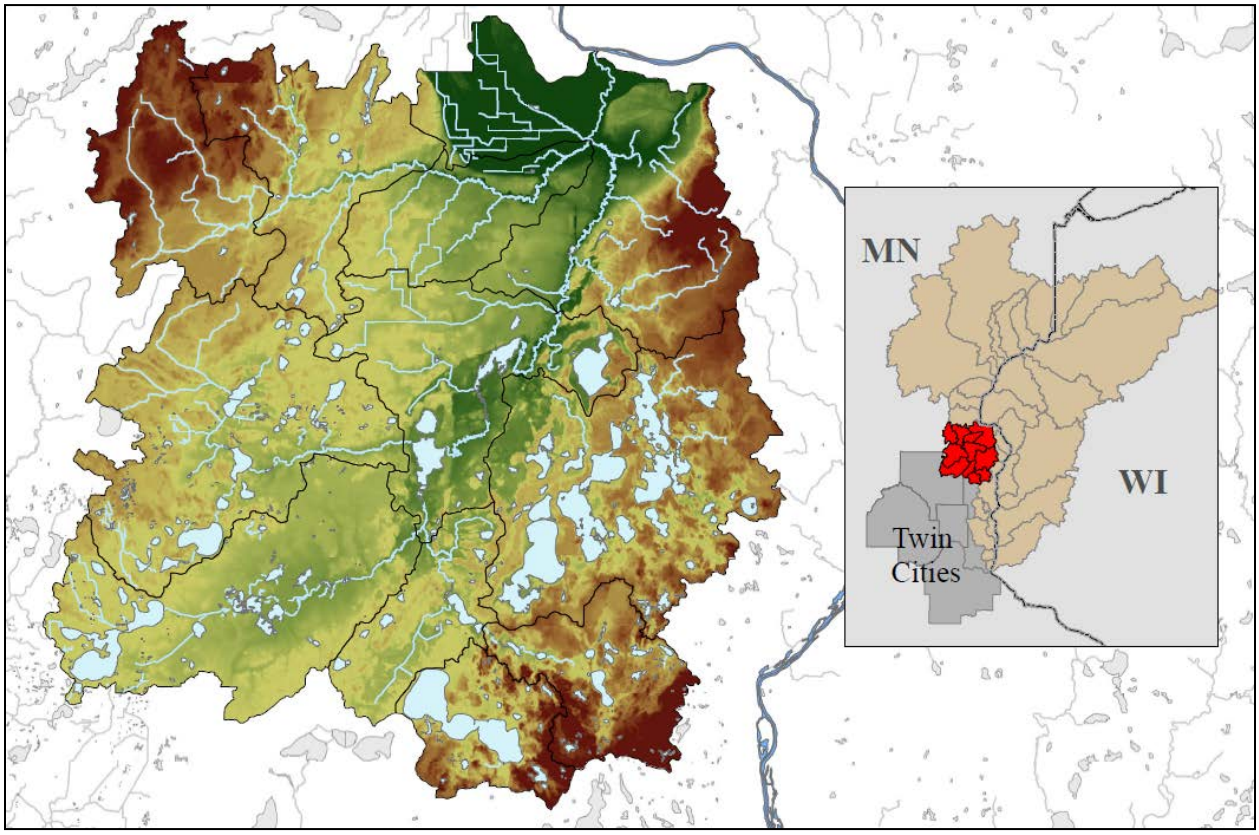
Watershed Study Report

For The

Sunrise River Watershed, MN



November 2013

DRAFT
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Executive Summary

A watershed study was performed for the Sunrise River Watershed, including all areas upstream of the Sunrise River confluence with the St. Croix River. The study focused on priority water resource issues identified through collaboration with Chisago County, Minnesota Pollution Control Agency and stakeholders. This included evaluating existing conditions for water quality; aquatic habitat; wetlands presence and historical loss; geomorphic conditions; and groundwater/surface water interactions. The potential for future development was assessed, including the potential impact of future land use on phosphorus and sediment loading. Various land use scenarios were considered to assess potential for reduced future phosphorus loading from the watershed. Finally, recommendations were made to direct future watershed management. A brief summary of findings include the following:

The Sunrise River was believed to be one of the largest relative contributors of phosphorus and sediment to the St. Croix River. While this study suggests loading contributions may not be as substantial as originally thought, the watershed is still an important contributor of phosphorus and sediment to the St. Croix. Northern and eastern parts of the watershed appear to contribute the greatest sediment and phosphorus loading to the watershed. Tributaries such as the West Branch and South Branch Sunrise also have high phosphorus concentrations. Rivers that flow directly to the St. Croix provide the greatest loading to downstream areas, while rivers that flow through lakes, impoundments and wetlands likely have at least some of their loads trapped.

Intensive watershed monitoring was performed to assess stream health. Stream areas with the best overall health included the Sunrise River below approximately Kost Dam. The North Branch was generally of moderate health, with several locations that met standards for biotic health, but a couple locations that resulted in scores below standards. Streams with poor health included the upper Sunrise; as well as the West Branch and South Branch Sunrise. Some of these impairments in the upper watershed may be due not only to poor habitat and water quality, but also a loss of connectivity caused by several dams.

To augment stream habitat assessments, a geomorphic assessment was conducted on key tributaries. In addition to helping describe existing stream and river habitat, the assessment documented baseline conditions of key geomorphic criteria. Aquatic habitat loss also was described through review of historical wetland conditions. The watershed currently has 75,851 acres of wetlands. Historically, the watershed may have contained about 103,000 acres of wetlands, suggesting a loss of over 27,000 acres of wetland since European settlement. The most dramatic changes have occurred in the far northern and eastern portions of the watershed.

The watershed study evaluated potential changes in water quality resulting from future land-cover and wastewater loads as a result of projected population increases. It also assessed options to reduce phosphorus and sediment loading to the Sunrise River. This included assessing the ability to meet future loading goals identified in the Lake St. Croix Total Maximum Daily Load Study (TMDL; 2012). The TMDL identified goals of annual phosphorus loading reductions from the Sunrise to the St. Croix River of about 8,300 kg/yr (33% reduction).

The conditions that were assessed included:

1. Projected future water quality conditions (future without any actions).
2. Loading conditions with modified agriculture land use practices
3. Loading conditions with modified urban land use practices
4. Loading conditions with wetland restoration actions

A Soil and Water Assessment Tool (watershed model known as SWAT) was configured to the watershed. Potential land use changes were projected based on total population increases of about 32% by 2020; and 54% by 2030. From the 2000s to 2030, phosphorus loads to rivers and lakes in the watershed would increase by 7%, while the total phosphorus load at the mouth of the Sunrise increased about 5%.

The land use conditions identified above were evaluated for their potential to meet the phosphorus reduction goals of the Lake St. Croix TMDL. For agricultural practices, actions such as vegetated filter strips and grassed waterways show promise for loading reductions. However, to get the most benefit, these would be required on most ag lands, which requires some land loss to implement these features (potentially 2 to 3% loss per feature). Measures to reduce soil phosphorus also could have substantial reductions, but would take many years to be recognized, and would require reduced fertilizer applications in the years before and after.

For urban practices, the SWAT model proved ineffective at assessing how well urban changes would reduce loading. That doesn't mean urban practices should be completely ignored. However, they need further evaluation to gain a better understanding of just how effective they may be.

For wetland restoration, the potential to reduce phosphorus loading appears considerable. Modeling suggests that increasing wetlands downstream of the Sunrise River North Pool by 25% and 50% would reduce phosphorus loading to the St. Croix River by about 9% and 19%. Increasing wetlands in the Chisago Lake Improvement District by 25% and 50% reduced loading to lakes by about 11% and 19%.

Basic recommendations are included for protection of water resources, with a focus on water quality. Recommendations include actions that can be undertaken by stakeholders including improved land use and property management, smart development, stormwater management and other activities. Improvement measures in the lower watershed would have a systemic effect to the St. Croix River. Improvements in the upper watershed would have more localized, site-specific benefits.

While this study provides suggestions to potentially meet future objectives, the reality is that environmental conditions and stakeholder priorities change over time. Any of the recommendations in this report should be revisited and considered collaboratively by basin stakeholders moving forward. Stakeholders should work together to refine watershed priorities and management actions to meet these priorities. Their efforts should also include monitoring to evaluate the effectiveness of various actions. Ultimately, successful watershed management can only be done collaboratively and adaptively over time to meet changing conditions. This study provides the baseline for beginning this process, but basin stakeholders must take the initiative to work together on challenging issues to move forward toward improving environmental quality in the Sunrise River Watershed.

1 INTRODUCTION

1.1 Project Authority

The Sunrise River Watershed Study is authorized by a Resolution of the Committee on Transportation and Infrastructure of the U.S. House of Representatives, September 25, 2002:

> *Resolved by the Committee on Transportation and Infrastructure of the United States House of Representatives, That the Secretary of the Army is requested to review the report of the Chief of Engineers on the St Croix River, Wisconsin and Minnesota, published as House Document 462, 71st Congress, 2nd Session, and other pertinent reports to determine whether modifications to the recommendations contained therein are advisable at the present time in the interest of flood damage reduction, environmental restoration and protection, water quality and related purposes to include developing a comprehensive coordinated watershed management plan for the development, conservation, and utilization of water and related land resources in the St. Croix River Basin and its tributaries.*

The Sunrise River Watershed Study was included in the ST. CROIX RIVER BASIN RECONNAISSANCE STUDY 905(b) Analysis Report, which was approved on March 8, 2007. That report included a series of recommendations including integrated watershed analysis and detailed planning for several St. Croix Basin subwatersheds, including the Sunrise River. Federal (Corps of Engineers) interest in the Sunrise River is based on the potential local and systemic benefits of a watershed study.

During the spring of 2007, Chisago County, Minnesota expressed an interest in partnering on a detailed feasibility study for the Sunrise River. The Minnesota Pollution Control Agency also expressed interest in supporting Chisago County in pursuit of a watershed study. Based on the recommendations contained in the 905(b) report, as well as interest expressed by Chisago County, the federal government entered into a Feasibility Cost Share Agreement on December 3, 2007. The study was cost shared 50/50 between the non-federal sponsors and the federal government.

1.2 Purpose of Report and Scope

Although the St. Croix River Basin is generally considered to be of good quality, there is concern water quality and habitat has and will continue to degrade. Since significant watershed protection has been proposed for the St. Croix Basin, it is appropriate that a watershed study should be performed for areas that strongly influence water and habitat quality of the basin. The Sunrise Watershed is believed to be one of the greatest influences on water quality within the lower St. Croix River. As such, a study that would aid in understanding and protecting water quality and aquatic habitat in this watershed will help ensure water flowing to the St. Croix River is of a quality to meet aquatic habitat objectives at locations further downstream.

The primary objective of the study is to prepare a plan for watershed and water quality management and resulting aquatic ecosystem protection and restoration. This includes providing a programmatic overview of key water resource conditions, assessing potential measures to address resource concerns, and providing these observations in a comprehensive watershed study report. Concerns will be addressed within a watershed context, linking conditions on the landscape with key water resource issues. Connections also will be drawn to link environmental values with social and economic values.

The study addresses a number of aquatic resource issues to facilitate watershed planning in the Sunrise Watershed. Interests evaluated were primarily environmental in nature. As a part of this effort, the study investigated opportunities for federal (Corps) construction projects in support of primary watershed objectives. However, no such opportunities for future Corps engineering and construction projects were identified. Recommendations have been made for other entities, primarily local government, to act on to preserve water quality and environmental conditions.

1.3 Project Location

The study area includes the entire Sunrise River Watershed (Watershed) upstream of its confluence with the St. Croix River (Figures 1 and 2), encompassing nearly 383 square miles, all of which are in Minnesota. Major tributaries include the North Branch, West Branch and South Branch Sunrise Rivers. The Watershed includes many miles of stream, river and lake habitat, as well as wetland and uplands.

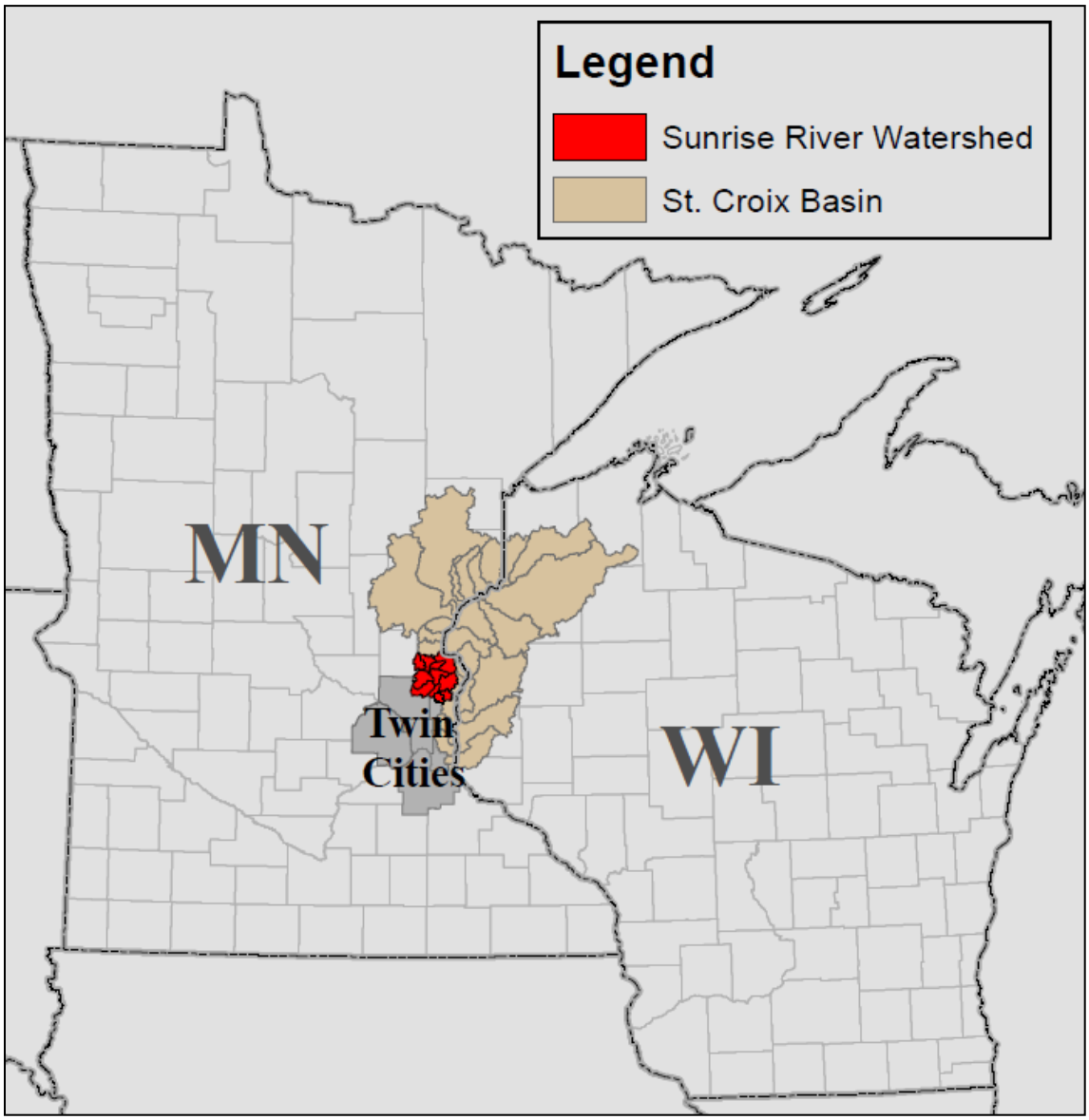

Figure 1: Location of the Sunrise River Watershed in eastern Minnesota.

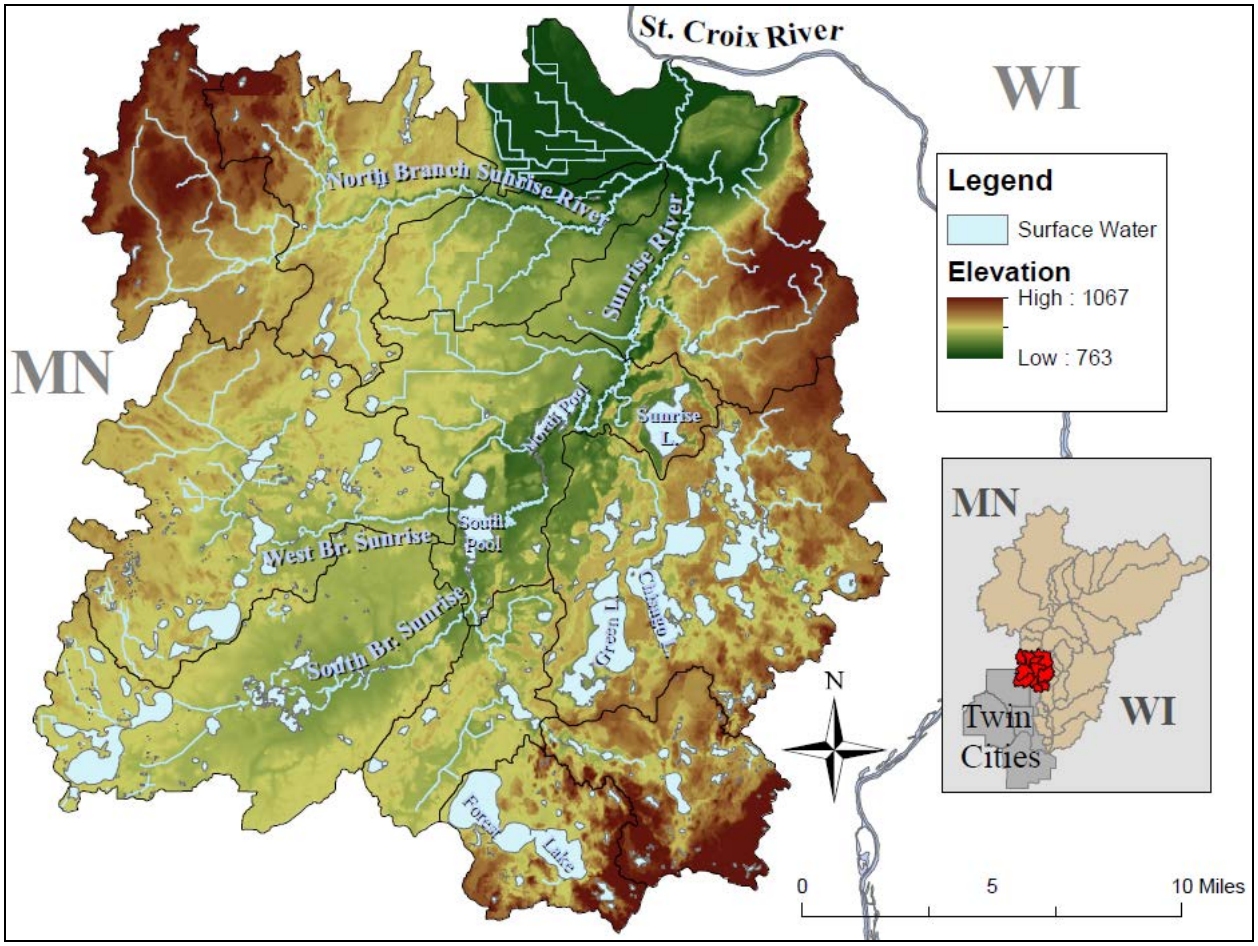

Figure 2: Surface waters and topography of the Sunrise River Watershed.

1.4 Discussion of Prior Studies, Reports, and Existing Water Projects

Applicable studies, reports, and projects include the following:

- Chisago County Local Water Management Plan 2013-2023 and Priority Concerns Scoping Document. Under development by Chisago County, Minnesota. Priority Concerns Scoping Document for this plan was completed in October 2012.

- Lake St. Croix Nutrient Total Maximum Daily Load. Prepared in Partnership by Minnesota Pollution Control Agency and Wisconsin Department of Natural Resources; with St. Croix Basin Water Resources Planning Team, Science Museum of Minnesota, St. Croix Watershed Research Station and Barr Engineering Company. Final May 2012.

- ST. CROIX RIVER BASIN RECONNAISSANCE STUDY Section 905(b) Analysis (Water Resources Development Act of 1986) Minnesota and Wisconsin; USACE, St. Paul District; January 2007.

- St. Croix Watershed Basin-wide Phosphorus Reduction Goal. An interagency team consisting of federal, State and local units of government have teamed up to establish broad goals of total phosphorus reduction in the St. Croix Basin. This includes a broad goal of reducing basin-wide phosphorus loading 20 percent by the year 2020.

- Davis, P. 2004. St. Croix basin phosphorus-based water-quality goals. St. Croix Basin Water Resources Planning Team, August 2004.

- St. Croix River Final Feasibility Report (July 1986): This St. Paul District, Corps of Engineers, report was prepared as a follow-up to the 1984 reconnaissance report. Detailed analysis was performed for flood damage reduction alternatives at Stillwater and New Richmond. The feasibility study identified no structural or nonstructural plans that were feasible for Stillwater. At New Richmond, tentative plans for flood damage reduction were formulated. However, the community decided to discontinue its involvement on the study.

- St. Croix River Reconnaissance Report (January 1984): The St. Paul District, Corps of Engineers, prepared this report to update the evaluation of flood problems and needs in the St. Croix River basin and describe the proposed conduct of this feasibility study.

- Water Resources Subregion Plan for the Saint Croix River Basin (June 1979): This report was prepared by the Upper Mississippi River Basin Commission to describe existing conditions in the basin and recommend a comprehensive water resources plan for the region .

- Upper Mississippi River Comprehensive Basin Study (1972): This report, completed by the Upper Mississippi River Basin Coordinating Committee, suggested a potential flood control project on the St. Croix River consisting of a reservoir near St. Croix Falls.

- The St. Croix National Scenic Riverway, which includes both the Namekagon and St. Croix Rivers, was established in 1968 under the National Wild and Scenic Rivers Act. This riverway begins immediately downstream of Gordon Dam.

- Phase I Report on Study of Flood Control and Related Purposes for St. Croix River Basin, Minnesota and Wisconsin (January 12, 1968): The report examined various problems and needs in the basin including flood control, navigation, water power, irrigation, watershed protection, land drainage, fish and wildlife needs, and recreation. The study concluded that reservoirs would best meet the objectives of an overall plan and offers a solution to the problems and needs of the basin. The report recommended that further study of a multiple-purpose reservoir near St. Croix Falls be undertaken. The study also found that a local flood protection project was feasible for Stillwater, but this measure was not included in the recommended plan. Further study was not begun because of the pending Wild and Scenic River designation of the St. Croix River.

- Plan of Survey for Flood Control and Related Purposes, St. Croix River, Minnesota and Wisconsin (May 10, 1966): This report was prepared by the St. Paul District, Corps of Engineers, and recommended a study to determine the most suitable plan for a multiple-purpose development to meet the water resource needs of the St. Croix River basin, estimate the cost of improvements selected, and determine the economic feasibility of the improvements.

- Review of Reports on St. Croix River, Minnesota and Wisconsin, at Hudson, Wisconsin (January 31, 1940): This report was prepared by the U.S. Engineer Office, St. Paul, in accordance with a resolution by the Committee on Rivers and Harbors of the U.S. House of Representatives. The report found that the need for a small-boat harbor at Hudson was local and that Federal participation in such a development was not justified. A review of reports on the St. Croix River at Stillwater, dated April 24, 1940, recommended no further work.

- Numerous studies and reports have been made on the water and related land resources in the St. Croix River basin. Several reports on the upper Mississippi River basin have also addressed the St. Croix River basin. Listed below are the reports having significance to water resources in the St. Croix River basin.

2. PROJECT OBJECTIVES

2.1 Problems and Opportunities

Problems and Opportunities for the St. Croix Basin

A description of problems and opportunities for the broader St. Croix Basin is provided in the 905(b) Reconnaissance Report (USACE 2007). Key issues are described below.

Recent problems and opportunities for the St. Croix Basin have been focused on environmental concerns. The concerns are as follows: elevated sediment and nutrient loading to the St. Croix River; loss of aquatic and riparian habitat; and aquatic invasive species. Endangered aquatic species recovery also has received considerable attention in the basin. Watershed planning was favorably sought as a way to holistically address environmental concerns in the basin. Some concerns with flooding have previously been identified, though recent concerns were relatively smaller in scale that involved few people. No focused flood damage reductions needs were identified through the 905b.

Detailed planning specifically for St. Croix Basin phosphorus management has been underway for several years. It has recently culminated in a Final Total Maximum Daily Load Study (TMDL) for Nutrients, produced in partnership between the Minnesota Pollution Control Agency and the Wisconsin Department of Natural Resources (TMDL 2012; Figure 3). Through this lengthy process, the TMDL has proposed a standard of 40 µg/L total phosphorus (June through September mean concentration) be implemented for protection of Lake St. Croix (lower St. Croix River). Extensive study indicates that this level best represents the state of the lake in the 1940s prior to extensive land use changes in the basin and the modernization of agricultural practices (TMDL 2012). The TMDL also sets goals of 12 µg/L Chlorophyll-a, and 1.5 m, Secchi depth.

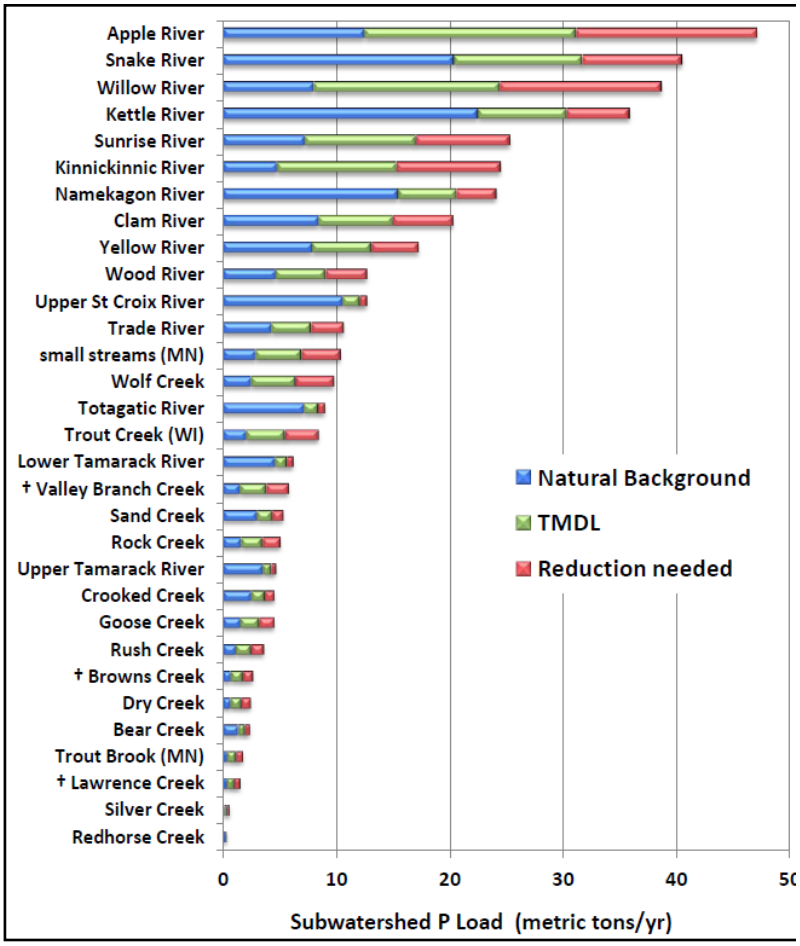

Figure 3: Lake St. Croix Sub-watershed Phosphorus Export for all major subwatersheds. (Source TMDL 2012).

Within this TMDL, the Sunrise Watershed was identified to have phosphorus exports of over 36,000 lbs/yr (TMDL 2012). Only a small percentage of this is from natural sources (Figure 3; TMDL 2012). The TMDL targets a goal of phosphorus export reduction of about 11,800 lbs/yr, or approximately 33% to meet phosphorus targets in Lake St. Croix (TMDL 2012).

Problems and Opportunities for the Sunrise River Watershed

As discussed above, water quality has become a major focus in the St. Croix Basin, particularly in terms of total phosphorus loading. Previous studies suggested that the Watershed is a major contributor of phosphorus and sediment to the St. Croix River (Figure 4; Lenz et al. 2003). Given the strong desire to reduce phosphorus loading to the St. Croix River, the Sunrise is a primary target for future water quality management. In addition to broad loading concerns, impaired water quality also has been identified for several individual surface waters in the basin.

In addition to water quality concerns, a focused effort was made to identify additional key water resource issues for consideration within this watershed study. This included scoping meetings with local and State resource agencies, as well as the general public. These open meetings were meant to identify the range of potential water resource issues/concerns within the Watershed. Through this process, study interests were identified that were almost entirely environmental.

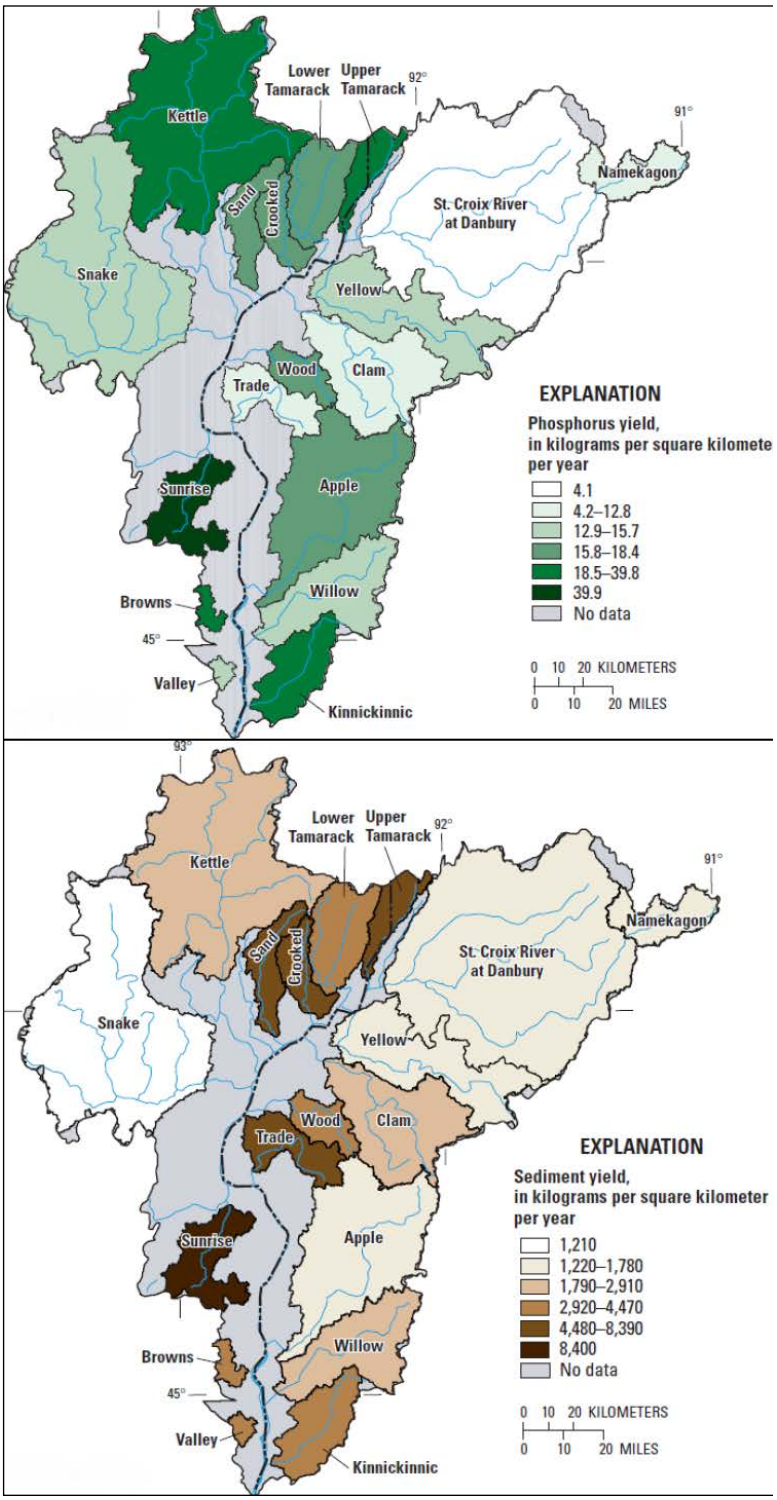

Figure 4: Phosphorus and sediment yield during 1999 for St. Croix basin tributaries. Figure obtained from Lenz et al, 2003.

The watershed contains an abundance of water resources including lakes, wetlands, streams and rivers. Unfortunately, degradation has occurred in many areas of the Watershed. This has likely occurred due to several factors, including broad land use changes, development and point-source pollution. Moreover, this area has the potential for extensive future development given its close proximity to the Twin Cities metropolitan area. Degradation of water quality will continue in the future with additional development, particularly if development progresses without careful management. This degradation will not only impact local water resources, but also the downstream St. Croix River.

Problems or concerns identified by the sponsor and local constituents included the following:

- Existing impairments to Watershed surface waters.
- Elevated nutrient levels and nutrient loading to lakes, tributaries and St. Croix River.
- Impact of future development on water and habitat quality.
- Lack of understanding of groundwater movement, especially in the Chisago Lakes area.
- Lack of a comprehensive knowledge of historical and existing wetland conditions.
- Loss of wetland habitat and wetland function.
- Reduced habitat quality, particularly for riparian habitat and sensitive aquatic habitat.
- Continued spread and resulting impacts of invasive species.
- Protection of aquatic endangered species within the St. Croix River.

2.2 Planning Goals and Objectives

Planning objectives for this study were developed through collaboration with project sponsorship and local stakeholders. Chisago County is concurrently developing a County Water Management Plan to guide future water resource management. The majority of Chisago County falls within the Sunrise Watershed. The Chisago County Water Plan has developed goals and objectives around the following basic interests or resource areas:

- Protecting quality and quantity of groundwater
- Monitor and manage for aquatic invasive species
- Address noncompliant septic systems
- Improve land use practices to protect water quality and the environment
- Make informed decisions on future land use and water resource management, including adaptive management and monitoring
- Identify sufficient resources to implement the water plan.

This list includes topics needing strong technical analysis to fully understand the issues at hand. Based on this need, results of the scoping efforts, and the needs of other similar water resource planning efforts, this watershed study established the following study goals. The goals were developed to address specific water resource issues and were fully supported by the project sponsor and key agency partners.

Goal 1: Characterize existing water quality. Develop recommendations to *restore and protect water quality* in order to meet water quality objectives of State and local governments, and citizens.

Goal 2: Characterize existing aquatic habitat conditions. Develop detailed recommendations to *improve and protect aquatic habitat* for prioritized lakes, rivers and wetlands.

Goal 3: Characterize existing wetland conditions, including identifying areas of drained wetlands. Develop recommendations to *restore, protect and conserve wetland functions*.

Goal 4: Characterize general groundwater resources. Develop an understanding of how lakes within the Lake Improvement District interact with groundwater. Develop recommendations to *identify and protect ground water recharge areas*.

Goal 5: Develop detailed and comprehensive recommendations for *land use management, development and growth* that are consistent with goals identified in this study.

Goal 6: Develop action plan to *prioritize, evaluate and implement recommendations of this study* that may include new regulatory and voluntary policies, education and marketing and identifying potential funding sources.

2.3 Watershed Study Approach

Building upon these identified watershed problems, opportunities and objectives, collaboration with the sponsor during development of the project management plan identified a series of specific priority issues for analysis within this watershed study. They included:

Priority Water Resource Issues Evaluated:

1. Water quality, including nutrient and sediment transfer
2. River and tributary aquatic health assessment
3. River and tributary geomorphic assessment
4. Wetlands resource assessment
5. Groundwater assessment for Chisago Lakes area
6. Future land use and alternative BMPs assessment

The study characterized existing conditions for each of these priority water resource issues. Given the primary concern for water quality conditions in light of potential future development, a watershed modeling analysis was performed to consider how future development might affect future resource conditions for future loading of phosphorus and sediment throughout the Watershed. The modeling exercise also evaluated how alternative land use practices, including agricultural BMPs, Urban BMPs, and wetlands restoration might influence phosphorus and sediment loading. Based on these results, recommendations are then provided to minimize the effects of future development on priority water resource issues. The report concludes with broad recommendations to best meet the study goals identified above.

2.4 Resource Significance

St. Croix Basin

Resources of the St. Croix River basin are ecologically, economically, and culturally significant. At least four federally listed endangered mussel species occur in the basin: the Higgins' eye pearly mussel (*Lampsilis higginsii*), winged mapleleaf (*Quadrula fragosa*), snuffbox (*Epioblasma triquetra*) and spectaclecase (*Cumberlandia monodonta*). The winged mapleleaf is especially representative in that it

was historically found in 34 rivers in 12 states. Habitat degradation has reduced winged mapleleaf to only a couple remaining populations in the world, one of which is a confirmed reproducing population limited to a single stretch of the St. Croix River. Given their life history, mussels are excellent indicators of habitat quality. As such, the high-quality habitat provided by this midsize river is extremely rare.

In addition to its ecological importance, the St. Croix River basin is heavily used for recreation. Portions of the basin are federally recognized for their scenic and recreational importance. The St. Croix National Scenic Riverway, which extends 252 miles, includes the majority of both the St. Croix and Namekagon Rivers. The upstream extent of the Wild and Scenic River designation begin at Gordon Dam of the St. Croix Flowage.

Given its proximity to Minneapolis/St. Paul, as well as several communities in western Wisconsin, the basin is within easy access of more than 3 million people. This location subjects the watershed not only to heavy recreational use, but also to urban expansion and growing population. These pressures increase the potential for stressors to water resources within the basin. These stressors will threaten the ecological integrity that is so important within the basin.

In addition to the ecological, recreational and aesthetic resources identified above, the basin also provides important economic values. The southern part of the basin includes extensive agricultural use that provides important economic income for the area. Recreational use of the basin brings in tourism dollars. Urban growth and development in the area has been and will continue to be important for the local economy, especially in the southern part of the basin.

Sunrise River Watershed

Significance will be described in terms of technical, public and institutional significance, as required by Corps policy (ER 1105-2-100).

The Sunrise Watershed is a major source of nutrient and sediment loading for the valuable St. Croix Basin described above. As such, the Watershed is critical in determining water quality, sediment transport and other functions that drive habitat quality in the downstream St. Croix River. For these reasons, the Watershed is technically significant.

The watershed contains an abundance of water resources including lakes, wetlands, streams and rivers. These surface waters are important to the area providing not only ecological value, but social, recreational and economic value. Many local communities are centered on these aquatic resources. Recreational use of the watershed is high and brings in dollars through tourism. Land in the area, particularly water front property, is highly desirable and is an important source of revenue (via property taxes) for local governments. The vast majority of waterfront property is for permanent, year-round residency. The development within the area, including extensive development adjacent to water resources, puts great stress on water and habitat quality. For these reasons, the Watershed is publically significant.

The Sunrise River has a great influence on habitat and water quality of the St. Croix River Basin. The St. Croix River, downstream of the Watershed, includes reaches with the endangered Higgins' eye and winged mapleleaf mussel. Early studies have identified the Sunrise Watershed as having among the highest loading yields for both phosphorus and total suspended solids in the entire St. Croix Basin. Substantial planning has been performed by State and local agencies to address nutrient and sediment

concerns in areas of the St. Croix River downstream of the Watershed. As such, addressing water quality problems in the Watershed appears paramount to improving water quality in the St. Croix River. This was one of the critical drivers to perform this watershed study. For these reasons, the Watershed is institutionally significant.

2.5 Constraints

Constraints are factors that restricted the planning process or implementation of features. Constraints include legal, policy, funding resources and environmental factors. The study authorization provides the initial study boundaries. In this case, the authorization is quite broad, with the study limited to evaluation of water resource issues within the Watershed. Priority issues were identified through collaboration with the project sponsor, agencies and the public. These issues received the majority of project focus, including available funds. Project funding also is a constraint for the U.S. Army Corps of Engineers, Chisago County and Minnesota Pollution Control Agency, and limited the scope and depth of analyses performed.

2.6 Federal Interest Determination

Opportunities were sought for potential Corps construction projects. Primary focus was for environmental restoration, and considered opportunities in the watershed for wetlands restoration, riparian corridor restoration, and other opportunities. However, no projects were identified that would be good candidates for Corps projects. While the projects considered would result in environmental benefits, cursory review indicated these efforts could best be handled by local entities through basic low cost measures. Both wetland and riparian habitat restoration would likely be based largely on land acquisition. Project proposals that consist primarily of land acquisition are not appropriate for Corps action (ER 1105-2-100). In the absence of any realistic potential projects, no detailed alternatives formulation, design or cost estimation, or formal cost-benefits analyses were performed as part of this study.

This study also does not make any recommendations for additional site-specific project evaluations or watershed studies. The study did not identify any federal (Corps) construction projects, or other activities, that warrants Corps participation. However, it should be reiterated that these analyses and recommendations provide important guidance to local water resource managers and will positively benefit the Watershed and its many residents and users.

3. WATERSHED OVERVIEW

A brief overview of existing conditions is provided for water resources in the Sunrise Watershed. A brief summary of economic, social and cultural resources also is provided. Section 4 provides more detailed discussion of key water resource characteristics, as well as issues identified for evaluation through this study.

3.1 Basic Watershed Characteristics

Watershed Delineation

A surface watershed is the land area where runoff from precipitation drains to a water body or wetland. A watershed is determined by topography and drainage patterns. The methods for delineation of the Sunrise Watershed are outlined by Minnesota DNR (2009). This information resulted in the following watershed boundary (Figure 1), including boundaries for each of the indicated major sub-watersheds.

The watershed area includes the entire Sunrise Watershed upstream of the confluence with the St. Croix River (Figure 2). This includes nearly 383 square miles and is located within parts of Washington, Anoka, Isanti and Chisago Counties.

General Surface Water Features

The Sunrise River Watershed is drained by a network of streams, rivers and drainage ditches that culminate in the Sunrise River. Major tributaries include the North, West and South branches of the Sunrise River. There are an abundance of deep and shallow water lakes in the watershed, ranging in size from almost 2,300 acres down to less than 10 acres. Many lakes are connected naturally, or via man-made connections, and eventually drain to the Sunrise River. The Watershed also includes almost 76,000 acres of wetlands (31% of watershed area).

A major resource feature in this watershed is a series of shallow reservoirs, several of which are associated with the Carlos Avery State Wildlife Management Area (managed by the Minnesota Department of Natural Resources). This wildlife area is located in the central part of the watershed and includes twenty impoundments on or near the Sunrise River, as well as the South Branch (Figure 5). The largest of these impoundments are the South Pool (490 acres, 7ft maximum depth) and North Pool (578 acres; 6ft maximum depth) on the Sunrise River (Figure 2). All of these impoundments are managed specifically to promote the growth of wild rice and attract waterfowl. To this end, water levels during the growing season are maintained at a constant elevation. During winter months, reservoir levels may be drawn down to help control common carp populations and thus help maintain aquatic vegetation. The

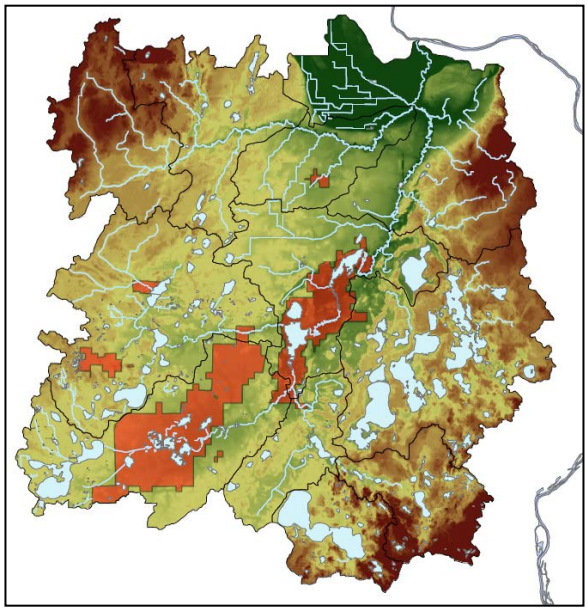

Figure 5: Location of the Carlos Avery State Wildlife Management Area in red shading within the Sunrise River Watershed.

presence and maintenance of these reservoirs certainly influences water quality, sediment transport and other aspects of habitat within the Watershed.

Geology, Soils, and Topography

Geology, soils, and topography provide the foundational drivers of the hydrology and water quality within a watershed. Each plays a role in how much water runs off the landscape or infiltrates to groundwater, as well as the basic chemistry of surface water. Soil type is used to help predict the fraction of precipitation that infiltrates or becomes runoff and the potential movement of pollutants within a watershed. Sandy soils have a greater potential to infiltrate and transport water and contaminants than organic and clay-rich soils.

Soils in the Watershed are comprised of glacial deposits of Late Wisconsinan age (10,000 to 35,000 years ago). The deposits are a complex mixture of glacial till, lacustrine sand, and coarse-grained fluvial outwash from multiple glacial advances and retreats across the area (Figure 6). The last glacial advance was the Grantsburg sublobe of the Des Moines lobe, which moved northeast across the area and incorporated material previously deposited by the Superior lobe (Meyer and others, 1990 as cited in Appendix F). Grantsburg sublobe sediment is described as unsorted, yellowish-brown to gray, loamy texture, with pebbles, cobbles and boulders (Meyer and Lusardi, 2001). Superior lobe sediment is described as unsorted, reddish-brown to reddish-gray, sandy texture, with pebbles, cobbles and boulders. The sediment from each glacial advance is intermixed with sand which was deposited in lakes formed when the Grantsburg sublobe stalled out.

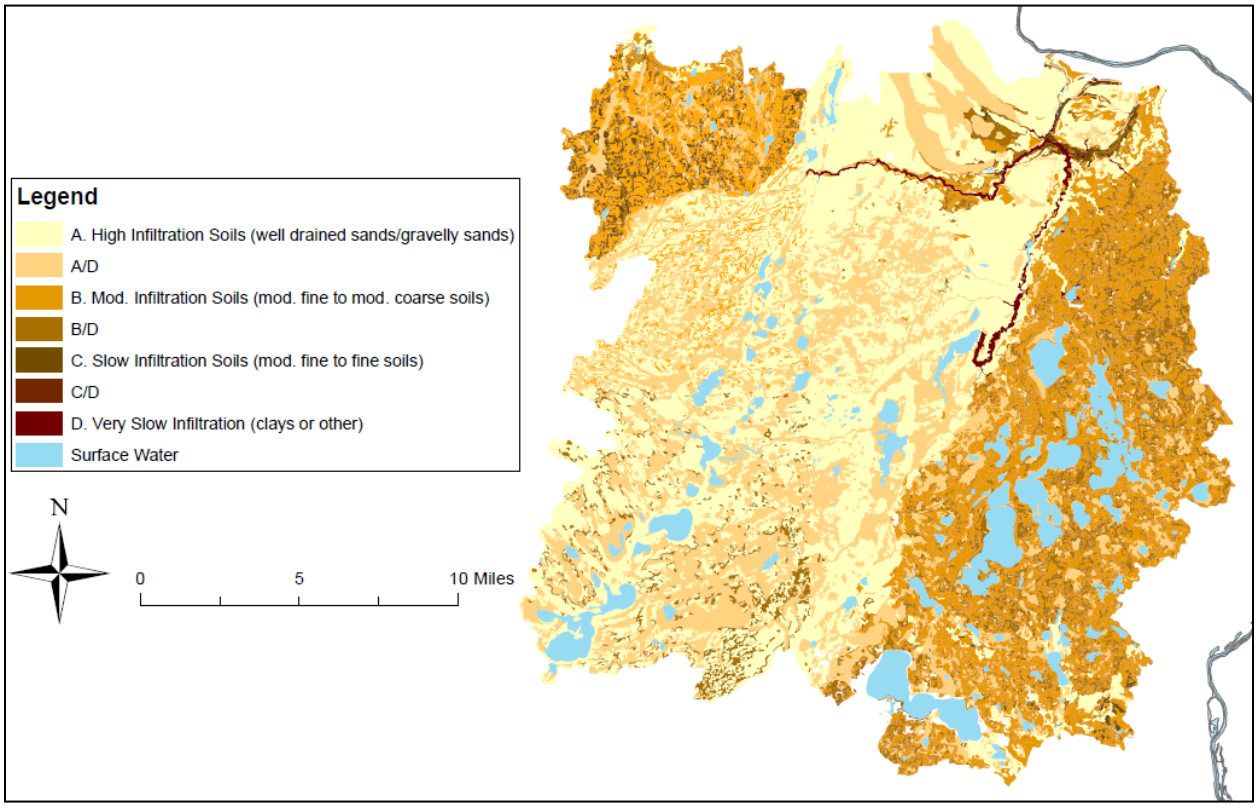

Figure 6: Soil types within the Sunrise River Watershed. Source: USDA-NRCS SSURGGO soil coverage. If a soil is assigned to a dual hydrologic group (A/D, B/D, or C/D), the first letter is for drained areas and the second is for undrained areas. Only the soils that in their natural condition are in group D are assigned to dual classes.

A review was conducted of well driller's logs in the vicinity of the Chisago Lakes area. These logs indicate that bedrock occurs generally 200-300 feet below ground surface (bgs). The uppermost bedrock encountered in the logs is sandstone and shale of the Franconia Formation. A variety of soil layers are present above the bedrock.

The Watershed is covered by a mixture of soil types including broad areas with sand-textured soils, with organic-rich soils in low-lying wetland areas (Figure 6). The permeability of sandy soils is very high, with organic-rich soils in wetland and low-lying river floodplain areas of the watershed have much lower infiltration rates. Although higher infiltration rates reduce runoff volumes, there is an inherent increase in the potential for groundwater contamination. Some of the factors affected by soil type are: the ability of an aquifer to recharge during periods of abundant precipitation or following a drought, the capacity for contaminant removal, and background nutrient concentrations are some of the factors affected by soil type.

Topography plays an important role in water quality by influencing runoff generation, erosion rates, and groundwater recharge rates. The rolling topography, a product of the multiple glaciations of the region, has many gradual slopes which allows for the slowing and infiltration of runoff. Surface elevations in the watershed range from about 763 to 1,060 ft above mean sea level (Figure 2).

Groundwater

A more detailed discussion of groundwater is provided in Section 4 and in Appendix F. In brief, a groundwater watershed is the land area where groundwater flows to wetlands, streams, and lakes. Lake surface and stream elevations during baseflow are considered a reflection of water-table elevations. Groundwater flow paths are assumed to be perpendicular to water-table elevation lines, with groundwater flowing from areas of higher water-table elevation to areas of lower water-table elevation.

A water-table map is a useful tool for the management of groundwater resources. It can be used to identify upland recharge and lowland discharge areas, which can then be afforded the proper consideration or protection. Groundwater flow directions determined from the map allow for the delineation of groundwater watersheds on a smaller scale and this can also assist in land management decisions. For example, if groundwater is entering a lake from the east, a possible management action would be to implement rules to minimize the impacts from septic systems servicing a large number of people on the east side of the lake. Another use of water-table maps is defining wellhead protection areas for high capacity/municipal wells.

Areas of groundwater inflow and the locations of springs were identified for select watershed areas through a search of historical records (Appendix F). Based on well logs, groundwater in area wells ranges from approximately 10 to 60 feet bgs, depending on which geologic layer the well screen or borehole intersects. Shallow groundwater flows mostly in a horizontal direction towards low points such as the Sunrise River, and roughly parallel to the ground surface. Static water levels in shallow wells (less than 50 feet below ground) are generally higher than the wells in deeper aquifers, however, meaning a portion of the shallow groundwater (including lake water) flows naturally downward into deeper geologic layers. This is called a downward vertical flow gradient; it implies water is more likely to drain out the bottom of the lakes and shallow aquifers, and less likely to be recharged from deeper groundwater below.

Climate

The St. Croix River is within the humid continental climate, characterized by variable weather patterns and large seasonal temperature changes. The average annual precipitation for this area is approximately 31 inches. Rainfall in the east central region displays no significant trend over the last 20 years (Figure 7). Though rainfall has varied in intensity on an annual basis, average precipitation in east-central Minnesota has not changed dramatically over this time period.

Although recent trends were not completely obvious, year to year variations certainly occur. During the period of this watershed study, precipitation fell below normal values during select years (Figure 8). The summers of 2006 thru 2009 all generally included dry or drought conditions for the Watershed (Figure 8; U.S. Drought Monitor on-line data). This likely influenced data collected during this study for hydrology and water quality which occurred during open water months.

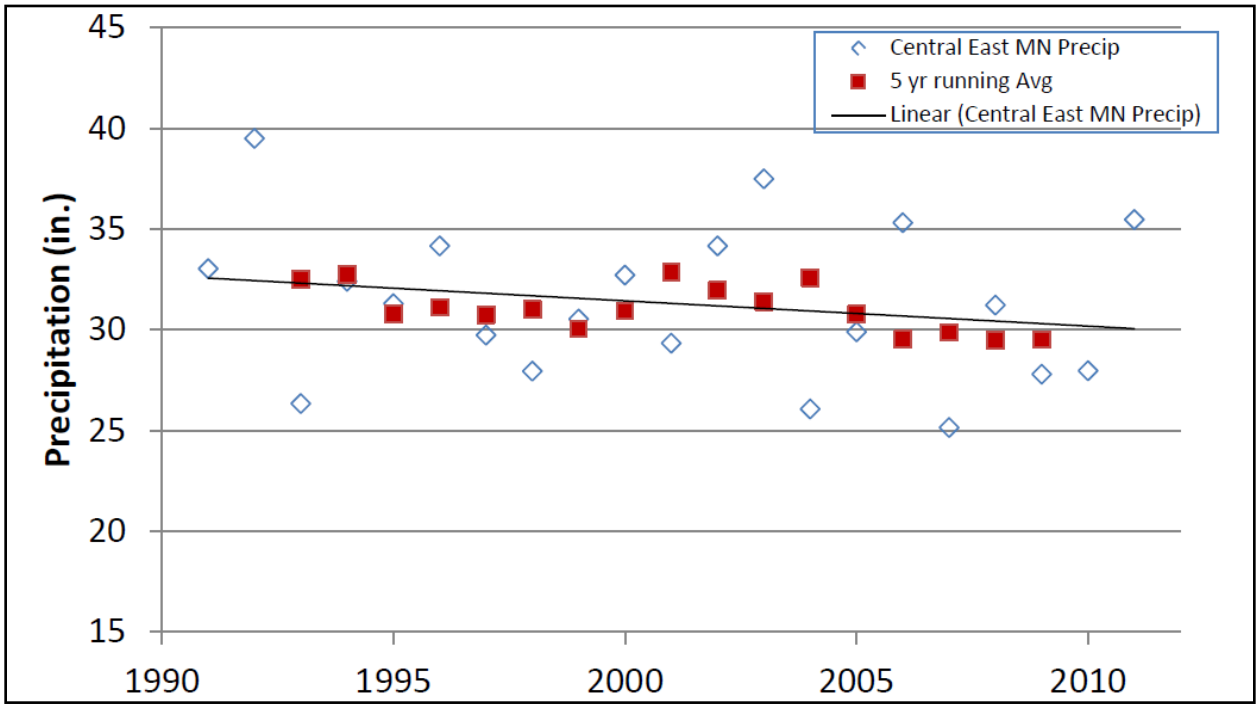

Figure 7: Precipitation trends in east central Minnesota across the last 20 years.

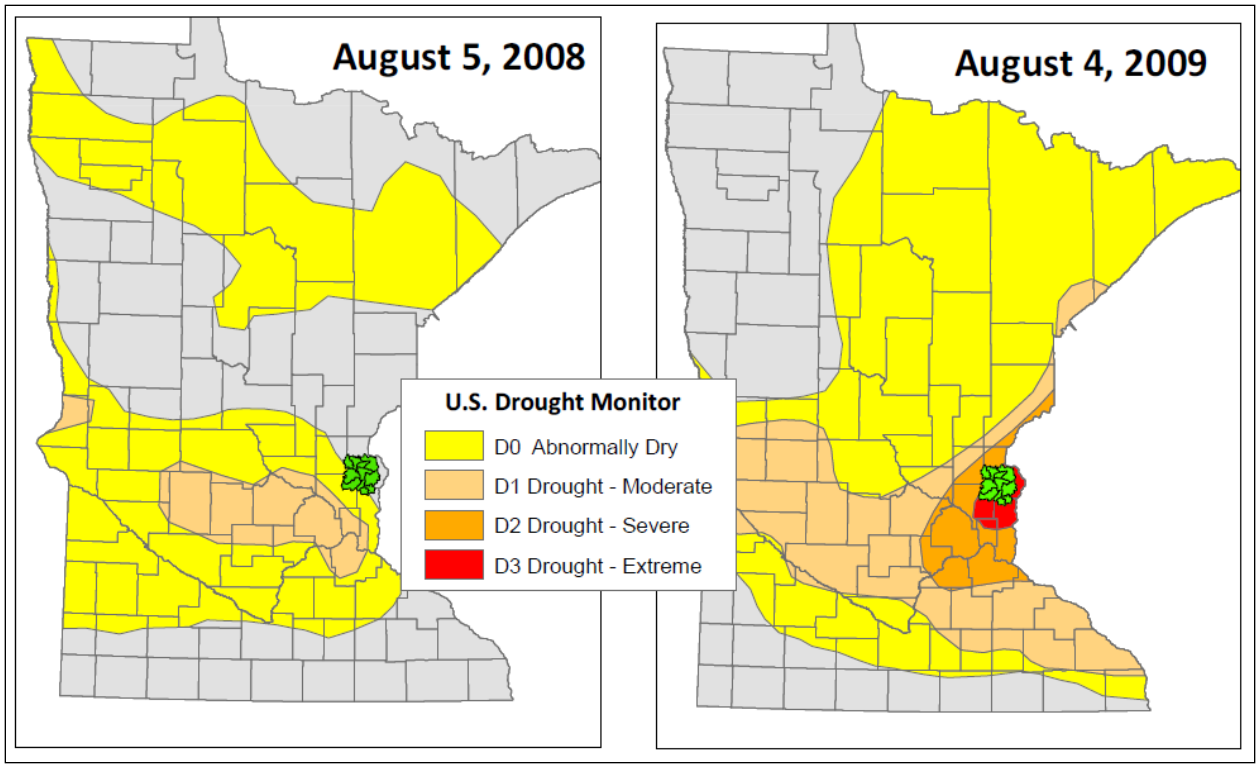

Figure 8: Climatic conditions for the State of Minnesota during August 2008 and 2009. Sunrise River Watershed is in green shading and experienced dry to extreme drought conditions during 2008 and 2009.

Watershed History

Before European settlement, the landscape was impacted by indigenous populations of the region. These populations engaged in intentional burning of vegetation of grasslands and forests to improve travel, encourage the growth of berry producing plants and to attract game to newly forming shoots. This resulted in plant communities that were adapted to fire and generally contained less woody plant and shrub growth. Following Columbian contact 500 years ago, 90% of the indigenous population was wiped out by disease, altering the fire regime, and allowing woody plants and trees to expand into areas previously dominated by grasses (Lentz 2000; as cited in Appendix D).

Farming practices beginning in the late 1800s converted portions of the landscape from predominately deciduous forest, mixed forest, shrublands, and herbaceous wetlands (Chisago County, 2006) to cropland and non-native grasses. These practices have included draining of wetlands, ditching and stream modifications to increase usable agricultural land. Agriculture and its impact to native landscapes remained generally consistent through the twentieth century. However, since 1960, development pressures have also increased in the watershed. For example, the population of Chisago County has quadrupled (273.6%) between 1960 and 2007 and was the sixth fastest growing county in the State between 2000 and 2007. (Minnesota Department of Employment and Economic Development, 2008).

Existing Land Cover

The Sunrise Watershed is located within three ecological landscapes in eastern Minnesota (Figure 9). The Anoka Sand Plain and Mississippi Valley Outwash covers much of the western half of the watershed. It consists of undulating sandy plain with wetlands, some lakes, small grains, row crops, woodlands, and suburban development. The McGrath Till Plain and Drumlins occupies the eastern and northwestern portions of the watershed. This area is generally characterized by undulating and rolling plain with drumlins and mix of woodland, row crops, and pasture. The St. Croix Outwash Plain and Stagnation Plains occurs in the far southeastern portion of the watershed (Figure 10). This includes rolling hills interspersed with depressions of small lakes and wetlands, extensively covered by urban and suburban development, but also pasture and some crops and woodland.

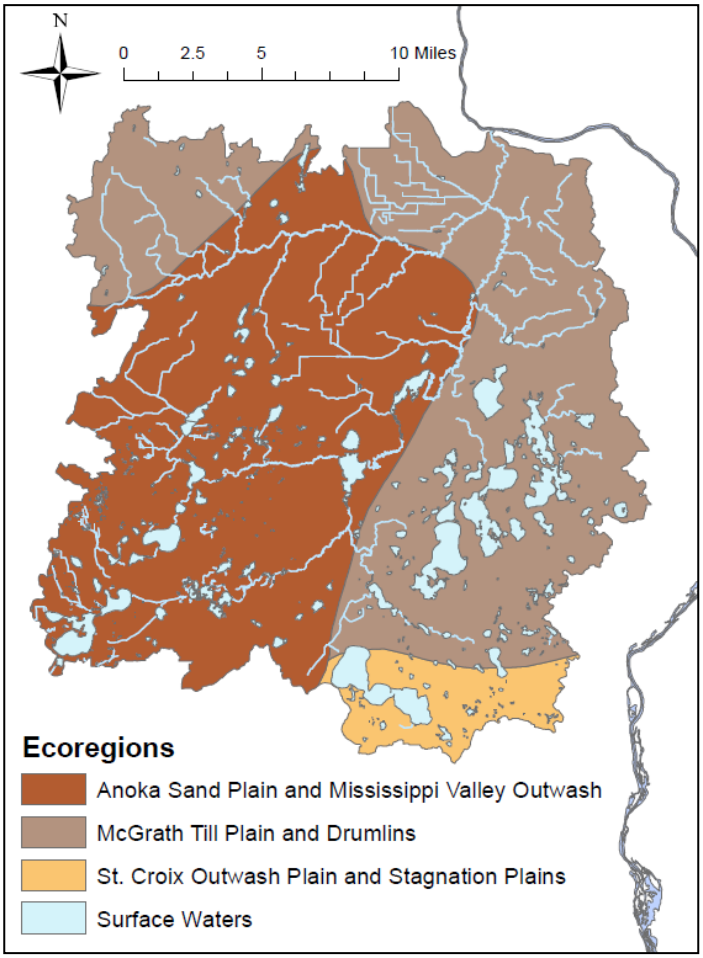

Figure 9: Ecoregions of the Sunrise River Watershed.

Existing Land Use

Both land cover and land use management practices have a strong influence on water quality. Development, whether municipal, industrial or agricultural, often leads to modifications of natural drainage patterns and changes in vegetative cover. Impervious surfaces, such as roads, rooftops and compacted soils, and water diversions via culverts drainage systems and road cuts, can reduce or prevent the infiltration of runoff. This can result in a decrease in groundwater recharge and an increase in the amount of stormwater flowing directly to lakes and streams. The removal of native plants, which provide shade and filter and decelerate runoff, can lead to warmer water and higher sediment and nutrient loads in a water body. Possible long-term effects on a stream from these changes include a decrease in stream baseflow, a flashier stream response to rain events, and an increase in stream temperatures. This effect is more pronounced during periods of below-normal precipitation. The warmer water may distress aquatic organisms and the changed stream bed materials and dynamics may alter the entire stream ecosystem. For both lakes and streams, the removal of riparian vegetation causes an increase in the amount of nutrient rich soil particles transported to the water body during precipitation events.

A variety of land-cover data sets are available that can describe existing land conditions in the Watershed. These include, but are not necessarily limited to the National Land Cover Datasets (NLCD) for 1992 and 2001, University of Minnesota (UM) land cover data sets for 2000 and 2007, and the Crop Data Layers (CDL) for 2006-08. The Crop Data Layer (2007) is provided at Figure 10 for the Watershed.

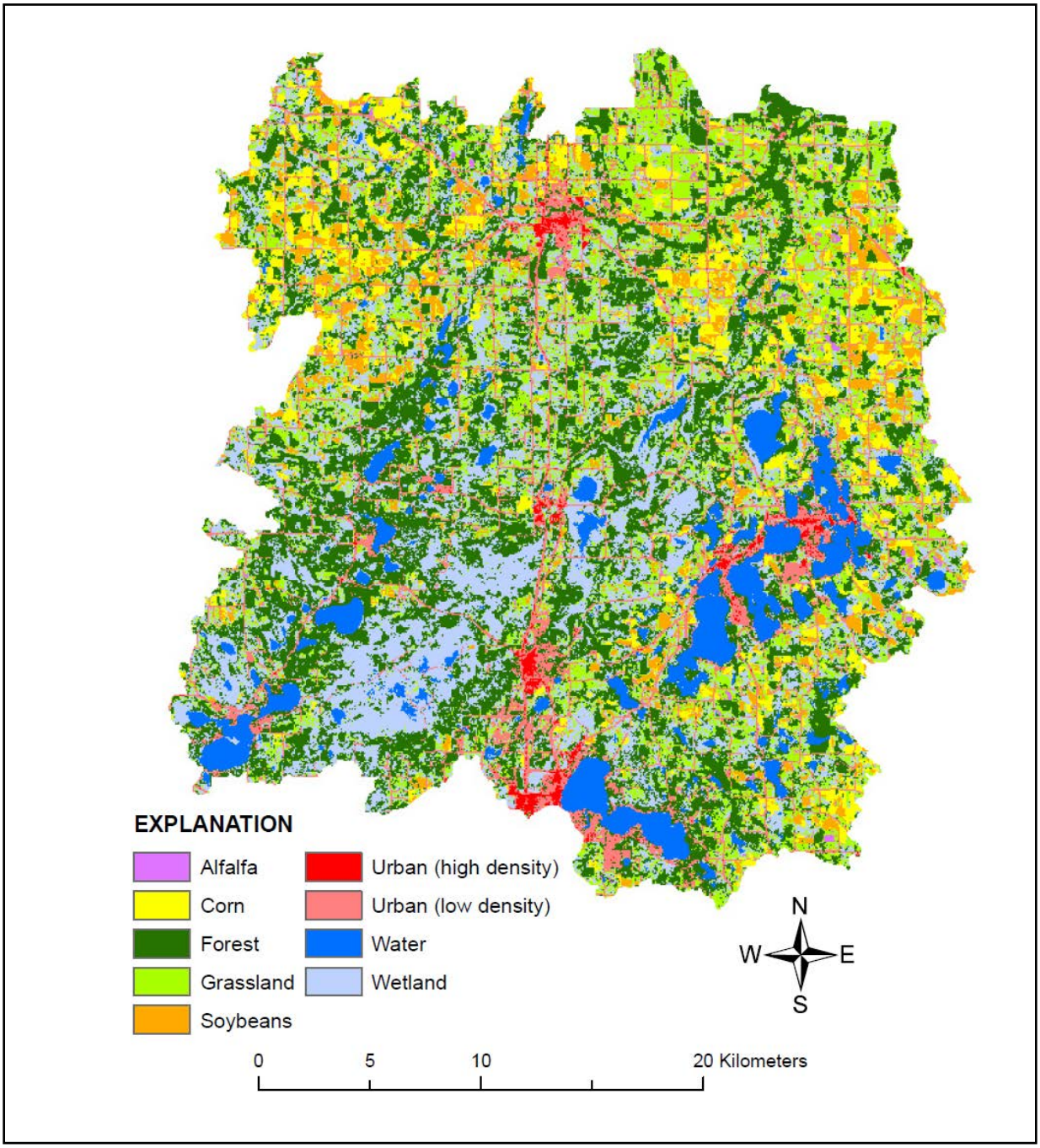

Figure 10: Land cover in the Sunrise River watershed according to the Crop Data Layer (CDL) for 2007.

Impervious Surface

Another important consideration in watershed management is the presence and influence of impervious surfaces. Impervious surfaces, such as roads, rooftops, and compacted soils, can reduce or prevent the infiltration of runoff and increase the amount of stormwater flowing directly to lakes and streams. This can negatively impact water quality and aquatic habitat. Wang et al. (1997) observed that the amount of

urban land had a strong negative relationship with stream biotic integrity, and there appeared to be a threshold between 10-20% urban land use where Index of Biotic Integrity scores declined dramatically. Watersheds above 20% urban land had poor Index of Biotic Integrity scores (Wang et al, 1997). When considering coldwater streams in Minnesota and Wisconsin, Wang et al. (2003) observed that imperviousness of less than about 6% appeared to support quality coldwater fish communities. Imperviousness above 11% resulted in poor quality communities. Between 6% and 11%, minor changes in urbanization could result in major changes in stream fishes.

A recent study by the Center for Watershed Protection (CWP) (Zielinski, J, 2002) correlated watershed imperviousness with stream quality. This study identified levels of degradation when the impervious fraction reached 10 percent and 25 percent and established three minor basin categories. Watersheds with less than 10 percent imperviousness have a "sensitive" watershed classification and are characterized by high quality streams, stable channels, and excellent habitat. Watersheds with imperviousness greater than 10 percent show signs of deterioration whereby sensitive stream elements are lost from the system. Watersheds with greater than 25 percent imperviousness have an "impacted" minor basin classification and are characterized by poor water quality, stream instability and poor biodiversity.

An impervious surface analysis is outlined in Appendix D. Overall the impervious fraction varied from 0 percent to 10 percent in the watershed (Figure 11). Only 7 of the 85 minor subwatersheds had an impervious fraction greater than 5 percent and no minor subwatershed had an impervious fraction greater than 10 percent. All of the minor subwatersheds would be classified as "sensitive" according to the CWP watershed classification and would not be expected to show signs of aquatic degradation. Since many of the streams and lakes in the Sunrise River watershed are defined as impaired by the Minnesota Pollution Control Agency, this suggests that imperviousness does not correlate well with aquatic degradation in this watershed.

Fisheries Resources

The following is a general characterization of fisheries resources based on existing information. Detailed information on aquatic habitat and biotic conditions are presented in Section 4.

Fisheries resources in the Sunrise Watershed include a diverse mix of lake and riverine habitat. Riverine habitat includes warmwater fisheries. Rivers below instream barriers (e.g., Sunrise River below Kost Dam) may have higher diversity via connection with the St. Croix River, a fishery with great diversity and habitat value. The Sunrise River below Kost Dam also has areas with high abundance and diversity of mussels. Mussel's resources are globally imperiled and their protection is important. Measures to improve habitat and water quality also would benefit mussel communities.

The Watershed also includes an abundance of lakes that contain typical cool- and warm-water fish communities for Minnesota lakes. These fishery resources provide recreational values that are used by the public 12 months a year. Although several lakes are identified as impaired, lake use is extremely high. Waterfront property is extremely attractive, and most all land open to development has been built upon. Waterfront and riparian development is an important stressor for water quality and habitat for area lakes.

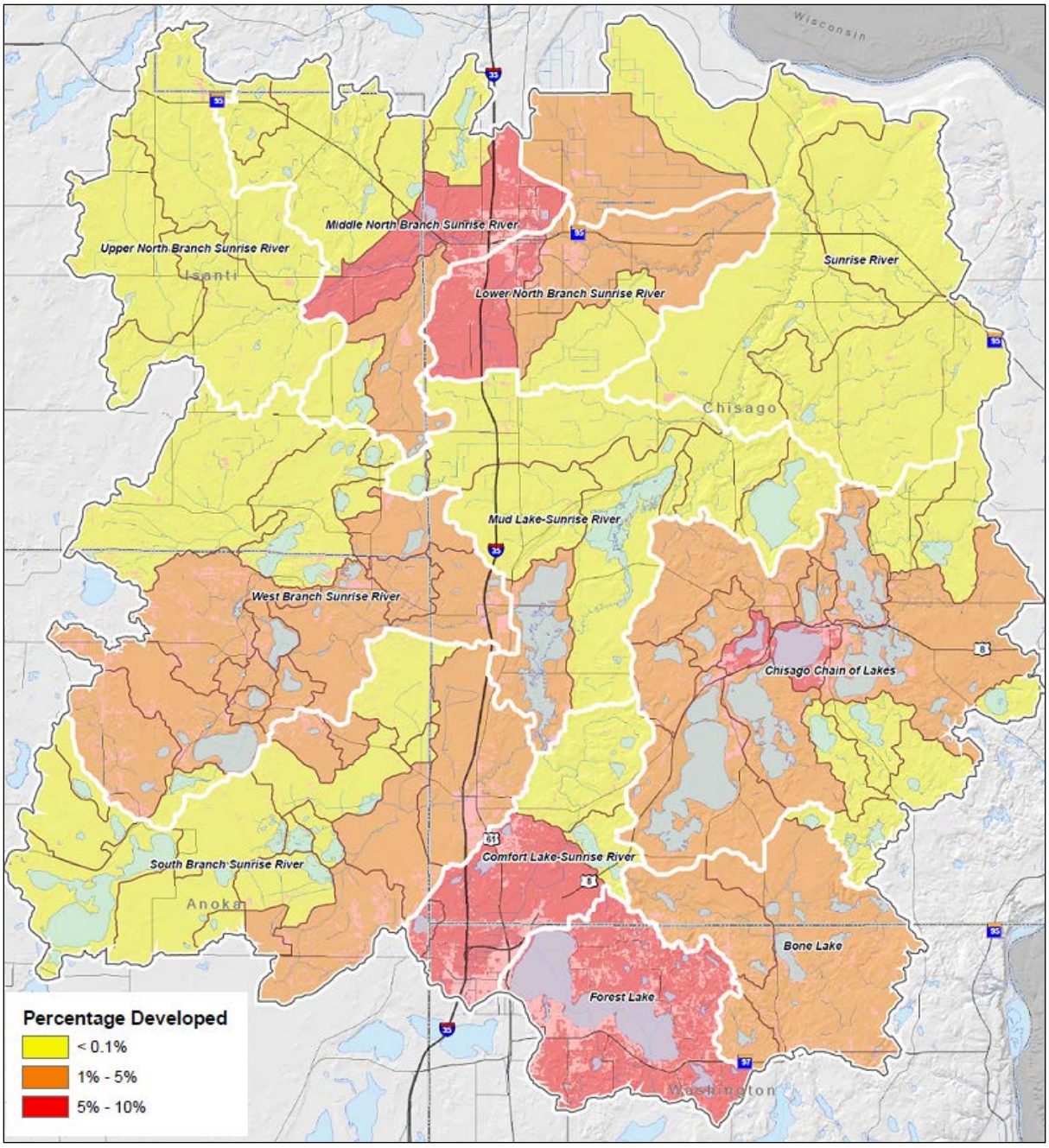

Figure 11: Relative amount of impervious surface, by sub-watershed, for the Sunrise River Watershed.

3.2 Social Setting

The Sunrise Watershed falls within portions of Chisago, Washington, Anoka and Isanti counties in east-central Minnesota (Figure 12). The majority of watershed area is within Chisago County. Population within the watershed is largely located in cities and towns along the major highway corridors of I-35 and U.S. Highway 8. The watershed area is generally considered within "commuting distance" to the Twin Cities metropolitan area, particularly the southern portion of the watershed. In 2010, workers from Chisago County had a mean travel time to work of 32 minutes, likely reflecting this commute.

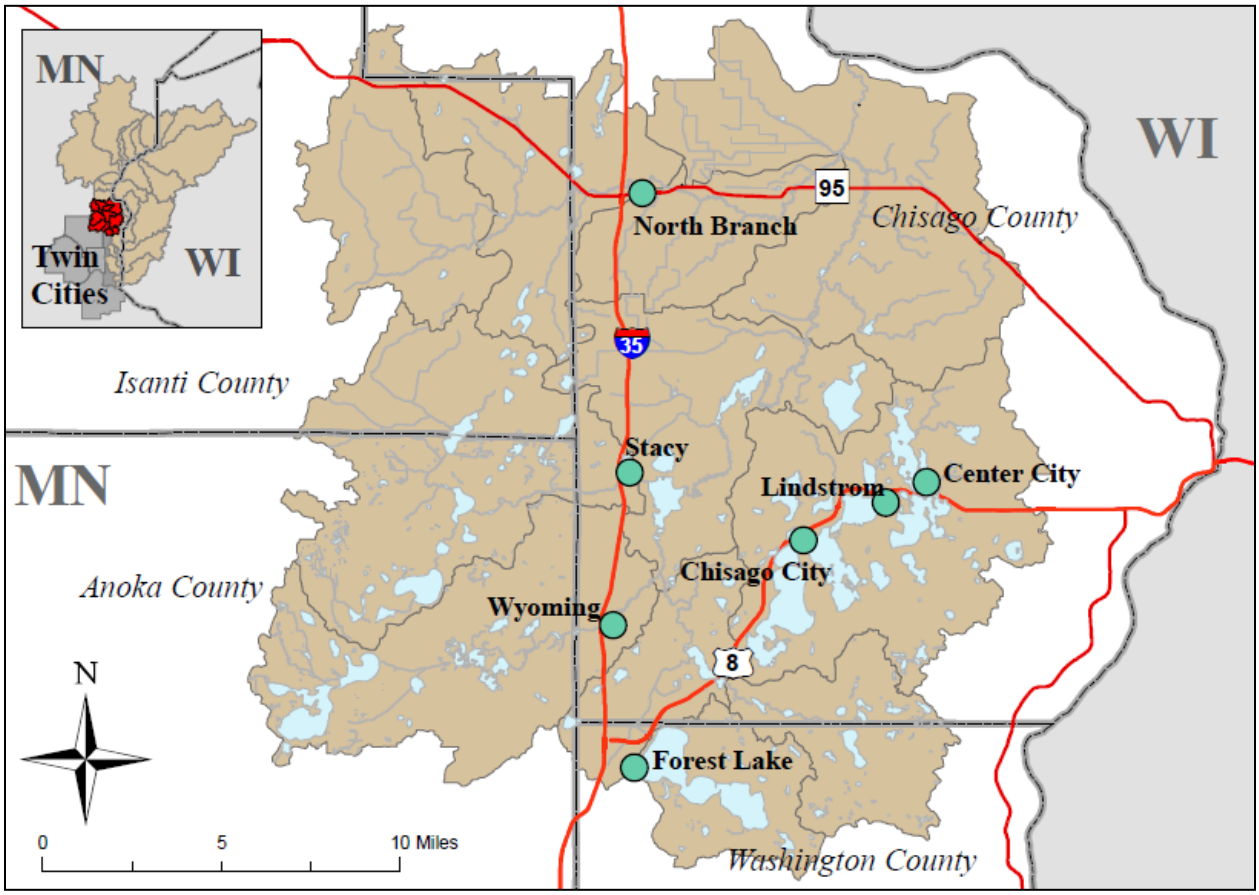

Figure 12: Social setting of the Sunrise River Watershed.

The population of the primary cities within the watershed is provided in Table 1, with further discussion in Appendix B. At the beginning of the 2000s, this general area was one of the fastest growing locations in Minnesota. The 2000 U.S. census predicted a 39% growth in population for the lower St. Croix Basin by the year 2020 (SCBWRPT 2004). Recent projections for the four counties under consideration here still suggest increases in population of approximately 32% by 2020, and 54% in 2030 (Appendix B). Given the general economic slow-down since 2008, these growth predictions seem large. However, it is likely these population increases will occur at some point in the future, if not by 2020 and 2030.

Recreational use is extremely important in the watershed and provides social and related economic values. Recreational use of water resources is especially important given the large numbers of lakes and rivers in the watershed. Recreational activities include boating, swimming, fishing, scenery or wildlife observations and canoeing/kayaking.

The Carlos Avery State Wildlife Management Area is a major recreational feature in the central part of the watershed. The area is managed primarily for deer, waterfowl and turkeys; it is very popular for both hunting and for bird watching. The area includes 18 wheelchair accessible blinds that are available for use during the turkey season or as part of periodic special deer hunts. The area also includes 4,500 acres that are posted as Wildlife Sanctuary and closed to all trespassing.

Another social and economic value for the Watershed is water front property. Water front property in the region is valued higher than land-locked property. Because waterfront property is valued higher, the resulting property tax revenue also is higher. This is valuable revenue for local government and provides important financial benefits. While much of this report focuses on environmental protection, it also should be recognized that waterfront property is a tremendous financial benefit to the local units of government that are in the Watershed.

Table 1: Estimated population for cities and townships who's center lies within the Sunrise River Watershed (further explained in Appendix B).

Name	**Population**				
Anoka County	**1990**	**2000**	**2010**	**2020**	**2030**
Linwood Township	3,588	4,668	4,920	5,000	5,400
Chisago County					
Center City	481	582	687	803	894
Chisago City	2,022	2,622	4,821	5,695	6,392
Lindstrom	2,586	3,015	4,568	5,651	6,541
North Branch	4,267	8,023	13,635	19,883	25,267
Stacy	1,089	1,278	1,491	1,707	1,874
Wyoming	2,163	3,048	4,421	5,642	6,660
Chisago Lake Twnshp	2,888	3,276	4,078	4,685	5,156
Lent Twnshp	1,789	1,992	2,702	3,191	3,582
Sunrise Twnshp	1,125	1,594	2,298	2,926	3,449
Wyoming Twnshp	2,946	4,379	4,221	5,460	6,501
Isanti County					
North Branch Twnshp	1,486	1,654	2,065	2,433	2,752
Oxford Twnshp	638	799	1,085	1,371	1,619
Washington County					
Forest Lake	12,523	14,440	22,200	33,300	38,300
New Scandia Twnshp	3,197	3,692	4,370	5,000	5,400
Total	**42,788**	**55,062**	**77,562**	**102,747**	**119,787**

NOTES: Data for 1990 and 2000 were from the U.S. Census Bureau. Projections for 2010, 2020 and 2030 for Anoka and Washington counties were from the Metropolitan Council of Minnesota. The same future projections for Chisago and Isanti counties were from the Minnesota State Demographer's office.

One last social-economic relationship to note is the positive relationship that exists between water quality of surface water and the value of adjacent property. Select studies have been conducted that to document this relationship. Some studies have even quantified the effect that water quality can have on property values similar to the effects of structural or locational qualities. Work done by the North Temperate Lakes – Long Term Ecological Research (NTL-LTER) program has demonstrated important economic and ecological links among property valuation, shoreline zoning regulations and water quality (Provencher 2005). While zoning regulations may adversely affect the value of a parcel of land due to

use restrictions, the improvements to water quality and general aesthetics that lake-wide regulation provides may enhance property values. Improvements in water clarity of Vilas County lakes, for example, have been shown to raise the value of undeveloped lakeshore property by about 3.6 percent (Provencher 2005). Another study in Maine concluded that water clarity significantly affects property values around lakes (Holly et al 1996). A 1-meter improvement in water clarity resulted in increased average property values ranging from $11 to $200 per foot of lake frontage. These findings provide support to the economic value of clean and healthy waters.

4. EXISTING CONDITIONS FOR PRIORITY WATER RESOURCE ISSUES

Building upon these identified watershed problems, opportunities and objectives, collaboration with the sponsor during development of the project management plan identified a series of specific priority issues for analysis within this watershed study.

Priority Water Resource Issues Evaluated:

1. Water quality, including nutrient and sediment transfer
2. River and tributary geomorphic assessment
3. River and tributary aquatic health assessment
4. Wetlands resource assessment
5. Groundwater assessment for Chisago Lakes area
6. Land use and smart growth development

Detailed evaluations were performed to address these priority issues. These evaluations are included as technical appendices to this report and were used heavily, along with existing information, to summarize and evaluate conditions in the Watershed. These technical appendices include:

A1. Constructing a SWAT model of the Sunrise River watershed, eastern Minnesota.
A2. Applying a SWAT model of the Sunrise River watershed, eastern Minnesota, to predict water-quality.
B. Lower St. Croix River Watershed Monitoring and Assessment Report.
C. Sunrise River Geomorphic Study.
D1. Sunrise River Watershed - Inventory of Historical and Aerial Extent of Aquatic Resources.
D2. Sunrise River Watershed - Identification and Formulation of Compensatory Mitigation Opportunities.
E. Lake to Groundwater Study Interaction.

This report considers this available information to make recommendations for future watershed management, including what measures may be appropriate to meet priority watershed issues.

4.1. Hydrology and Water Quality

Water quality has become a major environmental focus in the St. Croix Basin, particularly in terms of total phosphorus loading. Previous studies have suggested the Sunrise Watershed is a major contributor of phosphorus and sediment to the St. Croix River. Water quality also has been identified as an impairment to several surface waters in the Watershed.

Within this study component, detailed evaluations were done to better understand water quality and hydrology of surface waters. Focused evaluations were performed for several river/stream areas. Studies also were performed to understand general contributions, flow and quality of groundwater. Sediment and nutrient loading were a priority issue for stakeholders and has been included in this assessment. An assessment of how future development could impact water quality also was performed through use of the Soil and Water Assessment Tool (SWAT). This specific evaluation will be discussed in Section 6. Lentic (lake) environments included review of available historical data.

Water quality variables considered within this analysis focused on phosphorus and suspended sediment as these are constituents of interest. Data was also collected for nitrogen, chloride (an indicator of human disturbance), and other variables. The collection and analysis of this data culminated in the development of a SWAT model calibrated to conditions in the Sunrise River. This allowed for a more

detailed assessment of hydrology and constituent loading throughout the watershed. The specific reports outlining the development of the Sunrise River SWAT model are included in Appendix A and B, and are summarized here. Data was collected from the field at key points in the watershed. Loading out of the flowage thus represents what is being released to the St. Croix River at the beginning of its Wild and Scenic River Designation.

Watershed and Stream Hydrology and Water Quality

The following discussion focuses on hydrology and water quality conditions for rivers and streams contributing to the St. Croix River. Figure 13 demonstrates the locations where hydrology and water quality variables were measured. This data allowed for the calculation of loading estimates.

Hydrology

Streamflow data at several points in the Sunrise watershed were collected from various time periods by different agencies from 1998 through 2009 (Appendix A). Daily mean flows near the outlets of many St. Croix tributaries, including the main stem Sunrise River at Sunrise, were reported for water year 1999 by Lenz et al. (2003), in a cooperative study between federal agencies (USGS and NPS) and State agencies (WDNR, MPCA, and MDNR). Since that study, State and local agencies have continued flow monitoring at selected sites during the ice-free seasons. Daily mean flows were available for 2006-08 for the main stem near the confluence of the St. Croix River (G. Flom, MDNR, unpublished digital data, 2009), and for 2005-08 for the North Branch at Hwy 95 (C. Klucas, MPCA, and C. Thiel, Chisago SWCD, unpublished digital data). In addition, flows were available for parts of 2008-09 at four other sites: Sunrise at Hwy 14, Sunrise at Comfort Lake, West Branch Sunrise at Lyons, and South Branch Sunrise at Hwy 30 (E. Stefanik, USACE, unpublished digital data, 2009). Figures 14 and 15 provide a general idea on seasonal hydrologic conditions for the Sunrise and North Branch Sunrise rivers during these years. However, it should be noted that the summers of 2006 thru 2009 all generally included dry or drought conditions for the Watershed (U.S. Drought Monitor on-line data). Figures 14 and 15 thus represent flows during dry periods. SWAT estimates of average flow during the period 2006 thru 2008 for the Sunrise River at Sunrise are 151 cfs. Conversely, SWAT estimated the long-term average flow for the Sunrise River at Sunrise at about 193 cfs (estimated 20-year average flow for the period 1990-2009). Similarly, the SWAT average flow for the North Branch for the period 2005 thru 2008 was 60 cfs. The long-term SWAT average flow (1990 thru 2009) for the North Branch at Hwy 95 was estimated at 64 cfs (Appendix A and B).

Real-time stream gage data is available via the Minnesota DNR/PCA cooperative gauging site for the Sunrise: http://www.dnr.state.mn.us/waters/csg/site_report.html?mode=getsitereport&site=37030001

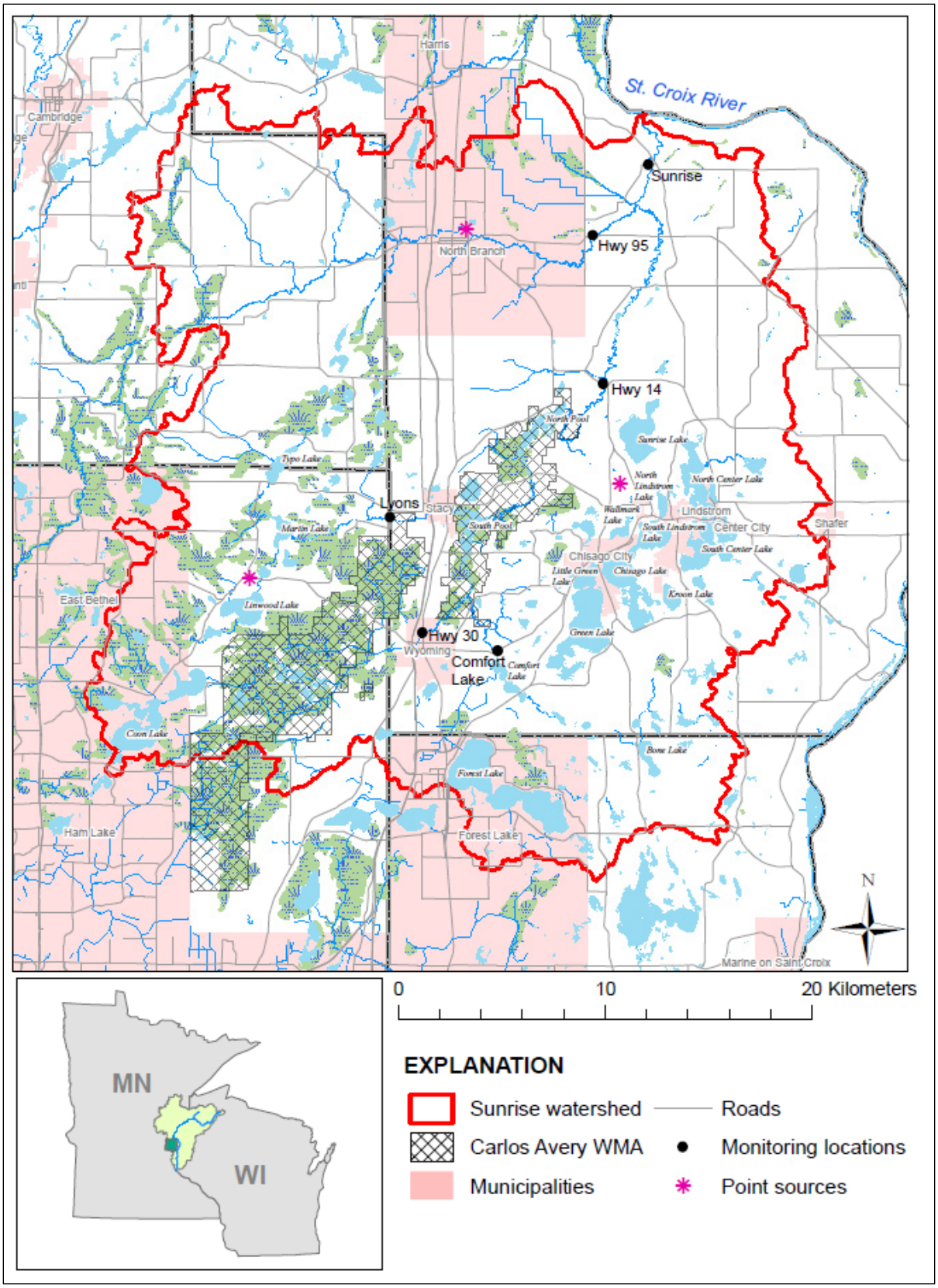

Figure 13: Monitoring location for stream discharge and water quality on tributaries and the main stem of the Sunrise River.

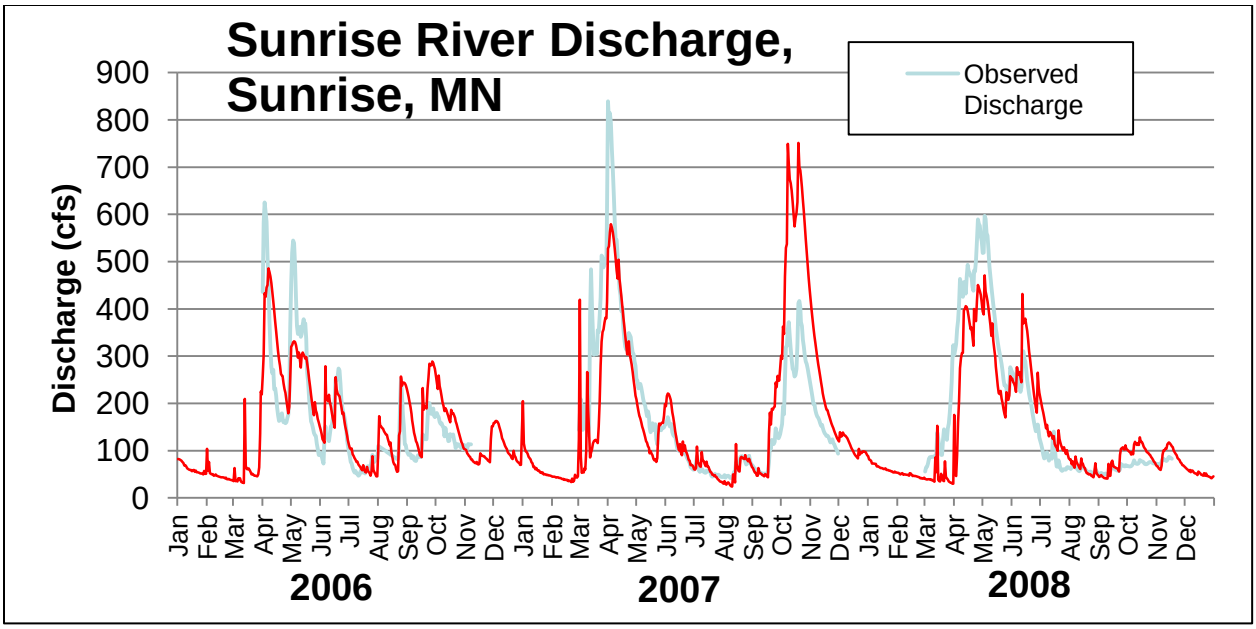

Figure 14: Observed and modeled daily mean discharge (cfs) for the Sunrise River at Sunrise, MN (just upstream of confluence with St. Croix River) for the period 2006 thru 2008.

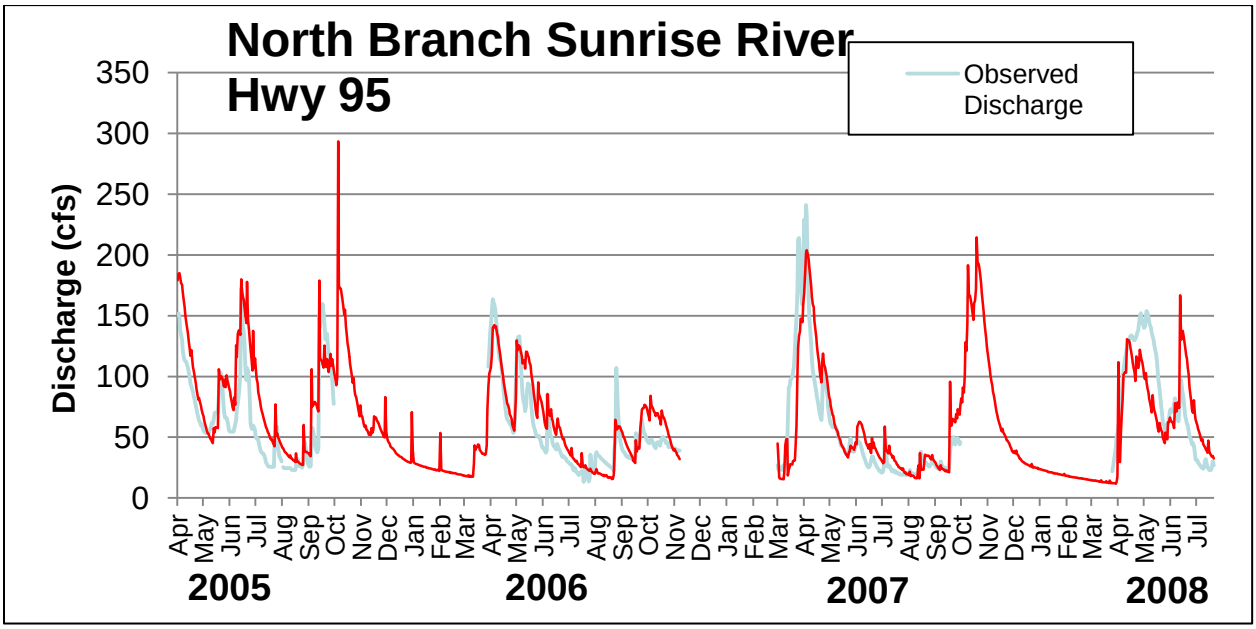

Figure 15: Observed and modeled daily mean discharge (cfs) for the North Branch of the Sunrise River (at Hwy 95 just upstream of confluence with Sunrise River) for the period 2005 thru 2008.

Basic Water Chemistry

Basic water quality characteristics are discussed here for watershed rivers. Specific water quality impairments are discussed here, as well as under aquatic stream health (Section 4.2). During this study, observations for stream pH levels typically ranged from 7.9 to 8.3 for the Sunrise, North Branch and West Branch Sunrise rivers. The West Branch Sunrise River (Hwy 77) has seen historic values as low as 6.2. This is potentially due to high nutrient levels and algal respiration driving the swing in pH values.

For dissolved oxygen (DO), point measurements for the Sunrise, North Branch and West Branch were typically above 7 parts per million during the spring and summer months. However with the great variability that can occur with D.O. both daily and seasonally, caution should be exercised with these results. Brief periods of low D.O., or even anoxic conditions, can be detrimental to the ecosystem. Historical low D.O. has been observed on the Sunrise above Kost Dam, as well as the South Branch sub-watersheds (Appendix C).

Conductivity varied throughout the watershed (Appendix D). High variations in specific conductance are not uncommon in natural systems but can also be increased by cultural inputs. Measured values for the Sunrise and North Branch generally ranged from 270 to 495 micro-Siemens per centimeter (µS·cm-1). Observations for the West Branch Sunrise were slightly lower, with measured values from approximately 150 to 320 micro-Siemens per centimeter (µS·cm-1).

Existing River Impairments

The following river sections (table 2) have established impairments within the Watershed:

Table 2: Existing impairments for the Sunrise River and tributaries.

River	Location	Year Listed	Affected Use	Stressor
Sunrise R.	Upstream from Comfort Lk	2010	Aquatic Recreation	*Escherichia coli*
Sunrise R.	Comfort Lk to Pool 1	2012	Aquatic Life	Aquatic Macroinvertebrate Bioassessments
Sunrise R.	Comfort Lk to Pool 1	2012	Aquatic life	Fishes Bioassessments
Sunrise R.	Comfort Lk to Pool 1	2012	Aquatic Life	Oxygen, Dissolved
Sunrise (Pool 3)	Sunrise Pool 3	2012	Aquatic life	Fishes Bioassessments
Sunrise R.	Pool 3 to Kost Dam Reservoir	2012	Aquatic life	Fishes Bioassessments
Sunrise R.	Pool 3 to Kost Dam Reservoir	2006	Aquatic Life	Oxygen, Dissolved
Sunrise R.	N Br Sunrise R to St Croix R	2012	Aquatic Recreation	*Escherichia coli*
North Branch S.R.	Headwaters to Sunrise R	2012	Aquatic life	Fishes Bioassessments
South Branch S.R.	Unnamed lk (02-0500-00) to Sunrise R	2012	Aquatic Life	Oxygen, Dissolved
West Branch S.R.	Martin Lk to Sunrise R (Pool 1)	2012	Aquatic Life	Aquatic Macroinvertebrate Bioassessments
West Branch S.R.	Martin Lk to Sunrise R (Pool 1)	2004	Aquatic life	Fishes Bioassessments
West Branch S.R.	Martin Lk to Sunrise R (Pool 1)	2008	Aquatic life	Turbidity
West Branch S.R.	Typo Lk to Martin Lk	2006	Aquatic life	pH
West Branch S.R.	Typo Lk to Martin Lk	2006	Aquatic life	Turbidity

The following Total Maximum Daily Load studies have been completed to address identified river and stream impairments:

- Fecal Coliform Total Maximum Daily Load (TMDL) - North Branch of the Sunrise River; December 2006.

Phosphorus and Sediment

Phosphorus and sediment loading was one of the primary focus points of this watershed study. To evaluate existing loading conditions, detailed monitoring of river discharge and water quality were performed to estimate phosphorus and sediment loading for the years 1999 and 2006 thru 2009. In addition, a Soil and Water Assessment Tool (SWAT) Model was calibrated to observed field conditions to support evaluation of potential measures to reduce future constituent loading. Discussion below is based on field observations and subsequent modeling output of existing conditions for sediment and phosphorus loading.

Estimates of annual phosphorus and sediment loading were made based on field data collection and subsequent SWAT modeling output (Appendix A and B). Loading observations for key watershed locations are presented in Figure 16. Annual sediment loading at Sunrise, Minnesota (bottom of the watershed) ranged from approximately 1,400 to 3,700 metric tons during years sampled; while total phosphorus loading has typically ranged from 8,200 to 20,000 kg per year. However, this included observations from the summers of 2006 thru 2009, all of which generally included dry or drought conditions for the Watershed (U.S. Drought Monitor on-line data). SWAT estimated long-term average annual (period 1990 thru 2009) sediment loading to the St. Croix River of 4,700 metric tons/yr, with average annual total phosphorus loading of about 21,700 kg/yr to the St. Croix (Appendix B).

Observations from the Sunrise River at Hwy 14 (just below impoundments in the Carlos Avery Wildlife Area) show considerably less sediment and phosphorus loading (Figure 16). The upper watershed, above the Hwy 14 monitoring site, contributed small amounts of nonpoint-source loads, only about 4% of the sediment and 10% of the phosphorus (Appendix A). These small amounts are likely because of the many lakes and wetlands that can trap sediment and nutrients in the upper watershed. The North Branch provided about 27% of the sediment and 33% of the phosphorus reaching the watershed outlet. By difference, the lower watershed (below the North Branch and Hwy 14 stations and above the Sunrise station) was the largest contributor of both sediment (69%) and nonpoint-source phosphorus (44%) (Appendix A). The majority of sediment transported in this part of the watershed appeared to be from channel erosion or other riparian sources; much of the phosphorus load was most simply explained as being delivered by groundwater discharge. Calculated yields of sediment and phosphorus for the Sunrise watershed were in the same range as the other tributaries in the lower St. Croix basin.

Maps of sediment yield (Figure 17) and phosphorus yield (Figure 18) was prepared from SWAT to evaluate where phosphorus and sediment loading may be occurring within the Watershed (Appendix B). These maps generally show similar patterns. The central part of the watershed with low-gradient, sandy soils generate low yields, whereas steeper, finer-grained soils associated with agriculture generate higher yields in the eastern and northwestern parts of the watershed. Phosphorus yields also are higher in subwatersheds intersecting the urban areas of Forest Lake, Wyoming, Stacy and North Branch. The maps show the loads generated by each subwatershed, not what is delivered to the mouth of the Sunrise. That is, substantial portions of loads from higher-yielding subwatersheds in the upper watershed may get trapped by lakes and wetlands and never get transported downstream.

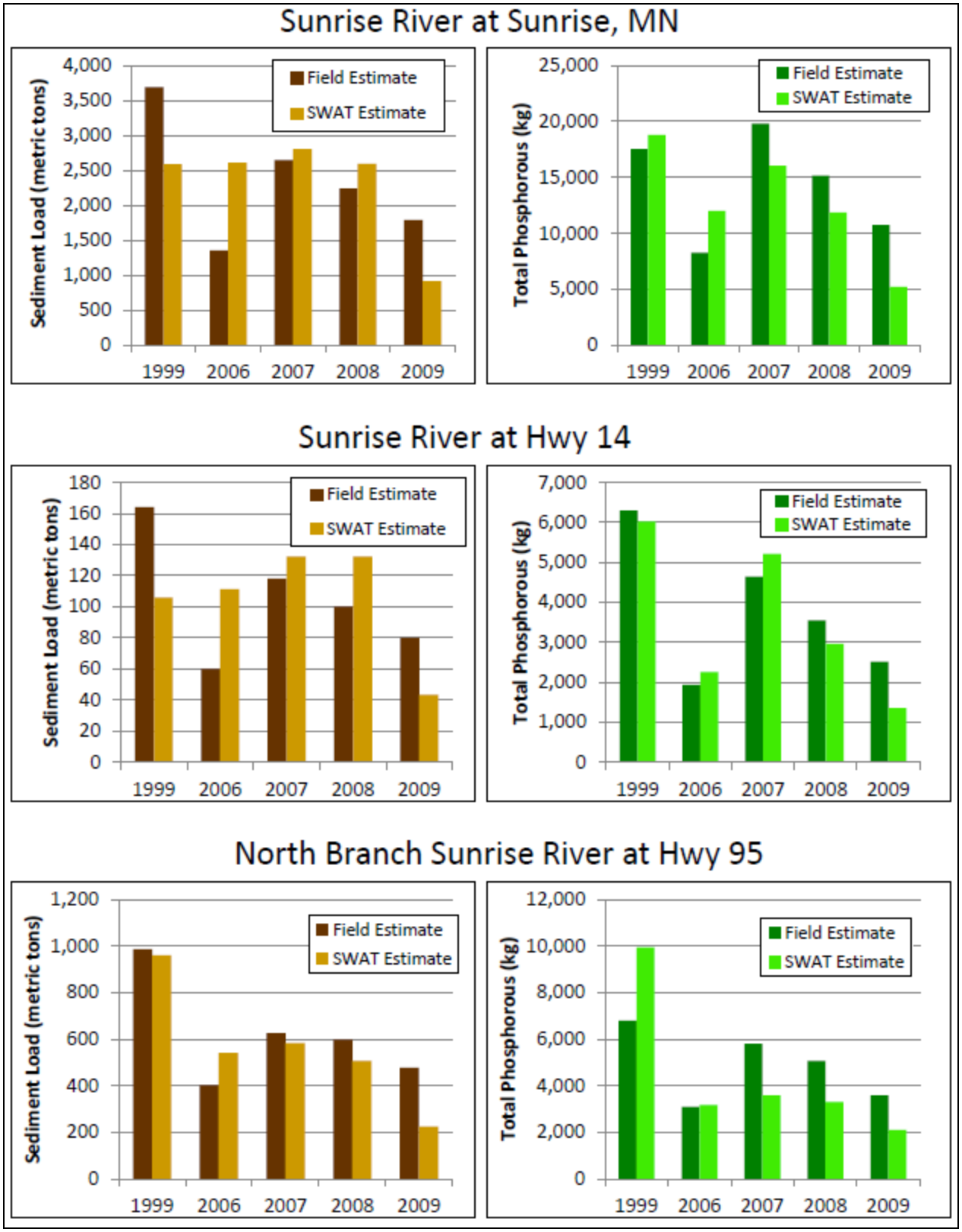

Figure 16: Modeled versus field estimated loads of sediment and total phosphorus for the Sunrise River at Sunrise; the Sunrise River at Highway 14; and the North Branch at Highway 95 (Appendix B). Annual loads shown for calendar years 1999 and 2006-09.

Observations from this study suggest the yields of sediment and nutrients for the Sunrise presented in Lenz et al. (2003; Figure 4), which identified the Sunrise watershed as the highest-yielding contributor of sediment and phosphorus to the St. Croix River, were significantly overestimated. The overestimate may be most likely due to a misunderstanding in assessing watershed area. They used only the central subwatershed area for the main stem of about 439 km2, whereas the total watershed area, including the North Branch, Lake Improvement District, and West Branch subwatersheds, is really about 991 km2. Hence, in calculating yields, they divided loads by an area that was much too small, overestimating yields by more than a factor of two. Whereas Lenz et al. (2003) reported watershed-wide yields of 8.4 metric tons/km2/yr for sediment and 39.9 kg/km2/yr for phosphorus during water year 1999, more appropriate values would be 3.72 metric tons/km2/yr for sediment and 17.7 kg/km2/yr for phosphorus. These values place the Sunrise well within the range of similar tributaries in the lower St. Croix basin. However, even though the loads per unit area (yields) may be reduced by this re-calculation, the loads themselves are not in question, and the loads from the Sunrise – as for nearly all tributaries to the St. Croix – could still be reduced with selected management practices.

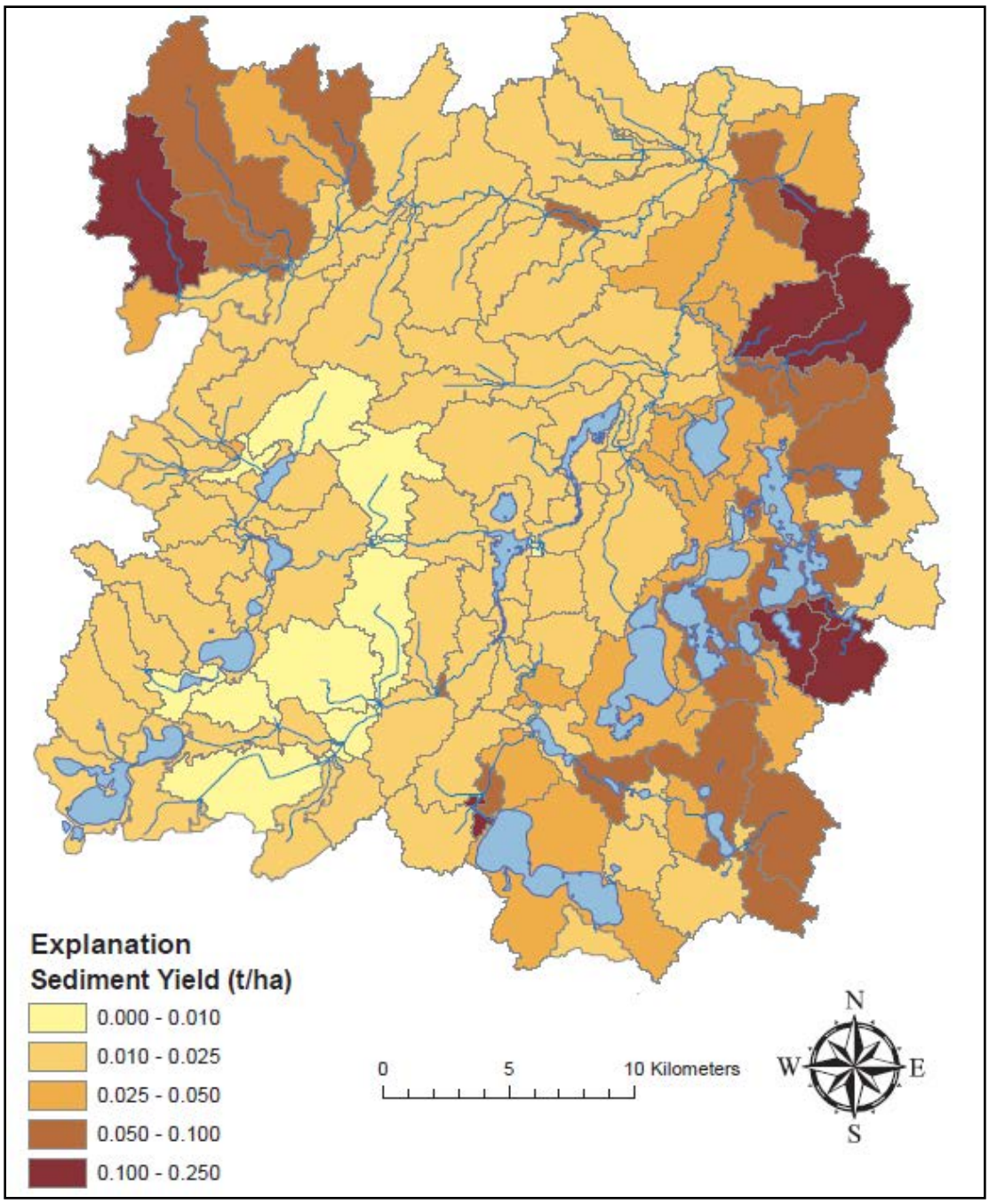

Figure 17: Average modeled subwatershed yields of sediment in the Sunrise River Watershed for the modeled period 2000 thru 2009 (Appendix A).

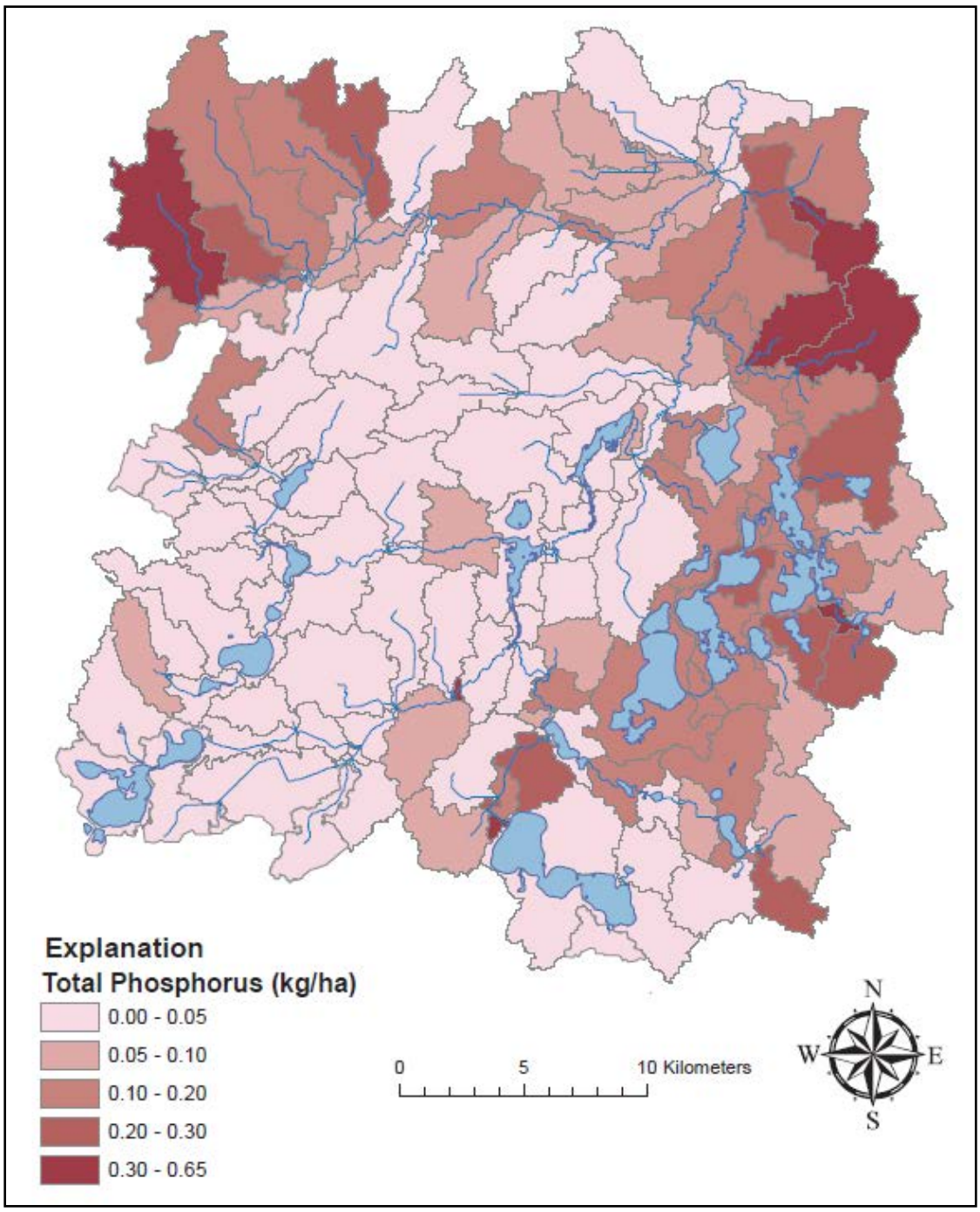

Figure 18: Average modeled subwatershed yields of total phosphorus in the Sunrise River watershed for the modeled years 2000 thru 2009 (Appendix A).

Lake Water Quality

The following focuses on water quality conditions for lakes within the Sunrise Watershed. The Watershed includes lentic environments from ponds less than an acre in size, to Forest Lake which is almost 2,300 acres. Most of these are directly connected (many artificially connected) and contribute to water quality of the Sunrise River.

The following lakes (Table 3) have established impairments within Watershed:

Table 3: Existing impairments for lakes in the Watershed.

Lake	Year Listed	Affected Use	Stressor
Kroon L.*	2008	Aquatic recreation	Nutrient/Eutrophication Biological Indicators
Linwood L.	2002	Aquatic recreation	Nutrient/Eutrophication Biological Indicators
Second L.	2012	Aquatic Recreation	Nutrient/Eutrophication Biological Indicators
Vibo L.	2012	Aquatic Recreation	Nutrient/Eutrophication Biological Indicators
White Stone L.	2012	Aquatic Recreation	Nutrient/Eutrophication Biological Indicators

*Kroon Lake has been proposed by Minnesota Pollution Control Agency for delisting from the impaired waters list in 2014. It is still listed as impaired as of this report.

The following Total Maximum Daily Load studies have been completed to address lake impairments previously identified:

- Comfort Lake-Forest Lake Watershed District Six Lakes TMDL; March 2010 (Includes identified impairments to Comfort, Moody, Bone, School and Shield lakes).
- Typo Lake and Martin Lake TMDL; February 2012 (Includes identified impairments to Martin and Typo lakes).
- Chisago Lakes Chain of Lakes Watershed TMDL; February 2013 (Includes identified impairments to South Center, North Center, Wallmark, Little, Ogren, Linn, Pioneer, School and Emily lakes)

Lake trophic status for available lakes is provided in Figure 19. Data for this figure is from the Minnesota Pollution Control Agency web-based Lake and stream water quality data. Several lakes are identified as hyper-eutrophic. This is based on Minnesota Pollution Control Agency's Trophic State Index (TSI), which is a number that summarizes a lake's overall nutrient richness. Total phosphorus (TP) is most often the limiting factor controlling primary production in freshwater lakes in Minnesota, and is the nutrient of focus for impairments involving eutrophication in lakes. Phosphorus is sometimes referred to as the causal factor; as phosphorus concentrations increase, primary production also increases, as measured by higher chlorophyll-a concentrations. Chlorophyll-a concentrations are used as a proxy to measure the concentration of algae within the water column. Higher concentrations of chlorophyll lead to lower water transparency. Both chlorophyll-a and Secchi transparency are referred to as response factors, since they indicate the ecological response of a lake to excessive phosphorus input.

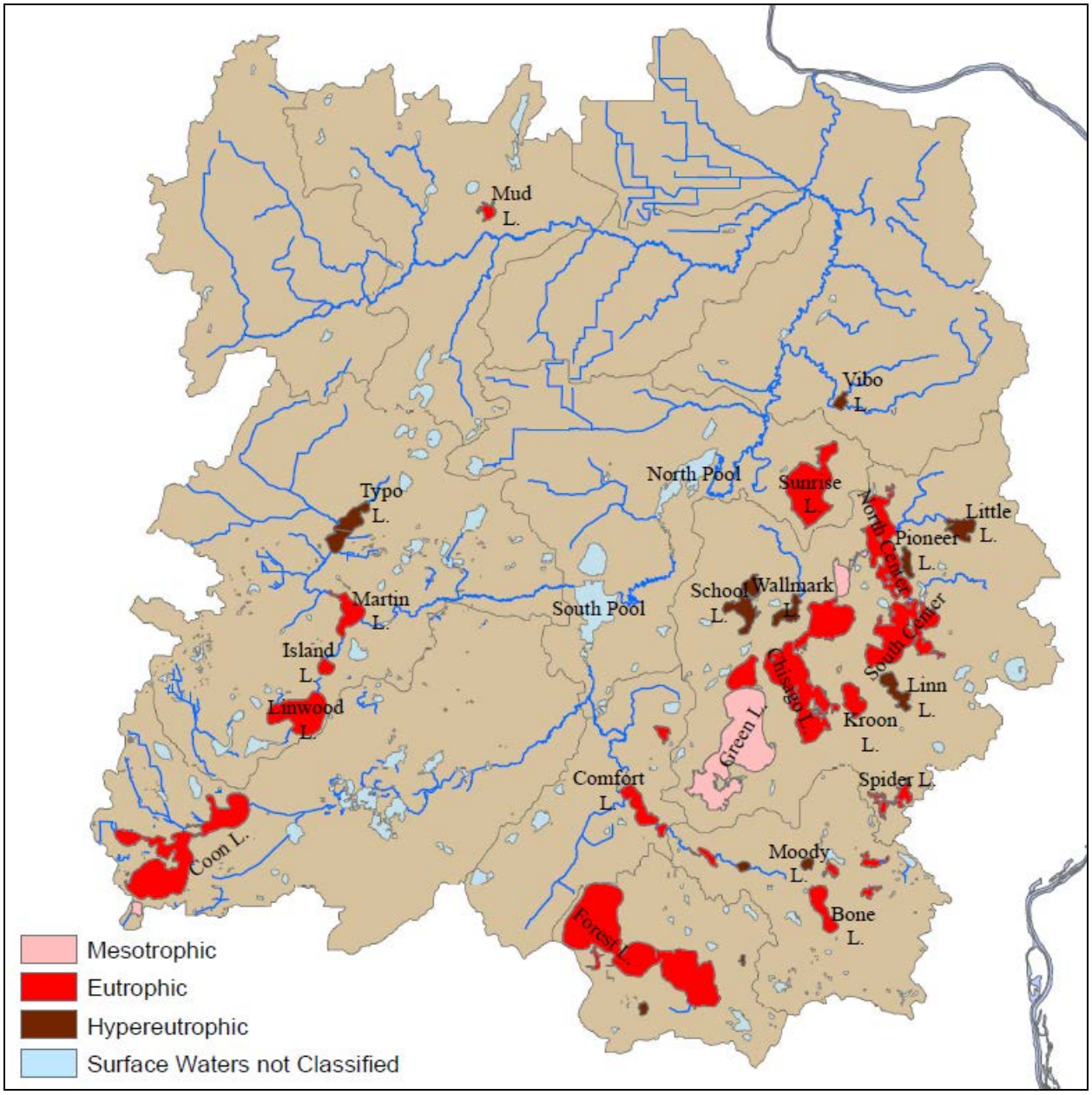

Figure 19: Trophic status of lakes with available data within the Sunrise River Watershed. Source: MnPCA.

4.2 Stream Health Assessments

The health of a stream or river can be judged by the fish and macroinvertebrate communities it contains. It also can be evaluated by observations of physical habitat and water quality. To evaluate water resource health, streams and lakes within a watershed periodically undergo intensive monitoring to determine the overall health of water resources, identify the stressors that drive this health, identify impaired waters, and to identify waters in need of additional protection efforts.

Intensive watershed monitoring for stream health in the Watershed was performed during the summer of 2009. This was combined with similar observations collected over the past 10 years to assess system

health. The most recent data may be given more weight during the comprehensive watershed assessment. When conducting a stream health assessment, the goal is to use data from the 10-year period that best represents current conditions. Using data over a 10-year period provides a reasonable assurance that data will have been collected over a range of weather and flow conditions. This is especially important in this case as drought conditions experienced in 2009 certainly influenced observations of fish, macroinvertebrates and water quality, increasing the need to consider historical data. Locations with data used for assessing water resource conditions are provided in Figure 20.

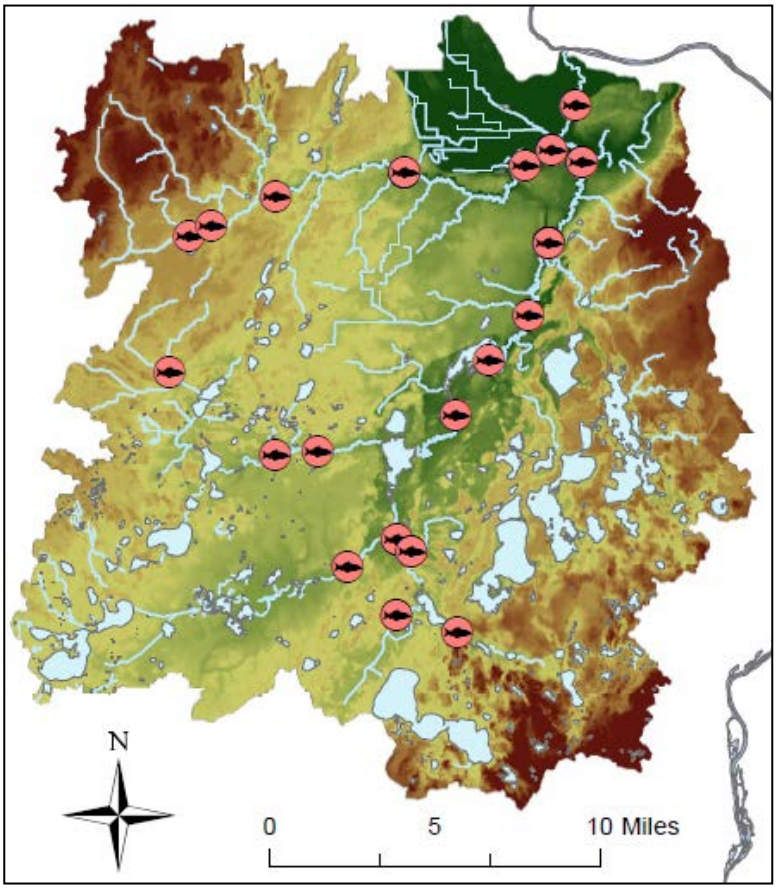

Figure 20: Locations for collection of fish, invertebrate and/or habitat data by Minnesota Pollution Control Agency for stream health assessments within the Sunrise River Watershed (Appendix C).

To measure the health of aquatic life at each biological monitoring station, indices of biological integrity (IBI), specifically for fish and invertebrates, were calculated based on monitoring data collected for each of these communities (Figures 21 and 22). Biological Integrity scores higher than an impairment threshold indicate that the stream reach supports aquatic life. Contrarily, scores below the impairment threshold indicate that the stream reach does not support aquatic life. Confidence limits around the impairment threshold help to ascertain where additional information may be considered to help inform the impairment decision. When Biological Integrity scores fall within the confidence interval, interpretation and assessment of waterbody condition involves consideration of potential stressors, and draws upon additional information regarding water chemistry, physical habitat, and land use activities, etc. Water quality observations are compared against similar thresholds to identify potential impairments. Habitat conditions are scored according to Minnesota Stream Habitat Assessment guidelines and described as “good,” “fair” or “poor.” A complete discussion of the Index of Biological Integrity, water quality and habitat assessment work, including field methodology, score calculation and detailed results discussion is included in Appendix C.

Figure 21: Fish collection during Index of Biological Integrity activities on the Sunrise River during 2009.

Figure 22: Fish identification during Index of Biological Integrity field activities on the Sunrise River during 2009.

North Branch Summary

Sub-watershed Description: The North Branch Sunrise River Watershed Unit drains approximately 76 square miles in eastern Isanti and central Chisago Counties (Figure 23). The North Branch flows east approximately 24.1 miles, through the city of North Branch before reaching its confluence with the Sunrise River in Sunrise Township. Along its course, four named tributaries flow into the North Branch Sunrise River: County Ditch 7, County Ditch 19, Judicial Ditch 4, and Hay Creek. Agricultural landscapes comprise 60.2 percent of this watershed's area, with 40.6 percent in cropland and 19.6 percent in rangeland.

Existing Impairments: The North Branch of the Sunrise River was placed on Minnesota's impaired waters list in 2012 for impaired aquatic life due to low fish bioassessment scores observed in 2010. The impairment extends from its headwaters in Isanti County to its confluence with the Sunrise River in Chisago County. A TMDL for fecal coliform bacteria on the North Branch also has been approved by the EPA on February 22, 2007. The Implementation Plan was approved by the Minnesota Pollution Control Agency in February 2007 and TMDL implementation activities are currently underway.

Biotic Conditions: There was a large amount of biological data available from stations on the North Branch Sunrise River. These stations generally had average fish communities, with five of seven observations reporting fish IBI scores that exceeded standards (one sampling location sampled multiple times). Two fish IBI observations resulted in scores below standards. The invertebrate community was in good condition with observations exceeding standards. A station on the lower North Branch has a history of biological impairment which may be due to excessive sedimentation. Habitat scores indicate average conditions to support aquatic communities.

Aquatic Habitat Conditions: Habitat scores were rated as "fair" for five stations on the North Branch, with one station scored as "good." The riparian corridor of this river is largely undisturbed outside of the city of North Branch, where impervious surfaces decrease natural infiltration of runoff and storm water.

Water Quality: Water quality data was available on the North Branch Sunrise River and partial datasets on a number of tributaries. Turbidity and dissolved oxygen were meeting standards on the North Branch Sunrise River. Excess bacteria were present in this reach, resulting in an aquatic recreation use impairment. The upstream tributaries had partial datasets for bacteria, and while not enough to determine impairment, each reach had a number of values that were elevated.

Other: Limited biological data was available on one channelized reach within this subwatershed; its fish communities were in poor condition. Overall, habitat seems average for supporting aquatic communities in the channelized reach, but lack of cover for certain aquatic species could be contributing to poor diversity.

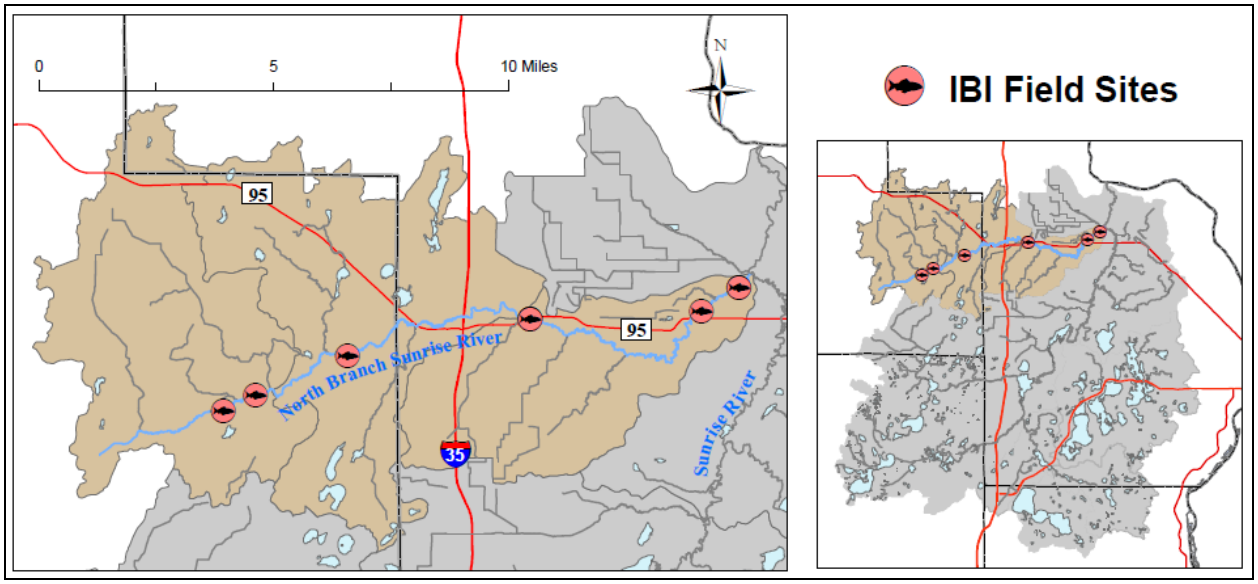

Figure 23: Locations for stream health monitoring on the North Branch of the Sunrise River (Appendix C).

West Branch Summary

Sub-watershed Description: The West Branch Sunrise River Watershed Unit is located in the west central portion of the lower St. Croix basin, encompassing roughly 55.7 square miles in parts of Isanti, Anoka, and Chisago Counties (Figure 24). The West Branch Sunrise River begins in the township of Oxford, and then flows in a southeasterly direction 15.4 miles until it reaches Pool 1 of the Sunrise River just east of the town of Stacy. In that span, this waterway flows through two nutrient impaired lakes (Typo and Martin) and a mix of agricultural land use and wetland complexes. Twenty-two basins are in the watershed, all but one are shallow. Agricultural production accounts for 34.1 percent of the land use in this watershed, with 22.4 percent being cropland and 11.7 percent rangeland. The outlet of this watershed is represented by station 09SC005 on the West Branch Sunrise River, which is located near Stacy.

Existing Impairments: The West Branch of the Sunrise River between Typo and Martin lakes was placed on Minnesota's impaired waters list in 2006 due to turbidity and pH. The West Branch between Martin Lake and Sunrise River Pool 1 were listed as impaired in 2004 for fish bioassessments, in 2008 for turbidity, and in 2012 for macroinvertebrate assessments. All of these impairments were identified for aquatic life. A Total Maximum Daily Load plan is currently under development. Excessive nutrient conditions in Martin and Typo lakes are a major contributor to these impairments for the West Branch.

Biotic Conditions: Fish and Invertebrate communities on the West Branch Sunrise River downstream of Martin Lake show an impaired condition, with tolerant species dominating the communities resulting in low fish and invertebrate Biological Integrity scores.

Aquatic Habitat Conditions: Poor habitat quality at separate stations on the reach downstream of Martin Lake could be driving low diversity in the aquatic communities. Habitat scores were rated as "poor" for three stations on the West Branch, and one tributary. Homogenous channel development throughout this stretch of river is characteristic of a low gradient system (i.e. absence of riffles); these stations were scored in the low gradient fish class but still fail to meet thresholds.

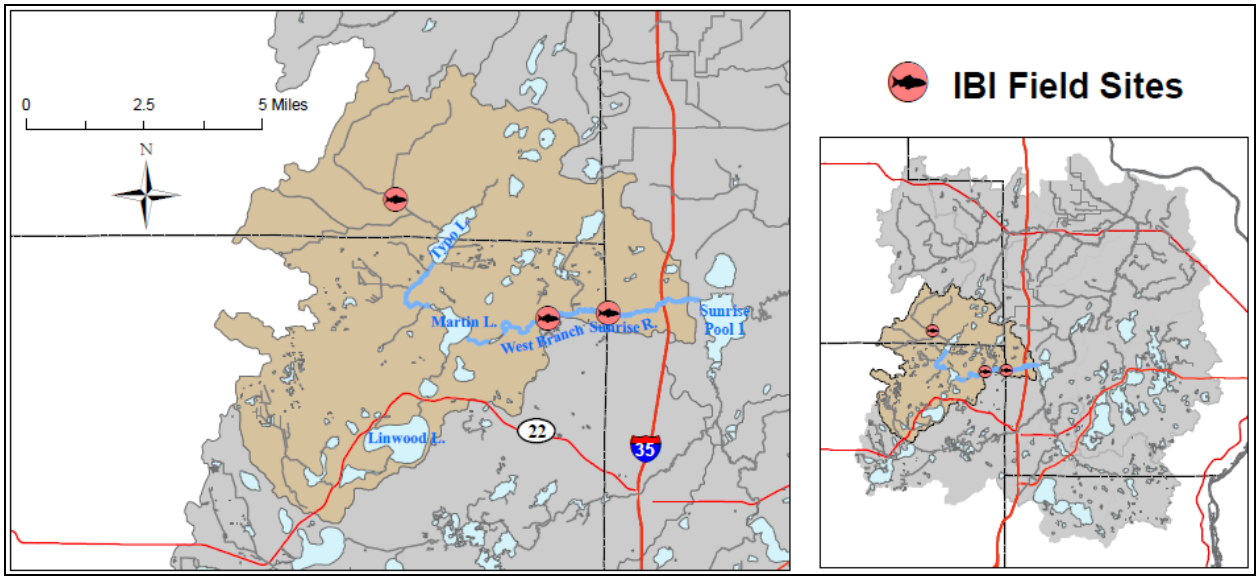

Figure 24: Locations for stream health monitoring on the West Branch of the Sunrise River (Appendix C).

Water Quality: Water quality data was available on three reaches of the West Branch Sunrise River as follows: upstream of Typo Lake, between Typo and Martin lakes, and downstream of Martin Lake to Pool 1 of the Sunrise River. The reach downstream of Martin Lake is impaired for aquatic life due in part to impairment involving turbidity exceedances from excess algae growth, which can be attributed to the extreme nutrient impairment in Martin Lake. This reach meets nitrate standards for drinking water. This reach also was previously listed for pH (downstream of a highly eutrophic lake), but more recent data indicates that pH is within standards, so it will be removed from the impaired waters list. The reach between Typo and Martin lakes is impaired for aquatic life use due to excess turbidity and pH. Typo and Martin Lakes are highly eutrophic and high nutrient levels and algal respiration may drive the swing in pH values observed. Dissolved oxygen levels are low in the reach upstream of Typo Lake; this reach also is completely channelized and within a large wetland complex. With the exception of Fawn Lake, all the basins in this watershed are shallow. As a result, reductions in watershed phosphorus loads and addressing internal loading will be important to see improved water quality in the area lakes. The TMDL for Martin and Typo Lakes has been completed.

Sunrise River Summary

Sub-watershed Description: The Sunrise River Watershed Unit is the largest subwatershed in the lower St. Croix, draining 93.2 square miles within central Chisago County (Figure 25). This watershed unit begins just east of the town of Stacy where the West and South Branch Sunrise River combine at the Sunrise Pool 1. The main stem Sunrise River drains northeast through Carlos Avery Wildlife Management Area (WMA) where the riparian area is dominated by wetland complexes and forests. The lower portion of this watershed unit, outside of the Carlos Avery Wildlife Management Area, maintains an intact forested riparian area, while cropland dominates the landscape outside of the riparian corridor. A series of small dams were built on this 24.3 mile stretch of the Sunrise River, creating a few small, nutrient rich impoundments. Below the Kost Dam, gradient increases greatly relative to the upstream reaches of the river; this allows for a more natural riverine environment. Fifteen basins are located in the watershed, all of which are small and shallow. Agricultural production accounts for 60.2 percent of the land use in this watershed, with 39.2 percent vested in cropland and 29 percent vested in pasture lands. The outlet

for this watershed unit is represented by biological station 09SC001, located on the main stem of the Sunrise River 6 miles east of North Branch.

Existing Impairments: The Sunrise River has several listed impairments, including recent listings. This includes the following:

- Sunrise River upstream of Comfort Lake: Aquatic Recreation impairment for E. coli.
- Sunrise River from Comfort Lake to Pool 1: Aquatic Life impairment for macroinvertebrate and fish IBI observations; and low dissolved oxygen.
- Sunrise River Pool 3 (Carlos Avery): Aquatic life impairment for fish IBI observations.
- Sunrise River from Pool 3 to Kost Dam: Aquatic life impairment for fish IBI observations; and low dissolved oxygen.
- Sunrise River from the North Branch confluence to the St. Croix River: Aquatic recreation impairment for E. coli.

Biotic stressors in this reach include low dissolved oxygen levels because of the operation of the Carlos Avery Pools. While this is a problem, it is largely related to pool elevation. No TMDL will be developed to address these issues. The impairments downstream of Comfort Lake are largely due to upstream nutrient inputs from Comfort Lake, which has a TMDL due to the habitat changes that resulted in the formation of Carlos Avery.

Biotic Conditions: Fish and invertebrate community data was also available at numerous stations on the mainstem Sunrise River and its tributaries. From the headwaters to Kost Dam, the Sunrise River has fish communities that fall below standards for the low gradient class. Six of seven stations recently observed had fish Biological Integrity scores that fall below threshold values. Below the Kost Dam to the St. Croix River, both fish and invertebrate communities improve significantly, indicating the stream is supporting aquatic life use. Three stations recently observed were all above Biological Integrity threshold values.

Aquatic Habitat Conditions: From the headwaters to Kost Dam, river habitat quality is average. All five stations with recent habitat observations were classified as “fair.” Below the Kost Dam to the St. Croix River, habitat quality is in better condition in this stretch of river providing support to healthy aquatic communities. Two stations were classified as having “good” habitat, while a third had “fair” habitat.

Water Quality: Water quality data was available on two reaches of the Sunrise River, two reaches of Hay Creek, and one ditch that drain from Wallmark Lake to the Sunrise River northwest of Lindstrom. The reach upstream of Pool 1 was considered to be fully supporting of aquatic recreation uses with low bacteria counts. Upstream of Kost Dam also is falling below standards for dissolved oxygen on both reaches; dissolved oxygen may be a potential stressor. Turbidity was meeting standards on these reaches. Downstream of the North Branch Sunrise River, the Sunrise River is impaired for aquatic recreation use due to excess bacteria. This reach has good levels of both dissolved oxygen and turbidity, and is fully supporting aquatic life uses.

Other: One station was located on a channelized segment and was deferred for aquatic life use assessment. Overall, the fish community was in average to below average biological condition at this station, and habitat quality was in poor condition. The ditch from Wallmark Lake (becoming Bloomquist Creek prior to its confluence with the Sunrise) is impaired for aquatic life use due to both low dissolved oxygen and excess un-ionized ammonia. The impairments in this reach are due to the Chisago Lakes Joint Sewage Treatment Facility. Permits associated with this facility have been changed and now reflect what is needed to protect local water quality. Hay Creek is impaired for aquatic recreation due to excess bacteria. The headwaters reach is supporting for aquatic recreation. Downstream of Beaver Creek,

dissolved oxygen may be a stressor to aquatic life, but the dataset was not adequate enough to make an assessment. Wallmark, Vibo, and School lakes exceed the eutrophication standard for recreational uses. These basins are small and shallow; internal loading is contributing to extremely high phosphorus concentrations observed.

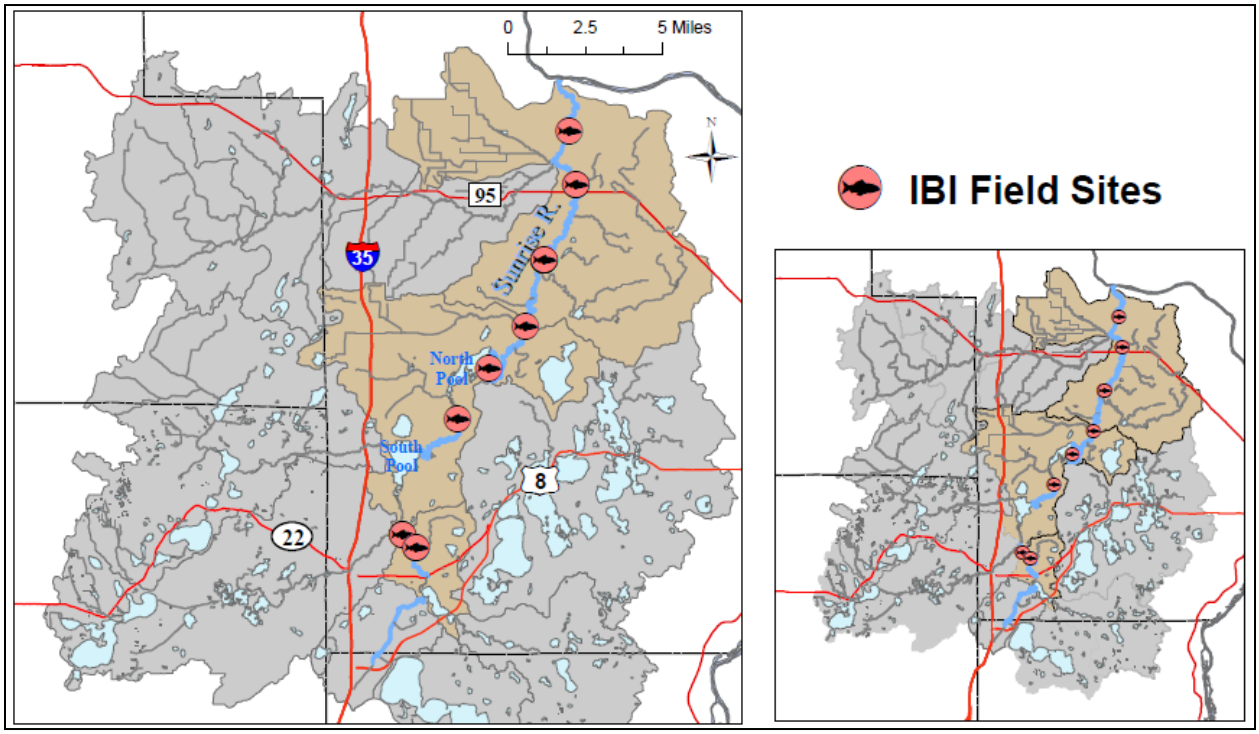

Figure 25: Locations for stream health monitoring on the Sunrise River (Appendix C).

<u>South Branch and Upper Sunrise Summary</u>

Sub-watershed Description: The South Branch Sunrise River Watershed Unit is located in the west central part of the lower St. Croix basin, draining 79.9 square miles in eastern Anoka, northern Washington and southern Chisago Counties (Figure 26). The South Branch Sunrise River begins in the township of Columbus within the Carlos Avery Wildlife Management Area, and continues flowing northeast across numerous wetland complexes approximately 5.1 miles until it drains into the main stem Sunrise River, two miles northeast of the town of Wyoming. Agricultural production accounts for 33.4 percent of this watersheds land use, of that, 21.9 percent is pasture while 11.5 percent is cropland. Three unnamed creeks and two unnamed ditches are located within this watershed unit. Sixteen lakes in the watershed had data available for assessment with a mix of deep and shallow basins. The outlet of this watershed is represented by station 09SC007 on the South Branch Sunrise River, located in Wyoming. Environmental issues in this reach appear strongly tied to the management and operation of the water control structures associated with the Carlos Avery Wildlife Management Area.

Existing Impairments: The South Branch Sunrise River has impairments (2012) for aquatic life due to low dissolved oxygen. This was identified from an Unnamed lake (02-0500-00) to Sunrise River.

Biotic Conditions: Fish and invertebrate community assessments on data from a station in this sub watershed were deferred due to stations being located on predominately channelized stream reaches.

Aquatic Habitat Conditions: The habitat quality observed at three locations was in fair to poor condition, possibility from the influence of altered stream courses. Out of three stations recently observed, two stations were classified as having "fair" habitat, while a third had "poor" habitat. Total average habitat score for these three locations graded as "poor" habitat.

Water Quality: Water quality data was available on a five mile reach of the South Branch Sunrise River immediately upstream of the Sunrise River, Judicial Ditch 2, and on a series of creeks that connect a chain of lakes in the watershed. This subwatershed has a large amount of both wetlands and altered waterways. Low dissolved oxygen was identified as aquatic life use impairment in four of the reaches; two of those are deferred due to highly altered channels. Excess bacteria resulted in aquatic recreation use impairments on three creeks between Bone and Little Comfort Lakes, and one on the Sunrise River. In addition, toxic levels of chloride were identified on Judicial Ditch 2 resulting in aquatic life impairment.

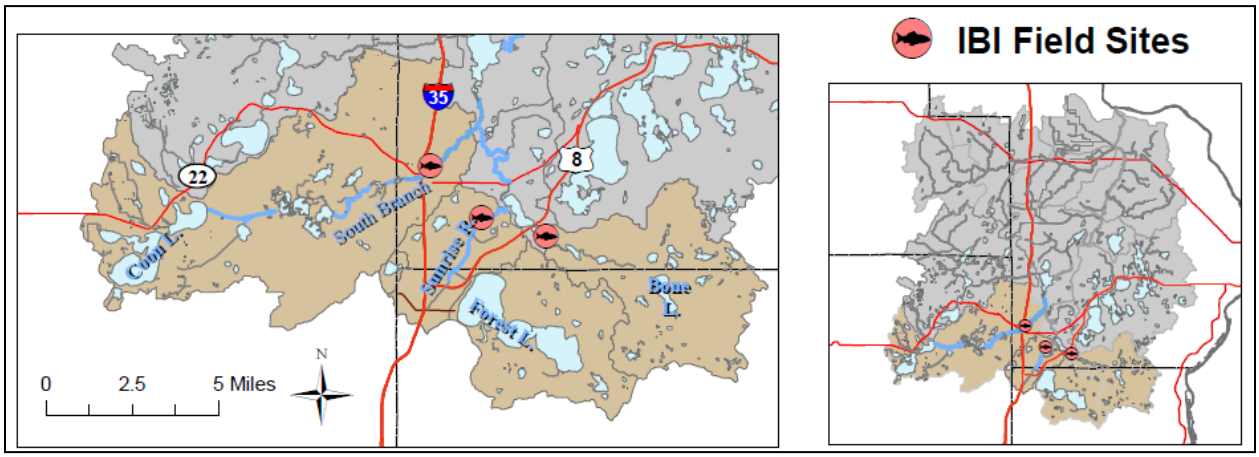

Figure 26: Locations for stream health monitoring on the South Branch and upper Sunrise River (Appendix C).

Other: Assessments were completed for eleven lakes in the subwatershed. Four of the lakes have TMDLs completed through the Comfort Lake-Forest Lake Watershed District Impaired Lakes TMDL (Moody, School, Bone, and Shields Lakes), and one of the lakes has a TMDL completed through the Carnelian Marine St. Croix Watershed District Lakes TMDL (Goose Lake). Second and Sunfish lakes also are considered impaired for aquatic recreation use. These lakes are less developed than other watersheds, but the land use in the larger watershed has been converted from forest to agricultural uses. Forest, Coon, Sylvan, and Third lakes are all meeting the recreation use standard. Forest and Coon Lakes are large and relatively deep, which will allow for greater assimilation of phosphorus into the basin without an immediate visible change in the chlorophyll-a and Secchi. However, both lakes are approaching the phosphorus threshold, and in Forest Lake, the chlorophyll-a levels do exceed the threshold. These lakes also are the most heavily developed in the watershed. Work in this watershed to reduce phosphorus runoff would benefit all the lakes. A number of the impaired lakes also are shallow, which will require addressing internal loading in addition to watershed sources to improve their water quality.

Chisago Lakes Summary

This watershed area includes several lake basins with a mix of deep and shallow, large, and small lakes. There also are mixes of land uses including agricultural, forested and developed. The sub basin includes several small creeks that drain to area lakes. However, outflow from this area to the Sunrise River is limited and dependent on area hydrology. Given this limited connectivity, no detailed assessments of fish or invertebrate IBIs or stream habitat were performed.

Observations were made on water quality for select water bodies. The small creeks draining to North and South Center lakes had elevated phosphorus levels. Seven lakes supported aquatic recreation uses, including North and South Lindstrom and Chisago Lakes, and eight are not supporting aquatic recreation use, including North and South Center lakes. The remaining basins did not have sufficient data to make a determination of support. A TMDL has been completed for both the lakes of the Comfort Lake-Forest Lake Watershed District, as well as the Chisago Lakes Chain of Lakes.

4.3 Wetland Resources

Wetlands Summary

An evaluation of wetland resources was performed to better understand and map existing and historic wetlands of the Sunrise Watershed. This evaluation is detailed at Appendix D and summarized here. This effort was done collaboratively with the regulatory program of the Corps St. Paul District.

Existing conditions were defined as aquatic resources existing during the summer of 2009 (when the 2009 aerial photographs were taken of the entire watershed). A large body of data is available for conducting the existing inventory, including aerial photographs, National Wetland Inventory, Public Waters Inventory, topographic data, and the use of ground reconnaissance.

The approach for mapping existing wetlands used soil survey data and National Wetland Inventory data to identify areas that may contain aquatic features. Areas that possibly contained aquatic features were searched for visually by inspecting air photos from a number of years, including 2009, 2008, 2006 infrared, and 1991 black and white (leaf off) photos. Select areas that did not contain hydric soils or National Wetland Inventory wetlands also were visually inspected in the field. The Public Waters Inventory generally identified shallow marshes, deep marshes, shallow open water communities that also were identified in the National Wetland Inventory, as well as lakes. All of this data, along with Soil Surveys, topographic data, and earlier air photos were used to identify possible aquatic resources. The final identification and delineation of a given aquatic body was based on its appearance in the 2009 air photo.

Any area identified as an aquatic resource was digitized manually in GIS and assigned a code (based on visual indicators described in Appendix D) identifying the aquatic resource type. The type was determined by visually inspecting the air photo to determine vegetative cover and hydrology of the wetland. Topographic data, where available, was used to refine the placement of the wetland line once a wetland was identified.

The Historic Wetland Inventory is defined as conditions existing at the time of European settlement in the mid 19th century. Data for conducting the historic inventory is limited to Original Land Survey and County Soil Survey data.

For the purpose of this study, the soils data was used to determine historic wetlands based on the assumption that hydric soils take long periods of time to form. Therefore, hydric soils in former wetlands drained by humans would tend to retain the hydric characteristics that were observed during the soil survey. Areas developed or significantly disturbed at the time of the soil survey may not have been classified as a hydric soil and would therefore not be inventoried as a historic wetland. The soil survey has a relatively small fraction that is classified as disturbed soils so the net effect of unidentified wetlands on the analysis is assumed to be minor. The Original Land Survey was used as supplemental data to validate the accuracy of the soils data.

It is estimated that the watershed currently includes almost 76,000 acres of wetlands (31% of total watershed area). A summary of wetland types is presented in Table 4. Figure 27 identifies the locations of existing wetland areas in the Watershed.

Table 4: Wetland types present in the Sunrise River Watershed.

Basic Wetland Type	**Acres**	% of wetlands
Deep Marsh	8,488.2	11.2%
Excavated Pond / Stormwater Pond	430.8	0.6%
Forested Wetland	8,140.7	10.7%
Lake	12,910.7	17.0%
Riverine (Riparian)	1,939.4	2.6%
Seasonally Flooded Basin	278.6	0.4%
Shallow Marsh	19,829.4	26.1%
Shallow Open Water Community	2,185.9	2.9%
Shrub Carr / Alder Thicket	13,478.3	17.8%
Wet Meadow / Sedge Meadow / Wet Prairie	8,153.9	10.7%
Wet Meadow (Ditch)	15.4	0.0%
Total	**75,851.4**	100.0%

Historically, the Watershed may have contained about 103,000 acres of wetlands. This suggests a loss of over 27,000 acres of wetland since European settlement. The areas with the most concentrated wetland loss are in the north and eastern portions of the watershed (Figures 28 and 29), where wetland losses of 60 percent to over 80 percent have been observed. The most dramatic changes are located in the far northern portion of the watershed, near the confluence of the Sunrise River and St. Croix River. As might be expected, agriculture and development appeared to account for the losses. Several of the largest historical wetland complexes have been lost through the ditching and draining activities associated with sod farming of the area. Only small forested wetland patches remain. Large patches of lost wetlands also are observed in the lower North Branch Sunrise River, and Mud Lake – Sunrise River sub-watersheds. While developed areas were associated with areas experiencing significant wetland losses, it is difficult to discern how much wetland loss occurred from pre-existing agricultural activities versus the development itself.

Wetland losses in the Chisago Chain of Lakes area also have been substantial (Figures 28 and 29). The combination of agriculture and development in this area has resulted in individual wetland losses that are smaller in size, but cumulatively more numerous. This led to a fragmentation of the landscape,

resulting in smaller remnant patches of wetlands, as well as losses to entire small wetlands. Because the Chicago Chain of Lakes is in close proximity to these wetland losses and this is an area experiencing development in recent decades, it raises concerns about water quality for the lakes in the sub watershed. A similar pattern of many small wetland losses were observed in the upper North Branch Sunrise River and the middle North Branch Sunrise River sub watersheds in the northwest portion of the watershed. These areas also are heavily dominated by agriculture. This area lacks the lakes of other areas of the watershed, but water quality impacts to the North Branch of the Sunrise River are a concern.

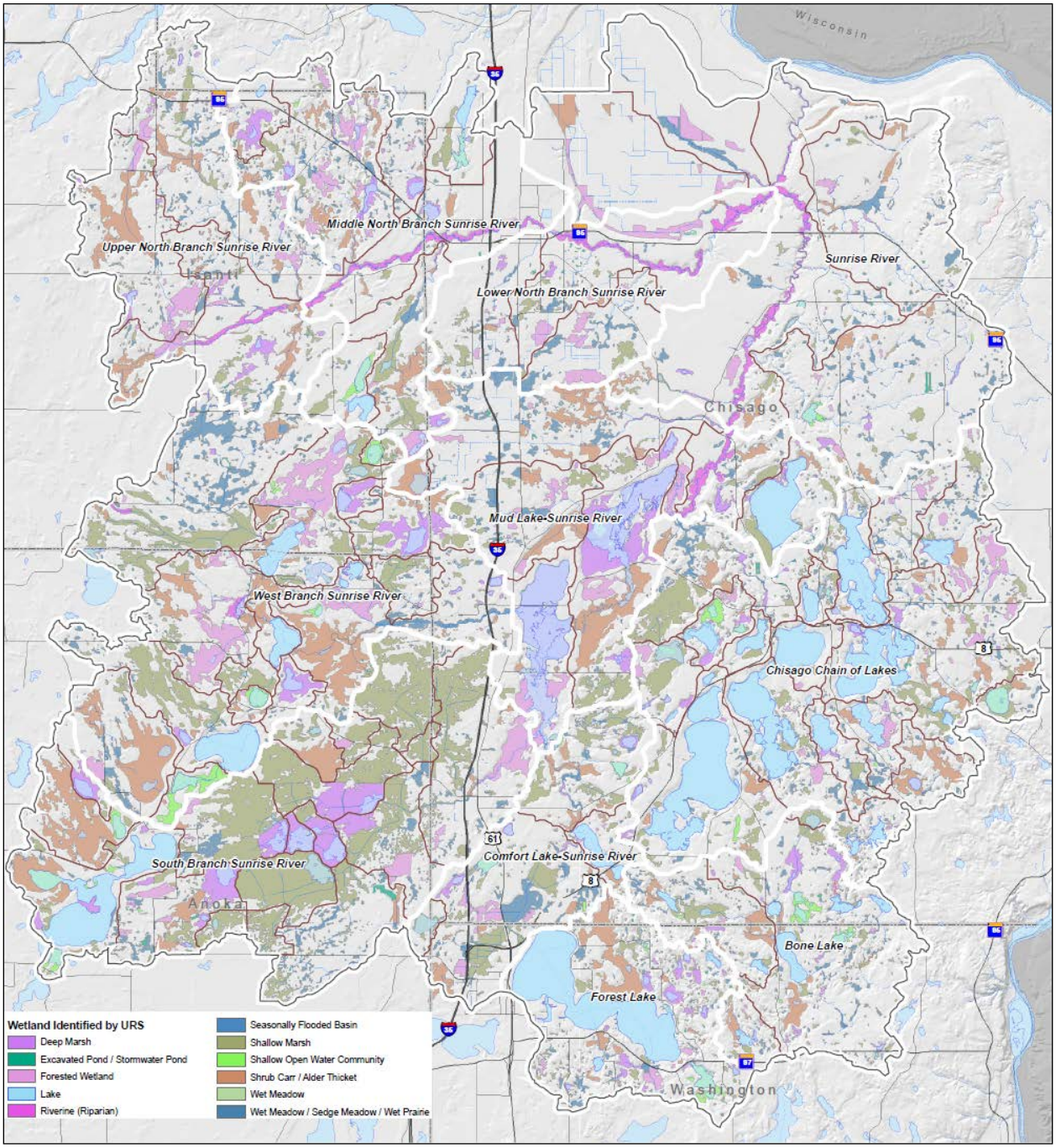

Figure 27: Existing wetland areas identified for the Sunrise River Watershed.

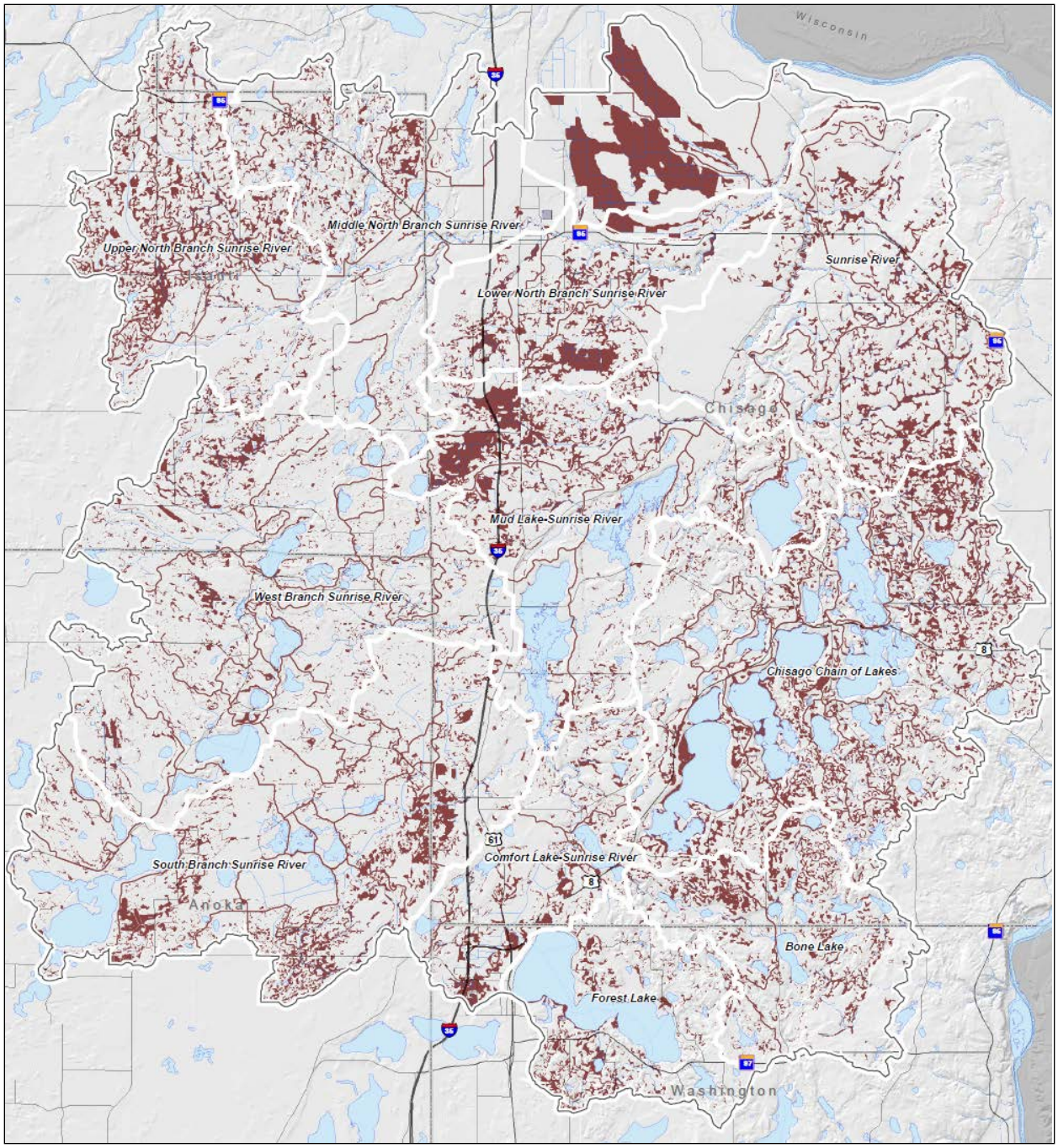

Figure 28: Areas of lost wetlands in the Sunrise River Watershed. Lost wetland areas indicated in dark shading.

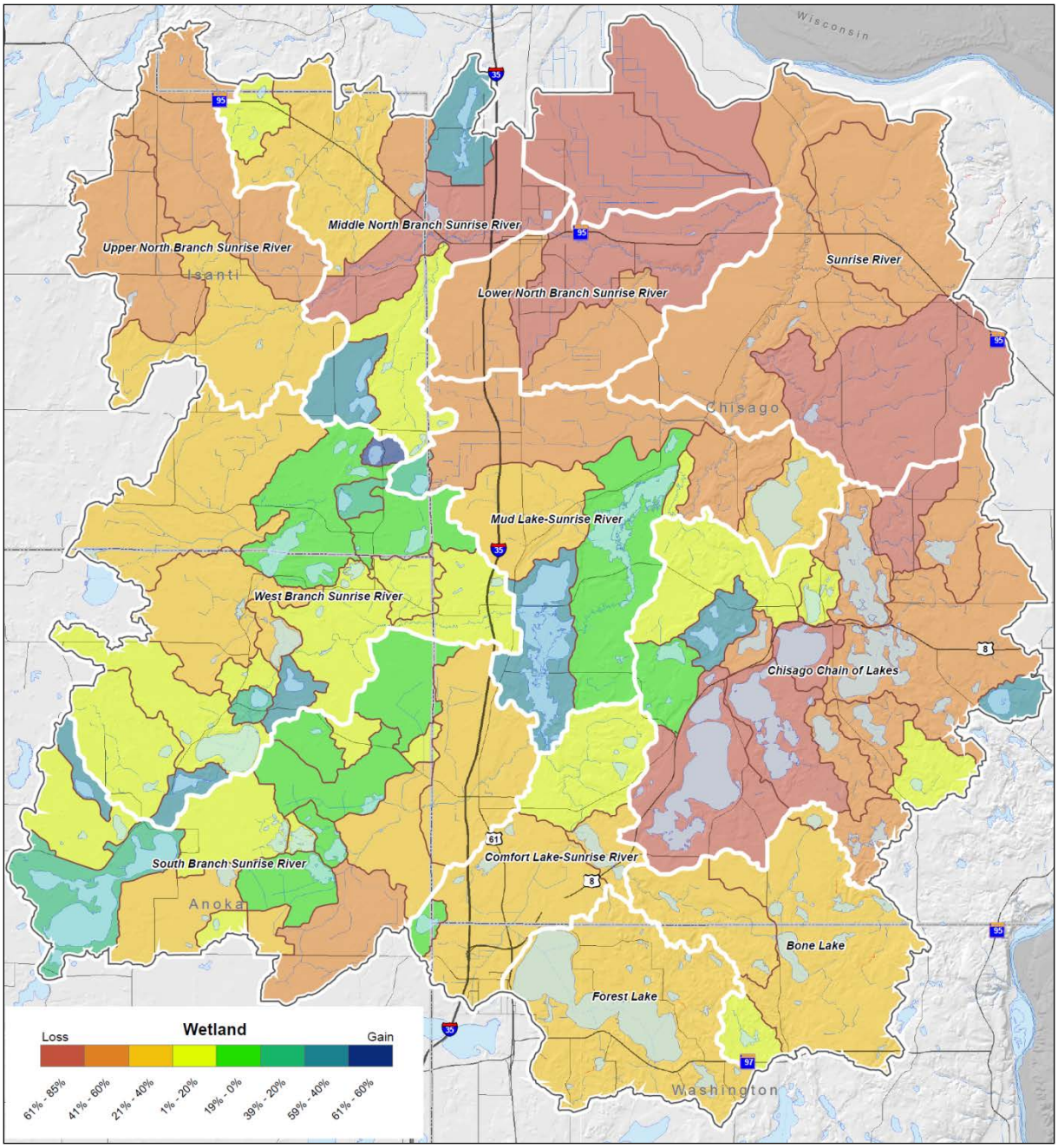

Figure 29: Relative change in wetland quantity by sub-watershed for the Sunrise River Watershed. Wetland losses are indicated with colors ranging from yellow to red; wetland gains are shown with colors from green to blue.

Areas experiencing wetland gains over time appear to often be associated with creation of impoundments. This includes areas adjacent to the North and South Pools (impoundments) of the Sunrise River (within the Carlos Avery State Wildlife Area). The area adjacent to Coon and Linwood lakes in the southwestern watershed also has experienced net gain in wetland acreage.

4.4 Geomorphic Assessment

Overview

A geomorphic study for the Sunrise River Watershed was performed in an effort to better understand the existing conditions in the watershed from a stream morphology perspective. The locations for field sites assessed are given in Figure 30. This assessment provides an excellent characterization of baseline conditions for stream and river stability, channel type, bank erosion and other key factors. This helps to understand how existing conditions are influencing stream/river conditions, and provides a baseline that can be compared to in the future to evaluate whether conditions have changed. With increased development come many stressors that can influence stream and river hydrology. A detailed geomorphic assessment allows for comparisons to determine whether physical stream/river conditions have changed over time. Results from this geomorphic survey also were used as a part of the stream health assessments discussed above.

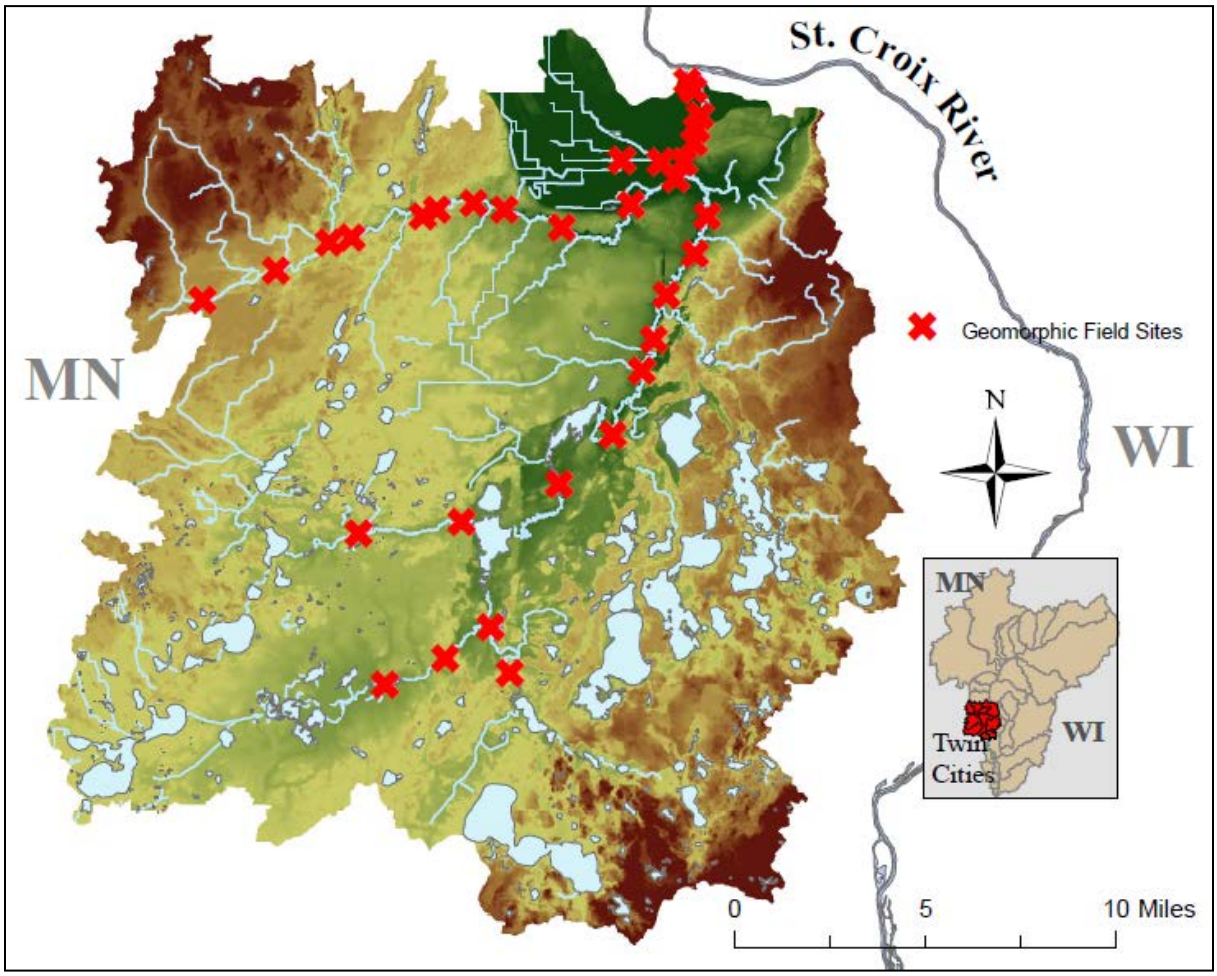

Figure 30: Geomorphic field sites within the Sunrise River Watershed.

The scope of the geomorphic study included:

- Identification & collection of available data
    - Historic aerial photos
    - GIS data (watershed delineations, stream centerline, etc.)

    - Best available digital elevation data
- Field data collection at stream sites throughout watershed including:
    - Identification and measurement of bankfull width and depth
    - Description of bed material
    - Assessment of channel stability
    - Collection of bed material and eroding bank material at several sites, and analysis of the those samples for grain size distribution and phosphorus concentration
- Other data collection
    - Fall 2009 leaf-off high resolution aerial photos of streams of interest
    - Cross section surveys of several reaches throughout the watershed
- Analysis of data
    - Identification of historic stream plan-form changes from aerial photos
    - Calculation of morphological parameters at each field site and creation of spatial database

Detailed descriptions of the methods used in the study are outlined in Appendix E. This includes field measurements (Figure 31), creation of a database of geomorphic parameters, a series of maps, and supporting data.

Figure 31: Field crew collecting geomorphic data within the upstream reaches of the Sunrise River Watershed.

Trends, Conclusions, and general observations:

The streams of the Sunrise River watershed have a general trend of increasing slopes and stream power from upstream to downstream. The main stem of the Sunrise downstream of Kost Dam and the North Branch of the Sunrise downstream of Highway 95 (first crossing upstream of City of North Branch) in particular are reaches with markedly increased slopes (on the order of 0.001 ft/ft) compared to the rest of the watershed. These reaches generally correspond with the presence of visible, tall cut banks where active erosion is taking place. The calculated geomorphic parameters verify this overall trend, and it is clear that the great majority sediment supply due to in stream erosion is from these reaches.

Although several eroding banks along the streams are present in the lower portion of the watershed (Figure 32), several sets of historical aerial photos are available back to 1938. It proved difficult to quantify the stream bank erosion or rate of erosion at specific banks due to the relatively small migration of the channel, quality of the historic photos, and error associated with the geo-rectification of the historic photos. Therefore volumetric estimates of annual stream-bank erosion were not made.

The upper reaches of the watershed are typically characterized by wide flood plains and flatter slopes (typically less than 0.0004 ft/ft). Analysis of historical photos indicates that the streams in the upper watershed commonly erode new channels and leave oxbows within the floodplain as they typically have very little constraint in terms of high banks. The historic channel shifts tend to leave the streams with a similar overall sinuosity, indicating similar sediment transport capacity. Several impoundments exist in the upper watershed, all of which trap nearly all of the sand size sediments and a large percentage of the finer sediments that enter from upstream. As evidenced by the low slopes, lack of high banks, and historically stable sinuosity, and the presence of impoundments, the upper reaches do not contribute a large amount of sediment to the Sunrise River system.

The presence of reddish heavy clay was noted along the North Branch and Sunrise main stem downstream of Kost Dam. Clay clasts of various sizes were noted as part of the bed material at several locations; a field site on the Sunrise above the confluence with the North Branch has a bed that consists of a solid, thick layer of the clay. This material is of significance to the geomorphology of the system as the clay particles being transported have properties that effect their transport that are different that those of quartz sand. The layer of clay at this site is significant as the material requires high shear stress to erode due to the cohesive properties of the clay and is likely preventing downward erosion of the stream bed in the area.

Figure 32: Bank erosion on the lower Sunrise River near Wild River State Park.

4.5 Groundwater

The Chisago Lakes area is a hydrologically complex setting including several lakes of varying sizes. The largest lakes fall along both sides of U.S. Highway 8. Many of these lakes are connected through either open channels or pipes allowing water to flow between the lakes during high flow events. These artificial connections have resulted in altered hydrology and changing lake surface levels. Previous studies identified water losses from lakes that could not be explained through evaporation or surface flow. It was suspected that the water losses from the system were related to groundwater flows.

With modeling efforts under this study, and potential future modeling efforts, subsurface flows will factor into the development of a water budget. While estimates can be made of the effects of groundwater losses on the water budget of the lakes system, this groundwater study was undertaken to confirm and quantify these losses. The results of this study improve our understanding of lake water-groundwater interactions in the Chisago Lakes area and will improve the quality of the results of SWAT or other modeling.

During the winter months, ice coverage on the lakes limits surface inflows and lake evaporation losses. Any changes to lake water surface elevations during this time would be predominantly the result of subsurface groundwater flows.

The following fourteen lakes were monitored as part of the study:

- North Center Lake
- South Center Lake
- Kroon Lake
- North Lindstrom Lake
- South Lindstrom Lake
- Chisago Lake
- Sunrise Lake
- School Lake
- Wallmark Lake
- Martha Lake
- Little Green Lake
- Green Lake
- Little Lake
- Lake Ellen

In order to determine water surface elevations, benchmarks with known elevations were needed in proximity to each lake survey location. A Registered Land Surveyor was used to set benchmarks at each site with GPS equipment. Lake elevations were surveyed bi-weekly for a period of 14 weeks, resulting in seven observations.

Observations during this study generally reflected those by Palen et al. (1993) demonstrated the dominant shallow groundwater flow direction in the Chisago Lakes area is north-northwest toward the Sunrise River, with localized deflections towards lakes and other topographic depressions. The groundwater "divide" in the Chisago Lakes area occurs approximately 1 to 2 miles southeast of the Chisago Lakes (Figure 33). Groundwater on the northwest side of the divide flows generally northwest, through the lakes area to the Sunrise River. Groundwater to the southeast side of the divide flows away from the lakes area and is eventually discharged to the St. Croix River. The groundwater divide has the same location as the divide for surface runoff.

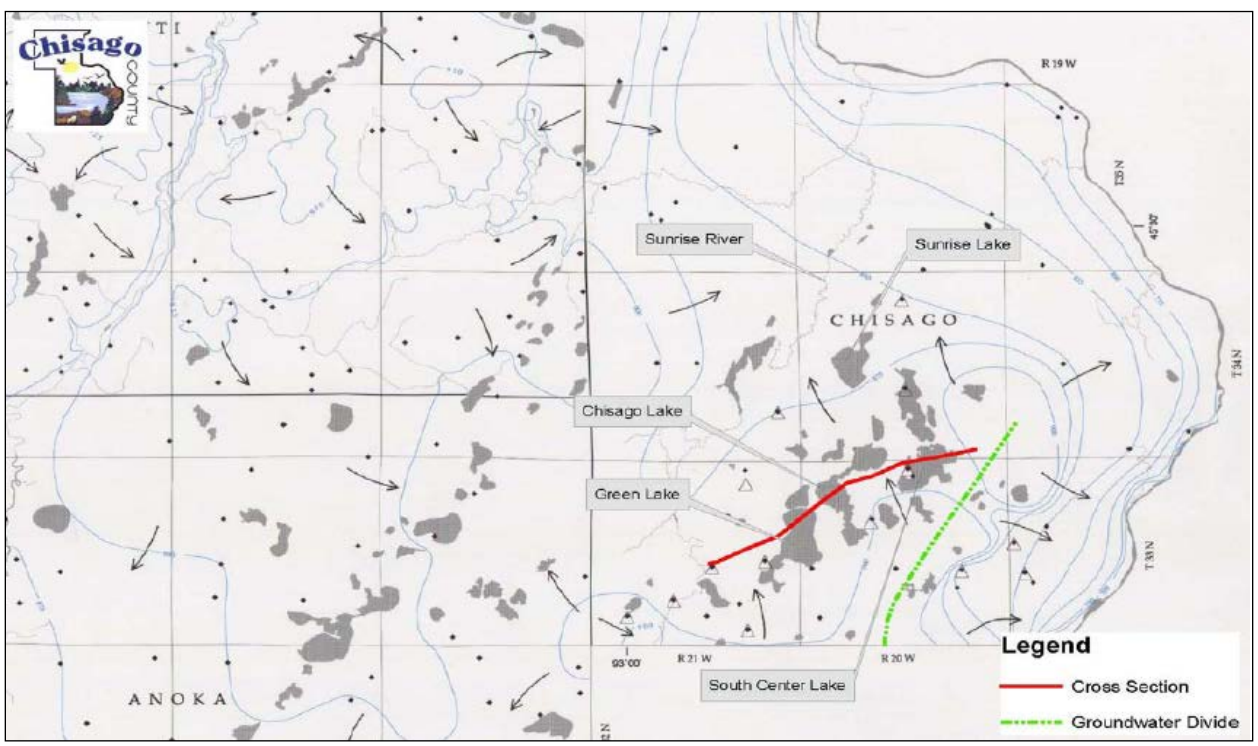

Figure 33: Groundwater contour map and flow direction, with focus on the Lake Improvement District groundwater survey area.

Based on the behavior of the lakes during the time they were monitored, the Chisago Lakes can be classified as follows:

- Losing Lakes (those that lose lake water to groundwater): North and South Center, South Lindstrom, Chisago, Sunrise, Little Green, and Green Lake
- Flow-through Lakes: Kroon, School, Wallmark, Little, Ellen, Martha, and North Lindstrom Lake
- Gaining Lakes (those that gain lake water from groundwater): None

Green, North Center and South Center lakes had the most significant wintertime total water loss to groundwater (Table 5; Appendix F).

Table 5: Volumetric water loss to groundwater during winter period observed (December 2007 to March 2008).

Lake	Total Water Loss (acre feet)
Green Lake	2,423
South Center Lake	1,171
North Center Lake	1,014
Chisago Lake	306
Little Green Lake	216
South Lindstrom Lake	186
Sunrise Lake	184
North Lindstrom	68

The DNR published a document entitled “Natural Ordinary High Water Determination for the Chisago Chain of Lakes”. This document states that elevations of the Chisago Lakes have fluctuated as much as 22 feet from 1848 to 1981. The early 1930’s represented a particularly dry period. The DNR indicates that Chisago Lake had an elevation of 882.0 in 1935. This is approximately 13.7 feet below the elevation recorded for Chisago on this study’s initial survey date (12/19/2007).

A review of historic lake elevations revealed that although there are regular short term lake level variations, long term lake elevations have remained relatively stable over the last four decades, and in some cases have risen. This indicates that over the last four decades, the lakes in this study that lose water to groundwater in the winter months are similarly recharged from precipitation, overland flow, or groundwater discharge during other months. Lake water surface elevations will likely continue to have short term and long term fluctuations in the future.

5. EVALUATION OF POTENTIAL FUTURE CONDITIONS

5.1 Overview

The goal of this analysis was to estimate the changes in water-quality resulting from future changes in land-cover and waste-water loads as a consequence of projected population increases in the Sunrise River watershed. It also was to assess possible options to improve water quality and reduce phosphorus and sediment loading to the Sunrise and St. Croix Rivers. This included assessing the ability to meet future loading goals identified in the Lake St. Croix TMDL (2012). The TMDL identified goals of annual phosphorus loading reductions from the St. Croix River of about 8,300 kg/yr. This is approximately a 33% reduction over conditions identified in the TMDL.

The future conditions that were assessed included:

5. Projected future water quality conditions (Future Without any actions).
6. Future loading with modified agriculture land use practices.
7. Future loading with modified urban land use practices.
8. Future loading with wetland restoration actions.

The discussion below evaluated these future conditions and is summarized from the analyses provided in Appendix B. This and other appendices related to SWAT modeling are also available as stand-alone reports through the Minnesota Pollution Control Agency: http://www.pca.state.mn.us/zihya01.

5.2 Methods for Forecasting Future Development

Because population has nearly always grown throughout history, and because most of this growth now occurs in cities and urban fringes, population projections have an air of inevitability about them. The question is generally not if, but when population will grow, thereby consuming land for residential and commercial uses. Hence we treat population projections as “what-when” scenarios that form “future baselines” for further what-if scenarios. We note, however, that even in the face of probable population growth, land managers may have substantial discretion about how land is developed to accommodate this growth.

Configuring the SWAT model for these projected runs required three steps: acquisition of population growth projections, calculation of increased waste-water loads, and estimation of increased developed land cover. Methods and results of these projections are provided in Appendix B. With this information, SWAT was able to project future water quality conditions.

This analysis assessed existing water quality conditions as well as conditions in 2020 and 2030. Existing population levels for the Watershed were obtained from the U.S. Census Bureau. Projected data for 2010, 2020, and 2030 were obtained from the Metropolitan Council for Anoka and Washington counties, and from the Minnesota State Demographer’s office for Chisago and Isanti counties. Average data for 2000-2010 were used to represent current conditions in the SWAT model, and data for 2020 and 2030 were chosen to represent future conditions. Discussion of how available data was summarized for the Watershed is provided in Appendix B.

Typical Corps planning documents assess future changes across a 50-year period. However, projecting population and land cover conditions 50 years into the future is extremely challenging. The data outlined above suggest that the total population could increase from about 78,000 in 2010 to 103,000 in

2020 (a 32% increase) and to 120,000 in 2030 (54% increase from 2010). This population growth could result in an increase in developed lands from 16% (current) to 24% of the total watershed area. Given the general economic slow-down since 2008, and resulting slumps in growth and development from 2008 thru 2011, these growth predictions seem optimistically large. However, we presume they will eventually be achieved at some time in the future, if not by 2020 then by 2030.Thus, the projections may better represent potential population increases over a future period approaching 40 to 50 years.

Appendix B provides complete discussion of projections for population growth projections, calculation of increased waste-water loads and estimation of increased developed land cover. This includes all assumption with changes in future land use (Figure 34) that is integral to SWAT's calculation of future water quality.

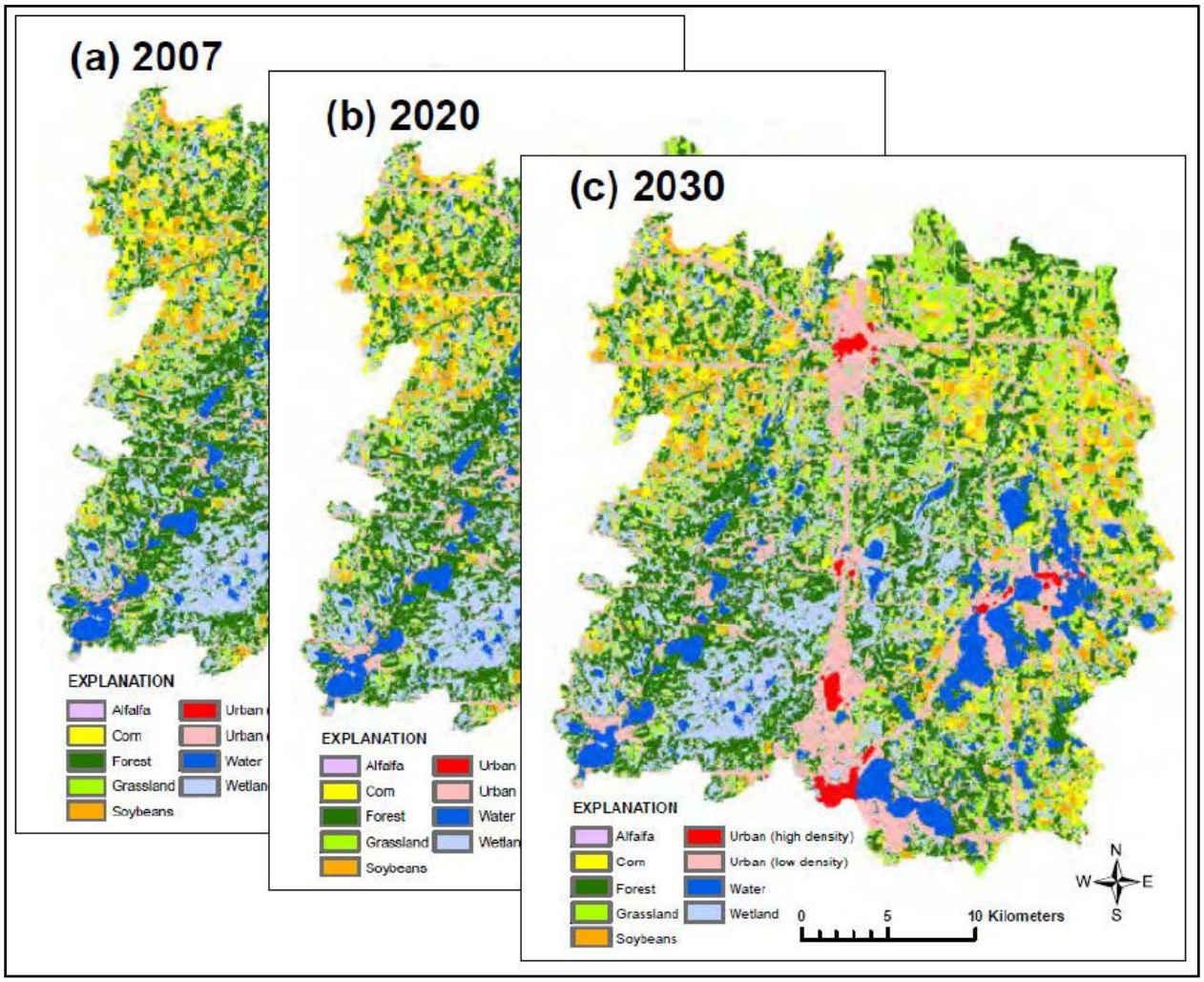

Figure 34: Projected future land cover conditions, based on projected population growth, for the Sunrise River Watershed (Appendix B).

5.3 Projected Future Water Quality Conditions (Future without Action)

SWAT calculated changes to hydrology, sediment and phosphorus loading throughout the Watershed under existing and potential future conditions (Appendix B). In all cases, projected future land use

changes resulted in reduced water infiltration and increased runoff. This is due to the increase in soil compaction and impervious surfaces relative to the previous land cover. The end result is that SWAT projects an increase in surface flows under future conditions (Table 6).

Table 6: Estimated flows, sediment and total phosphorus loads to selected locations in the Sunrise River Watershed for existing (2000s) and projected future (2030, 2030) land cover conditions.

River Location	Flow (cfs)			Sediment Load (met t/yr)			Total Phosphorus Load (kg/yr)		
	2000s	**2020**	**2030**	**2000s**	**2020**	**2030**	**2000s**	**2020**	**2030**
Sunrise_atMouth	194.6	204.1	209.4	4,661	4,710	4,751	21,683	22,219	22,683
Sunrise_atSunrise	193.2	203.1	208.0	4,218	4,236	4,260	21,587	22,116	22,574
Sunrise_atHwy95	110.9	116.2	119.0	2,087	2,122	2,139	9,476	9,840	10,099
Sunrise_Hwy 14	91.8	96.8	99.2	152	149	147	2,812	3,194	3,463
Sunrise_belowComfortLk	14.5	15.9	16.2	60	67	69	313	353	360
NorthBr_atHwy95	63.6	66.0	67.5	1,045	1,055	1,061	7,955	8,211	8,383
HayCk_atMouth	9.9	11.3	12.0	93	48	41	1,193	1,098	1,122
SE_Br_belowLID&WWTP	11.7	13.1	13.8	69	64	60	1,610	1,856	2,045
SoutheastBr_belowLID	8.1	8.8	9.2	32	31	30	369	385	394
SouthBr_atWyoming	13.1	13.4	13.8	24	27	28	1,108	1,273	1,373
WestBr_nrStacy (Lyons)	38.8	39.6	40.3	227	231	232	416	427	435

Loads of sediment and nutrients at selected monitoring points along the river incorporate all possible sources, including delivery from each upstream subwatershed, from each upstream lake, from channel erosion, from groundwater discharge, and from point sources. At the outlet of the watershed, SWAT projects sediment load would increase by about 2%, and total phosphorus load would increase by about 5% from the 2000s to 2030 (Table 6; Appendix B).

The increase in sediment appeared to come partly from high-density urbanization along the I-35 corridor and adjacent cities and partly from increased channel erosion due to increased flow. Despite the reduced loading of phosphorus in some subwatersheds (Figure 35), evidently the loads in other subwatersheds upstream from these monitoring points were large enough to result in net increases. Phosphorus loads to rivers and lakes in the watershed would increase by 7% (Appendix B). The total phosphorus load at the mouth of the Sunrise increased about 5% from the 2000s to 2030, from about 21,700 to 22,700 kg/yr. Of this 1000 kg increase, about 450 kg could be a result of increased point-source discharges, leaving the remainder coming from nonpoint sources. These simulated loads resulting from increased urbanization rely on default SWAT parameters that do not reflect any urban best-management practices that might be employed.

SWAT also projected sediment and phosphorus loading to lakes within the Watershed. On-channel lakes, called reservoirs in SWAT (whether man-made or not), receive non-point source pollution not only from their directly contributing subwatershed, but in most cases also from an inlet stream that has accumulated inputs from all upstream subwatersheds. These loads include not only those discussed above from the subwatershed surface, but also sediment from channel scour and phosphorus from groundwater discharge. In theory the model can account for trapping of sediment and phosphorus in lakes by settling, and so downstream lakes are somewhat protected by upstream lakes. However, data for calibrating the sediment and nutrient settling parameters were not available, and the default values that were used may be significantly in error. As such, model projections for individual lakes must be

considered carefully. However, the results may suggest how lakes might experience sediment and phosphorus loading in the future.

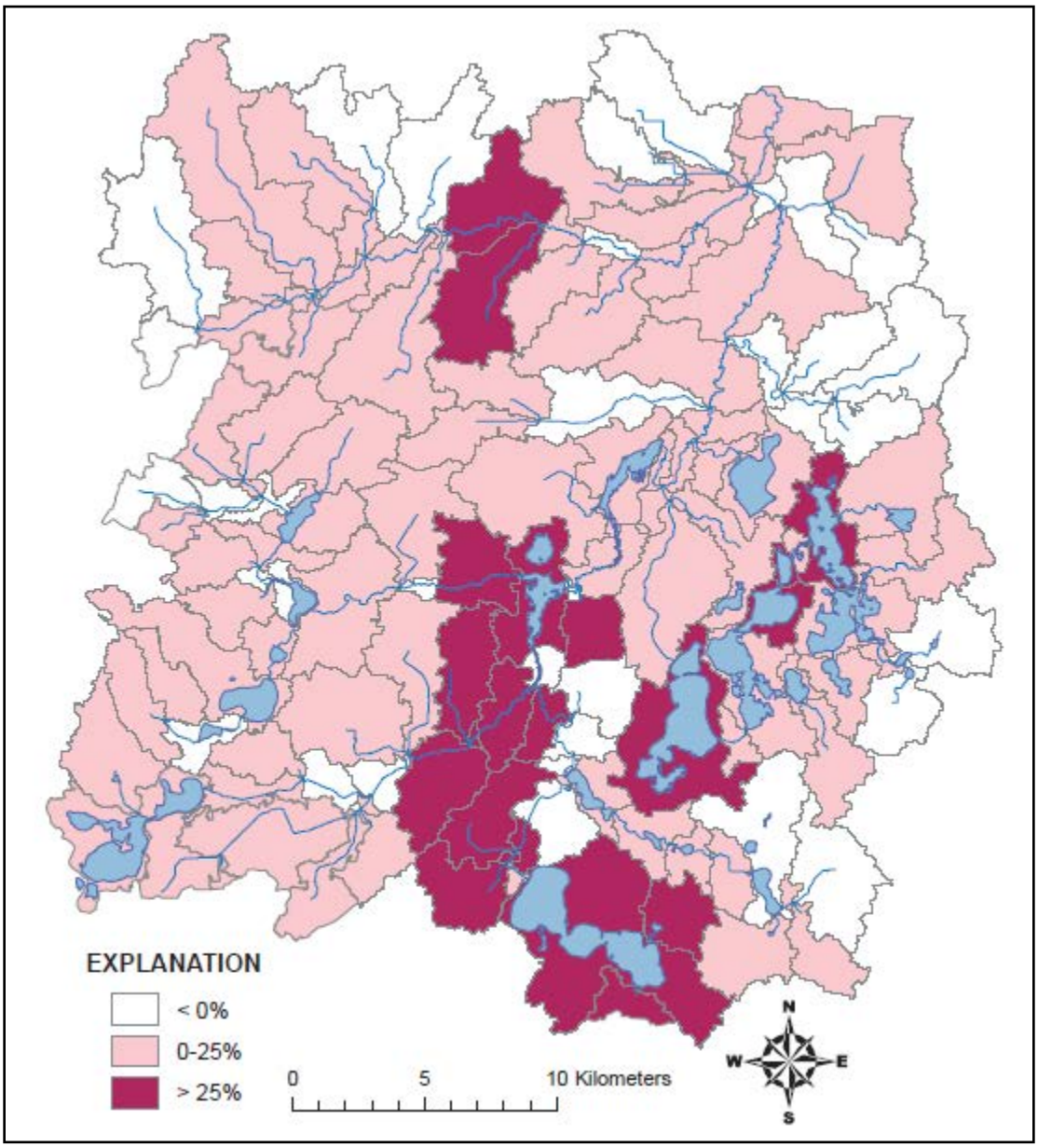

Figure 35: Percent change in subwatershed total phosphorus loads transported by overland and shallow flow, from current (2000s) loads to 2030 loads based on projected population increases and attendant urban and residential land use.

Modeled sediment loads to lakes ranged from 3 metric t/yr (Coon Lake) to 360 metric t/yr (South Pool, 2030; see Table 7). Among those lakes receiving at least 100 metric t/yr of sediment in the 2000s, the percentage change from 2000s to 2030 ranged from a 23% decrease (Chisago and Green lakes) to a 15% increase (Comfort Lake), with an overall average reduction to all modeled lakes of about 4%.

Phosphorus loads ranged from 240 kg/yr (North Lindstrom, 2000s) to about 3000 kg/yr (South Pool, 2030) (Table 8). Large loads here are mostly a result of large drainage area and amount of groundwater

discharge, hence the large loads entering South Pool and North Pool. Apparently catchment size and groundwater discharge overwhelm the trapping of phosphorus by upstream lakes, which otherwise reduce loads to downstream lakes. Most lakes experienced an increase in phosphorus loading from 2000s to 2030, with an overall increase of 13%. The increases were driven by expansion of urban land in the model, principally when these types of land uses replaced grassland or forest.

Table 7: Estimated sediment and total phosphorus loads to selected lakes in the Sunrise River Watershed for existing (2000s) and projected future (2030, 2030) land cover conditions. Trophic Status, M = mesotrophic; E = eutrophic; H = Hypereutrophic.

	Sediment Load (met t/yr)				Total Phosphorus (kg/yr)				Trophic
Lake Name	**2000s**	**2020**	**2030**	***Change***	**2000s**	**2020**	**2030**	***Change***	***Status***
Sunrise	42	34	30	*-27.1%*	349	352	355	*1.8%*	*E*
Typo	62	60	58	*-6.4%*	959	960	963	*0.4%*	*H***
Linn	97	95	94	*-3.9%*	431	432	433	*0.5%*	*H*
South Center	306	297	291	*-4.9%*	1,875	1,955	2,005	*6.9%*	*E***
North Center	213	206	201	*-5.7%*	1,538	1,615	1,664	*8.2%*	*E***
North Lindstrom	13	15	16	*18.4%*	240	279	289	*20.4%*	*M*
South Lindstrom	10	13	14	*35.4%*	353	466	469	*32.6%*	*E*
Linwood	12	12	12	*-0.4%*	489	497	503	*2.8%*	*E***
Martin*	na	na	na	*na*	675	684	691	*2.4%*	*E***
Kroon	39	37	36	*-8.2%*	248	257	262	*5.7%*	*E***
Chisago	94	81	72	*-23.1%*	629	705	751	*19.5%*	*E*
Green	141	121	108	*-23.1%*	1,018	1,171	1,266	*24.4%*	*M*
Coon	3	3	3	*4.4%*	345	357	367	*6.6%*	*E*
Bone	277	273	270	*-2.6%*	1,490	1,479	1,474	*-1.1%*	*E***
Forest	81	72	68	*-16.2%*	696	897	969	*39.3%*	*E*
Comfort	150	166	172	*14.6%*	1,629	1,838	1,865	*14.5%*	*E***
South_Pool	350	359	360	*3.0%*	2,510	2,844	3,036	*21.0%*	--
North_Pool	63	66	67	*6.8%*	1,680	1,900	2,027	*20.6%*	--
Total	1,954	1,911	1,873	*-4.1%*	17,155	18,692	19,390	*13.0%*	

*Sediment loads to Martin Lake are not available (na). Model output does not appear realistic.
**Identifies existing water quality impairment.

Total phosphorus loading was summarized from SWAT for major land-cover types. For the future (2030) condition, urban areas accounted for 38% of phosphorus loading, agricultural areas accounted for 46%, and other land cover types accounted for the remaining 16% (Table 8).

Table 8: SWAT-estimated phosphorus yields, relative areas, and relative phosphorus loads for basic land-cover types in the Sunrise River watershed.

		% Watershed Area		% Phosphorus Load	
	Phosphorus Yield	Baseline 2000s	2030	Baseline 2000	2030
	(kg/ha)	%	%	%	%
Developed		16%	24%	27%	38%
Urban, high density	2.18	0.4%	1%	2%	3%
Urban, low Density	0.85	10%	14%	23%	31%
Rural Residential	0.21	6%	9%	2%	4%
Agriculture		21%	18%	55%	46%
Row Crop Rotations	1.34	13%	11%	51%	46%
Pasture and Hay	0.34	8%	7%	4%	3%
Other (forest, grassland)	0.11	63%	58%	17%	16%

5.4 Loading with modified agriculture land use practices

Under existing conditions, agricultural land occupies only 21% of the Sunrise River watershed but delivers 86% of the sediment and 55% of the phosphorus nonpoint-source loads from uplands to receiving waters, i.e., streams, lakes, and wetlands (Appendix B). Modifying agricultural practices could serve to improve sediment and phosphorus loading. Simulating agricultural practices is probably the greatest strength of the SWAT model. Agricultural practices have been changing to reduce losses of soil and nutrients from fields. Collectively, these new methods are called best management practices, or BMPs. Selected BMPs were implemented in the SWAT model to estimate how much phosphorus loads might be reduced from the baseline upland load of about 53 metric tons/yr. As for the yields discussed above, loads given here are those delivered from uplands to receiving waters, namely streams, lakes, and wetlands. Loads leaving the watershed (baseline of 22 metric tons/yr) are much less because much of the phosphorus entering wetlands or lakes are trapped.

A complete discussion of this analysis, including all assumptions, is included in Appendix B. The following briefly outlines each BMP and the potential impact each might have on reducing phosphorus loading. Analysis of agricultural BMPs included several scenarios that are described below with results presented in Table 9.

No-till (NT): No-till agriculture tends to reduce sediment loads because of increased vegetative and residue cover that protects the soil from erosion. Two scenarios converted half, and then all, of the Corn-Soybean rotation land and Corn-Alfalfa rotations to no-till agriculture. Reductions in upland phosphorus load were decidedly modest with only about 2% and 4%, respectively (Table 9). No-till practices seem more effective at reducing losses of sediment than phosphorus.

Switchgrass: Switchgrass is a potential crop for energy production from biomass. One scenario converted half the corn-soybean lands to perennial switchgrass, and phosphorus loads were substantially reduced by 18% (Table 9). A second scenario replaced all corn-soybean lands on steep slopes with switchgrass, which is good management, but there were so few of these areas in the model that the resulting change was inconsequential.

Vegetated filter strips: A vegetated filter strip is a strip of grassland along the downhill edge of an agricultural area, here set to 2% of the area. For a square 40-acre field, the strip would be about 25 ft wide. Resulting phosphorus load reductions were substantial (Table 9). Adding this to half or all corn-soybean lands resulted in phosphorus load reductions of about 6-10%. Adding vegetated filter strips to corn-alfalfa lands resulted in little additional reduction, mostly because the area of corn-alfalfa lands was small.

Grassed waterways: In the Sunrise SWAT model, grassed waterways were implemented as a 10-m wide strip of grassland with a length set to the square root of the field area, e.g., a single waterway down the middle of a square field. For a 40-acre field, this would amount to about 2.5% of the total field area. Results were consistent with the vegetated filter strips results, namely that grassed waterways provided substantial reductions in phosphorus loads (Table 9). Various scenarios were considered on corn-soybean and corn-alfalfa lands, with resulting reductions in phosphorus loads of 8-18% (Table 9).

Soil-test phosphorus reductions: Soil-test phosphorus can be lowered by reducing fertilizer additions of phosphorus below that removed by crop harvest and runoff. Reductions in soil-test phosphorus of a few parts per million (ppm) per year could require several decades to reach target levels. One scenario reduced soil-test phosphorus in corn-soybean and corn-alfalfa lands with high soil-test phosphorus (60 ppm) down to medium levels (40 ppm). The reduction in load (4%; Table 9) was modest but useful because implementation required only 25% of the tilled lands, those with the highest soil-test phosphorus. Another scenario reduced soil-test phosphorus to 20 ppm in all corn-soybean land and 30 ppm in all corn-alfalfa land, thereby reducing phosphorus loads by a substantial 17% (Table 9). Two more scenarios reduced soil-test phosphorus in grass hay fields and pasture (forage crops), first in those few grasslands with high (60 ppm) levels down to medium (40 ppm) and second in all grasslands down to 20 ppm. Load reductions were modest because such grasslands were not large contributors of phosphorus in the first place in the model. However, combining all these soil-test phosphorus reductions resulted in a nearly 20% reduction in phosphorus load (Table 9).

Converting daily-haul (DH) manure applications to seasonal: Seasonal applications of manure, if incorporated by chisel plowing, can reduce phosphorus loads compared to daily-haul operations that spread some manure on frozen ground in early spring. Converting all daily haul operations on corn-alfalfa land to seasonal manure applications (scenario 16, Table 9) resulted in only a modest phosphorus load reduction (2%), mostly because of the small area of these lands.

Conclusions

Even though the phosphorus load reduction from any one agricultural BMP may be modest, in aggregate the reductions could be substantial. Furthermore, the model could not include the entire range of large soil-test phosphorus values or manure application rates that might be present in the watershed. Resource managers should work to find such sites and target them first for their potential benefits to water quality.

Table 9: Percent phosphorus reduction from baseline conditions for various agricultural BMPs within the Sunrise River Watershed (full results in Appendix B).

Scenario Description	% Reduction in phosphorus from baseline
Reduce soil-test phosphorus in hay fields and pastures from 60 ppm to 40 ppm.	0 %
Switchgrass implemented on all Corn-Soybean Lands w/ steep slopes. Fertilizer, no till.	1 %
Reduce soil-test phosphorus in hay fields and pastures in all areas down to 20 ppm.	1 %
No-Till: Half of all corn-soybean and corn-alfalfa lands converted to no-till agriculture	2 %
Converting daily-haul manure applications on corn-alfalfa land to seasonal	2 %
No-Till: All of corn-soybean and corn-alfalfa lands converted to no-till agriculture	4 %
Soil-test phosphorus reduced from 60 parts per million to 40 parts per million on ag lands (25% of tilled lands)	4 %
Vegetated filter strip on half of corn-soybean lands. 2% of field area where applied.	6 %
Grassed Waterways (10 m width). Implement on half of corn-soybean land	8 %
Vegetated filter strip on all of corn-soybean lands. 2% of field area where applied	10 %
Veg filter strips on all corn-soybean and corn-alfalfa lands. 2% of area where applied	11 %
Grassed Waterways (10 m width). Implement on all of corn-soybean land	15 %
Soil-test phosphorus reduced to 20 ppm on corn-soybean lands; and 30 ppm on corn-alfalfa lands	17 %
Grassed Waterways (10 m width). Implement on all of corn-soybean and corn-alfalfa land	18 %
Switchgrass implemented on half of all corn-soybean Lands. Fertilizer, no till.	18 %
Reducing soil-test phosphorus by all measures identified above	20 %

5.5 Loading with changes in urban practices

This section discusses efforts to reduce nonpoint phosphorus loads from developed lands by changing selected characteristics of these lands. Developed land, i.e., urban and rural residential, currently occupies about 16% of the area of the Watershed but accounts for about 27% of the nonpoint-source phosphorus load reaching aquatic resources (wetlands, rivers, and lakes) (Table 8). By 2030, developed lands are projected to occupy about 24% of the watershed area and deliver 38% of the nonpoint phosphorus load. Phosphorus also can come from point sources such as wastewater treatment plants; improvements in treatment technology suggest loads from point sources will remain small despite projected population increases (Appendix B). Loads of sediment from urban areas can be substantial and should not be ignored in many cases. However, in the Sunrise watershed, urban sources of sediment appear small compared to agricultural sources and channel erosion (about 46% of total sediment leaving the watershed).

Phosphorus loads from uplands can be reduced in either of two ways: reduce the amount of surface runoff that transports the phosphorus; or reduce the phosphorus content of that runoff. Modeled upland phosphorus loads from scenarios attempting to use these methods were compared to current baseline loads, as well as to projected loads for the year 2030. Note that the watershed-wide total phosphorus load from the uplands exceeds 50 metric tons per year, which is far greater than the total load delivered from the Sunrise to the St. Croix River (Appendix B). The difference is caused by the trapping of phosphorus in lowlands (ponds, wetlands) and lakes. These water bodies help protect the St. Croix River from excess phosphorus but can suffer from impaired water quality themselves as a consequence.

Baseline upland phosphorus loads totaled about 52.2 met tons (115,000 pounds), about 27% of which comes from developed lands. Expansion of existing urban and rural residential areas to accommodate projected population increases by 2030 may increase the upland phosphorus load to 55.6 metric tons.

Runoff from urban lands can be greatly influenced by the fraction of impervious cover and connected impervious cover that are directly connected to channelized flow paths provided by curbs, gutters, and storm sewers. Several scenarios tested the effect of reducing impervious cover by 20% in urban lands (both high density and low density development). Runoff was in fact reduced, but only slightly, about 1% or less for scenarios 2-4 and 5% for scenario 5. Consequently, modeled reductions in upland phosphorus loads were insubstantial, essentially zero for scenarios 2-4 and only 3% for scenario 5 (Appendix B).

Another scenario tested the effect of changing totally impervious surfaces to having some infiltration capacity, for example by having pervious pavement. Again, reductions in runoff volume (2%) and upland phosphorus load (1%) were insubstantial (Appendix B). The minimal changes seen in our model runs suggest that there are idiosyncrasies in the SWAT code dealing with high- and low-density urban lands that need further examination. This technique may be more effective than our SWAT effort suggests.

We also modeled the effect of increasing the infiltration capacity of rural-residential lands to the natural state of grasslands or woodlands. However, runoff was not large from rural residential lands in the baseline model, and so reducing runoff further resulted in only minor reductions in the total volume of runoff and in upland phosphorus loads.

The phosphorus content of runoff can be reduced by reducing the phosphorus content of the surface soil in contact with the runoff. We tested the effect of reducing the soil-test phosphorus levels in rural residential soils by half, from 20 ppm (part per million) to 10 ppm. Again, because rural residential lands delivered a fairly small load in the baseline run, reducing the load further resulted in only a 1% drop in the total upland phosphorus load (Appendix B).

Lakes are among the most highly valued aquatic resources in the Sunrise River watershed, thereby attracting the very development that can contribute to their impairment. We evaluated phosphorus loads to ten selected lakes in the Sunrise River watershed for all the scenarios discussed above, with similarly disappointingly small load reductions.

An alternative to reducing the runoff and phosphorus loads generated by upland urban surfaces is to treat the runoff by routing it through a wetland before discharging it to receiving waters. A final scenario tested the effect of routing an additional 20% of runoff through wetlands for each of the nine subwatersheds in the model that contained urban high density lands, i.e., the most densely urban subwatersheds. Loads from each of these urban subwatersheds were reduced substantially, but the total load received by these ten lakes was reduced by only by 4%, which is somewhat disappointing in face of the projected 18% increase in loads by the year 2030 (Appendix B). The larger message is that phosphorus loads to these lakes is controlled by more than simply the nine urban high density-containing subwatersheds. In particular, growth of urban high density lands in other nearby subwatersheds is the source of most of the projected increase in phosphorus loads, and these subwatersheds likewise need mitigation efforts. A more exhaustive look at use of wetlands to treat subwatershed runoff is presented in the next section of this report.

Conclusions

The SWAT model gave reasonable phosphorus loads from developed lands (urban high density; urban low density; and rural residential) for baseline and 2030-projected model runs. However, the model proved ineffectual in testing scenarios for reducing these loads by changing the character of these lands. We suggest that the SWAT model code needs examination and adjustment to allow for better implementation of urban best management practices. SWAT was much more effective in altering non-urban lands and in treating runoff by wetlands to reduce phosphorus loads. Finally, despite the undoubted influence of urban high density lands on nearby lakes, protecting these lakes will require addressing development elsewhere in their catchments as well.

5.6 Loading with wetland restoration actions

Wetlands can play a critical role in reducing phosphorus loading to lakes and streams by trapping runoff water and sediment. The Sunrise watershed currently contains many wetlands. Topographic and land cover analyses estimate that about 10% of the total watershed area is covered by wetlands, with about 40% of the total watershed area draining to wetlands. There also is potential to create or restore wetlands in the Watershed. The Watershed has experienced significant wetland loss over time, including many localized areas where losses have been 40 to 85% of historical wetlands (Figures 28 and 29). In addition, an engineered structure may direct more runoff to an existing wetland, thereby treating more water without necessarily increasing wetland area. The model results discussed here focus on two outcomes of interest: the Sunrise River's phosphorus loading to the St. Croix River and phosphorus loading to the lakes in the Lake Improvement District.

In the Lake Improvement District, the landscape is closely connected to the lakes and the streams that flow into the lakes. This results in significant loading from all subwatersheds within the Lake Improvement District. However, the extent to which phosphorus inputs from the landscape contribute to St. Croix River loading depends on where in the watershed they originate. An estimated 40% of the total watershed phosphorus load is generated by areas in the upper region of the Sunrise, upstream of the North Pool (representing about 50% of the total watershed area). However, most all of this phosphorus from the upper watershed region is trapped in wetlands and lakes, including the North and South Pools. The result is that only 5% of the total load at the confluence with the St. Croix River is predicted to have originated from upstream of the North Pool. As a result, wetlands scenarios for St. Croix phosphorus reduction considered only subwatersheds downstream of the North Pool.

The Sunrise SWAT model estimates that existing wetlands reduce phosphorus loading to the St. Croix River and into the lakes of the Lake Improvement District by 25% and 40%, respectively. Increasing the number of wetlands in the Sunrise River watershed is predicted to be an effective method to further reduce phosphorus. To simulate this effectiveness, model scenarios were created by increasing the extents of wetlands in subwatersheds (1) downstream of the North Pool (and Lake Improvement District) to reduce phosphorus loads to the St. Croix River and (2) within the Lake Improvement District to reduce phosphorus loads to lakes (Figure 36). Results of these model simulations show that increasing the extents of wetlands downstream of the North Pool by 25% and 50% would reduce phosphorus loading to the St. Croix River by about 9% and 19%, respectively (Figure 36). Likewise, increasing extents of wetlands of the Lake Improvement District by 25% and 50% reduced phosphorus loading to lakes by about 11% and 19%, respectively.

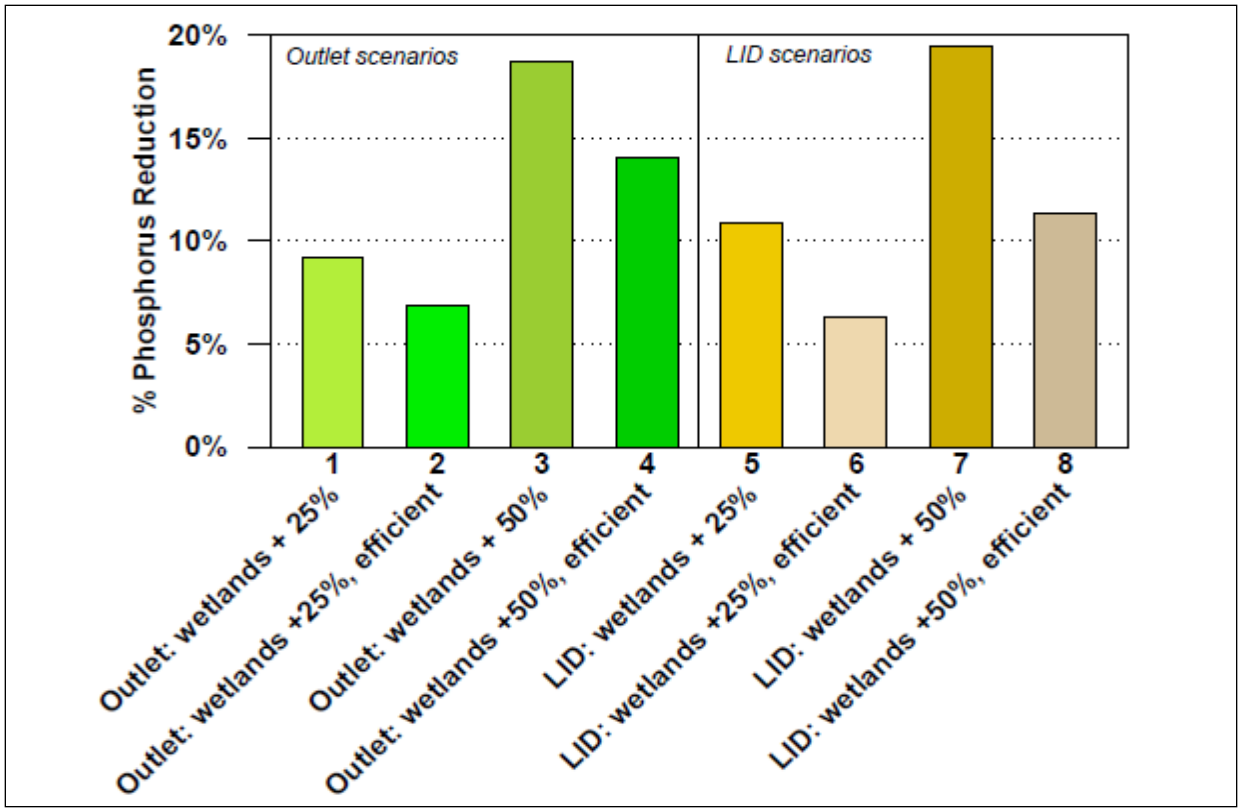

Figure 36: Phosphorus reduction from wetland mitigation scenarios for the Sunrise River outlet to the St. Croix River and for the Chisago Lake Improvement District.

In alternative scenarios, increases in wetland extent of 25% and 50% were simulated as previous but only in those subwatersheds where both phosphorus yields and current wetland phosphorus reduction were highest (arbitrarily chosen as the upper 50%, see Figure 37). These results are shown in Figure 36 and labeled as the "efficient" scenarios. The efficient scenarios showed that in the case of loading from the Sunrise River outlet to the St. Croix River, 75% of the total predicted reduction could be achieved by only increasing wetland extents by 50% when compared to the non-efficient scenarios. This effect in the Lake Improvement District was less pronounced and was only slightly more efficient than the non-efficient scenario (58% reduction for 50% increase in wetland extent when compared to non-efficient).

Conclusions

The potential for wetland mitigation in the Sunrise River watershed to reduce phosphorus loading is considerable. When used as part of combined effort that includes agricultural and urban BMPs, the effects could be substantial. It is important to note that wetlands also provide other benefits such as nitrogen and sediment removal, flood attenuation, and wildlife habitat. This suite of benefits makes wetland mitigation in the Sunrise River watershed a valuable and viable tool for resource managers.

Because most phosphorus generated in the upper watershed (above the North Pool) is already trapped by wetlands and lakes, wetland mitigation there would have little effect in reducing loads from the Sunrise to the St. Croix. However it could benefit site-specific waters.

From a management perspective, increasing the extent of wetlands can take two forms: (1) restoration or creation of wetlands that will receive runoff from areas of the landscape not currently draining to wetlands, or (2) increasing the area draining to existing wetlands, thereby increasing their use. Depending on the area of the landscape and socio-economic factors therein, it is probable a combination of both of forms would be most practical.

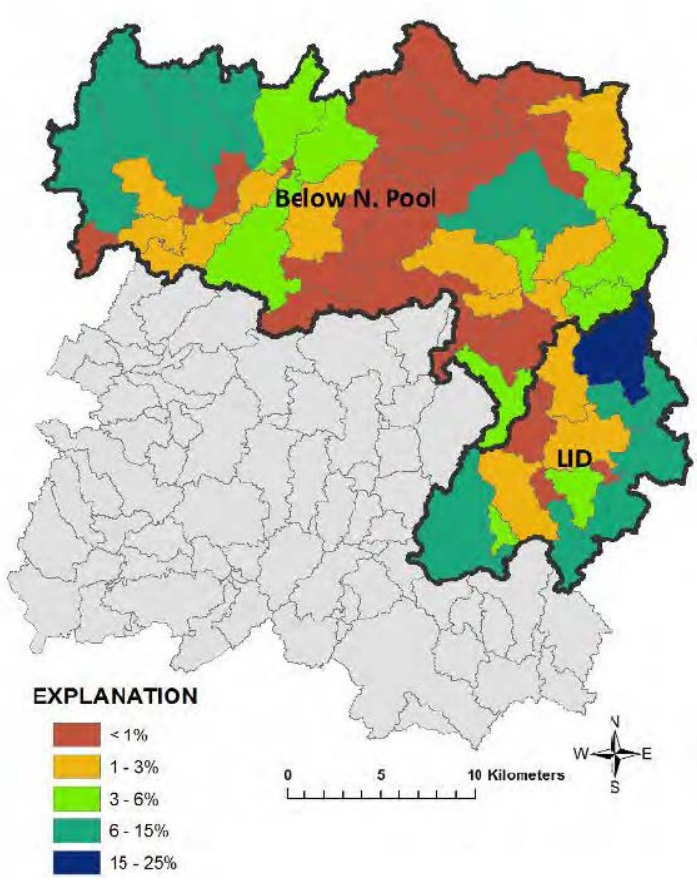

Figure 37: Distribution of phosphorus reduction from wetland mitigation scenarios for the Sunrise River outlet and Chisago Lake Improvement District focus areas. Percentages indicate the proportion of the total phosphorus reduction each subwatershed contributes in the associated area of focus. Subwatersheds with the highest percentages would be likely targets for efficient mitigation efforts. Note that subwatershed percentage in the Below North Pool and LID areas each add up to 100%.

5.7 Summary of measure effectiveness

Overall, modeling suggests that reducing nonpoint load of phosphorus is feasible, but that there is no easy solution. Reducing loads from the agricultural sector would require substantial participation in land management (e.g., grassed waterways) and reduced phosphorus applications. Treating runoff with wetland mitigation would require substantial wetland creation or re-routing of runoff through existing wetlands. Reducing urban runoff may substantially benefit the adjacent lakes, although urban BMPs could not be effectively simulated in SWAT. Implementing urban BMPs will be particularly important in the face of projected increases in population and development pressure. Even if significant growth and development does not occur by the year 2030, it will occur eventually.

6. CONCLUSIONS AND RECOMMENDATIONS

These and other recent analyses provide valuable information for management of water resources. Existing land management coupled with future development will put increased pressure on these resources. The level water resources could degrade in the future is dependent on where, when and how land use changes occur. Any hope of reducing constituent loading, and maintaining quality lakes, rivers and wetlands is predicated upon improved land management and smart growth and development.

6.1 Long Term Goals

Long term management goals can be established for any of the priority resources discussed. These can remain flexible over time and be adjusted based on priorities, shifting conditions, etc. The following are basic management goals and objectives for priority water resource issues. However, these can and should be tailored by basin stakeholders based on the results obtained from this and future studies and the collective goals for watershed quality shared by these stakeholders.

Water Quality

The Lake St. Croix TMDL (2012) targets a phosphorus export reduction goal of about 8,300 kg/yr (18, 300 lbs/yr; approximately 33%) from the Sunrise River Watershed. This would result in annual phosphorus loading of approximately 17,000 kg/yr (37, 500 lbs/yr). Phosphorus reductions of this magnitude would be difficult to achieve with existing land use practices coupled with projected future development. However, improvement in land use combined with managed future growth could work towards that goal. The project sponsor has expressed a strong interest in doing its part to help meet nutrient TMDL goals. Local agencies, including Soil and Water Conservation Districts, watershed districts and counties; as well as State and federal agencies, also are actively working to help meet these long-term goals. Land and water management in the Watershed could target to meet this nutrient loading condition at the confluence with the St. Croix River.

Future goals for watershed nutrient loading can also be tailored to address the long-term needs identified for the Minnesota Nutrient Reduction Strategy (Minnesota 2013). This report was still under development at the time this study was completed. The State reduction strategy is being developed in response to the Gulf Hypoxia Action Plan (GHAP 2008). That plan called for each state in the Mississippi River Basin to develop a strategy by 2013 to reduce the amount of phosphorus and nitrogen carried in rivers from the state to address the biological "dead zone" in Gulf of Mexico. Future Watershed nutrient loading goals can also be tailored to meet those identified in the final version of this broader State plan.

In addition to basin phosphorus loading, loading to individual waterbodies also is important for water quality. Site specific water quality goals can be established for any individual lake, river or stream. If more stringent goals are lacking, site-specific goals could revert to State water quality standards. Priority waterbodies should include those with existing impairments. Locations with known impairments should move forward with appropriate TMDL studies to address these impairments. Such TMDL studies are largely moving ahead because of the State's Watershed Approach for water quality.

In addition, high priority waterbodies could include lakes identified in Table 4 where projected phosphorus loading could substantially increase. While SWAT is limited in accurately projecting lake phosphorus loading, cautious interpretation of model output can still provide useful input to resource

managers. SWAT estimated potential increases in phosphorus loading of approximately 20% or more for North and South Lindstrom, Chisago, Green and Forest lakes. These lakes could be strong candidates for further evaluation of future loading threats, and the best options to reduce loading. Long term goals could be flexible, but might potentially target, at a minimum, maintaining existing phosphorus levels or trophic status designation into the future.

Aquatic and Riparian Habitat

Long-term goals could include maintaining aquatic and riparian habitat conditions similar to those found under existing conditions. More specific objectives could include maintaining river/stream habitat to a level that qualifies as maintaining standards for biotic use (fish and macroinvertebrates) and either "fair" or "good" according to the Minnesota Pollution Control Agency physical habitat scoring methodology. Stream reaches discussed above that were graded as below biotic standards or were graded as "poor" for physical habitat could be targets for habitat improvement. Portions of the South Branch, West Branch and main stem Sunrise would be target locations for actions to improve habitat. The Minnesota Pollution Control Agency methodology could serve as metrics to verify changes to biotic use and physical habitat in the future and relative success or failure in meeting long-term goals.

Results from future geomorphic investigations could be compared to those from this study to verify whether physical changes in stream geomorphology could be occurring as a result of altered hydrology, land use or other human influences.

Wetlands

Typical philosophy for management of wetland activities is for no net wetland loss from fill or similar action. This goal could be maintained in the future at both the watershed and subwatershed level, and even within individual drainages (e.g., contributing area of a lake). Protection against wetland loss could apply not only to wetland type, but also wetland function. This would help ensure important wetland functions such as Nutrient Transformation, Surface Water Detention and others are maintained.

Wetland restoration would provide valuable habitat and improved water quality. Placement of new wetlands in areas that have lost historical wetland functions would be valuable. Long-term goals could include increasing wetland areas to replace some of these losses. Several locations in the watershed have seen an overall net loss in wetland area and would be candidates for future restoration. Placement of these wetlands should be optimized, to the extent possible, to maximize water quality benefits. Suggestions on where to position such projects for water quality benefits are discussed below under recommendations.

Groundwater

Long term goals could include protecting groundwater resources, including recharge areas and surface waters that percolate into groundwater. These locations include portions of the Lake Improvement District identified where surface water feeds into groundwater.

6.2 Recommendations

The following recommendations are based on work performed here, and additional outside studies, including the Lake St. Croix TMDL (2012). Implementation will help to maintain and improve water quality, habitat and other resource goals established above. In addition to benefiting water quality and habitat, these recommendations will help to benefit recreational use and aesthetic values. These provide direct economic benefits to the area, including benefits at the county and local levels.

Focus Areas

Lakes and wetlands in the upper watershed are generally very efficient at trapping sediment and nutrients. To meet long-term nutrient goals for the Lake St. Croix TMDL, as well as reducing sediment loading, focus should be placed on implementing land use changes within connected drainage areas in the lower Sunrise Watershed. This includes drainage areas downstream of the Sunrise River North Pool impoundment (Figure 38). Implementation of land use changes within the drainage area of the Lake Improvement District (LID) and upper Sunrise Basin would provide localized benefits to surface waters, but would provide limited downstream benefits (Figure 38).

Some general patterns are evident from the data. First, similar watershed areas appear to experience elevated sediment and nutrient loading (Figure 39). Upper reaches of the North Branch, as well as land areas in the eastern watershed are some of the heaviest contributors of sediment and phosphorus. Additionally, these general areas have a notable loss of wetlands. Targeted efforts for land use BMPs in these areas would be most beneficial to water quality improvements.

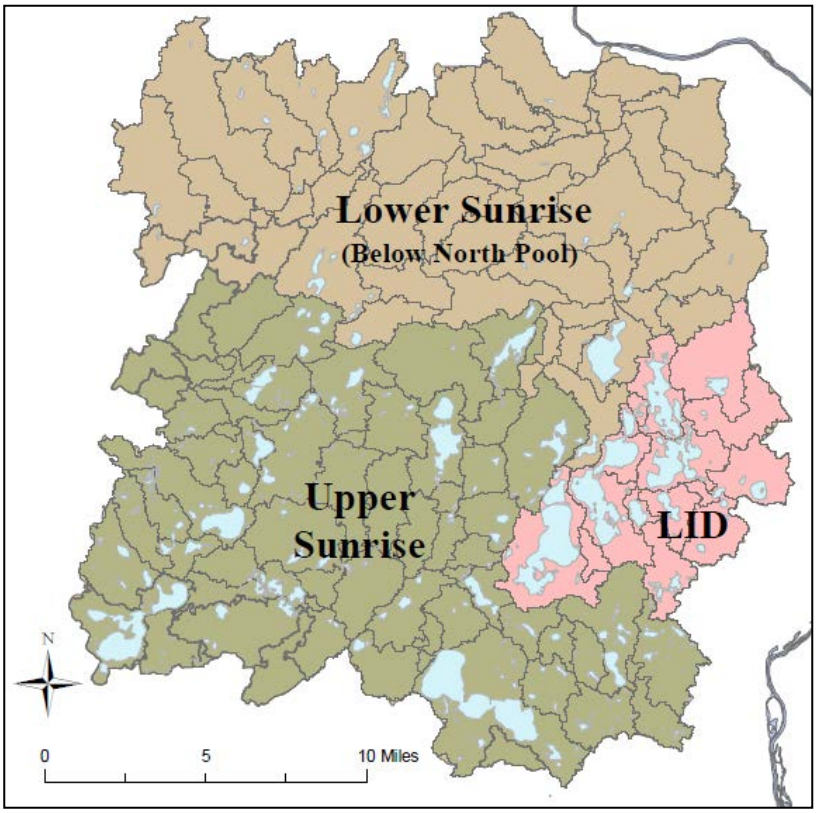

Figure 38: General drainage areas for the Sunrise River Basin. Areas of the Upper Sunrise drain through the North Pool of the Sunrise River. All areas downstream of the North Pool drain to the St. Croix River. Areas of the Lake Improvement District (LID) must drain through one or more lakes prior to reaching the Sunrise River.

Projected land use changes over the next twenty years also would result in localized increases in constituent loading. Increases in subwatershed phosphorus loading are noted in Figure 35 (% change by basin), with potential impacts to individual lakes noted at Table 7. Not surprisingly, the greatest changes are clustered in areas with the greatest development, namely along the I-35 and US Highway 8 corridors. Surface waters in these areas are at risk for water quality impacts, including several lakes that

are popular for home ownership and recreation. These areas should be prioritized for smart growth/development and improved land use to minimize increases to phosphorus loading. However, it should be recognized that actions in many of these areas (e.g., the Lake Improvement District) would have less systemic benefits.

Additional water quality impairments exist in the southern and western watershed, including listings on the West Branch and South Branch, and the Sunrise above North Pool. Lake impairments also are present (e.g. Typo and Martin lakes). Efforts have been made to address these site-specific impairments and should continue until completed. Similar to the Lake Improvement District and other areas above North Pool, land use changes in these subwatershed areas would not have broader systemic benefits. They could, however, be very important for improving water quality and habitat within specific receiving waters.

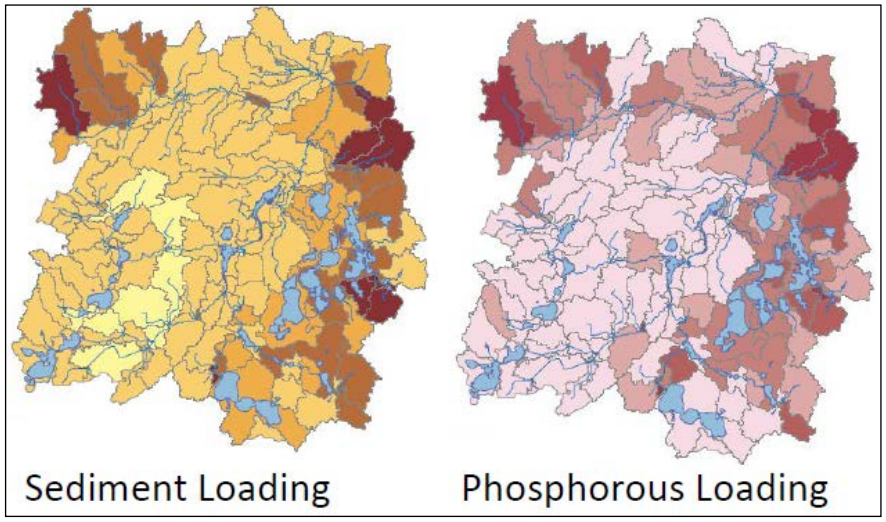

Figure 39: SWAT estimated loading for sediment and phosphorus. Focus areas include those with the greatest levels of loading (darkest shading).

Agricultural BMPs

Several BMPs were evaluated within SWAT for their effectiveness to meet water quality goals. Two BMPs that could be implemented with immediate results include using vegetated filter strips and grassed waterways in agricultural fields. These are essentially grassed areas along the downhill edge of fields, or grassed areas that funnel drainage water to ditches, streams and rivers. Greatest benefits would occur by applying BMPs to row crops areas (e.g., corn and soy bean fields). Benefits are less when applied to alfalfa, but could still be meaningful. These BMPs could be pursued immediately within priority areas discussed above for both systemic and local benefits. No-till BMPs were evaluated here and results suggest they would be more effective at reducing sediment loads than phosphorus. Other agricultural BMPs not considered here also could be valuable in reducing loading.

Another way to make substantial reductions in phosphorus loading is through reductions in soil phosphorus levels (soil-test phosphorus). This can be done by reducing fertilizer additions of phosphorus below that removed by crop harvest and runoff. Reductions in soil phosphorus of a few parts per million per year could require several decades to reach target levels. Thus, this BMP requires a much longer commitment. However, the benefits can be substantial. Thus it should be considered another management tool in reaching long-term reduction goals.

The level of BMPs needed to achieve overall loading goals depends on the effectiveness of all measures. If the general goal of a 33% phosphorus reduction was applied to agricultural areas (33% reduction in baseline phosphorus from ag lands), then BMPs for filter strips, grassed water ways, and soil phosphorus

reductions may need to be fully applied to all ag lands. This may not be realistic, and emphasizes the need to apply additional reduction strategies. However, agriculture BMPs will need to be a major feature for meeting systemic phosphorus reduction goals.

Wetland Restoration

Wetland restoration would help meet goals for wetland habitat and function. Wetland restoration was evaluated within SWAT for its effectiveness to meet water quality goals. Wetlands could be applied in two ways to reduce constituent loading: (1) restoration or creation of wetlands that will receive runoff from areas of the landscape not currently draining to wetlands, or (2) increasing the area draining to existing wetlands, thereby increasing their utilization. Figure 40 provides insight into where wetlands could be most valuable. Areas that most likely would provide the greatest systemic benefit for reduced phosphorus loading include the headwaters area of the North Branch, as well as drainage areas on the Sunrise below Kost Dam. The North Branch headwaters area in particular has experienced historical wetland loss, and these actions could provide back wetland functions.

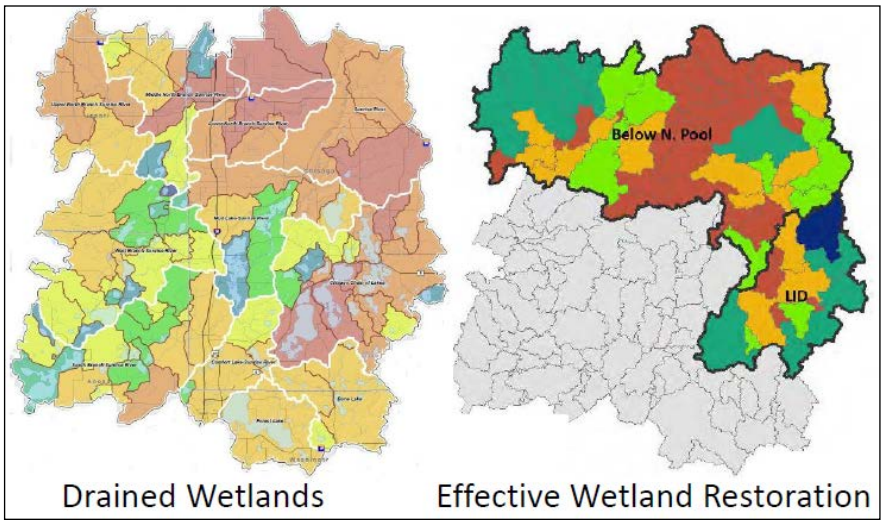

Figure 40: Drained wetland areas, and wetland placement sites for water quality benefits. Darker blue and green indicate areas likely to be most efficient sites for achieving water quality benefits via wetlands.

SWAT modeling suggests wetland restoration could be valuable to reducing phosphorus loading within the Lake Improvement District. While SWAT suggested lower benefits for directly treating urban runoff, wetland restoration could still have value in broader benefits for treating water running off urban and ag landscapes. This could be beneficial to several lakes, some of which have elevated nutrient enrichment. For example, drainage areas on the eastern part of the basin that drain towards North Center and South Center could be strong candidates for wetland restoration (Figure 40). While forecasted future loading increases to these two lakes were more modest (e.g., less than 10%, Table 7), both lakes are already eutrophic with high existing phosphorus loads and identified impairments. Kroon, Linn and Green lakes are additional lakes that may benefit from wetlands restoration that filters drainage waters. Green Lake is identified as mesotrophic, but could experience substantial increases in phosphorus loading in the future (Table 7). Efforts that reduce external phosphorus loading to this lake would be beneficial to protecting its water quality.

There are several existing impairments in the southern and western part of the watershed, including Typo and Martin Lakes, as well as the West Branch. Wetland restoration in these areas may generally be less effective given the relatively high levels of existing wetlands, fewer drained wetlands, and the lower

levels of urban and agricultural lands. With that said, wetland restoration might still be effective in these areas in select instances.

Urban BMPs

Several Urban BMPs were evaluated within SWAT for their effectiveness to improve water quality. This included measures to reduce run-off, an option to reduce phosphorus within run-off and use of wetlands to treat runoff water before entering surface waters. Unfortunately, the model proved ineffectual at testing scenarios for reducing loads by the measures described. While it is possible that urban BMPs may not be dramatically effective, it is more likely that SWAT is not well adapted to assessing phosphorus moving from urban landscapes.

Although the watershed study was inconclusive on the effectiveness of urban BMPs, they represent an opportunity for urban areas to participate in loading reductions to surface waters. Urban areas contribute 27% of existing phosphorus loading, with an increase to 38% with forecast development. Figure 35 demonstrates where loading increases would occur. Because of the need and desire to reduce nutrient loading, it is advisable that existing and future development consider BMPs to both reduce runoff, and improve quality of runoff. The following are typical BMPs that can be incorporated to help reduce urban disturbance, reduce urban runoff and improve runoff quality.

Smart Growth and Development

Implementation of land use policies, regulations and non-regulatory strategies are a critical component for protecting valuable aquatic resources including aquatic habitat, wetlands and water quality. In addition to benefits for aquatic resources, planning, zoning and other conservation tools can be used for ensuring the management of wildlife habitat, providing for sustainable development, protecting property values and maintaining community character. The following are land use and voluntary land protection recommendations.

- Pursue Direct Drainage Overlay Zone – prevent potentially polluting sources from locating in susceptibility areas. Overlay zoning is an effective approach that does not require major revisions to the existing ordinances. The overlay district can share common boundaries with the base zone or cut across base zone boundaries. For example, the direct drainage areas can be placed over the existing base zoning districts as an overlay zone with special provisions, like setting impervious surface limits, in addition to those from the underlying base zone (Figure 41).

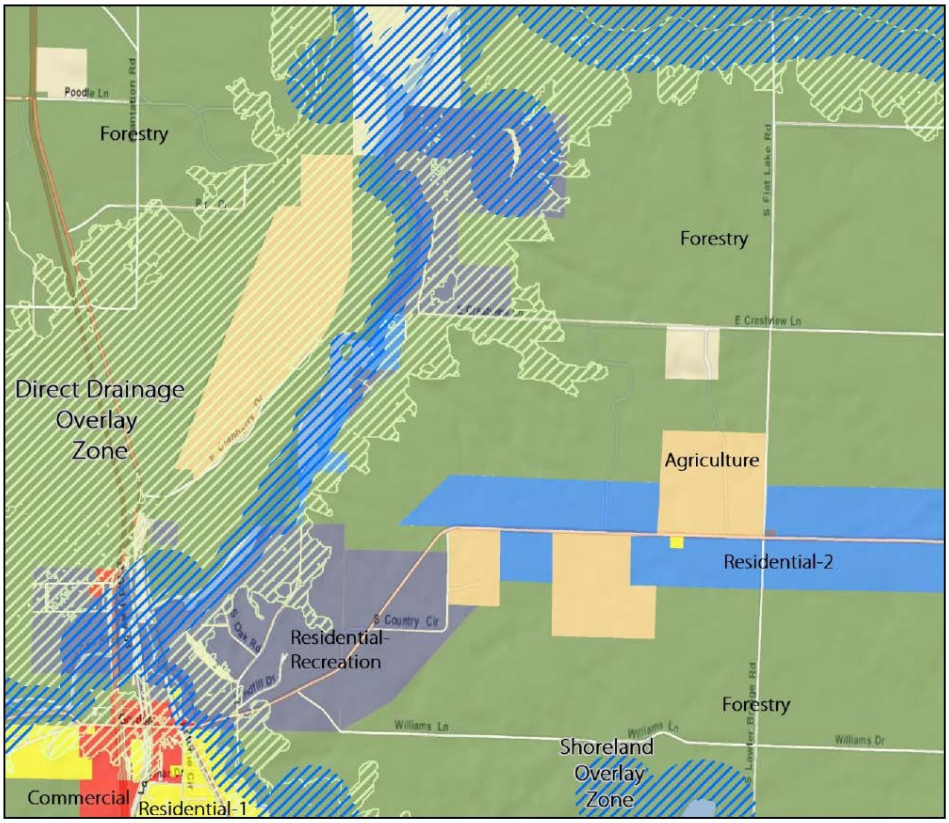

Figure 41: Example: a direct drainage overlay has special provisions in addition to the requirements of the base county zones in order to protect water quality and riparian habitat.

- Consider conservation easements to protect sensitive areas in the direct drainage areas and throughout the watershed. A conservation easement is an incentive-based legal agreement voluntarily placed on a piece of property to restrict the development, management, or use of the land in order to protect a resource. It is an effective avenue for protecting a watershed's natural resources.

- Conservation subdivision designs should be promoted throughout the watershed and especially within direct drainage areas and districts already zoned for residential development. A conservation design (cluster development) is a type of "Planned Unit Development" in which the underlying zoning and subdivision ordinances are modified to allow buildings (usually residences) to be grouped together on part of the site while permanently protecting the remainder of the site from development (Figure 42). This type of development provides great flexibility of design to fit site-specific resource protection needs while allowing for the same number of residences under current zoning and subdivision regulations. The conservation subdivision concept could potentially preserve the rural character of the watershed and limit the potential for runoff associated with higher density development near shoreline regions.

Figure 42: An example of a conservation subdivision design from Walworth County, WI. Minimum lot sizes were reduced, but design allowed for 70 acres of common open space, the protection of a stream corridor, and natural stormwater management.

- A transfer of development rights program could be considered to help limit the amount of development within direct drainage areas. Transfer of Development Rights (TDR) is a voluntary, incentive-based program that allows landowners to sell development rights from their land to a developer or other interested party who then can use these rights to increase the density of development at another designated location (Figure 43). In this case, the preservation zone would be the delineated direct drainage areas so that the immediate riparian areas would be protected from future development and impervious surfaces.

- Work with the towns and cities in the watershed to develop their own subdivision ordinance to be more restrictive than the county's. Each town and city could, for example, adopt a subdivision ordinance that classifies all new lots under a certain size as a major land division, thus requiring minimum standards to be met related to impervious surfaces, building placement and sanitation. Together with zoning, this approach could help to shape the layout, design, and density of future development in the watershed.

- Work with local stakeholders to implement Minimal Impact Design Standards (MIDS). MIDS represents the next generation of stormwater management and contains three main elements that address current challenges:
    - **A higher clean water performance goal** for new development and redevelopment that will provide enhanced protection for Minnesota's water resources.
    - **New modeling methods and credit calculations** that will standardize the use of a range of "innovative" structural and nonstructural stormwater techniques.
    - **A credits system and ordinance package** that will allow for increased flexibility and a streamlined approach to regulatory programs for developers and communities.

The development of Minimal Impact Design Standards is based on **low impact development** — an approach to storm water management that mimics a site's natural hydrology as the landscape is developed. Using the low impact development approach, storm water is managed on site and the rate and volume of predevelopment storm water reaching receiving waters is unchanged. The calculation of

predevelopment hydrology is based on native soil and vegetation (Minnesota Statutes 2009, section 115.03, subdivision 5c).

The three communities in the Chisago Lakes area - Lindstrom, Chisago City, and Center City - have been chosen for a Minimal Impact Design Standards pilot project. This was established to help St. Croix Basin communities meet State water quality regulatory requirements and provide a real testing ground for the application of the new MIDS performance goals, credits and calculators and the community assistance package. The pilot community project involves regional and focused community assistance in the form of education, training, review and consultation services and tools and resources such as model ordinances, all with the intent to apply the MIDS package.

Additional information on MIDS and the St. Croix Basin pilot project is available at: http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/stormwater-minimal-impact-design-standards-mids.html

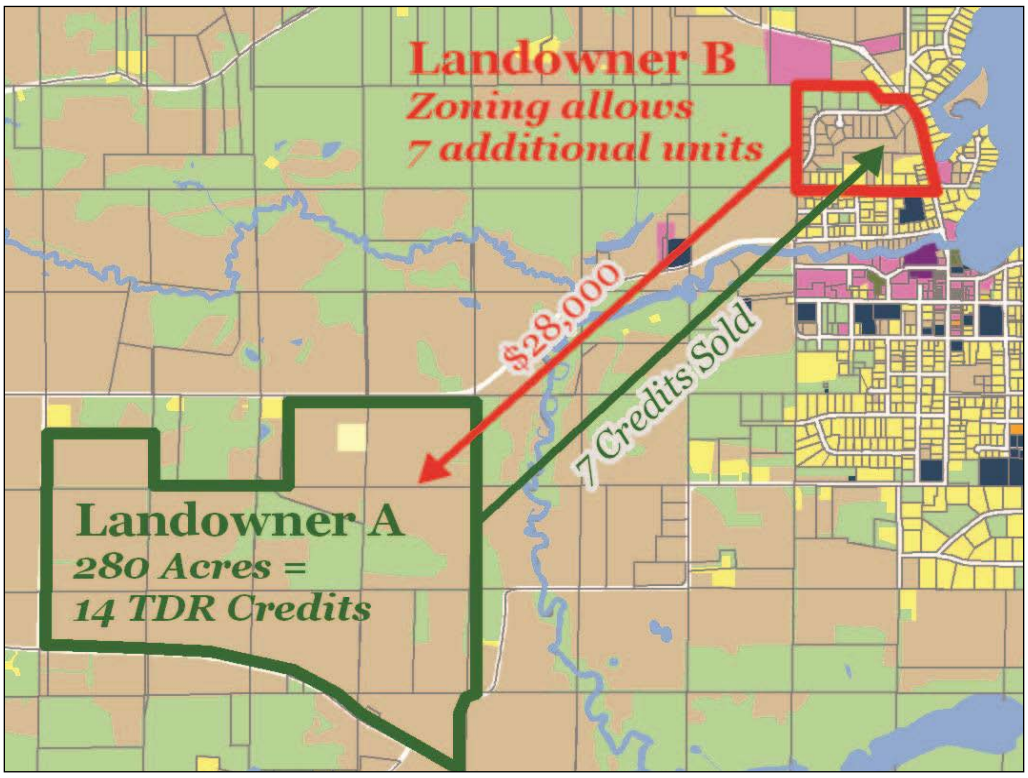

Figure 43: Landowner A, a farmer, would like to get additional economic return from his property. In exchange for restrictions on his land, landowner A sells the development rights that are part of his property. This permanent prevention of development helps the community reach its farmland preservation goals. Landowner B would like to develop her property in the receiving area which already has public services. Landowner B finds that she would earn a larger profit by purchasing TDR credits from Landowner A, thereby allowing her to build more housing units.

Homeowners Actions

Every citizen and visitor to the basin can make simple adjustments that will make a difference in the amount of phosphorus reaching the surface waters. Household wastes discharged through our home plumbing either reach an individual septic system or a community wastewater facility for further treatment and some level of phosphorus removal. Yard wastes and land use also affect sediment and

nutrients in runoff carried to ditches, dry runs, small tributaries, wetlands, lakes and rivers throughout the watershed. Here are some recommendations for everyone in the basin:

- Use phosphorus-free dish detergent and fabric softener.
- Compost food wastes and lawn clippings.
- Keep leaves and grass clippings out of the storm sewer drains and systems.
- Dispose of pet waste properly.
- Use phosphorus-free lawn fertilizers.
- Let driveway and roof top runoff soak into the ground (use rain gardens, vegetative swales, etc.).
- Minimize hard surfaces like rooftops and driveways on your property.
- Properly maintain septic systems.
- Plant trees, shrubs and gardens in place of turf to help capture rainwater and minimize runoff.

Actions for Businesses, Churches, Schools, etc.

In addition to the recommendations above for homeowners, below are some general recommendations for these sectors:

- Use low or no-phosphorus products in manufacturing, cleaning and lawn care.
- Reduce runoff from roofs and parking areas through infiltrative practices.
- Implement water conservation measures.

Shorefront Property Actions

Shorefront property owners are another vital group for protecting aquatic habitat and water quality. These include reducing direct input of nutrients and sediment. Here are some recommendations for better managing riparian lots and shorelines:

- Properly maintain septic systems.
- Restore native vegetation and shorefront buffers to control runoff, minimize shoreline erosion and decrease grassed areas (in compliance with local zoning ordinances).
- Leave aquatic vegetation, fallen trees and woody habitat in place in the shallow water zone to provide valuable habitat and protect the shoreline from wave erosion.
- Where absent, consider opportunities to restore woody debris and aquatic vegetation in shallow riparian areas.
- Identify sources of runoff and find ways to intercept and infiltrate rainwater (rain barrels, rain gardens, infiltration pads, etc.).
- Use best management practices for erosion control around any ground-disturbing activities to prevent runoff and siltation.

Stormwater Management

The following activities can be undertaken to reduce contaminated runoff to local waterbodies:

- Develop a stormwater plan for future improvements to deal with the runoff using infiltration wherever possible (rather than piping it directly to surface water).
- Develop and enforce a stormwater ordinance to protect surface waters.
- Monitor for success and provide adequate funding for local efforts.
- Continue regular street sweeping and stencil storm drains (e.g., label storm drains to advise public they drain to surface waters).
- Educate citizens or the public about the sources of runoff and what they can do to reduce the runoff from their property.

Habitat Considerations

Habitat efforts at a minimum should focus on identified deficiencies. TMDL projects should be implemented in a timely fashion to address site-specific impairments (Table 2 and 3). Consideration should be given to implementing projects to address other stressors identified during the stream health assessments (Appendix C). Often the stressors are tied to water quality and land use that also will be addressed via the actions outlined above.

Additional projects could be implemented to improve physical habitat. Strategic wetland restoration discussed above would provide strong habitat and water quality benefits. Waterfront property owners should be encouraged to implement BMPs identified above to improve aquatic and riparian habitat conditions. Incentive programs to encourage riparian restoration could be employed. Future road projects should implement "fish friendly" culverts to ensure biodiversity is not limited due to reduced connectivity.

Groundwater Considerations

Groundwater evaluations were primarily limited to the Lake Improvement District given the importance of this area and the unique groundwater characteristics. Evaluations identified seven lakes that appear to lose water to groundwater (Table 5). Three of these, Green, North Center and South Center lakes, appear to be the largest contributors. Although the interactions are not fully known, these lakes that lose water to groundwater could play a role in general groundwater quality. Thus, efforts to protect water quality in these lakes could also be important for groundwater. Water quality concerns should not be limited to nutrient enrichment, but efforts to avoid/minimize aquatic contaminants also could be valuable given the importance of groundwater as a drinking water source. BMPs discussed above for urban development could be valuable in helping minimize contaminants that load to these areas.

6.3 Prioritization and Adaptive Management

Many environmental needs have been identified within the watershed. This is especially evident for water quality, which includes both systemic and site-specific actions. Some actions, such as TMDLs/Watershed Restoration and Protection Strategies to address identified impairments, are specific requirements. Other actions to protect water quality may be more elective. However, protection of water quality and habitat is undoubtedly less expensive and problematic then restoration once a resource has become severely impaired or degraded.

With a finite amount of time and resources, local and State resource managers will need to prioritize restoration/improvement activities. This may be best accomplished through an adaptive process where managers meet regularly (e.g., quarterly) to review projects across the watershed, including study or project implementation status, prioritization, monitoring/study results, funding status, etc. This type of effort has already been applied across the larger St. Croix Basin via the St. Croix Basin Water Resources Planning Team. A similar team could be developed to collaborate and guide water resource planning within the Watershed.

Projects also may be best implemented in an adaptive fashion. Implementing BMPs over time is most realistic, and could include periodic monitoring to evaluate measure effectiveness, and whether or not goals are progressing. Data collected through this study provides an excellent baseline for comparison of

future water quality, aquatic habitat and geomorphic condition. Watershed managers should be sure future monitoring is based on clearly defined monitoring goals and objectives, with an understanding of how such data will be used. Monitoring should be prioritized and focus on appropriate areas. At a minimum, this would likely include evaluating watershed phosphorus loading to the St. Croix River, as well as nested TMDLs/Watershed Restoration and Protection Strategies which should have their own monitoring requirements. Monitoring needs could include water quality, habitat and geomorphic condition, recognizing each would require consideration for timing, need and value for decision making. Monitoring needs should be initially established by the watershed agency team, and modified through time as necessary to meet future needs.

6.4 Implementation

Implementation of any of these recommendations presents a tremendous challenge. It will be challenging to identify large numbers of landowners, counties, municipalities or others willing to participate with the land use changes proposed here. Land use changes are often unpopular and can cause economic expense such as lost crop production, decreased land value or limitations to development. Requiring people to implement certain actions (i.e., forcing change by regulatory requirement) is politically unpopular. However, ways must be identified to implement actions that will allow meeting local and systemic water quality goals. Implementation could be accomplished through some combination of the following actions.

1) Civic Engagement. Watershed managers should reach out to local stakeholders and public decision makers to inform them of the study results, proposed actions and need for change. Working with local constituents will help begin the process of educating them on the importance and need for change. Meeting these lofty water quality objectives will take strong local and political support.

2) Volunteer participation. Meet and work with local land owners, municipalities and county governments to garner willing participation in the BMPs and actions identified above.

3) Incentive Programs. Work with local government officials to identify all local, State and federal government programs that may be available for financial incentive to participate in land use BMPs. Work with these officials to identify how to best help interested parties in competitively applying for funding. Work with local interests to encourage economic ventures that may help meet water quality and habitat goals. For example, establishment of a mitigation bank within the watershed could help meet project goals. While a bank (by definition) allows for other wetland fill activities, a strategically placed bank might provide substantial water quality and habitat benefits.

4) Regulatory Programs. Work within existing regulatory programs to ensure appropriate land development, water quality and habitat goals are met. For example, enforcing existing zoning requirements can help manage future growth. Avoid waivers or variances to zoning or land use standards that could result in development that works against water quality goals. Modifications to zoning and subdivision ordinances also could be done to further improve the ability to manage growth in a way that helps meet water quality goals. Enforce or strengthen requirements for septic systems and for riparian land use. Follow existing regulatory requirements to avoid, minimize or mitigate wetland losses. Follow through with TMDL requirements to address site-specific impairments.

7. COORDINATION AND VIEWS

7.1 Study Coordination and Public Review

Members of the public were engaged periodically throughout the study through discussions at local meetings. The majority of interested participants were from local and State governmental agencies that also have a strong interest in protecting water quality and habitat of the St. Croix River.

The public will be offered the opportunity to review the final watershed report. The sponsor also has requested a strong civil engagement component to the watershed study. This would entail meeting with local, county and State government officials to review study results and discuss opportunities for implementing study recommendations.

7.2 State and Federal Agencies

State agencies have been directly involved throughout the study. The project sponsor received funding support via the Minnesota Pollution Control Agency. Minnesota Pollution Control Agency used their own staff for several aspects of the project, as well as a local SWAT modeling expert to perform large portions of the hydrology and water quality analysis. Existing information was provided by Minnesota Pollution Control Agency and Minnesota Department of Natural Resources.

Federal agency involvement has been more limited. Corps regulatory staff provided much of the wetlands analysis. USFWS elected to limit participation except where needed for requirements associated with endangered species or the Fish and Wildlife Coordination Act.

7.3 Nongovernmental Organizations

Nongovernmental organizations participated during coordination for the study and will have an opportunity to review results during public review.

7.4 Tribal Interests

Study evaluations and recommendations are primarily focused on environmental protection, which often is a tribal interest. This includes recommendations to improve water quality, riparian and aquatic habitat, and wetland areas. No construction projects are recommended, thus no disturbance to tribal or cultural resources would be anticipated as a result of this report. A major resource feature in this watershed is a series of shallow reservoirs, several of which are associated with the Carlos Avery State Wildlife Management Area. These impoundments are managed specifically to promote the growth of wetland emergent vegetation, including wild rice. Wild rice is also important to Native American culture. No specific modifications to water level management were recommended in this study. Any future deviations in the way these impoundments are managed should consider potential impacts to Wild Rice, and the potential need to coordinate with tribal interests. The final watershed report will be made available to the public, including the tribes, for consideration and use toward future resource management.

8. References

Chisago County, MN, 2006. Chisago County Local Water Management Plan, 2006-2011

GHAP. 2008. Gulf Hypoxia Action Plan. Mississippi River/Gulf of Mexico Watershed Nutrient Task Force. 2008 http://water.epa.gov/type/watersheds/named/msbasin/actionplan.cfm#documents

Holly, M; J. K. Boyle, and R. Bouchard. February 1996. Water Quality Affect Property Prices: A Case Study of Selected Maine Lakes. Miscellaneous Report 398. Maine Agricultural and Forest Experiment Station, University of Maine.

Lenz, B. N.; D. M. Robertson, J.D. Fallon, and R. Ferrin. 2003. Nutrient and Suspended-Sediment Concentrations and Loads, and Benthic- Invertebrate Data for Tributaries to the St. Croix River, Wisconsin and Minnesota, 1997–99. U.S. GEOLOGICAL SURVEY. Water-Resources Investigations Report 01–4162. (Revised and reprinted January 2003). Middleton, WI.

Lentz, D. L., ed 2000. Imperfect balance: landscape transformations in the Precolumbian Americas. New York: Columbia University Press. pp. xviii-xix

Meyer, G.N. and Lusardi, B.A., 2001, Surficial geology, plate 1, *in* Aggregate Resource Potential of Chisago County, Minnesota: Minnesota Geological Survey Miscellaneous Map Series M-116, scale 1:100,000.

Meyer, G.N., Baker, R.W., and Patterson, C.J., 1990, Surficial geology, plate 3, *in* Geologic atlas of Washington County, Minnesota: Minnesota Geological Survey County Atlas Series C-5, scale 1:100,000.

Minnesota. 2013. The Minnesota Nutrient Reduction Strategy. Review Draft. Produced in cooperation with multiple State and local agencies. http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/nutrient-reduction/nutrient-reduction-strategy-report.html.

Minnesota Dept of Employment and Economic Development, 2008. *Chisago County Labor Market Profile*. Prepared with Cameron Macht. http://chisagocounty.org/pdf-files/07-08ChisagoCoLaborProfile.pdf

Mn DNR. 2009. DNR Watershed Delineation: Project History, Methodology and Terminology. Prepared by Sean R. Vaughn, GIS Hydrologist, Watershed Delineation Project Manager. Minnesota Department of Natural Resources, Cambridge, Mn.

Provencher, 2005. North Temperate Lakes' Study Ties Lakefront Property Values to Water Clarity. LTER Network News Spring 2005, Vol. 18 No.1

SCBWRPT 2004. St. Croix Basin Phosphorus-Based Water-Quality Goals. Report on the Recommended Water-quality goals of the St. Croix Basin Water Resources Planning Team. http://www.pca.state.mn.us/index.php/view-document.html?gid=9978. August 2004.

TMDL 2012. Lake St. Croix Nutrient Total Maximum Daily Load study. Prepared in Partnership by Minnesota Pollution Control Agency and Wisconsin Department of Natural Resources; with St. Croix Basin Water Resources Planning Team, Science Museum of Minnesota, St. Croix Watershed Research Station and Barr Engineering Company. Final May 2012.

Walker, W.J., 1999. Simplified Procedures for Eutrophication Assessment and Prediction: User Manual. US Army Corps of Engineers Instruction Report W-96-2.

Wang, L.; J. Lyons; and P. Kanehl. Impacts of Urban Land Cover on Trout Streams in Wisconsin and Minnesota Transactions of the American Fisheries Society, Volume 132, Issue 5, 2003, Pages 825 – 839

Wang, L.; J. Lyons; P. Kanehl; R. Gatti. Influences of Watershed Land Use on Habitat Quality and Biotic Integrity in Wisconsin Streams. Fisheries, Volume 22, Issue 6, 1997, Pages 6 - 12

USACE 2007. St. Croix Basin Reconnaissance Study, Section 905(b) Analysis (Water Resources Development Act of 1986); Minnesota and Wisconsin; USACE, St. Paul District, January 2007.

USEPA. 2001. Ambient Water Quality Criteria for Rivers and Streams in Nutrient Ecosystem VII. EPA Publication 822-B-01-015, 142 p.

USEPA. 2006. Volunteer Estuary Monitoring: A Methods Manual, Second Edition. Ohrel, Jr. R.L. and K. M. Register (Editors).

Zielinski, J. 2002. *Watershed Vulnerability Analysis*. Center for Watershed Protection, January 2002.

Appendix A

Sunrise SWAT Model Construction

Appendix B

SWAT Evaluation of Land Use Changes

Appendix C

Stream Health Assessment

Appendix D

Wetlands Assessment

Appendix E

Geomorphic Assessment

Appendix F

Groundwater Assessment