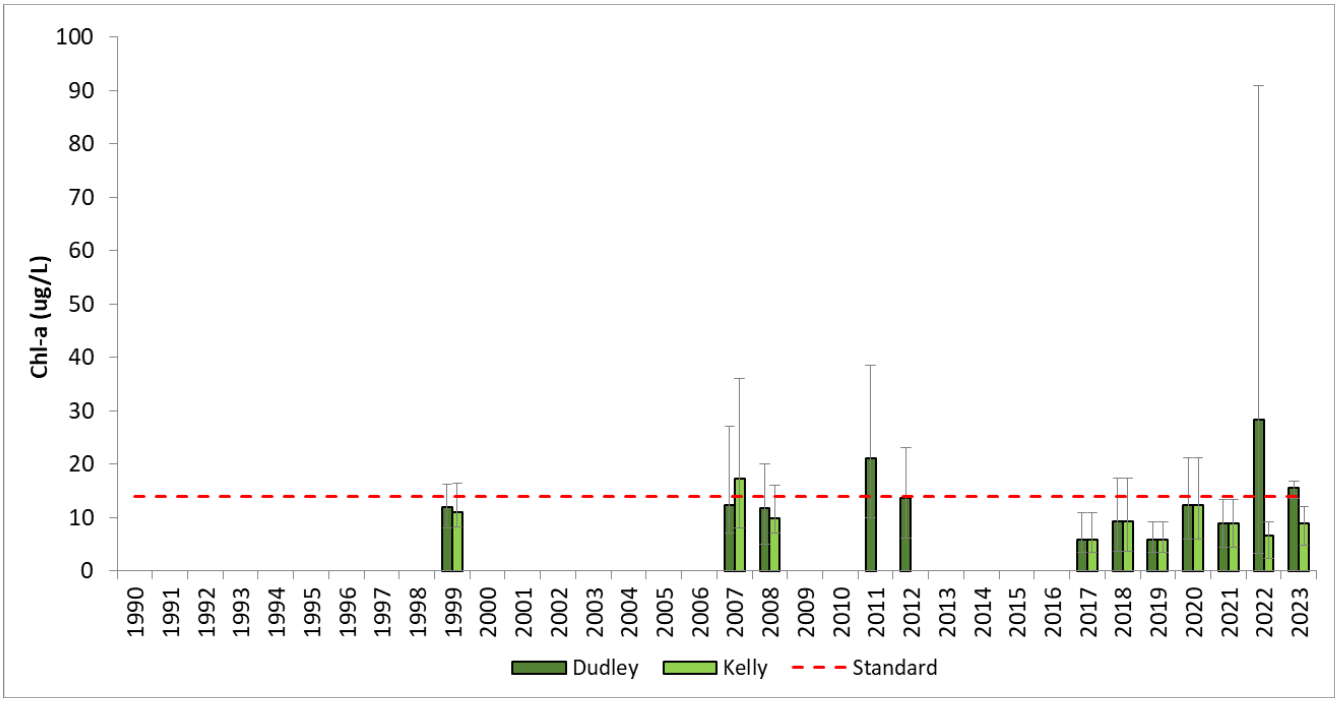
	TP (µg/L)			Chl-*a* (µg/L)			Secchi (m)		
Lake	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**
Dudley (1990 - 2023)	32	38	28	13	28	6	2.1	2.7	1.5
Kelly (1990 - 2023)	32	53	27	10	17	6	2.1	2.5	1.6
NCHF lake standards	≤40			≤14			≥ 1.4		

Figure 87. Dudley and Kelly lakes summer growing season mean TP concentrations (solid bars) from 1990 through 2023 for years in which at least three samples were collected.



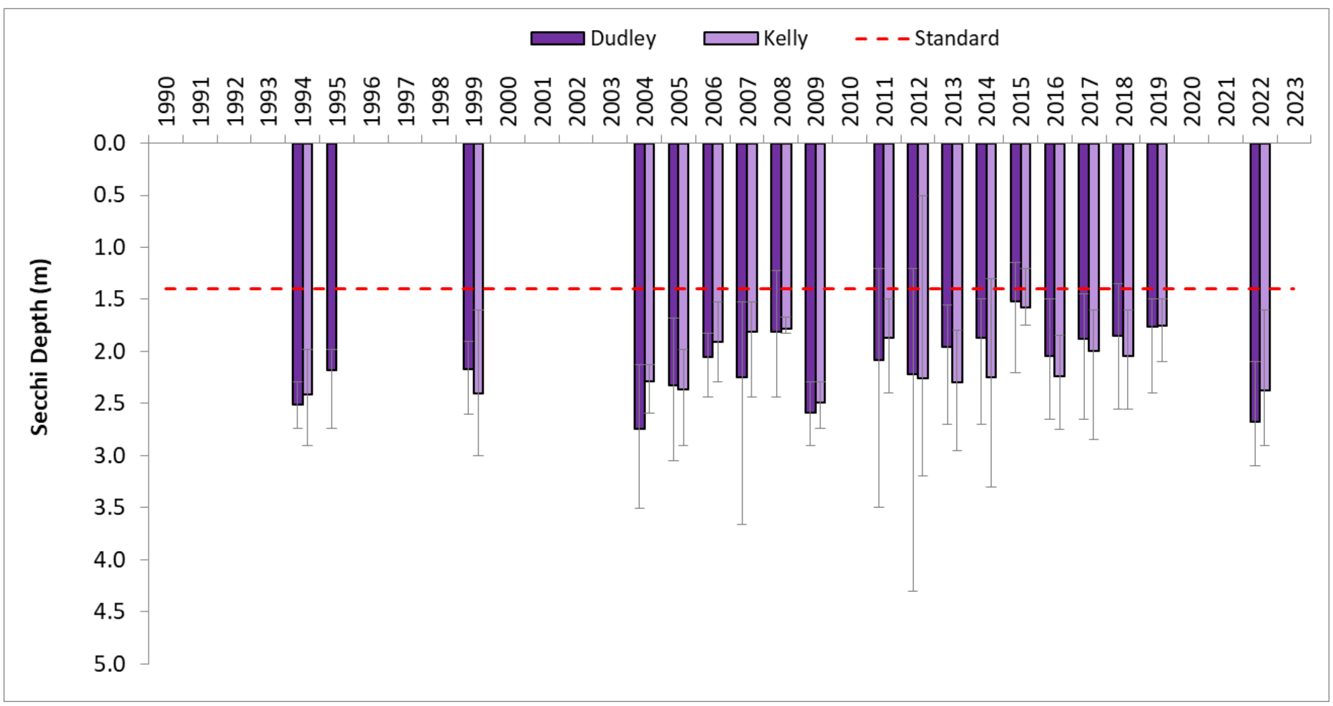
Error bars represent maximum and minimum summer growing season TP concentrations.

Figure 88. Dudley and Kelly lake summer growing season mean chl-*a* concentrations (solid bars) from 1990 through 2023 for years in which at least three samples were collected.



Error bars represent maximum and minimum summer growing season chl-*a* concentrations. Data includes discrete measurements from EQuIS (entire period) and satellite derived measurements from University of Minnesota Lake Browser (2017 through 2021).

Figure 89. Dudley and Kelly lake summer growing season mean Secchi depth (solid bars) from 1990 through 2023 for years in which at least three samples were collected.



Error bars represent maximum and minimum summer growing season Secchi depth measurements. Data only includes discrete measurements available in EQuIS.

Fisheries

Kelly and Dudley lakes are primarily managed by the DNR for bluegill, largemouth bass, and northern pike. Fish populations in Kelly and Dudley are self-sustaining, as stocking has not occurred since 1983. During the most recent DNR fisheries surveys in 2021, bluegill catch rates were between the median and upper normal range compared to similar lakes (DNR Lakefinder). Mean bluegill size was near the median compared to similar lakes suggesting the bluegill population is of high quality in terms of both size and numbers. Largemouth bass numbers were relatively low and mean size indicated slow growth rates. Bass are difficult to sample in Kelly and Dudley due to high water clarity and therefore only part of the population is likely represented. Kelly and Dudley lakes are generally known to be popular with bass anglers in this region. The 2021 catch rates for northern pike were near the upper normal range and average weight was near the median compared to similar lakes. In general, the pike population was dominated by small, slow growing fish and both lakes are included in the Southern Zone Northern Pike regulations. Anglers are limited to two northern pike daily which must be at least 24 inches in length. One species that is associated with poor water quality conditions, common carp was not sampled in 2021 and has not been sampled since the 1988 survey. Black bullhead, another species often linked to poor water quality, were sampled near the median range and average weight were near the lower normal range in 2021. Other species sampled in Kelly and Dudley lakes in 2021 include black crappie, bowfin (dogfish), brown bullhead, pumpkinseed sunfish, yellow bullhead, and yellow perch.

A common misconception is that if a lake supports a quality gamefish population (e.g., high abundance or desirable size structure of a popular gamefish species), it should be considered a healthy lake. This is not always the case because both game and nongame fish species must be considered when holistically evaluating fish community health. Oftentimes, the smaller nongame fishes serve ecologically important roles in aquatic ecosystems and are generally the most sensitive to human-induced stress. In order to better evaluate the entire fish community, the DNR uses a FIBI scoring system to assess lakes throughout the State of Minnesota. The FIBI assessments utilize fish community data collected from a combination of trap nets, gill nets, beach seines, and backpack electrofishing. From these data, an FIBI score can be calculated for a lake that provides a measure of overall fish community health based on species diversity and composition. If biological impairments are found, stressors to the fish community must be identified. More information about the sampling and assessment process can be found at the DNR Lake Biological Monitoring and Assessment website.

Kelly and Dudley Lakes were sampled and assessed in 2022 using the DNR's FIBI scoring system. Results of the FIBI assessment indicate the lakes (FIBI score = 44) scored above the FIBI impairment threshold established for similar lakes (FIBI threshold = 38); therefore, are supportive of AQL use and is not considered impaired for AQL at this time.

Vegetation

Submergent and emergent aquatic vegetation are critical to lakes, providing spawning and cover for fish, habitat for macroinvertebrates, refuge for prey, sediment and water column nutrient uptake, and stabilization of sediments. Declines in the abundance and diversity of aquatic vegetation can be an indication of a shifting biological community and water quality state. As disturbances increase, sensitive vegetation species are lost from the system and often replaced with less desirable species (e.g., aquatic invasive species) or no vegetation at all.

Kelly and Dudley lakes are rare for lakes in southern Minnesota because they are relatively clear and support a diverse and abundant aquatic vegetation community. At total of 22 submerged and floating plant species were sampled in a 2007 survey of Kelly and Dudley lakes performed by the DNR (DNR Lakefinder). Subsequent July point intercept surveys for Kelly Lake by DNR in 2014, 2016, and 2018 found a total of 9, 17, and 20 submerged and floating plant species, respectively. DNR surveys for Dudley Lake noted 9, 10, and 14 submerged and floating plant species in 2014, 2016, and 2018, respectively. Several emergent and shoreline plant species were also present in the littoral zone during these surveys, providing important habitat for fish and aquatic insects. Only one invasive species (AIS) has been noted during the vegetation surveys - CLP.

Lakeshore conditions

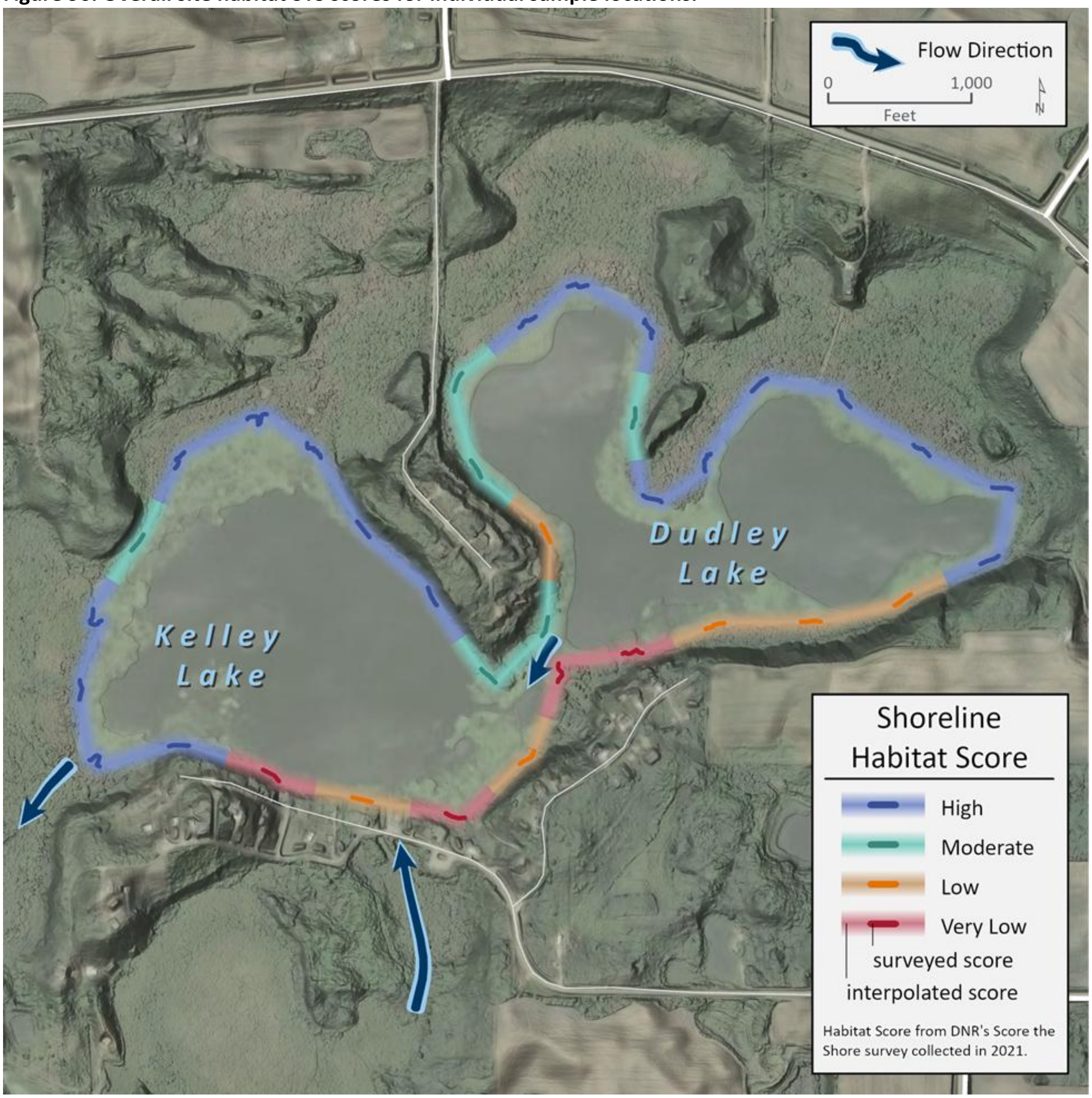
Lakeshore habitat assessments were conducted by the DNR in 2021. The primary tool used in the assessments was the DNR STS Rapid Assessment (DNR 2019a) which were performed by DNR staff. STS is a protocol developed to rapidly assess the quantity and integrity of lakeshore habitat. The survey is designed to assess differences in habitat between lakes and to detect changes over time. STS surveys require visual observation of lands accessible by boat. The intent of the survey is to assess habitat, not to inspect for violations. The STS assessments consist of surveying 100-foot sections of shoreline at predefined, equally spaced survey locations along the entire shoreline of the lake. Since only 100 feet of shoreline is surveyed per location, the full assessment covers a relatively small portion of the total shoreline and results are not tied to individual properties. During the surveys, three lakeshore zones (upland/shoreland, shoreline, and aquatic) are assessed independently at each survey location. Within each zone, surveyors score specific features related to habitat, which are then summed for an overall Zone Habitat Score. Higher scores indicate a greater amount of habitat. Lower scores indicate a low percent of the site remains natural and a higher amount has been physically disturbed or altered by humans. The feature scores within each zone are summed for an overall site habitat score. This scoring process provides a simple method of ranking sites based on the percent of each site that is in a natural condition versus the percent of the site that has been altered. A lakewide score is calculated using the mean site habitat score. Scores range from 0 to 100 and lakes with a high percentage of unaltered habitat score higher than lakes that have been highly altered. More information about the methods used for the STS surveys can be found in the Minnesota Lake Plant Survey Manual (DNR 2019a).

The combined DNR STS assessment results for Kelly and Dudley lakes are summarized in Table 50. Figure 90 illustrates the results of the overall habitat scores for the 35 STS survey locations. In this figure, the dark colored lines show the results of the individual surveyed locations (i.e., 100-foot survey sections). The lighter, thicker lines along the shoreline represent interpolated scores between the 100-foot surveyed sections. The overall score for Kelly and Dudley lakes (75) is considered moderate and exceeds the mean score of all surveyed lakes in the Cannon River Watershed (mean score = 70; N = 19). The overall score for Kelly and Dudley also exceeds the average score for lakes surveyed throughout the state of Minnesota (mean score = 74; N = 764). A moderate score indicates that the lake has a high percentage of unaltered habitat but at least one zone has lower habitat quality than a high scoring site. Residential development around the perimeter of Kelly and Dudley lakes is relatively limited, resulting in stretches of undisturbed shoreline and riparian zone. The majority of the shore is surrounded by a forested riparian zone with cattail marshes being present at the northern shores of the lake. It is estimated that Kelly and Dudley lakes have approximately 22 docks (~6.8 docks per mile of shoreline) based on review of 2023 Google imagery. Dock densities exceeding 16 docks per mile can significantly affect fish communities and habitat (Jacobson et al. 2016, Dustin 2017).

Table 50. DNR STS survey results for Kelly and Dudley lakes.

Category	Result
Dock density (#/mile)	6.8
Survey locations	35
Percent developed	51%
Shoreland zone score	22.8 moderate
Shoreline zone score	25.7 moderate
Aquatic zone score	26.7 moderate
TOTAL SCORE	75.1 moderate

Figure 90. Overall site habitat STS scores for individual sample locations.



Climate

The *Climate summary for watersheds: Cannon River* (DNR 2019b) report shows that annual average temperatures in the Cannon River Watershed have increased over the last 40 years and that most years during the past two decades have been warmer than average. Monthly average temperatures in the Cannon River Watershed peak in July, and winter temperatures on average have increased over time. Annual precipitation has also shown an upward trend across the watershed since around 1940. Monthly precipitation is typically highest in June and increases in precipitation in recent years were most pronounced in April through August. The frequency of 1-inch and 3-inch rain events has increased in general in Minnesota, along with the size of the heaviest rainfall of the year. Minnesota has also experienced an increase in devastating, large-area extreme rainstorms (DNR 2022). Climate projections indicate these big rains will continue increasing into the future (DNR 2022).

Statewide lake data collected by the DNR, MPCA, and local partners shows that the climate trends described above have already impacted lakes throughout the state and region. According to MPCA's Climate Change and Minnesota's Surface Waters Viewer, lake surface temperatures have warmed during all seasons throughout southern Minnesota. During the summer growing season (June through September), lakes in southern Minnesota are, on average, approximately 2.7˚F to 4.4˚F warmer now than they were 50 years ago. Additionally, warmer winters have resulted in about 9 less days of ice coverage on average for lakes throughout the region since the mid-1970s.

Reduced ice coverage, higher year-around water temperatures, and more intense and frequent precipitation events can result in significant impacts to lakes and lake users, including but not limited to (MPCA 2021):

- Overall increase in flow, sediment, and nutrient loading from the lake drainage area
- Longer periods of stratification and anoxia resulting in increased internal P recycling
- Longer open water and growing season for algae and cyanobacteria blooms
- Larger fluctuations in lake level from year to year
- Potential for increased densities of aquatic invasive plants, such as CLP and EWM
- Decreases in walleye (who prefer summer water temps at 65˚F to 70˚F) in smaller, warmer lakes
- Potential for more fish kills as fish are squeezed into smaller zones to access oxygen
- Shortened season for safely recreating on ice-covered lakes

Although long-term supporting data is limited, it is likely that Kelly and Dudley lakes have or are currently experiencing many of the climate impacts described above. These impacts create additional challenges to protect lake water quality and support healthy plant and fish communities. Adaptation strategies such as improving water management practices, enhancing soil health, planting conservation perennials, and natural shoreline buffers should be considered for Kelly and Dudley lakes to build resilience to these impacts and threats.

F.5.2 Lake phosphorus budgets and models

P budgets and eutrophication models (BATHTUB) were established for Kelly and Dudley lakes using methods similar to the lake TMDLs in the *Cannon River Watershed Total Maximum Daily Load Report* (MPCA 2016) and other lake TMDLs throughout the State. The four primary P sources considered for the lake models were loading from the lake's drainage area, septic systems, atmosphere, and internal recycling. Each of these sources, and how they were estimated, are discussed below in more detail.

Drainage area

Precipitation that falls within the drainage area of a lake flows across the land surface and/or through subsurface drain tiles, and a portion of it eventually reaches the lake. P is carried with the runoff water and delivered to the lake. The primary P sources in runoff in the Kelly and Dudley lakes drainage areas include soils, fertilizer, vegetation, wetlands, and impervious surfaces and lawns in residential areas surrounding the lakes.

Watershed runoff volumes and TP loads from the Kelly and Dudley lakes drainage areas were estimated using the Cannon River Watershed HSPF model (2019 version). HSPF is a comprehensive, mechanistic model of watershed hydrology and water quality that allows the integrated simulation of point sources, land and soil nutrient runoff and subsurface processes, and in-stream hydraulic and sediment-chemical interactions. Model documentation contains additional details about the Cannon River HSPF model development and calibration (LimnoTech 2015). The modeling period for the Cannon River HSPF model covers 1996 through 2019. In the model, the Kelly and Dudley lakes drainage areas are not explicitly modeled but are included in a larger reach/subwatershed within the model (HSPF Reach 326). Table 51 and Table 52 present the HSPF predicted mean annual flow and TP load by land cover type for HSPF Reach 326 that were used to represent each lake's drainage area. Based on these rates, approximately 35 lbs of TP is delivered to Dudley Lake each year from its drainage area with cropland (32%) and developed/residential (30%) being the largest loading sources to the lake. Kelly Lake's drainage area delivers approximately 146 lbs/year of TP with cropland (58%) representing a majority of the load.

Table 51. Model estimated flow volume and TP loading rates and annual totals for the Dudley Lake drainage area (modeled years = 2010 through 2019).

Land cover category	Area (acres)	Modeled flow rate (in/yr)	Modeled flow volume (acre-ft/yr)	Modeled TP load rate (lbs/acre/yr)	Modeled TP load (lbs/yr)
Cropland	17	15.6	23	0.65	11.3
Developed/residential	19	21.3	34	0.55	10.6
Wetland	44	7.9	29	0.06	2.6
Forest and shrubland	51	13.9	59	0.07	3.6
Hay/pasture	31	17.2	44	0.23	7.0
TOTAL	162	14.0	189	0.22	35.1

Table 52. Model estimated flow volume and TP loading rates and annual totals for the Kelly Lake drainage area (modeled years = 2010 through 2019).

Land cover category	Area (acres)	Modeled flow rate (in/yr)	Modeled flow volume (acre-ft/yr)	Modeled TP load rate (lbs/acre/yr)	Modeled TP load (lbs/yr)
Cropland	131	15.6	171	0.65	85.0
Developed/residential	38	21.2	67	0.53	20.2
Wetland	127	7.9	84	0.06	7.5
Forest and shrubland	102	14.1	120	0.07	7.6
Hay/pasture	114	17.2	163	0.23	25.7
TOTAL	512	14.2	605	0.29	146.0

Septic systems

Flow and TP loads from septic systems were estimated using methods similar to the *Lower Minnesota River Watershed TMDL* (MPCA 2020a). It is estimated that there are approximately 16 residences surrounding Kelly Lake and 14 residences surrounding Dudley Lake based on review of 2023 Google imagery. Assumptions were made regarding the number of people per household (~2.1), and the percent of homes that are occupied year around (50%) versus seasonally (50%). Estimated septic compliance rates (~50% compliant and ~50% failing or noncompliant) were assumed based on estimates supplied by the county (Rice SWCD personal communication). Septic system TP removal rates for compliant systems were assumed to be approximately 80%, while removal rates of 57% were assumed for failing systems (Barr Engineering 2004). Through this analysis it was estimated that compliant septic systems currently contribute approximately 5.1 and 4.5 lbs/year of TP to Kelly and Dudley lakes, respectively. Noncompliant systems contribute approximately 11.0 lbs/year TP to Kelly Lake and 9.6 lbs/year to Dudley Lake.

Atmosphere

P is bound to atmospheric particles that settle out of the atmosphere and are deposited directly onto surface water. P loading from atmospheric deposition to Kelly and Dudley lakes is estimated to be approximately 25 lbs/year/lake based on the average deposition rate across the Lower Mississippi River basin (0.38 lbs/acre-year; Barr Engineering 2007).

Upstream lakes

Dudley Lake is located upstream of Kelly Lake, and the two lakes are connected by a short, narrow channel that enters Kelly Lake on the west side of the lake. P loading from Dudley Lake to Kelly Lake was explicitly included in the BATHTUB model for Kelly Lake by multiplying Dudley Lake's outflow volume by its average summer growing season TP concentration. This resulted in an average TP load of approximately 17 lbs/year.

Internal phosphorus recycling

Internal P recycling, often referred to as "internal loading," is a common occurrence in eutrophic and hypereutrophic lakes throughout central and southern Minnesota. P contained in the sediment of lakes originates as an external P load that settles out of the water column to the lake bottom. Typically, a significant amount of the external load to Kelly and Dudley lakes is delivered during snow melt and spring and early summer runoff. During this time, low water temperatures and flushing limit the amount of algae growth and biological activity within the lake. As water temperatures increase in mid-summer (e.g., late June and July), lakes can become thermally stratified during quiescent periods and biological activity increases, which leads to higher rates of algae growth and bacterial decomposition. As this happens, DO is consumed by bacteria, and anoxic conditions (i.e., low DO) can develop at the sediment-water interface which leads to the release of P from the lake sediments. The P that is released from the sediments is in a soluble form that is readily available to algae for uptake. P that has accumulated near the sediment-water interface can be readily mixed into the surface waters during strong winds, storm events, and as stratification begins to weaken in the late summer and early fall. Internal P recycling is especially problematic in lakes during dry and hot summers, when lower flows provide less dilution for P loads recycled from lake bottom sediments. Further, algae growth rates and sediment decomposition rates are elevated during dry and hot summers due to higher water temperatures and longer hydraulic residence times (Walker 2011).

There is evidence from the available data for both Kelly and Dudley lakes that suggest internal P recycling occurs within each lake:

- Although temperature and DO profile data for both lakes are limited, surface TP and chl-*a* concentration spikes have been observed when thermal stratification starts to weaken and break down in late summer and early fall
- High TP concentrations up to 431 µg/L in Kelly Lake and up to 449 µg/L in Dudley Lake were observed in hypolimnion (i.e., depths greater than ~10 meters) samples collected during October 2022 as stratification was starting to break-down

At this time, there is not enough data available to explicitly quantify the amount of P that is typically recycled within Kelly and Dudley lakes each year. Since the lake maintains a stratified water column into October, it does not appear that a significant amount of the P that is released from the lake sediments during the summer mixes with surface waters until after the growing season index period (i.e., October or November). In order to better characterize internal recycling, additional data would need to be collected such as continuous or high-frequency temperature and DO profiles, hypolimnetic P samples, and/or sediment cores. Since internal P recycling reflects recycling of loads that originally entered the lake from the lake drainage area and atmosphere, the amount of P recycling is expected to vary with external load over time.

Common carp are another potential source of internal P recycling. When present in high densities, carp can exacerbate poor water quality in lakes by destroying/uprooting aquatic vegetation and resuspending/recycling TP from lake sediments. Studies have demonstrated how adult carp can increase turbidity, TSS, TP, and negatively affect macrophyte abundance through various direct and indirect processes (Parkos et al. 2003). Research suggests that negative impacts of common carp on turbidity and vegetation begin to occur at densities of around 89 lbs/acre (Bajer et al. 2009). To our knowledge, common carp density has not been assessed in Kelly and Dudley lakes. Although the gear used in the DNR trap and gill net surveys tend to underrepresent common carp abundance due to high net avoidance, these surveys can provide a relative means to track carp trends and changes over time within a lake and compare catch rates to other lakes. Based on our review of the DNR trap and gill net surveys, common carp catch rates for both lakes have remained well below the lower normal range of similar lakes since the 1980s. Negative impacts to lake habitat and water quality are likely negligible at these low levels but DNR catch rates should continue to be monitored.

CLP has also been hypothesized to contribute to internal P recycling and algae blooms in lakes after the plant dies back in midsummer. Although it can be found in a wide-range of environmental conditions, CLP is most common and abundant in alkaline (> 100 mg/L calcium carbonate alkalinity, $CaCO3$), P-rich lakes (TP between 50 – 100 µg/L; Bolduan et al. 1994) that are dominated by urban or agricultural land use in the southern half of the state (Heiskary and Valley 2012). Based on their review of sentinel lakes throughout the state with CLP infestations, Heiskary and Valley (2012) found that some shallow lakes exhibited mid-summer TP spikes around the time of CLP senescence, however it was difficult to determine how much of a role CLP plays compared to other internal and external sources.

Lake eutrophication model and final phosphorus budgets

A spreadsheet version of the lake model BATHTUB (Walker 1987) was established for both Kelly and Dudley lakes to model current lake water quality conditions. BATHTUB is a steady state model that predicts eutrophication response in lakes based on empirical formulas developed for nutrient balance calculations and algal response (Walker 1987). The model was developed by the U.S. Army Corps of Engineers and has been used extensively in Minnesota and across the Midwest for lake nutrient TMDLs. Several models (subroutines) are available for use within the BATHTUB model, and the Canfield-Bachmann model was used to predict P settling/retention and the lake response to TP loads in both lakes. The BATHTUB model requires flow and P loading inputs from the lake's drainage area, upstream lakes, and atmospheric deposition. Lake morphometric data are also required by the model.

Drainage area runoff volumes and P loading inputs to the Kelly and Dudley lakes BATHTUB models were derived from the HSPF model (Table 51 and Table 52). Flow and P loading from atmospheric deposition, septic systems, and upstream lakes using the methods described above were also added to each model. With the primary external sources defined, the model predicted in-lake P concentrations were compared to the 1990 through 2023 observed mean concentrations (Table 49). The model predicted in-lake TP concentrations were very close to the observed concentration and minimal adjustments were needed to match the monitored values.

The settling/retention model used in the BATHTUB models inherently includes an average amount of internal P recycling. In some cases, the amount of P recycled within a lake is greater than the amount inherent in the model and the modeler may choose to add additional load to improve model calibration. Alternatively, the Canfield-Bachman P sedimentation calibration factor can be adjusted to account for internal P recycling as recommended in the BATHTUB Version 6.1 Online Documentation (Walker 2006). Although there is evidence that P recycling occurs in Kelly and Dudley lakes, the BATHTUB models did not require an additional P load or significant adjustments to the P sedimentation calibration factor (Walker 2006). This suggests that internal recycling of P is not a major contributor to surface waters during most of the summer growing season and management of external sources is the most appropriate starting point to improve and protect in-lake water quality.

As shown in Table 53, loading from each lake's drainage area (47% for Dudley and 72% for Kelly) represents the largest source of P to each lake followed by atmospheric inputs (34% for Dudley; 12% for Kelly). Septic systems and upstream lakes (Kelly only) account for less than 10% of the load to each lake. Sedimentation/retention represents the largest sink of P for both lakes (77% for Dudley; 66% for Kelly) suggesting a significant amount of the annual load delivered to each lake is retained in the lake and its sediments.

Table 53. Current condition P budgets for Dudley and Kelly lakes (HSPF modeled years = 2010 through 2019).

	Dudley Lake		Kelly Lake	
Category	**Annual Load (lbs/yr)**	**Percent of Total**	**Annual Load (lbs/yr)**	**Percent of Total**
Sources (+)				
Drainage area	35	47%	146	72%
Upstream lakes	--	0%	17	8%
Atmosphere	25	34%	25	12%
Septic Systems	14	19%	16	8%
TOTAL	74		204	
Losses (-)				
Sedimentation/retention	57	77%	134	66%
Outflow	17	23%	70	34%
TOTAL	74		204	

F.5.3 Phosphorus targets and reductions

Establishing phosphorus goals to protect Kelly and Dudley lakes

The primary objective of this study is to protect water quality conditions in Kelly and Dudley lakes. Both lakes currently meet NCHF lake/reservoir standards for all three eutrophication parameters (Table 49). Therefore, an in-lake TP concentration target below the 40 µg/L standard and at or below the current mean TP concentrations (32 µg/L for both lakes) should be considered to protect future water quality conditions and minimize algae blooms. Here, we present two P reduction goals local partners could consider protecting Kelly and Dudley lakes water quality:

- Short-term goal – reduce TP loading to both lakes by 5%
- Long-term goal – reduce TP loading to both lakes by 10%

The DNR commonly uses a 5% P load reduction goal to protect lakes that comfortably meet state water quality standards such as Kelly and Dudley lakes. The 10% reduction goal should be viewed as a potential long-term goal after the 5% goal is achieved. The BATHTUB model and existing water quality data suggest that both goals may not lead to significant changes in algae levels or water clarity. Even if measurable improvements in chl-*a* or Secchi are not achieved, achieving these goals will help buffer the lake from future stressors such as changes in runoff patterns, temperature, and/or ecological shifts.

Load reduction goals

Table 54 presents the current TP load to both lakes, the TP target loads, and the load reductions required to achieve the target loads. Section 4 presents example strategies and BMP options to achieve the load reductions presented in Table 54.

Table 54. TP loads and reductions to meet in-lake water quality targets.

Lake	Phosphorus goal	Current TP (µg/L)	Current TP load (lbs/yr)	TP target load (lbs/yr)	TP load reduction (lbs/yr)	TP load reduction (percent)
Dudley	Short-term	32	71	67	4	5%
	Long-term			64	7	10%
Kelly	Short-term	32	200	190	10	5%
	Long-term			180	20	10%

F.5.3 Strategies to improve Kelly and Dudley lakes water quality and aquatic life

Example strategies were selected using a variety of sources, input from local stakeholders, and best professional judgement from MPCA staff. Example strategies presented in this section are intended to provide potential options to achieve the protection goals for Kelly and Dudley lakes. The strategies are not required, and implementation is considered voluntary. Stakeholders should use these example practices as a path to improve water quality, but it is anticipated that implementation may change as new information is learned and data is collected. It is recommended that stakeholders incorporate other known local issues or causes when implementing practices and strive to incorporate multiple benefits into projects.

Cropland best management practices

The MPCA developed a list of potential cropland BMP and land use change example scenarios that could be considered for Kelly and Dudley lakes to improve water quality. These scenarios include:

- Implement conservation till every year on all fields currently practicing conventional till and periodic conservation till
- Implement no-till on all fields currently practicing conventional till and periodic conservation till
- Implement cover
- crops on all cropland fields
- Convert 25% of cropland fields to grassland
- Convert 75% of cropland fields to grassland

P reductions for each BMP scenario described above were estimated using rates derived from the defaults in HSPF–SAM (version 2.0) and the Watershed Pollutant Load Reduction Calculator (MPCA 2022b). Table 55 presents the potential TP load reductions for each scenario. P reductions from the example scenarios range from 14 to 47 lbs/year and therefore, depending on the scenario selected and level of adoption, would achieve the reduction goals identified in Table 54.

Developed/residential BMPs

It is estimated that there are approximately 16 homes/residences surrounding Kelly Lake and 14 residences surrounding Dudley Lake. Residential areas account for approximately 7% and 12% of the land use in the Kelly and Dudley lakes drainage areas, respectively, and 14% (Kelly) and 30% (Dudley) of the estimated annual P load to each lake. Nearly all of the homes are on shoreline lots or in close proximity to the lakes. Based on investigation of air photos, most of the residential lots surrounding Kelly and Dudley lakes have about one-third acre of impervious surfaces (i.e., rooftops, driveways, walkways, roads). Due to their close proximity to the lakes, these impervious surfaces have high potential for stormwater to be delivered to Kelly and Dudley lakes via surface runoff, drain tile, and/or shallow groundwater pathways.

A rain garden is one of the most efficient residential stormwater BMPs used to intercept runoff from impervious surfaces and remove pollutants before they enter surface waters. Below are three rain garden BMP example scenarios to reduce P loading from residential areas throughout the Kelly and Dudley lakes drainage areas.

- Low adoption scenario – 10% of residences install and maintain a rain gardens to treat impervious areas (assumes 0.3 acres of impervious area is treated by rain garden)
- Moderate adoption scenario – 25% of residences install and maintain rain gardens
- High adoption scenario – 50% of residences install and maintain rain gardens

P reductions from rain gardens were estimated using default rates provided in the MPCA SE model. Table 55 presents the potential TP load reductions for each scenario. Total reductions for both lakes range from 0.6 lbs/year for the low adoption scenario to 2.3 lbs/year for the high adoption scenario. Although the total load reductions for the raingarden scenarios are less than the cropland BMP scenarios, raingarden TP reduction efficiency is higher than many of the cropland BMPs listed in Table 55.

Lakeshore BMPs

Shoreline development surrounding Kelly and Dudley lakes is moderate at this time but has the potential to impact both riparian vegetation and native floating-leaf and emergent plant stands that serve as important habitat for fish and other organisms. Further, replacement of riparian vegetation with riprap and open lawns can result in increased nutrient inputs from fertilizer and lawn clippings, reduced buffering capacity, destabilized shoreline, and elimination of future contributions of coarse woody habitat into the lakes.

Shoreland owners can significantly improve shoreline habitat by choosing to reestablish or maintain native plants along their property. Natural shorelines provide overhead cover to fish and wildlife species, contribute important coarse woody habitat into the lake, and provide a buffer for nutrient runoff from lawns and impervious surfaces. While shoreline restoration projects vary in scope and size, all can be completed in ways that are visually appealing and that maintain a view of the lake. Once completed, these projects have potential to provide many ecosystem benefits that a more traditional developed shoreline (e.g., riprap, mowed lawn, and sand beach) could not offer. The DNR maintains an interactive Restore Your Shore webpage that provides guidance for shoreland owners and professionals to use in implementing shoreland restoration projects. Protection and restoration of floating-leaf and emergent aquatic vegetation should also be prioritized, especially where aquatic habitat is limited. Shoreland owners should be aware of and adhere to current laws that regulate shoreline and aquatic plant control, riprap, sand blanket, and retaining wall installation, and other shoreline alterations.

The DNR estimates that a developed shoreline with turf grass to the water's edge allows seven to nine times more P to enter the lake than a naturally vegetated shoreline (Radomski and Van Assche 2014). While the amount of P entering the lake from shoreline lots varies due to soil, slope, and other site-specific conditions, the average pollution from 100 feet of nonbuffered shoreline has been estimated at 0.2 lbs/summer of TP compared to 0.03 lbs/summer for a lot with a native vegetated shoreline buffer. Based on air photo interpretation and results of the Kelly and Dudley lakes DNR STS survey (Table 50 and Figure 90), there is approximately 300 feet of shoreline along Dudley Lake and 500 feet of shoreline along Kelly Lake that could benefit from native shoreline buffers. Implementation of native buffers in these areas would result in TP reductions for both lakes of approximately 1.4 lbs/year and provide several ecosystem benefits as described above and in Table 55. Since shoreline for both lakes is moderate at this time, protecting and maintaining the lake's high-quality shoreline and habitat features will be a key protection strategy for these lakes.

Septic system improvements

It is estimated that about 50% of the septic systems (~8 systems for Kelly and ~7 systems for Dudley) in the drainage area for both lakes are noncompliant at this time (Rice SWCD personal communication). If these systems were brought into compliance, TP loading to both lakes would be reduced by approximately 11 lbs/year (Table 55).

Internal phosphorus recycling

As discussed in Section 2, net effects of internal P recycling were not explicitly estimated for this study. Although there is evidence that internal P recycling occurs within Kelly and Dudley lakes, it is assumed that the rate of recycling will decrease as the lake and sediments equilibrate to lower external P loads. Strategies to reduce internal recycling could be considered if water quality conditions in Kelly and Dudley lakes degrade in the future and/or if BMP efforts to reduce external loads fall short of the targets and goals set by the local partners. Internal recycling strategies could include, but are not limited to, water level drawdown, sediment dredging, sediment P immobilization or chemical treatment (e.g., alum and Phoslock®). The MPCA recommends feasibility studies for any lake in which major in-lake management strategies are proposed. The *Minnesota State and Regional Government Review of Internal Phosphorus Load Control* paper (MPCA 2020b) provides more information on internal load BMPs and considerations.

At this time, common carp do not appear to be significant contributor to P recycling in Kelly and Dudley lakes (see Sections 1 and 2). However, efforts to limit and prevent the migration and movement of common carp from upstream/downstream water bodies could be considered as a protection strategy to prevent this threat from becoming a problem in the future. It is recommended that local partners work closely with DNR if they are interested in pursuing carp management in these lakes.

As discussed in Section 2, the relationship between CLP and water quality varies substantially among lakes and clearly defining “cause and affect” can be difficult. Heiskary and Valley (2012) found little evidence supporting CLP as a driver of lake water quality conditions in Minnesota. While there are some case studies in Minnesota and Wisconsin that suggest CLP can have negative impacts on summer water quality (James et al. 2002, Welling 2010), pilot studies and published research actually demonstrate negative effects of large-scale removal of CLP on summer water quality in eutrophic lakes (Valley et al. 2006, Welling 2010). These studies concluded that a sole focus on killing CLP in lakes, especially where the plant is abundant, may carry more risks of harmful effects to water quality and fish habitat than leaving the plant unmanaged. Thus, local partners should not expect water quality enhancements by focusing exclusively on treating CLP without simultaneous, long-term measures to reduce internal and external P loads.

Table 55. Kelly and Dudley lakes BMP example scenarios and associated TP load reductions and other benefits.

Strategy type	BMP	BMP example scenario	Current level of adoption	BMP TP reduction rate/efficiency	TP load reduction (lbs/yr)	Other water quality and habitat benefits
Cropland BMPs	Conservation till	Conservation till on all cropland fields currently practicing conventional till (17 ac Dudley; 131 ac Kelly)	none	0.11 lbs/ac/yr[a]	2 (Dudley); 14 (Kelly)	sediment (reduction = 40 lbs/ac/yr[a]), nitrogen (reduction = 1.20 lbs/ac/yr[a]), improved soil health
	No till	No-till on all cropland fields practicing conventional till (17 ac Dudley; 131 ac Kelly)	none	0.22 lbs/ac/yr[a]	4 (Dudley); 29 (Kelly)	sediment (reduction = 80 lbs/ac/yr[a]), nitrogen (reduction = 2.88 lbs/ac/yr[a]), improved soil health
	Cover crops	Cover crops on all cropland fields (17 ac Dudley; 131 ac Kelly)	none	0.09 lbs/ac/yr[a]	2 (Dudley); 12 (Kelly)	sediment (reduction = 80 lbs/ac/yr[a]), nitrogen (reduction = 5.32 lbs/ac/yr[a]), improved soil health
	Cropland to grassland	Convert 25% of cropland fields to grassland (4 ac Dudley; 33 ac Kelly)	none	0.42 lbs/ac/yr[b]	2 (Dudley); 14 (Kelly)	sediment (reduction = 100 lbs/ac/yr[a]), nitrogen (reduction = 17.63 lbs/ac/yr[a])
		Convert 75% of cropland fields to grassland (13 ac Dudley; 98 ac Kelly)	none	0.42 lbs/ac/yr[b]	6 (Dudley); 41 (Kelly)	
Developed/ Residential BMPs	Rain gardens	Low adoption: 10% of residences (2 Dudley; 2 Kelly) install raingarden to treat 0.3 acres per residence	unknown	0.50 lbs/ac/yr[c]	0.3 (Dudley); 0.3 (Kelly)	sediment (reduction = 123 lbs/ac/yr[c]), water retention, groundwater recharge
		Moderate adoption: 25% of residences (4 Dudley; 4 Kelly) install raingardens to treat 0.3 acres per residence	unknown	0.50 lbs/ac/yr[c]	0.6 (Dudley); 0.6 (Kelly)	
		High adoption: 50% of residences (7 Dudley; 8 Kelly) install raingardens to treat 0.3 acres per residence	unknown	0.50 lbs/ac/yr[c]	1.1 (Dudley); 1.2 (Kelly)	

Strategy type	BMP	BMP example scenario	Current level of adoption	BMP TP reduction rate/efficiency	TP load reduction (lbs/yr)	Other water quality and habitat benefits
Shoreline BMPs	Native shoreline buffers	Implement native shoreline buffers on 300 (Dudley) and 500 feet (Kelly) of developed, nonbuffered shoreline	unknown	0.17 lbs/100-ft of shoreline[d]	0.5 (Dudley); 0.9 (Kelly)	filtering of sediment and other pollutants, reduced erosion, shoreline stabilization, habitat for insects, fish, birds, amphibians, decreased maintenance cost
Septic system improvements	Septic system upgrade	Upgrade all failing septic systems in watershed (~7 systems Dudley; ~8 systems Kelly)	50% currently compliant	0.74 lbs/system/yr[e]	5.1 (Dudley); 5.9 (Kelly)	nitrogen and fecal coliform reductions (not quantified)

[a] Source: Watershed Pollutant Load Reduction Calculator (MPCA 2022b)

[b] Source: Le Sueur River HSPF–SAM (version 2.0)

[c] Source: MPCA Simple Estimator model

[d] Source: Radomski and Van Assche 2014

[e] Source: MPCA 2020a and Barr Engineering 2004

F.5.4 Summary and future monitoring and analyses

This study identifies two water quality protection goals for Kelly and Dudley lakes that local partners can use to help guide protection efforts. The short-term goal is intended to reduce P loading to each lake by 5% per year (Table 54). The short-term goal could be achieved through low to moderate level of adoption of the BMP scenarios identified in Section 4 and Table 55. The long-term goal, which calls for P load reductions of 10% to each lake (Table 54), could be met through moderate to high level adoption of the BMP scenarios presented in Section 4. Implementation of cropland BMPs such as conservation till, no-till, and cover crops will be critical to meet both of the protection goals presented in this study. Septic system upgrades and rain gardens on residential properties surrounding both lakes should also be targeted as these are pollutant sources with direct pathways to the lake. Finally, although these lakes currently have moderate levels of shoreline development, ensuring native shoreline buffers remain in place will be an important strategy to protect fish and the lake's high-quality fish habitat.

The following list of monitoring activities and analyses would be beneficial over the course of the implementation period. These items will help refine and update the watershed and lake models, assist in prioritizing and targeting BMPs, and track response to BMPs as they are implemented using an adaptive management approach.

- Collect surface water quality samples (i.e., TP, chl-*a*, Secchi depth) at least one time per month from April/May through October. Although the lake standards require June through September sampling, spring and fall data would be beneficial to better understand nutrient dynamics and eutrophication response over the entire open water season.
- Consider adding TN (i.e., TKN and nitrate/nitrite) to the list of surface water monitoring parameters to investigate if/how N may be affecting eutrophication and biological communities.
- Continue monitoring nonnative species (e.g., common carp, CLP, EWM) where they are present to ensure they do not reach densities that could substantially alter water quality and physical habitat in the future.
- Continue mapping and surveying native submerged and emergent vegetation communities to document baseline conditions and track changes as management and protection efforts occur.
- Encourage individual lakeshore residents and lake association members to participate in the Lake Steward – Minnesota Lakes & Rivers Advocates and the Score Your Shore Survey to educate about sustainable land management, self-assess habitat conditions along their shorelines, and identify potential improvements.
- Utilize lidar-based terrain analysis products (e.g., PTMApp) to identify and target locations (both cropland and residential) with higher rates of soil loss and sediment delivery throughout the Kelly and Dudley lakes drainage areas.
- Periodically update the watershed model, lake model, and other models and tools as new data is collected and BMPs are implemented.

F.6 Roemhildts Lake Water Quality Improvement Study

Roemhildts Lake (40-0039-00) is located in southern Le Sueur County in the Upper Cannon River Subwatershed of the greater Cannon River Watershed. Recent water quality monitoring efforts for Roemhildts Lake suggest the lake currently meets water quality standards for AQR and therefore the lake has not been placed on the State of Minnesota's 303(d) list of impaired waters. The Cannon River Watershed local partner team has identified Roemhildts Lake as a high priority lake for water quality protection in their 1W1P comprehensive watershed management plan (EOR 2020) and other planning documents. The local partner team requested that a water quality study be completed for Roemhildts Lake as part of the WRAPS Update for MPCA's Cycle 2 work for the Cannon River Watershed. This technical memorandum presents the results of this work which includes the following components:

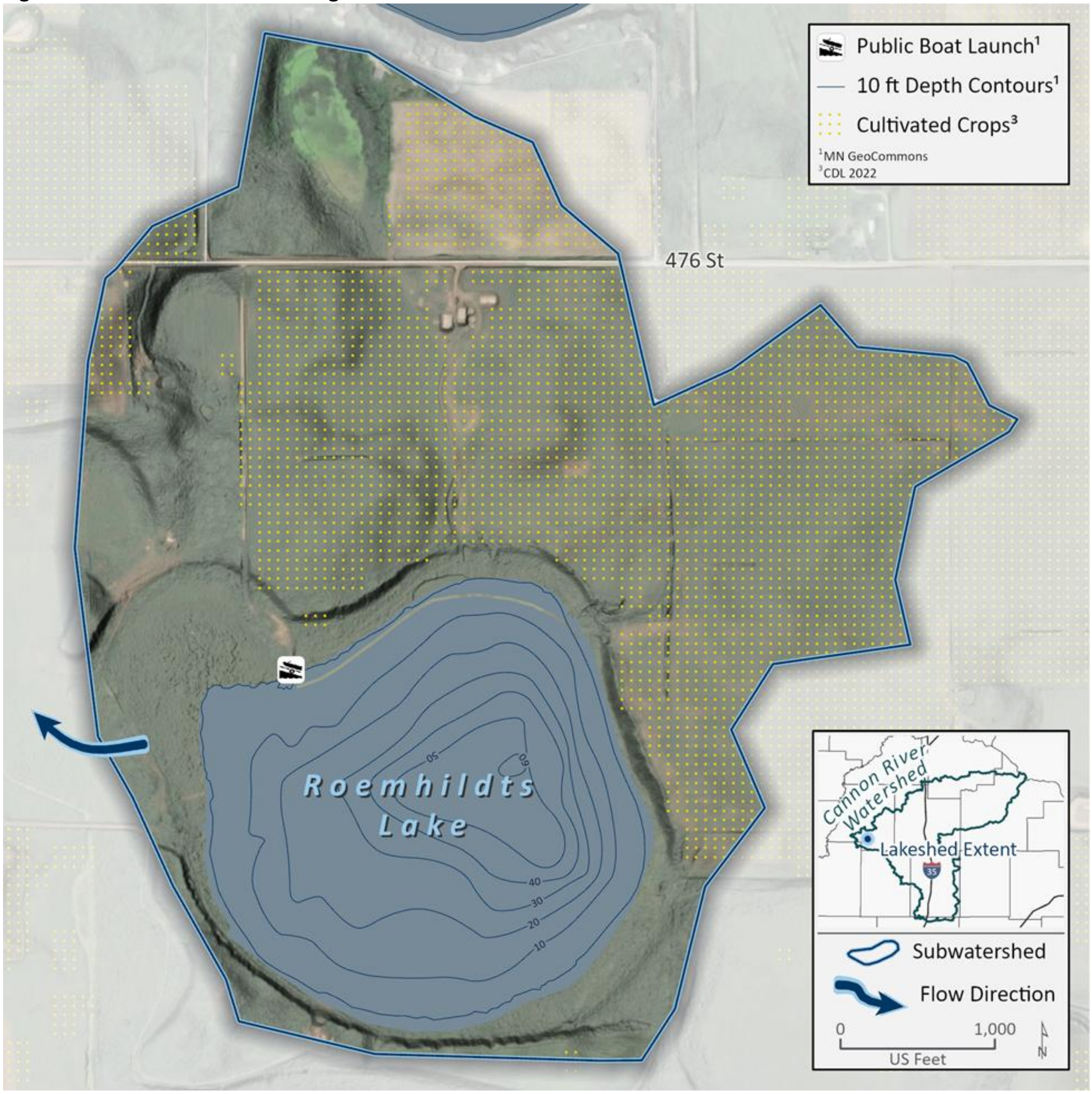
- Review of background information and data (Section F.6.1)
- Development of a lake P budget and water quality model (Section F.6.2)
- Establishment of in-lake P targets and load reductions to improve water quality (Section F.6.3)
- Potential strategies to achieve P targets and load reductions (Section F.6.4)
- Summary and considerations for future monitoring, assessments, and analyses (Section F.6.5)

F.6.1 Background information and data

Lake and watershed characteristics

Roemhildts Lake is a relatively small (~71 acres) deep lake (60 feet max depth and 21 feet average depth) located approximately 7.5 miles northwest of Waterville, Minnesota in the Cannon River Watershed (Figure 91). The DNR Level 9 drainage area boundary layer shows the Roemhildts Lake watershed is approximately 221 acres in size (292 acres including lake surface areas). Roemhildts Lake is considered a headwater lake meaning there are no major streams or upstream lakes flowing to it and it receives runoff from shoreline areas and fields surrounding the lake. Roemhildts Lake has a small watershed to lake area ratio (4 to 1) and an estimated hydraulic residence time of approximately 10 years which means the lake retains a significant amount of sediment, P, and other pollutants that enter the lake. Roemhildts Lake outlets to a wetland on the west side of the lake which then outlets to an unnamed ditch that flows to County Ditch 9 and eventually German Lake. There is a DNR public access on the north side of Roemhildts Lake and most of the lake's shoreline is undeveloped with only a few private residences surrounding the lake. At this time there one active feedlot with 240 registered animals (swine) located in the Roemhildts Lake drainage area. Land cover throughout Roemhildts Lake's 221-acre drainage area is primarily cropland (corn/soybean, 56%), followed by forest and shrubland (23%), wetland (8%), hay/pasture (7%), and developed/residential (6%) (Source: 2019 National Landcover Dataset).

Figure 91. Roemhildts Lake drainage area.



Water quality

Lake water quality is often evaluated using three associated parameters: TP, chl-*a*, and Secchi depth. P is typically considered the limiting nutrient in Minnesota lakes, meaning that algal growth will increase with increases in TP. Chl-*a* is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Secchi depth is a physical measurement of water transparency. Increasing Secchi depths indicate less turbidity in the water column and increasing water quality. Conversely, rising TP and chl-*a* concentrations point to decreasing water quality and thus decreased water transparency. Measurements of these three parameters are interrelated and can be combined into an index that describes water quality.

Historic and existing water quality conditions for Roemhildts Lake are described using data downloaded from the MPCA's EQuIS database and the University of Minnesota's Lake Browser. EQuIS stores data collected by the MPCA, partner agencies, grantees, and volunteers. All water quality sampling data utilized for assessments, modeling, and data analysis for this study and referenced reports are stored in this database and are accessible through the MPCA's Environmental Data Access (EDA) website. The University of Minnesota's Lake Browser provides satellite derived water quality data for over 10,000 Minnesota lakes. Data are created using an automated image processing system developed with resources from the University of Minnesota and the Environment and Natural Resources Trust Fund — Legislative and Citizens Commission on Minnesota Resources. The automated image processing system processes satellite data from Landsat 8 and Sentinel 2 and provides daily and monthly (May through October) lake clarity (i.e., Secchi depth), chl-*a*, and CDOM data for 2017 through 2021 (Page et al. 2019).

Water quality for Roemhildts Lake has been evaluated against Minnesota's lake eutrophication standards for class 2B lakes in the NCHF ecoregion. Minnesota State statute defines various categories of lakes for assessment purposes, including lake, reservoir, shallow lake, and wetland (Minn. R. ch. 7050.0150). The determination between the four categories requires an analysis of basin depth, littoral area, and other characteristics in Appendix D of the *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment* (MPCA 2022a). Roemhildts Lake, due to its depth and morphology, has historically been assessed by MPCA as a lake/reservoir during the water quality assessment process. Table 56 shows the current lake eutrophication water quality standards for lakes/reservoirs in the NCHF ecoregion.

Table 56. Lake eutrophication standards for class 2B lakes and reservoirs in the NCHF ecoregion.

Parameter	NCHF lakes and reservoirs
Total phosphorus (µg/L)	≤ 40
Chlorophyll-a (µg/L)	≤ 14
Secchi transparency (m)	≥ 1.4

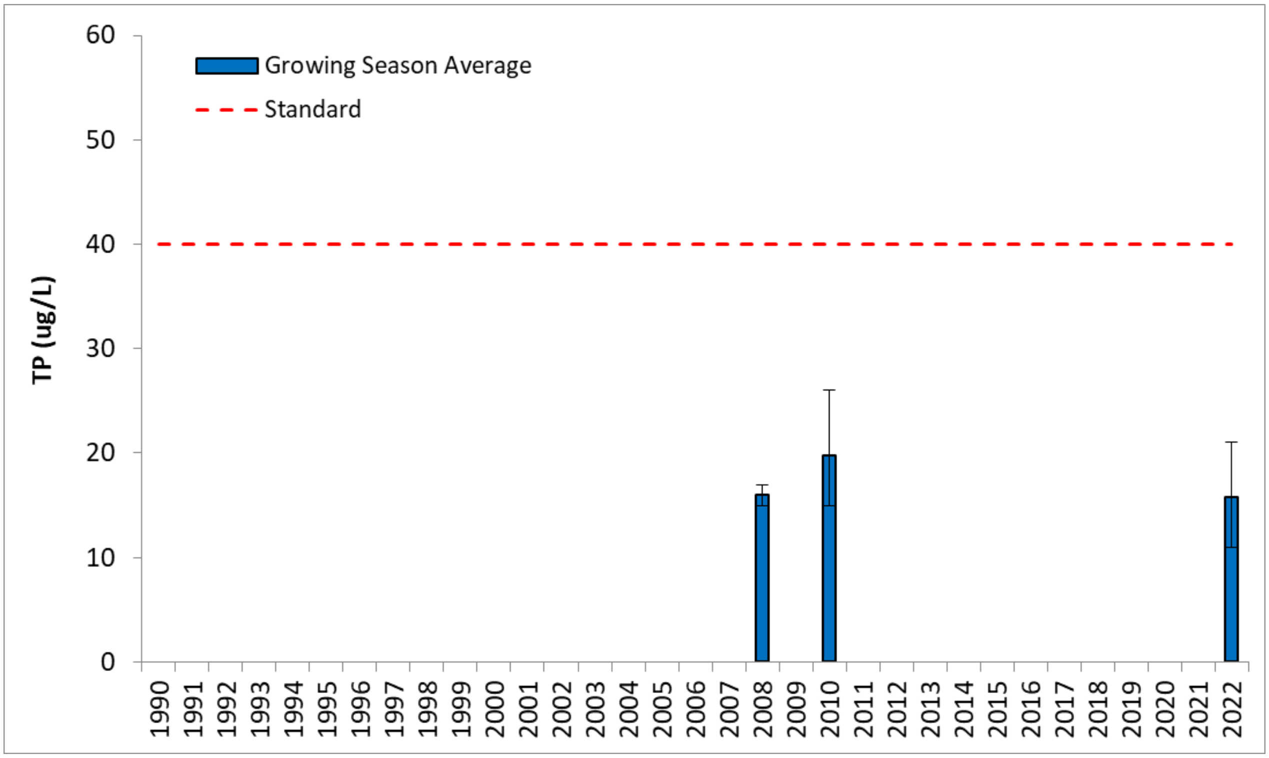
The earliest water quality data available for Roemhildts Lake in EQuIS are from the 2008. Since 2008, Roemhildts Lake has had only three years with three or more TP, chl-*a*, and Secchi measurements available in EQuIS during the summer growing season (i.e., June through September) and therefore lacks a consistent record for these parameters. University of Minnesota Lake Browser chl-*a* measurements are available for Roemhildts Lake from 2017–2021 and were combined with the field samples available in EQuIS for the analyses presented in this report. Minnesota Lake Browser Secchi depth measurements were not used in this report due to several high values that were outside the range of observed measurements reported in EQuIS.

Results of the historic TP, chl-*a*, and Secchi depth data for Roemhildts Lake are summarized in Table 57 and illustrated in Figure 92 through Figure 94. TP data indicate mean summer growing season concentrations have remained below the 40 µg/L NCHF lake/reservoir standard since sampling began in 2008. Roemhildts Lake summer chl-*a* concentrations have remained below the 14 µg/L NCHF lake/reservoir standard over the last 15 years. Mean summer Secchi depths have also consistently met the 1.4 meter standard since monitoring began in 2008.

Table 57. Summary of Roemhildts Lake mean summer water quality compared to state standards.

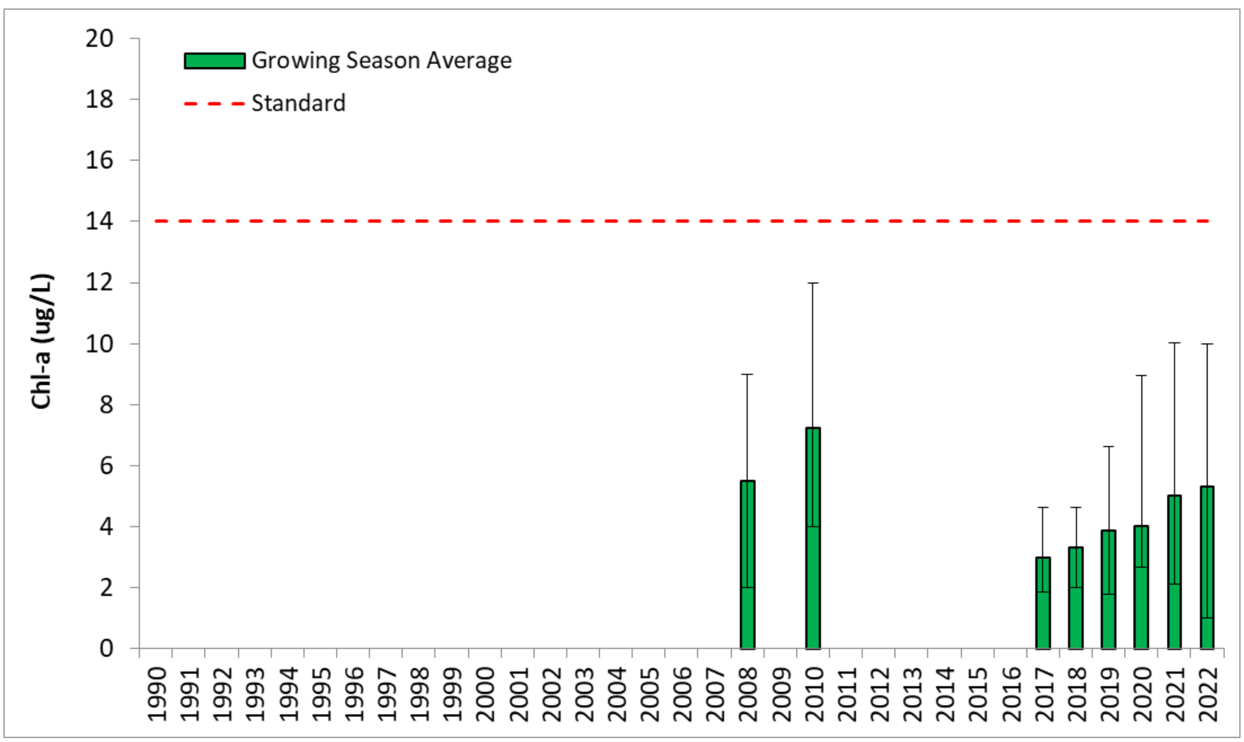
	TP (µg/L)			Chl-*a* (µg/L)			Secchi (m)		
Time period	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
Entire record (2008-2022)	17	20	16	5	7	3	3.1	3.1	3.0
NCHF lake standards	≤40			≤14			≥ 1.4		

Figure 92. Roemhildts Lake summer growing season mean TP concentrations (solid bars) from 1990 through 2022 for years in which at least three samples were collected.



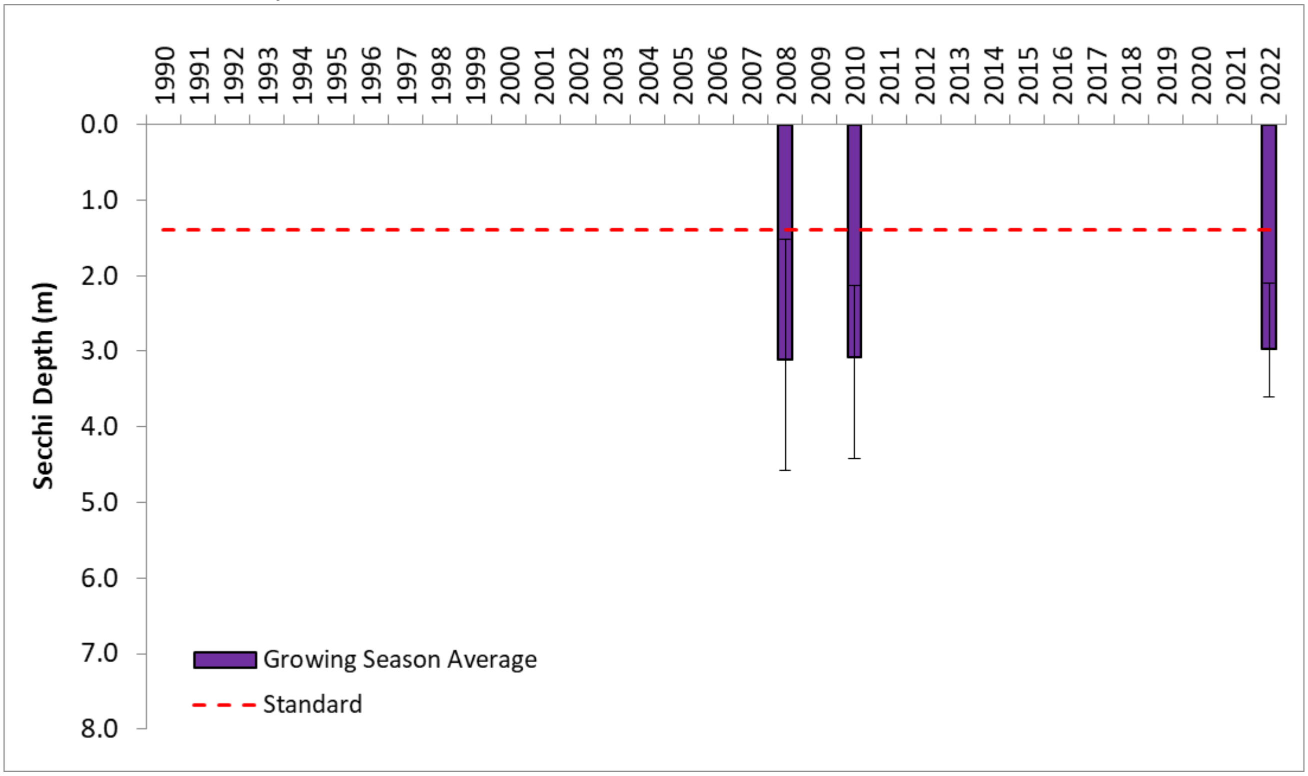
Error bars represent maximum and minimum summer growing season TP concentrations.

Figure 93. Roemhildts Lake summer growing season mean chl-*a* concentrations (solid bars) from 1990 through 2022 for years in which at least three samples were collected.



Error bars represent maximum and minimum summer growing season chl-*a* concentrations. Data includes discrete measurements from EQuIS (entire period) and satellite derived measurements from University of Minnesota Lake Browser (2017 through 2021).

Figure 94. Roemhildts Lake summer growing season mean Secchi depth (solid bars) from 1985 through 2022 for years in which at least three samples were collected.



Error bars represent maximum and minimum summer growing season Secchi depth measurements. Data only includes discrete measurements available in EQuIS.

Fisheries

Roemhildts Lake is primarily managed by the DNR for black crappie, bluegill, largemouth bass, and secondarily for northern pike. Fish populations in Roemhildts Lake are self-sustaining, as stocking has not occurred since 1981. During the most recent DNR fisheries surveys in 2022, black crappie catch rates were low and below the lower normal range compared to similar lakes (DNR Lakefinder). Bluegill catch rates were near the lower normal range of similar lakes and growth rates are slow; however, the lake provides excellent bluegill habitat and size structure for anglers. Although growth rates have been slow, largemouth bass catch rates peaked in 2022 (142 fish/hour). Northern pike catch rates also peaked in 2022 and were the most abundant species in the gill nets as the lake continues to support high-quality habitat and a consistent, quality pike population. Two fish species that are often associated with poor water quality conditions, common carp and black bullhead, were not sampled during the 2022 survey and catch rates have been very low since the 1980s. Other species sampled in Roemhildts Lake in 2022 include bowfin, freshwater drum, green sunfish, pumpkinseed, yellow bullhead, yellow perch, and hybrid sunfish. Overall, Roemhildts Lake offers a valuable and unique fishing experience to anglers in southern Minnesota due to its clear water, abundant vegetation, and mostly unaltered shoreline (DNR Lakefinder).

A common misconception is that if a lake supports a quality gamefish population (e.g., high abundance or desirable size structure of a popular gamefish species), it should be considered a healthy lake. This is not always the case because both game and nongame fish species must be considered when holistically evaluating fish community health. Oftentimes, the smaller nongame fishes serve ecologically important roles in aquatic ecosystems and are generally the most sensitive to human-induced stress. In order to better evaluate the entire fish community, the DNR uses a FIBI scoring system to assess lakes throughout the State of Minnesota. The FIBI assessments utilize fish community data collected from a combination of trap nets, gill nets, beach seines, and backpack electrofishing. From these data, an FIBI score can be calculated for a lake that provides a measure of overall fish community health based on species diversity and composition. If biological impairments are found, stressors to the fish community must be identified. More information about the sampling and assessment process can be found at the DNR Lake Biological Monitoring and Assessment website.

Roemhildts Lake was sampled and assessed in 2022 using the DNR's FIBI scoring system. Results of the FIBI assessment indicate Roemhildts Lake (FIBI score = 43) scored above the FIBI impairment threshold established for similar lakes (FIBI threshold = 38) and therefore is supportive of AQL use and is not considered impaired for AQL at this time.

Vegetation

Submergent and emergent aquatic vegetation are critical to lakes, providing spawning and cover for fish, habitat for macroinvertebrates, refuge for prey, sediment and water column nutrient uptake, and stabilization of sediments. Declines in the abundance and diversity of aquatic vegetation can be an indication of a shifting biological community and water quality state. As disturbances increase, sensitive vegetation species are lost from the system and often replaced with less desirable species (e.g., aquatic invasive species) or no vegetation at all.

Roemhildts Lake is rare for lakes in southern Minnesota in that it is a clear lake that supports a diverse and abundant aquatic vegetation community. At total of 26 submerged plant species were sampled in a 2007 survey performed by the DNR (DNR Lakefinder). Common species sampled included northern watermilfoil, water lilies, coontail, and various other pondweed species. Subsequent point-intercept surveys by DNR in August 2013 and 2014 found a total of 17 and 16 submerged and floating plant species, respectively. Several emergent and floating leaf species were also noted in the littoral zone during these surveys, providing important habitat for fish and aquatic insects. Two aquatic invasive species (AIS) were noted during the 2007 survey: EWM and CLP. However, EWM was not observed during the 2013 and 2014 surveys.

Lakeshore conditions

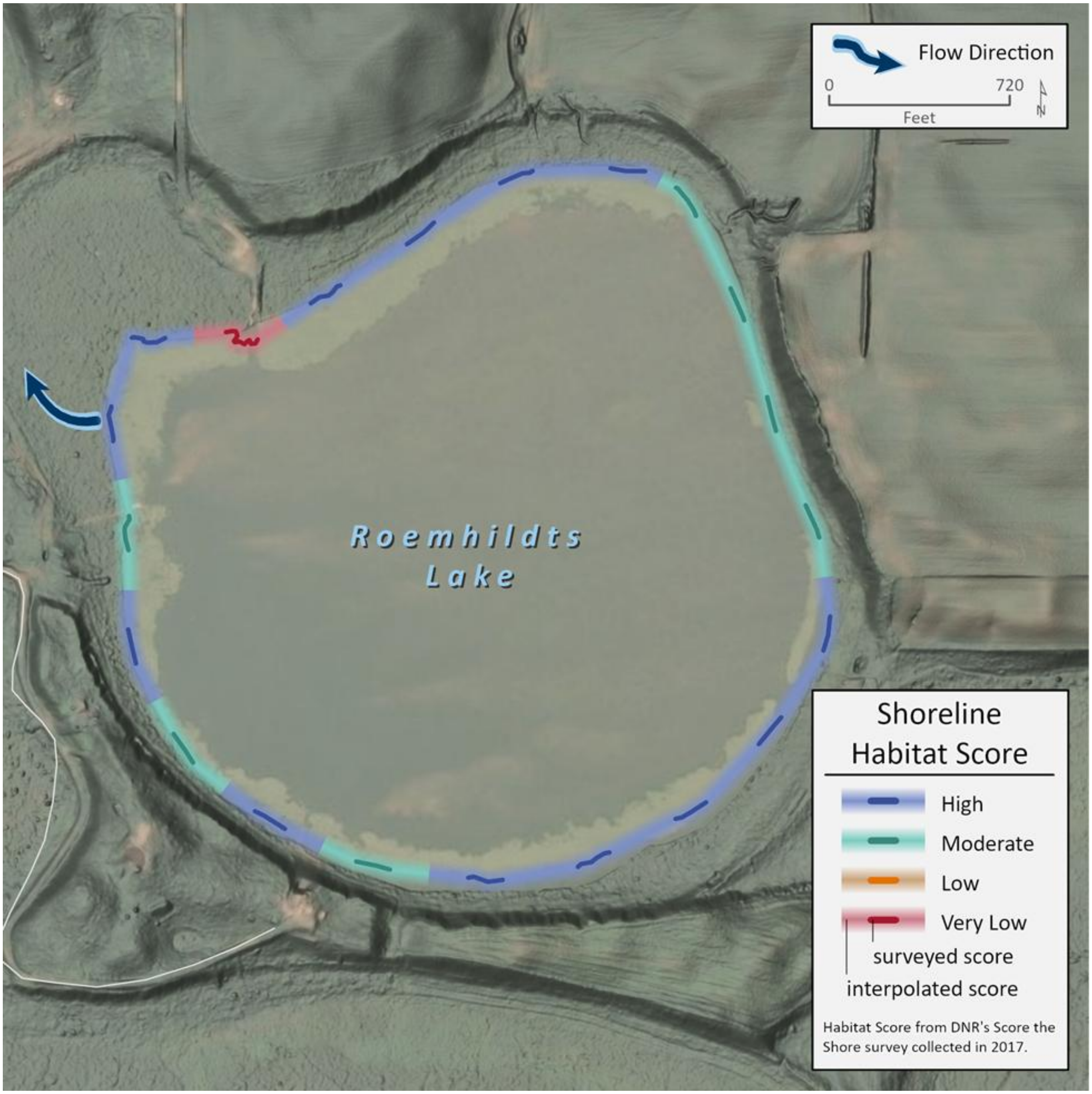
Lakeshore habitat assessments were conducted during the 2022 FIBI survey for Roemhildts Lake. The primary tool used in the assessments was the DNR STS Rapid Assessment (DNR 2019a) which were performed by DNR staff. STS is a protocol developed to rapidly assess the quantity and integrity of lakeshore habitat. The survey is designed to assess differences in habitat between lakes and to detect changes over time. STS surveys require visual observation of lands accessible by boat. The intent of the survey is to assess habitat, not to inspect for violations. The STS assessments consist of surveying 100-foot sections of shoreline at predefined, equally spaced survey locations along the entire shoreline of the lake. Since only 100 feet of shoreline is surveyed per location, the full assessment covers a relatively small portion of the total shoreline and results are not tied to individual properties. During the surveys, three lakeshore zones (upland/shoreland, shoreline, and aquatic) are assessed independently at each survey location. Within each zone, surveyors score specific features related to habitat, which are then summed for an overall Zone Habitat Score. Higher scores indicate a greater amount of habitat. Lower scores indicate a low percent of the site remains natural and a higher amount has been physically disturbed or altered by humans. The feature scores within each zone are summed for an overall site habitat score. This scoring process provides a simple method of ranking sites based on the percent of each site that is in a natural condition versus the percent of the site that has been altered. A lakewide score is calculated using the mean site habitat score. Scores range from 0 to 100 and lakes with a high percentage of unaltered habitat score higher than lakes that have been highly altered. More information about the methods used for the STS surveys can be found in the Minnesota Lake Plant Survey Manual (DNR 2019a).

The DNR STS assessment results for Roemhildts Lake are summarized in Table 58. Figure 95 illustrates the results of the overall habitat scores for the 21 STS survey locations. In this figure, the dark colored lines show the results of the individual surveyed locations (i.e., 100-foot survey sections). The lighter, thicker lines along the shoreline represent interpolated scores between the 100-foot surveyed sections. The overall score for Roemhildts Lake (83) is considered moderate and exceeds the mean score of all surveyed lakes in the Cannon River Watershed (mean score = 70; N = 19). The overall score for Roemhildts Lake also exceeds the average score for lakes surveyed throughout the state of Minnesota (mean score = 74; N = 764). A moderate score indicates that the lake has a high percentage of unaltered habitat but at least one zone has lower habitat quality than a high scoring site. Roemhildts Lake is one of the least developed lakes in the Waterville area and has very little residential development. Most of the riparian zone is wooded and intact which provides diverse and high-quality habitat and a riparian buffer from the surrounding agricultural fields. It is estimated that Roemhildts Lake has approximately four docks (~3.1 docks per mile of shoreline) based on review of 2023 Google imagery. Dock densities exceeding 16 docks per mile can significantly affect fish communities and habitat (Jacobson et al. 2016, Dustin 2017).

Table 58. DNR STS survey results for Roemhildts Lake.

Category	Result
Dock density (#/mile)	3.1
Survey locations	21
Percent developed	43%
Shoreland zone score	26.0 moderate
Shoreline zone score	28.3 high
Aquatic zone score	29.0 high
TOTAL SCORE	83.3 moderate

Figure 95. Overall site habitat STS scores for individual sample locations.



Climate

The *Climate summary for watersheds: Cannon River* (DNR 2019b) report shows that annual average temperatures in the Cannon River Watershed have increased over the last 40 years and that most years during the past two decades have been warmer than average. Monthly average temperatures in the Cannon River Watershed peak in July, and winter temperatures on average have increased over time. Annual precipitation has also shown an upward trend across the watershed since around 1940. Monthly precipitation is typically highest in June and increases in precipitation in recent years were most pronounced in April through August. The frequency of 1-inch and 3-inch rain events has increased in general in Minnesota, along with the size of the heaviest rainfall of the year. Minnesota has also experienced an increase in devastating, large-area extreme rainstorms (DNR 2022). Climate projections indicate these big rains will continue increasing into the future (DNR 2022).

Statewide lake data collected by the DNR, MPCA, and local partners shows that the climate trends described above have already impacted lakes throughout the state and region. According to MPCA's [Climate change and Minnesota's surface waters](), lake surface temperatures have warmed during all seasons throughout southern Minnesota. During the summer growing season (June through September), lakes in southern Minnesota are, on average, approximately 2.7 to 4.4 degrees F warmer now than they were 50 years ago. Additionally, warmer winters have resulted in about 9 less days of ice coverage on average for lakes throughout the region since the mid-1970s.

Reduced ice coverage, higher year-around water temperatures, and more intense and frequent precipitation events can result in significant impacts to lakes and lake users, including but not limited to (MPCA 2021):

- Overall increase in flow, sediment, and nutrient loading from the lake drainage area
- Longer periods of stratification and anoxia resulting in increased internal P recycling
- Longer open water and growing season for algae and cyanobacteria blooms
- Larger fluctuations in lake level from year to year
- Potential for increased densities of aquatic invasive plants, such as CLP and EWM
- Decreases in walleye (who prefer summer water temps at 65˚F to 70˚F) in smaller, warmer lakes
- Potential for more fish kills as fish are squeezed into smaller zones to access oxygen
- Shortened season for safely recreating on ice-covered lakes

Although long-term supporting data is limited, it is likely that Roemhildts Lake has or is currently experiencing many of the climate impacts described above. These impacts create additional challenges to protect Roemhildts Lake water quality and support healthy plant and fish communities. Adaptation strategies such as improving water management practices, enhancing soil health, planting conservation perennials, and natural shoreline buffers should be considered for Roemhildts Lake to build resilience to these impacts and threats.

F.6.2. Lake phosphorus budget and model

A P budget and eutrophication model (BATHTUB) were established for Roemhildts Lake using methods similar to the lake TMDLs in the *Cannon River Watershed Total Maximum Daily Load Report* (MPCA 2016) and other lake TMDLs throughout the State. The four primary P sources considered for the Roemhildts Lake model were loading from the lake's drainage area, septic systems, atmosphere, and internal recycling. Each of these sources, and how they were estimated, are discussed below in more detail.

Drainage area

Precipitation that falls within the drainage area of a lake flows across the land surface and/or through sub-surface drain tiles, and a portion of it eventually reaches the lake. P is carried with the runoff water and delivered to the lake. The primary P sources in runoff in the Roemhildts Lake drainage area include soils, fertilizer, vegetation, wetlands, and impervious surfaces and lawns in residential areas surrounding the lake.

Watershed runoff volumes and TP loads from the Roemhildt Lake drainage area were estimated using the Cannon River Watershed HSPF model (2019 version). HSPF is a comprehensive, mechanistic model of watershed hydrology and water quality that allows the integrated simulation of point sources, land and soil nutrient runoff and subsurface processes, and in-stream hydraulic and sediment-chemical interactions. Model documentation contains additional details about the Cannon River HSPF model development and calibration (LimnoTech 2015). The modeling period for the Cannon River HSPF model covers 1996 through 2019. In the model, the Roemhildts Lake drainage area is not explicitly modeled but is included in a larger reach/subwatershed within the model (HSPF Reach 370). Table 59 presents the HSPF predicted mean annual flow and TP load by land cover type for HSPF Reach 370 that were used to represent the Roemhildts Lake drainage area. Based on these rates, approximately 99 lbs of TP is delivered to Roemhildts Lake each year and cropland (86%) represents the largest loading source to the lake.

Table 59. Model estimated flow volume and TP loading rates and annual totals for the Roemhildts Lake drainage area (modeled years = 2010 through 2019).

Land cover category	Area (acres)	Modeled flow rate (in/yr)	Modeled flow volume (acre-ft/yr)	Modeled TP load rate (lbs/acre/yr)	Modeled TP load (lbs/yr)
Cropland	124	9.8	101	0.68	85
Developed/residential	13	11.6	12	0.47	5.9
Wetland	17	3.0	4	0.17	2.8
Forest and shrubland	51	5.9	25	0.05	2.5
Hay/pasture	16	8.2	11	0.18	2.9
TOTAL	221	8.3	153	0.45	99

Septic systems

Flow and TP loads from septic systems were estimated using methods similar to the *Lower Minnesota River Watershed TMDL* (MPCA 2020a). It is estimated that there are approximately four residences surrounding Roemhildts Lake based on review of 2023 Google imagery. Assumptions were made regarding the number of people per household (~2.1), and the percent of homes that are occupied year-round (100%) versus seasonally (0%). Estimated septic compliance rates (~50% compliant and ~50% failing or noncompliant) were assumed based on estimates supplied by the county (Le Sueur County Environmental Services personal communication). Septic system TP removal rates for compliant systems was assumed to be approximately 80%, while removal rates of 57% were assumed for failing systems (Barr Engineering 2004). Through this analysis it was estimated that compliant septic systems currently contribute approximately two lbs/year of TP to Roemhildts Lake while noncompliant systems contribute approximately four lbs/year.

Atmosphere

P is bound to atmospheric particles that settle out of the atmosphere and are deposited directly onto surface water. P loading from atmospheric deposition to Roemhildts Lake is estimated to be approximately 27 lbs/year based on the average deposition rate across the Lower Mississippi River basin (0.38 lbs/acre-year; Barr Engineering 2007).

Internal phosphorus recycling

Internal P recycling, often referred to as "internal loading," is a common occurrence in eutrophic and hypereutrophic lakes throughout central and southern Minnesota. P contained in the sediment of lakes originates as an external P load that settles out of the water column to the lake bottom. Typically, a significant amount of the external load to the Roemhildts Lake is delivered during snow melt and spring and early summer runoff. During this time, low water temperatures and flushing limit the amount of algae growth and biological activity within the lake. As water temperatures increase in mid-summer (e.g., late June and July), lakes can become thermally stratified during quiescent periods and biological activity increases, which leads to higher rates of algae growth and bacterial decomposition. As this happens, DO is consumed by bacteria, and anoxic conditions (i.e., low DO) can develop at the sediment-water interface which leads to the release of P from the lake sediments. The P that is released from the sediments is in a soluble form that is readily available to algae for uptake. P that has accumulated near the sediment-water interface can be readily mixed into the surface waters during strong winds, storm events, and as stratification begins to weaken in the late summer and early fall. Internal P recycling is especially problematic in lakes during dry and hot summers, when lower flows provide less dilution for P loads recycled from lake bottom sediments. Further, algae growth rates and sediment decomposition rates are elevated during dry and hot summers due to higher water temperatures and longer hydraulic residence times (Walker 2011).

There is evidence from the available data for Roemhildts Lake that suggests internal P recycling occurs within the lake:

- Although temperature and DO profile data for Roemhildts Lake is limited, surface TP and chl-*a* concentration spikes have been observed when thermal stratification weaken and break down in September and October (e.g., 2004, 2018, and 2019)
- Mean surface TP and chl-*a* concentrations are highest in September and October in most years despite generally decreasing precipitation, temperature, watershed runoff, and external TP inputs during this time period
- Mean surface chl-*a* concentrations are lower from June through August when thermal stratification is strongest and there is minimal mixing between surface and bottom waters.
- High TP concentrations ranging from 350 µg/L to over 450 µg/L were observed in hypolimnion (i.e., depths greater than ~10 meters) samples collected during September and October 2022 as stratification was starting to break down

At this time, there is not enough data available to explicitly quantify the amount of P that is typically recycled within Roemhildts Lake each year. Since the lake maintains a stratified water column into October, it does not appear that a significant amount of the P that is released from the lake sediments during the summer mixes with surfaces until after the growing season index period (i.e., October or November). In order to better characterize internal recycling, additional data would need to be collected such as continuous or high-frequency temperature and DO profiles, hypolimnetic P samples, and/or sediment cores. Since internal P recycling reflects recycling of loads that originally entered the lake from the lake drainage area and atmosphere, the amount of P recycling is expected to vary with external load over time.

Common carp are another potential source of internal P recycling. When present in high densities, carp can exacerbate poor water quality in lakes by destroying/uprooting aquatic vegetation and resuspending/recycling TP from lake sediments. Studies have demonstrated how adult carp can increase turbidity, TSS, TP, and negatively affect macrophyte abundance through various direct and indirect processes (Parkos et al. 2003). Research suggests that negative impacts of common carp on turbidity and vegetation begin to occur at densities of around 89 lbs/acre (Bajer et al. 2009). To our knowledge, common carp density has not been assessed in Roemhildts Lake. Although the gear used in the DNR trap and gill net surveys tend to underrepresent common carp abundance due to high net avoidance, these surveys can provide a relative means to track carp trends and changes over time within a lake and compare catch rates to other lakes. Based on our review of the DNR trap and gill net surveys, common carp catch rates for Roemhildts Lake have remained well below the lower normal range of similar lakes since the 1980s. Negative impacts to lake habitat and water quality are likely negligible at these low levels but DNR catch rates should continue to be monitored.

CLP has also been hypothesized to contribute to internal P recycling and algae blooms in lakes after the plant dies back in midsummer. Although it can be found in a wide-range of environmental conditions, CLP is most common and abundant in alkaline (> 100 mg/L calcium carbonate alkalinity, $CaCO_3$), P-rich lakes (TP between 50 – 100 µg/L; Bolduan et al. 1994) that are dominated by urban or agricultural land use in the southern half of the state (Heiskary and Valley 2012). Based on their review of sentinel lakes throughout the state with CLP infestations, Heiskary and Valley (2012) found that some shallow lakes exhibited mid-summer TP spikes around the time of CLP senescence, however it was difficult to determine how much of a role CLP plays compared to other internal and external sources.

Lake eutrophication model and final phosphorus budget

A spreadsheet version of the lake model BATHTUB (Walker 1987) was established for Roemhildts Lake to model current lake water quality conditions. BATHTUB is a steady state model that predicts eutrophication response in lakes based on empirical formulas developed for nutrient balance calculations and algal response (Walker 1987). The model was developed by the U.S. Army Corps of Engineers and has been used extensively in Minnesota and across the Midwest for lake nutrient TMDLs. Several models (subroutines) are available for use within the BATHTUB model, and the Canfield-Bachmann model was used to predict P settling/retention and the lake response to TP loads in Roemhildts Lake. The BATHTUB model requires flow and P loading inputs from the lake's drainage area, upstream lakes, and atmospheric deposition. Lake morphometric data are also required by the model.

Drainage area runoff volumes and P loading inputs to the Roemhildts Lake BATHTUB model were derived from the HSPF model (Table 59). Flow and P loading from atmospheric deposition and septic systems using the methods described above were also added to the model. With the primary external sources defined, the model predicted in-lake P concentration was compared to the 2008 through 2022 observed mean concentration (Figure 92 and Table 57). The model predicted in-lake TP concentration was higher than the observed concentration and therefore the P sedimentation calibration factor was adjusted (i.e., to increase sedimentation/retention) to match the monitored value.

The settling/retention model used in the Roemhildts Lake BATHTUB model inherently includes an average amount of internal P recycling. In some cases, the amount of P recycled within a lake is greater than the amount inherent in the model and the modeler may choose to add additional load to improve model calibration. Alternatively, the Canfield-Bachman P sedimentation calibration factor can be adjusted to account for internal P recycling as recommended in the BATHTUB Version 6.1 Online Documentation (Walker 2006). Although there is evidence that P recycling occurs in Roemhildts Lake, the BATHTUB model did not require an additional P load or any reduction to the P sedimentation calibration factor (Walker 2006). This suggests that internal recycling of P is not a major contributor to surface waters during most of the summer growing season and management of external sources is the most appropriate starting point to improve and protect in-lake water quality.

As shown in Table 60, loading from the Roemhildts Lake drainage area (75%) represents the largest source of P to the lake followed by atmospheric inputs (20%) and septic systems (5%). Sedimentation/retention represents the largest sink of P (95%) suggesting a significant amount of the annual load delivered to the lake is retained in the lake and its sediments.

Table 60. Roemhildts Lake current condition P budget (HSPF modeled years = 2010 through 2019).

Category	Annual Load (lbs/yr)	Percent of Total
Sources (+)		
Drainage area	99	75%
Atmosphere	27	20%
Septic Systems	6	5%
TOTAL	132	
Losses (-)		
Sedimentation/retention	125	95%
Outflow	7	5%
TOTAL	132	

F.6.3 Phosphorus targets and reductions

Establishing phosphorus goals to protect Roemhildts Lake

The primary objective of this study is to protect water quality conditions in Roemhildts Lake. Roemhildts Lake currently meets NCHF lake/reservoir standards for all three eutrophication parameters (Table 57). Therefore, an in-lake TP concentration target below the 40 µg/L standard and at or below the current mean TP concentration (17 µg/L) should be considered to protect future water quality conditions and minimize algae blooms. Here, we present two P reduction goals local partners could consider to protect Roemhildts Lake water quality:

- Short-term goal – reduce P loading to Roemhildts Lake by 5%
- Long-term goal – reduce P loading to Roemhildts Lake by 10%

The DNR commonly uses a 5% P load reduction goal to protect lakes that are comfortably meeting state water quality standards such as Roemhildts Lake. The 10% reduction goal should be viewed as a potential long-term goal after the 5% goal is achieved. The BATHTUB model and existing water quality data suggest that both goals may not lead to significant changes in algae levels or water clarity. Even if measurable improvements in hl-*a* or Secchi are not achieved, achieving these goals will help buffer the lake from future stressors such as changes in runoff patterns, temperature, and/or ecological shifts.

Load reduction goals

Table 61 presents the current TP load to Roemhildts Lake, the TP target load, and the load reduction required to achieve the target load. Section 4 presents example strategies and BMP options to achieve the load reductions presented in Table 61.

Table 61. TP loads and reductions to meet in-lake water quality targets.

Phosphorus goal	Current TP (µg/L)	Current TP load (lbs/yr)	TP target load (lbs/yr)	TP load reduction (lbs/yr)	TP load reduction (percent)
Short-term	17	132	125	7	5%
Long-term			119	13	10%

F.6.4 Strategies to improve Roemhildts Lake water quality and aquatic life

Example strategies were selected using a variety of sources, input from local stakeholders, and best professional judgement from MPCA staff. Example strategies presented in this section are intended to provide potential options to achieve the protection goals for Roemhildts Lake. The strategies are not required, and implementation is considered voluntary. Stakeholders should use these example practices as a path to improve water quality, but it is anticipated that implementation may change as new information is learned and data is collected. It is recommended that stakeholders incorporate other known local issues or causes when implementing practices and strive to incorporate multiple benefits into projects.

Cropland best management practices

MPCA developed a list of potential cropland BMP and land use change example scenarios that could be considered for Roemhildts Lake to improve water quality. These scenarios include:

- Implement conservation till every year on all fields currently practicing conventional till and periodic conservation till
- Implement no-till on all fields currently practicing conventional till and periodic conservation till
- Implement cover crops on all cropland fields
- Convert 25% of cropland fields to grassland
- Convert 75% of cropland fields to grassland

P reductions for each BMP scenario described above were estimated using rates derived from the defaults in HSPF–SAM (version 2.0) and the Watershed Pollutant Load Reduction Calculator (MPCA 2022b).

Table 62 presents the potential TP load reductions for each scenario. P reductions from the example scenarios range from 14 to 47 lbs/year and therefore, depending on the scenario selected and level of adoption, would achieve the reduction goals identified in Table 61.

Developed/residential BMPs

It is estimated that there are only four homes/residences surrounding Roemhildts Lake and residential areas account for 6% of the land use and 6% of the annual P load to Roemhildts Lake. Nearly all of the homes are on shoreline lots or in close proximity to the lake. Based on investigation of air photos, most of the residential lots surrounding the lake have about 1/3 acre of impervious surfaces (i.e., rooftops, driveways, walkways, roads). Due to their close proximity to Roemhildts Lake, these impervious surfaces have high potential for stormwater to be delivered to the lake via surface runoff, drain tile, and/or shallow groundwater pathways.

A rain garden is one of the most efficient residential stormwater BMPs used to intercept runoff from impervious surfaces and remove pollutants before they enter surface waters. Below are three rain garden BMP example scenarios to reduce P loading from residential areas throughout the Roemhildts Lake drainage area.

- Low adoption scenario – One residence (25%) installs and maintains a rain garden to treat impervious areas (assumes 0.3 acres of impervious area is treated by rain garden)
- Moderate adoption scenario – Two residences install and maintain rain gardens (0.7 acres treated)
- High adoption scenario – Four residences install and maintain rain gardens (1.3 acres treated)

P reductions from rain gardens were estimated using default rates provided in the MPCA SE model presents the potential TP load reductions for each scenario. Reductions range from 0.1 lbs/year for the low adoption scenario to 0.5 lbs/year for the high adoption scenario. Although the total load reductions for the raingarden scenarios are less than the cropland BMP scenarios, raingarden TP reduction efficiency is higher than many of the cropland BMPs listed in Table 62.

Lakeshore BMPs

Shoreline development for Roemhildts Lake is relatively low at this time but has the potential to impact both riparian vegetation and native floating-leaf and emergent plant stands that serve as important habitat for fish and other organisms. Further, replacement of riparian vegetation with riprap and open lawns can result in increased nutrient inputs from fertilizer and lawn clippings, reduced buffering capacity, destabilized shoreline, and elimination of future contributions of coarse woody habitat into the lake.

Shoreland owners can significantly improve shoreline habitat by choosing to reestablish or maintain native plants along their property. Natural shorelines provide overhead cover to fish and wildlife species, contribute important coarse woody habitat into the lake, and provide a buffer for nutrient runoff from lawns and impervious surfaces. While shoreline restoration projects vary in scope and size, all can be completed in ways that are visually appealing and that maintain a view of the lake. Once completed, these projects have potential to provide many ecosystem benefits that a more traditional developed shoreline (e.g., riprap, mowed lawn, and sand beach) could not offer. The DNR maintains an interactive Restore Your Shore webpage that provides guidance for shoreland owners and professionals to use in implementing shoreland restoration projects. Protection and restoration of floating-leaf and emergent aquatic vegetation should also be prioritized, especially where aquatic habitat is limited. Shoreland owners should be aware of and adhere to current laws that regulate shoreline and aquatic plant control, riprap, sand blanket, and retaining wall installation, and other shoreline alterations.

The DNR estimates that a developed shoreline with turf grass to the water's edge allows seven to nine times more phosphorus to enter the lake than a naturally vegetated shoreline (Radomski and Van Assche 2014). While the amount of phosphorus entering the lake from shoreline lots varies due to soil, slope, and other site-specific conditions, the average pollution from 100 feet of non-buffered shoreline has been estimated at 0.2 lbs/summer of TP compared to 0.03 lbs/summer for a lot with a native vegetated shoreline buffer. Based on air photo interpretation and results of the Roemhildts Lake DNR STS survey (Table 58 and Figure 95), there is approximately 300 feet of shoreline that could benefit from native shoreline buffers. Implementation of native buffers in these areas would result in TP reductions of approximately 0.5 lbs/year and provide several ecosystem benefits as described above and in Table 62. Since Roemhildts' shoreline is relatively undeveloped at this time, protecting and maintaining the lake's high-quality shoreline and habitat features will be a key protection strategy for the lake.

Septic system improvements

It is estimated that about 50% of the septic systems (~2 systems) in the Roemhildts Lake drainage are non-compliant at this time (Le Sueur County Environmental Services personal communication). If these systems were brought into compliance, TP loading to the lake would be reduced by approximately two lbs/year (Table 62).

Internal phosphorus recycling

As discussed in Section 2, net effects of internal P recycling were not explicitly estimated for this study. Although there is evidence that internal P recycling occurs within Roemhildts Lake, it is assumed that the rate of recycling will decrease as the lake and sediments equilibrate to lower external P loads. Strategies to reduce internal recycling could be considered if water quality conditions in Roemhildts Lake degrade in the future and/or if BMP efforts to reduce external loads fall short of the targets and goals set by the local partners. Internal recycling strategies could include, but are not limited to, water level drawdown, sediment dredging, sediment P immobilization or chemical treatment (e.g., alum and Phoslock®). The MPCA recommends feasibility studies for any lake in which major in-lake management strategies are proposed. The *Minnesota State and Regional Government Review of Internal Phosphorus Load Control* paper (MPCA 2020b) provides more information on internal load BMPs and considerations.

At this time, common carp do not appear to be significant contributor to P recycling in Roemhildts Lake (see Sections 1 and 2). However, efforts to limit and prevent the migration and movement of common carp from upstream/downstream water bodies could be considered as a protection strategy to prevent this threat from becoming a problem in the future. It is recommended that local partners work closely with DNR if they are interested in pursuing carp management in Roemhildts Lake.

As discussed in Section 2, the relationship between CLP and water quality varies substantially among lakes and clearly defining "cause and affect" can be difficult. Heiskary and Valley (2012) found little evidence supporting CLP as a driver of lake water quality conditions in Minnesota. While there are some case studies in Minnesota and Wisconsin that suggest CLP can have negative impacts on summer water quality (James et al. 2002, Welling 2010), pilot studies and published research actually demonstrate negative effects of large-scale removal of CLP on summer water quality in eutrophic lakes (Valley et al. 2006, Welling 2010). These studies concluded that a sole focus on killing CLP in lakes, especially where the plant is abundant, may carry more risks of harmful effects to water quality and fish habitat than leaving the plant unmanaged. Thus, local partners should not expect water quality enhancements by focusing exclusively on treating CLP without simultaneous, long-term measures to reduce internal and external P loads.

Table 62. Roemhildts Lake BMP example scenarios and associated TP load reductions and other benefits.

Strategy type	BMP	BMP example scenario	Current level of adoption	BMP TP reduction rate/efficiency	TP load reduction (lbs/yr)	Other water quality and habitat benefits
Cropland BMPs	Conservation till	Conservation till on all cropland fields currently practicing conventional till (124 ac)	none	0.12 lbs/ac/yr[a]	15	sediment (reduction = 80 lbs/ac/yr[a]), nitrogen (reduction = 0.98 lbs/ac/yr[a]), improved soil health
	No till	No-till on all cropland fields practicing conventional till (124 ac)	none	0.26 lbs/ac/yr[a]	32	sediment (reduction = 120 lbs/ac/yr[a]), nitrogen (reduction = 2.35 lbs/ac/yr[a]), improved soil health
	Cover crops	Cover crops on all cropland fields (124 ac)	none	0.11 lbs/ac/yr[a]	14	sediment (reduction = 120 lbs/ac/yr[a]), nitrogen (reduction = 4.39 lbs/ac/yr[a]), improved soil health
	Cropland to grassland	Convert 25% of cropland fields to grassland (31 ac)	none	0.50 lbs/ac/yr[b]	16	sediment (reduction = 160 lbs/ac/yr[a]), nitrogen (reduction = 14.53 lbs/ac/yr[a])
		Convert 75% of cropland fields to grassland (93 ac)	none	0.50 lbs/ac/yr[b]	47	
Developed/ Residential BMPs	Rain gardens	Low adoption: 1 residence installs raingarden to treat 0.3 acres	unknown	0.42 lbs/ac/yr[c]	0.1	sediment (reduction = 123 lbs/ac/yr[c]), water retention, groundwater recharge
		Moderate adoption: 2 residences install raingardens to treat 0.7 acres	unknown	0.42 lbs/ac/yr[c]	0.3	
		High adoption: 4 residences install raingardens to treat 1.3 acres	unknown	0.42 lbs/ac/yr[c]	0.5	
Shoreline BMPs	Native shoreline buffers	Implement native shoreline buffers on 300 feet of developed, nonbuffered shoreline	unknown	0.17 lbs/100-ft of shoreline[d]	0.5	filtering of sediment and other pollutants, reduced erosion, shoreline stabilization, habitat for insects, fish, birds, amphibians, decreased maintenance cost
Septic system improvements	Septic system upgrade	Upgrade all failing septic systems in watershed (~2 system)	50% (~2 systems)	1.1 lbs/system/yr[e]	2.2	nitrogen and fecal coliform reductions (not quantified)

[a] Source: Watershed Pollutant Load Reduction Calculator (MPCA 2022b)

[b] Source: Le Sueur River HSPF–SAM (version 2.0)

[c] Source: MPCA Simple Estimator model

[d] Source: Radomski and Van Assche 2014

[e] Source: MPCA 2020a and Barr Engineering 2004

F.6.5 Summary and future monitoring and analyses

This study identifies two water quality protection goals for Roemhildts Lake that local partners can use to help guide protection efforts. The short-term goal is intended to reduce P loading by 5% or approximately seven lbs/year (Table 61). The short-term goal could be achieved through low to moderate level of adoption of the BMP scenarios identified in Section 4 and Table 62. The long-term goal, which calls for P load reduction of 10% (13 lbs/year; Table 61), could be met through moderate to high level adoption of the BMP scenarios presented in Section 4. Implementation of cropland BMPs such as conservation till, no-till, and cover crops will be critical to meet both of the protection goals presented in this study. Septic system upgrades and rain gardens on residential properties surrounding Roemhildts Lake should also be targeted as these are pollutant sources with direct pathways to the lake. Finally, although Roemhildts Lake currently has a relatively low level of shoreline development, ensuring native shoreline buffers remain in place will be an important strategy to protect fish from the lake's high-quality fish habitat.

The following list of monitoring activities and analyses would be beneficial over the course of the implementation period. These items will help refine and update the watershed and lake models, assist in prioritizing and targeting BMPs, and track response to BMPs as they are implemented using an adaptive management approach.

- Collect surface water quality samples (i.e., TP, chl-*a*, Secchi depth) at least one time per month from April/May through October. Although the lake standards require June through September sampling, spring and fall data would be beneficial to better understand nutrient dynamics and eutrophication response over the entire open water season.
- Consider adding TN (i.e., TKN and nitrate/nitrite) to the list of surface water monitoring parameters to investigate if/how N may be affecting eutrophication and biological communities.
- Continue monitoring nonnative species (e.g., common carp, CLP, EWM) where they are present to ensure they do not reach densities that could substantially alter water quality and physical habitat in the future.
- Continue mapping and surveying native submerged and emergent vegetation communities to document baseline conditions and track changes as management and protection efforts occur.
- Encourage individual lakeshore residents and lake association members to participate in the Minnesota Lake Steward Program and the Score Your Shore Survey to educate about sustainable land management, self-assess habitat conditions along their shorelines, and identify potential improvements.
- Utilize lidar-based terrain analysis products (e.g., PTMApp) to identify and target locations (both cropland and residential) with higher rates of soil loss and sediment delivery throughout the Roemhildts Lake drainage area.
- Periodically update the watershed model, lake model, and other models and tools as new data is collected and BMPs are implemented.

F.7 References

Bajer, P.G, G. Sullivan, and P.W. Sorensen. 2009. Effects of a rapidly increasing population of common carp on vegetative cover and waterfowl in a recently restored Midwestern shallow lake. Hydrobiologia 632: 235-245.

Barr Engineering. 2004. Detailed Assessment of Phosphorus Sources to Minnesota Watersheds. Prepared for the Minnesota Pollution Control Agency, St. Paul, MN

Barr Engineering. 2007. Detailed Assessment of Phosphorus Sources to Minnesota Watersheds—Atmospheric Deposition: 2007 Update. Technical Memorandum prepared for Minnesota Pollution Control Agency, Saint Paul, MN.

Bolduan, B. R., G. V. Van Eeckhout, H. W. Quade, and J. E. Gannon. 1994. Potamogeton crispus - the other invader. Lake and Reservoir Management 10:113-125.

DNR (Minnesota Department of Natural Resources). 2019a. Minnesota lake plant survey manual, version 3, for use by DNR Fisheries Section, EWR Lake Unit, and EWR Minnesota Biological Survey Unit. https://files.dnr.state.mn.us/eco/lake-habitat/lake-plant-survey-manual.pdf

DNR (Minnesota Department of Natural Resources). 2019b. Climate Summary for Watersheds: Cannon River. https://files.dnr.state.mn.us/natural_resources/water/watersheds/tool/watersheds/climate_summary_major_39.pdf

DNR (Minnesota Department of Natural Resources). 2022. Climate Trends. https://www.dnr.state.mn.us/climate/climate_change_info/climate-trends.html

Dustin, D. L., and B. Vondracek. 2017. Nearshore habitat and fish assemblages along a gradient of shoreline development. North American Journal of Fisheries Management 37: 432-444.

EOR. 2020. Cannon River Comprehensive Watershed Management Plan. https://www.cannonriverwatershedmn.gov/cannon-comp-watershed-mgmt-plan

Flory, J. Personal communication, April 15, 2026.

Heiskary, S., and R. D. Valley. 2012. Curly-leaf Pondweed Trends and Interrelationships with Water Quality. Minnesota Department of Natural Resources Investigational Report 558. https://files.dnr.state.mn.us/publications/fisheries/investigational_reports/558.pdf

Jacobson, P. C., T. K. Cross, D. L. Dustin, and M. Duval. 2016. A fish habitat conservation framework for Minnesota lakes. Fisheries 41: 302-317.

James, W.F., J.W. Barko, H.L. Eakin, and P.W. Sorge. 2002. Phosphorus budget and management strategies for an urban Wisconsin lake. Lake and Reservoir Management 18: 149:163.

Limnopro. 2020. Cedar Lake Phosphorus Budget. Prepared for the Cedar Lake Association.

LimnoTech. 2015. Cannon River Watershed HSPF Model Development Project – Minnesota Pollution Control Agency, One Water Program. https://www.pca.state.mn.us/sites/default/files/wq-ws4-23d.pdf

MPCA (Minnesota Pollution Control Agency). 1993. Beaver Lake Lake Assessment Program (LAP) Report.

MPCA (Minnesota Pollution Control Agency). 2000. Status and Trend Monitoring Summary for Rice County, Minnesota 1999 (Lakes: Cannon, Wells, Kelly, Dudley, Circle, Cedar, and Roberds).

MPCA (Minnesota Pollution Control Agency). 2005. Minnesota Lake Quality Assessment Report: Developing Nutrient Criteria. https://www.pca.state.mn.us/sites/default/files/wq-lar3-01.pdf

MPCA (Minnesota Pollution Control Agency). 2015. BATHTUB Modeling to Support Watershed Protection and Restoration Strategy Development: Lakes of the Upper Cannon River Watershed – Working Paper. Water Quality Monitoring Unit, EAO Division. Minnesota Pollution Control Agency

MPCA (Minnesota Pollution Control Agency). 2016. Cannon River Watershed Total Maximum Daily Load. https://www.pca.state.mn.us/sites/default/files/wq-iw9-19e.pdf

MPCA (Minnesota Pollution Control Agency). 2016a. Cannon River Watershed Restoration and Protection Strategies. https://www.pca.state.mn.us/sites/default/files/wq-ws4-23a.pdf

MPCA (Minnesota Pollution Control Agency). 2020a. Lower Minnesota River Watershed Total Maximum Daily Load Report. https://www.pca.state.mn.us/sites/default/files/wq-iw7-49e.pdf

MPCA (Minnesota Pollution Control Agency), Minnesota Department of Natural Resources, Board of Water and Soil Resources, and Metropolitan Council. 2020b. Minnesota State and Regional Government Review of Internal Phosphorus Load Control. https://www.pca.state.mn.us/sites/default/files/wq-s1-98.pdf

MPCA (Minnesota Pollution Control Agency). 2021. Climate change impacting Minnesota lakes. https://www.pca.state.mn.us/sites/default/files/cc-wq2-1.pdf

MPCA (Minnesota Pollution Control Agency). 2022a. Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List. https://www.pca.state.mn.us/sites/default/files/wq-iw1-04l.pdf

MPCA (Minnesota Pollution Control Agency). 2022b. Watershed Pollutant Load Reduction Calculator. https://public.tableau.com/app/profile/mpca.data.services/viz/WatershedPollutantLoadReductionCalculator/WatershedPollutantLoadReductionCalculator

Page, B. P., L. G. Olmanson, and D. R. Mishra. 2019. A harmonized image processing workflow using Sentinel-2/MSI and Landsat-8/OLI for mapping water clarity in optically variable lake systems. Remote Sensing of Environment, 231: 111284. https://doi.org/10.1016/j.rse.2019.111284

Parkos, J., V. Santucci, and D. Wahl. 2003. Effect of adult common carp (Cyprinus carpio) on multiple trophic levels in shallow mesocosms. Can. J. Fish. Aquat. Sci. 60: 182-192.

Radomski, P. J. and K. Van Assche. 2014. Lakeshore Living: Designing Lake Places and Communities in the Footprints of Environmental Writers. Michigan State University Press. East Lansing.

Sagario, M.A. et al. 2005. Does High Nitrogen Loading Prevent Clean-water Conditions in Shallow Lakes at Moderately High Phosphorus Concentrations? Freshwater Biol. 50(1):27-41.

Valley, R. D., W. Crowell, C. H. Welling, and N. Proulx. 2006. Effects of a low-dose fluridone treatment on submersed aquatic vegetation in a eutrophic Minnesota lake dominated by Eurasian watermilfoil and coontail. Journal of Aquatic Plant Management 44:19-25.

Vollenweider, R. A.. 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. Ist. Ital. Idrobiol. 33: 53-83.

Walker, W.W. 1987. Empirical methods for predicting eutrophication in impoundments. Report 4, Applications manual, Tech. Rep. E-81-9. Prepared for U.S. Army Corps of Engineers Waterways Exp. Sta. Vicksburg, MS.

Walker, W..W. 2006. BATHTUB – Version 6.1 Simplified Techniques for Eutrophication & Prediction. Online Documentation. Developed for Environmental Laboratory USAE Waterways Experiment Station Vicksburg, Mississippi. https://www.wwwalker.net/bathtub/help/bathtubWebMain.html

Walker, W.W. 2011. Development of Phosphorus TMDL for Little Rock Lake, Minnesota. Prepared for Benton Soil and Water Conservation District. http://www.wwwalker.net/pdf/lrl_tmdl_www_2011.pdf

Welling, C. 2010. Lake-wide and selective control of curly-leaf pondweed and Eurasian watermilfoil: Status Report. Minnesota Department of Natural Resources Invasive Species Program, St. Paul.

Wetzel, R.G. 2001. Limnology. W.B. Saunders Co. Philadelphia. 3rd Ed.