Lake of the Woods Watershed Monitoring and Assessment Report

Minnesota Pollution Control Agency

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List of acronyms

AUID Assessment Unit Identification Determination

CCSI Channel Condition and Stability Index

CI Confidence Interval

CR County Road

CWA Clean Water Act

CWLA Clean Water Legacy Act

DO Dissolved Oxygen

EPA U. S. Environmental Protection Agency

EQuIS Environmental Quality Information System

EX Exceeds Criteria (Bacteria)

EXP Exceeds Criteria, Potential Impairment

EXS Exceeds Criteria, Potential Severe Impairment

FS Full Support

H Hypereutrophic

HUC Hydrologic Unit Code

IBI Index of Biotic Integrity

IF Insufficient Information

IJC International Joint Commission

K Potassium

LRVW Limited Resource Value Water

M Mesotrophic

MDA Minnesota Department of Agriculture

MDH Minnesota Department of Health

MDNR Minnesota Department of Natural Resources

MINLEAP Minnesota Lake Eutrophication Analysis Procedure

mL Milligram per Liter

MPCA Minnesota Pollution Control Agency

MSHA Minnesota Stream Habitat Assessment

N Nitrogen

Nitrate-N Nitrate Plus Nitrite Nitrogen

NA Not Assessed

NHD National Hydrologic Dataset

NH3 Un-ionized Ammonia

NS Not Supporting

NT No Trend

NWI National Wetlands Inventory

OP Orthophosphate

P Phosphorous

PCB Poly Chlorinated Biphenyls

SWAG Surface Water Assessment Grant

SWCD Soil and Water Conservation District

TALU Tiered Aquatic Life Uses

TKN Total Kjeldahl Nitrogen

TMDL Total Maximum Daily Load

TP Total Phosphorous

TSS Total Suspended Solids

TSVS Total Suspended Volitile Solids

UAA Use Attainability Analysis

USGS United States Geological Survey

WPLMN Water Pollutant Load Monitoring Network

Executive summary

The greater Lake of the Woods Watershed falls on the border of the USA and Canada. Though the majority of the watershed is in the Canadian provinces of Manitoba and Ontario, approximately 730,000 acres fall in the northernmost part of Minnesota. The primary focus of this report is on data collected and assessed in the Minnesota portion of the watershed. The watershed's namesake, the Lake of the Woods takes up about 41% of the total watershed area in Minnesota, with 71% of the land total in wetlands and lakes. Another 20% of the land is in agriculture, mostly found along the southern lake shore of the Lake of the Woods.

The Minnesota Pollution Control Agency (MPCA) began an Intensive Watershed Monitoring (IWM) Program within the Lake of the Woods Watershed in 2012. The monitoring was comprehensive and included the collection of samples from lakes, streams and groundwater. Biological data was collected from rivers and streams to assess aquatic life and aquatic consumption. Water chemistry information was collected to assess surface waters for aquatic life and aquatic recreation assessment. The work was carried out by staff from the MPCA, local partners, as well as citizen volunteers. The results of this monitoring effort were used to assess the Lake of the Woods Watershed in 2015.

Water quality in the watershed is in fair condition. The most common river and stream impairments were turbidity and stressed biological communities. Nutrients often meet standards with a few Assessment Unit Identification Determinations (AUID) experiencing higher than average concentrations. One recreational impairment was found on the West Branch of the Warroad River due to high E.coli levels. Fish consumption from both rivers and lakes should be limited, as mercury concentrations remain high in fish tissues.

Lake of the Woods is the prominent water resource in the watershed. The lake is a prime recreational, fisheries, and economic resource. The Minnesota portion of Lake of the Woods was declared impaired in 2008, due to exceedances of eutrophication criteria (high amounts of nutrients and algae). The most recent water quality assessment, as part of this watershed study, continues to indicate impairments of recreational use with nutrient and algae concentrations that are above the MPCA's criteria. An impaired waters study is currently underway to better understand the nature and extent of algae blooms in Lake of the Woods and develop appropriate restoration strategies. This work is being conducted with cooperation from numerous partner agencies and organizations, including the International Joint Commission's new Lake of the Woods Watershed Board.

Introduction

Water is one of Minnesota's most abundant and precious resources. The MPCA is charged under both federal and state law with the responsibility of protecting the water quality of Minnesota's water resources. MPCA's water management efforts are tied to the 1972 Federal Clean Water Act (CWA) which requires states to adopt water quality standards to protect their water resources and the designated uses of those waters, such as for drinking water, recreation, fish consumption, and aquatic life. States are required to provide a summary of the status of their surface waters and develop a list of water bodies that do not meet established standards. Such waters are referred to as "impaired waters" and the state must make appropriate plans to restore these waters, including the development of Total Maximum Daily Loads (TMDLs). A TMDL is a comprehensive study determining the assimilative capacity of a waterbody, identifying all pollution sources causing or contributing to impairment, and an estimation of the reductions needed to restore a water body so that it can once again support its designated use.

The MPCA currently conducts a variety of surface water monitoring activities that support our overall mission of helping Minnesotans protect the environment. To successfully prevent and address problems, decision makers need good information regarding the status of the resources, potential and actual threats, options for addressing the threats, and data on the effectiveness of management actions. The MPCA's monitoring efforts are focused on providing that critical information. Overall, the MPCA is striving to provide information to assess, and ultimately, to restore or protect the integrity of Minnesota's waters.

The passage of Minnesota's Clean Water Legacy Act (CWLA) in 2006 provided a policy framework and the initial resources for state and local governments to accelerate efforts to monitor, assess, restore, and protect surface waters. This work is implemented on an on-going basis with funding from the Clean Water Fund created by the passage of the Clean Water Land, and Legacy Amendment to the state constitution. To facilitate the best use of agency and local resources, the MPCA has developed a watershed monitoring strategy which uses an effective and efficient integration of agency and local water monitoring programs to assess the condition of Minnesota's surface waters, and to allow for coordinated development and implementation of water quality restoration and improvement projects.

The strategy behind the watershed monitoring approach is to intensively monitor streams and lakes within a major watershed to determine the overall health of water resources, identify impaired waters, and to identify waters in need of additional protection. The benefit of the approach is the opportunity to begin to address most, if not all, impairments through a coordinated TMDL process at the watershed scale, rather than the reach-by-reach and parameter-by-parameter approach often historically employed. The watershed approach will more effectively address multiple impairments resulting from the cumulative effects of point and non-point sources of pollution and further the CWA goal of protecting and restoring the quality of Minnesota's water resources.

This watershed-wide monitoring approach was implemented in the Lake of the Woods Watershed beginning in the summer of 2012. This report provides a summary of all water quality assessment results in the Lake of the Woods Watershed and incorporates all data available for the assessment process including watershed monitoring, volunteer monitoring and monitoring conducted by local government units.

The watershed monitoring approach

The watershed approach is a 10-year rotation for monitoring and assessing waters of the state on the level of Minnesota's 80 major watersheds (Figure 1). The major benefit of this approach is the integration of monitoring resources to provide a more complete and systematic assessment of water quality at a geographic scale useful for the development and implementation of effective TMDLs, project planning, effectiveness monitoring and protection strategies. The following paragraphs provide details on each of the four principal monitoring components of the watershed approach. For additional information see: Watershed Approach to Condition Monitoring and Assessment (MPCA 2008) (http://www.pca.state.mn.us/publications/wq-s1-27.pdf).

Watershed Pollutant Load Monitoring Network

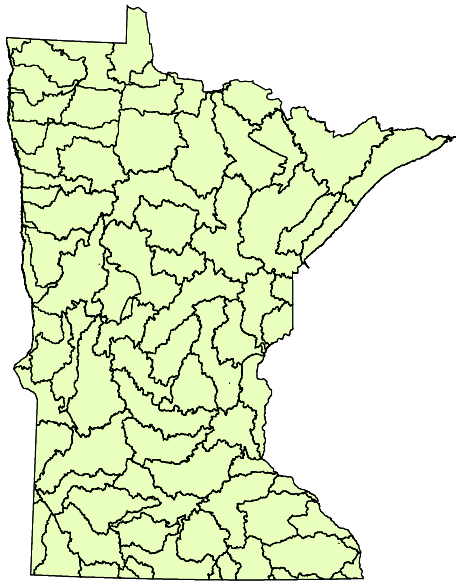

Figure 1. Major watersheds within Minnesota (8-Digit HUC).

Funded with appropriations from Minnesota's Clean Water Legacy Fund, the Watershed Pollutant Load Monitoring Network (WPLMN) is a long-term program designed to measure and compare regional differences and long-term trends in water quality among Minnesota's major rivers including the Red, Rainy, St. Croix, Mississippi, and Minnesota, and the outlets of the major tributaries (8 digit HUC scale) draining to these rivers. Since the program's inception in 2007, the WPLMN has adopted a multi-agency monitoring design that combines site specific stream flow data from United States Geological Survey (USGS) and Minnesota Department of Natural Resources (MDNR) flow gaging stations with water quality data collected by the Metropolitan Council Environmental Services, local monitoring organizations, and the MPCA to compute pollutant loads from 200 monitoring sites on streams and rivers across Minnesota. Monitoring sites span three ranges of scale with annual loads calculated for basin and major watershed sites, and seasonal loads for subwatershed sites:

Basin – major river mainstem sites along the Mississippi, Minnesota, Rainy, Red, Des Moines, and St. Croix rivers

Major watershed – tributaries draining to basin rivers with an average drainage area of 1,350 square miles (8-digit HUC scale)

Subwatershed – major branches or nodes within major watersheds with average drainage areas of approximately 300-500 square miles

Data will also be used to assist with: TMDL studies and implementation plans; watershed modeling efforts; watershed research projects, and watershed restoration and protection strategies.

More information can be found at the WPLMN website including a map of the sites.

Intensive watershed monitoring

The intensive watershed monitoring strategy utilizes a nested watershed design allowing the sampling of streams within watersheds from a course to a fine scale (Figure 2). Each watershed scale is defined by a hydrologic unit code (HUC). These HUCs define watershed boundaries for water bodies within a similar geographic and hydrologic extent. The foundation of this approach is the 80 major watersheds (8-HUC)

within Minnesota. Using this approach many of the smaller headwaters and tributaries to the main stem river are sampled in a systematic way so that a more holistic assessment of the watershed can be conducted and problem areas identified without monitoring every stream reach. Each major watershed is the focus of attention for at least one year within the 10-year cycle.

River/stream sites are selected near the outlet of each of three watershed scales, 8-HUC, aggregated 12-HUC and 14-HUC (Figure 2). Within each scale, different water uses are assessed based on the opportunity for that use (i.e., fishing, swimming, supporting aquatic life such as fish and insects). The major river watershed is represented by the 8-HUC scale. The outlet of the major 8-HUC watershed (purple dot in Figure 3) is sampled for biology (fish and macroinvertebrates), water chemistry and fish contaminants to allow for the assessment of aquatic life, aquatic recreation and aquatic consumption use support. The aggregated 12-HUC is the next smaller subwatershed scale which generally consists of major tributary streams with drainage areas ranging from 75 to 150 mi^2. Each aggregated 12-HUC outlet (green dots in Figure 3) is sampled for biology and water chemistry for the assessment of aquatic life and aquatic recreation use support. Within each aggregated 12-HUC, smaller watersheds (14 HUCs, typically 10-20 mi^2), are sampled at each outlet that flows into the major aggregated 12-HUC tributaries. Each of these minor subwatershed outlets is sampled for biology to assess aquatic life use support (red dots in Figure 3).

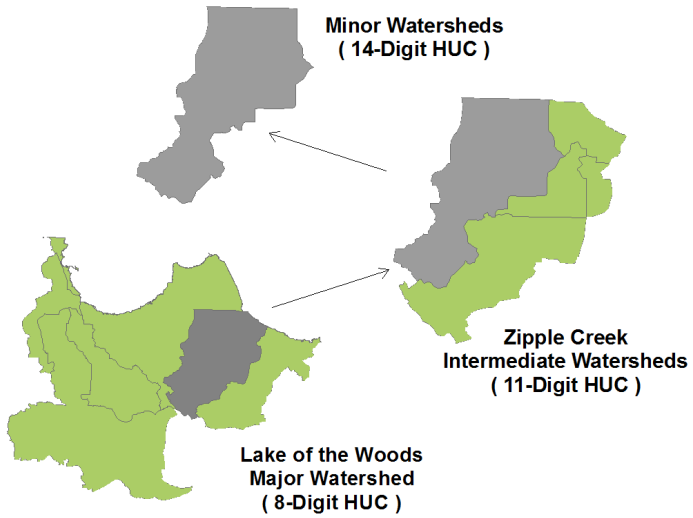

Figure 2. The intensive watershed monitoring design.

Within the IWM strategy, lakes are selected to represent the range of conditions and lake type (size and depth) found within the watershed. Lakes most heavily used for recreation (all those greater than 500 acres and at least 25% of lakes 100-499 acres) are monitored for water chemistry to determine if recreational uses, such as swimming and wading, are being supported. Lakes are sampled monthly from May-September for a two-year period. At the time of this study, there was no tool that allowed us to determine if lakes are supporting aquatic life; however, a method that includes monitoring fish and aquatic plant communities is in development.

Specific locations for sites sampled as part of the intensive monitoring effort in the Lake of the Woods Watershed are shown in Figure 3 and are listed in Appendix 2, Appendix 4.2, and Appendix 4.3.

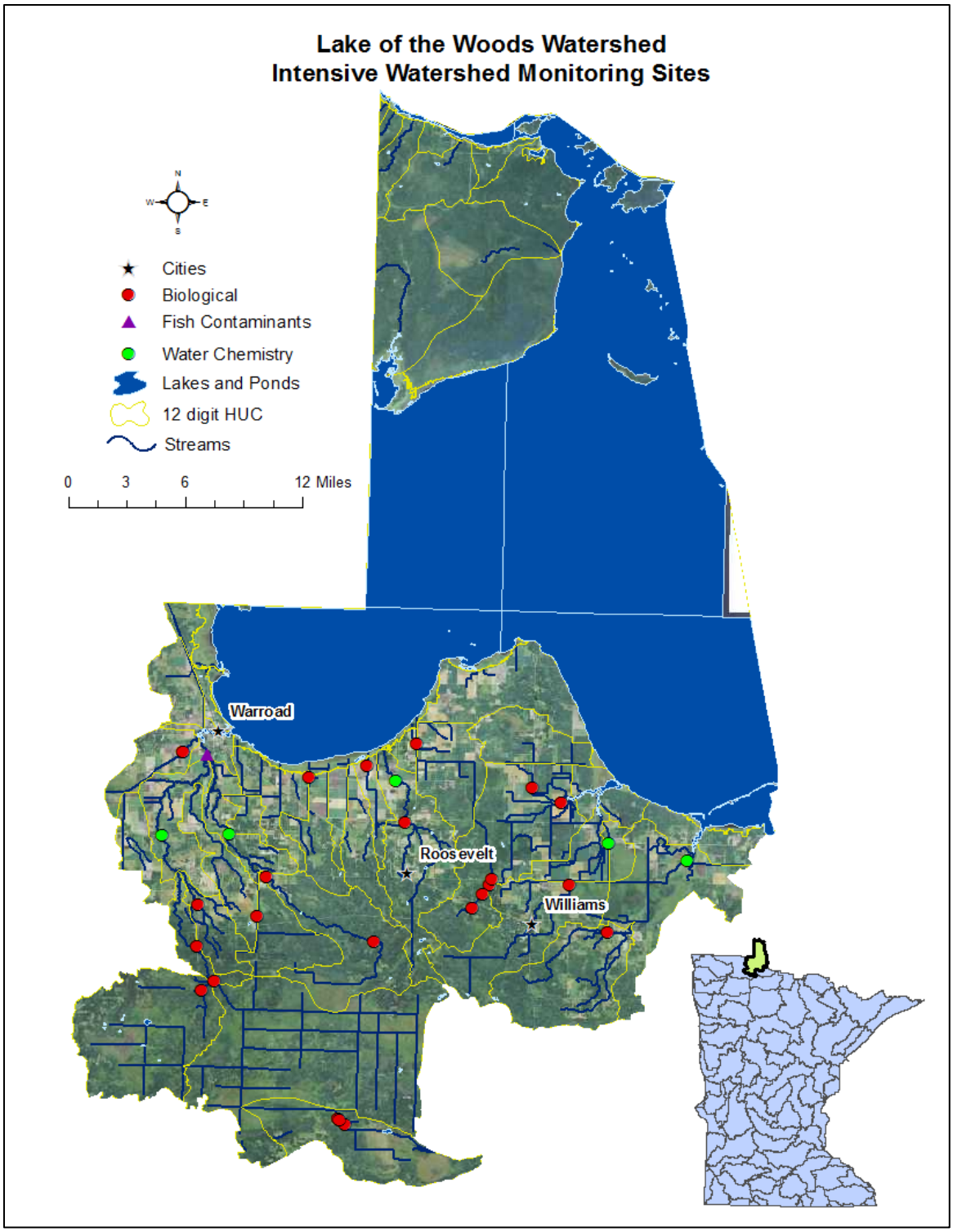

Figure 3. Intensive watershed monitoring sites for streams in the Lake of the Woods Watershed.

Citizen and local monitoring

Citizen and local monitoring is an important component of the watershed approach. The MPCA and its local partners jointly select the stream sites and lakes to be included in the intensive watershed monitoring process. Funding passes from MPCA through Surface Water Assessment Grants (SWAG) to local groups such as counties, soil and water conservation districts (SWCDs), watershed districts, nonprofits, and educational institutions to support lake and stream water chemistry monitoring. Local

partners use the same monitoring protocols as the MPCA, and all monitoring data from SWAG projects are combined with the MPCA's to assess the condition of Minnesota lakes and streams. Preplanning and coordination of sampling with local citizens and governments helps focus monitoring where it will be most effective for assessment and observing long-term trends. This allows citizens/governments the ability to see how their efforts are used to inform water quality decisions and track how management efforts affect change. Many SWAG grantees invite citizen participation in their monitoring projects and their combined participation greatly expand our overall capacity to conduct sampling.

The MPCA also coordinates two programs aimed at encouraging long term citizen surface water monitoring: the Citizen Lake Monitoring Program and the Citizen Stream Monitoring Program. Like the permanent load monitoring network, having citizen volunteers monitor a given lake or stream site monthly and from year to year can provide the long-term picture needed to help evaluate current status and trends. Citizen monitoring is especially effective at helping to track water quality changes that occur in the years between intensive monitoring years.

Assessment methodology

The CWA requires states to report on the condition of the waters of the state every two years. This biennial report to Congress contains an updated list of surface waters that are determined to be supporting or non-supporting of their designated uses as evaluated by the comparison of monitoring data to criteria specified by Minnesota Water Quality Standards (Minn. R. ch. 7050 2008; https://www.revisor.leg.state.mn.us/rules/?id=7050). The assessment and listing process involves dozens of MPCA staff, other state agencies, and local partners. The goal of this effort is to use the best data and best science available to assess the condition of Minnesota's water resources. For a thorough review of the assessment methodologies see: Guidance Manual for Assessing the Quality of Minnesota Surface Waters for the Determination of Impairment 305(b) Report and 303(d) List (MPCA 2012). http://www.pca.state.mn.us/index.php/view-document.html?gid=8601.

Water quality standards

Water quality standards are the fundamental benchmarks by which the quality of surface waters are measured and used to determine impairment. These standards can be numeric or narrative in nature and define the concentrations or conditions of surface waters that allow them to meet their designated beneficial uses, such as for fishing (aquatic life), swimming (aquatic recreation), or human consumption (aquatic consumption). All surface waters in Minnesota, including lakes, rivers, streams, and wetlands are protected for aquatic life and recreation where these uses are attainable. Numeric water quality standards represent concentrations of specific pollutants in water that protect a specific designated use. Narrative standards are statements of conditions in and on the water, such as biological condition, that protect their designated uses.

Protection of aquatic life means the maintenance of a healthy aquatic community, including fish, invertebrates and plants. The sampling of aquatic organisms for assessment is called biological monitoring. Biological monitoring is a direct means to assess aquatic life use support, as the aquatic community tends to integrate the effects of all pollutants and stressors over time. To effectively use biological indicators, the MPCA employs the Index of Biotic Integrity (IBI). This index is a scientifically validated combination of measurements of the biological community (called metrics). An IBI is comprised of multiple metrics that measure different aspects of aquatic communities (e.g., dominance by pollution tolerant species, loss of habitat specialists). Metric scores are summed together and the resulting index score characterizes the biological integrity or "health" of a site. The MPCA has developed IBIs for (fish and macroinvertebrates) since these communities can respond differently to various types of pollution. Because the rivers and streams in Minnesota are physically, chemically, and biologically diverse, IBIs are developed separately for different stream classes to account for this natural variation.

Further interpretation of biological community data is provided by an assessment threshold or biocriteria against which an IBI score can be compared within a given stream class. In general, an IBI score above this threshold is indicative of aquatic life use support, while a score below this threshold is indicative of non-support. Additionally, chemical parameters are measured and assessed against numeric standards developed to be protective of aquatic life, including pH, dissolved oxygen (DO), un-ionized ammonia nitrogen, chloride and turbidity.

Protection for aquatic life uses are divided into three tiers: Exceptional, General, and Modified. Exceptional Use waters support fish and macroinvertebrate communities that have minimal changes in structure and function from the natural condition. General Use waters harbor "good" assemblages of fish and macroinvertebrates that can be characterized as having an overall balanced distribution of the assemblages and with the ecosystem functions largely maintained through redundant attributes. Modified Use waters have been extensively altered through legacy physical modifications which limit the ability of the biological communities to attain the General Use. Currently the Modified Use is only applied to waters with channels that have been directly altered by humans (e.g., maintained for drainage, riprapped). These tiered uses are determined before assessment based on the attainment of the applicable biological criteria and/or an assessment of the habitat. For additional information, see: http://www.pca.state.mn.us/index.php/water/water-permits-and-rules/water-rulemaking/tiered-aquatic-life-use-talu-framework.html).

Protection of aquatic recreation means the maintenance of conditions safe and suitable for swimming and other forms of water recreation. In streams, aquatic recreation is assessed by measuring the concentration of E. coli bacteria in the water. To determine if a lake supports aquatic recreational activities its trophic status is evaluated, using total phosphorus (TP), secchi depth and chlorophyll-a as indicators. Lakes that are enriched with nutrients and have abundant algal growth are eutrophic and do not support aquatic recreation.

Protection of consumption means protecting citizens who eat fish from Minnesota waters or receive their drinking water from waterbodies protected for this beneficial use. The concentrations of mercury and polychlorinated biphenyls (PCBs) in fish tissue are used to evaluate whether or not fish are safe to eat in a lake or stream and to issue recommendations regarding the frequency that fish from a particular water body can be safely consumed. For lakes, rivers and streams that are protected as a source of drinking water the MPCA primarily measures the concentration of nitrate in the water column to assess this designated use.

A small percentage of stream miles in the state (~1% of 92,000 miles) have been individually evaluated and re-classified as a Class 7 Limited Resource Value Water (LRVW). These streams have previously demonstrated that the existing and potential aquatic community is severely limited and cannot achieve aquatic life standards either by: a) natural conditions as exhibited by poor water quality characteristics, lack of habitat or lack of water; b) the quality of the resource has been significantly altered by human activity and the effect is essentially irreversible; or c) there are limited recreational opportunities (such as fishing, swimming, wading or boating) in and on the water resource. While not being protective of aquatic life, LRVWs are still protected for industrial, agricultural, navigation and other uses. Class 7 waters are also protected for aesthetic qualities (e.g., odor), secondary body contact, and groundwater for use as a potable water supply. To protect these uses, Class 7 waters have standards for bacteria, pH, DO and toxic pollutants.

Assessment units

Assessments of use support in Minnesota are made for individual waterbodies. The water body unit used for river systems, lakes and wetlands is called the "assessment unit". A stream or river assessment unit usually extends from one significant tributary stream to another or from the headwaters to the first tributary. A stream "reach" may be further divided into two or more assessment reaches when there is a

change in use classification (as defined in Minn. R. ch. 7050) or when there is a significant morphological feature, such as a dam or lake, within the reach. Therefore, a stream or river is often segmented into multiple assessment units that are variable in length. The MPCA is using the 1:24,000 scale high resolution National Hydrologic Dataset (NHD) to define and index stream, lake and wetland assessment units. Each river or stream reach is identified by a unique waterbody identifier (known as its AUID), comprised of the USGS eight digit hydrologic unit code (8-HUC) plus a three character code that is unique within each HUC. Lake and wetland identifiers are assigned by the MDNR. The Protected Waters Inventory provides the identification numbers for lake, reservoirs and wetlands. These identification numbers serve as the AUID and are composed of an eight digit number indicating county, lake and bay for each basin.

It is for these specific stream reaches or lakes that the data are evaluated for potential use impairment. Therefore, any assessment of use support would be limited to the individual assessment unit. The major exception to this is the listing of rivers for contaminants in fish tissue (aquatic consumption). Over the course of time it takes fish, particularly game fish, to grow to "catchable" size and accumulate unacceptable levels of pollutants, there is a good chance they have traveled a considerable distance. The impaired reach is defined by the location of significant barriers to fish movement such as dams upstream and downstream of the sampled reach and thus often includes several assessment units.

Determining use attainment

For beneficial uses related to human health, such as drinking water or aquatic recreation, the relationship is well understood and thus the assessment process is a relatively simple comparison of monitoring data to numeric standards. In contrast, assessing whether a waterbody supports a healthy aquatic community is not as straightforward and often requires multiple lines of evidence to make use attainment decisions with a high degree of certainty. Incorporating a multiple lines of evidence approach into MPCA's assessment process has been evolving over the past few years. The current process used to assess the aquatic life use of rivers and streams is outlined below and in Figure 4.

The first step in the aquatic life assessment process is largely an automated process performed by logic programmed into a database application where all data from the 10 year assessment window is gathered; the results are referred to as 'Pre-Assessments'. Data filtered into the 'Pre-Assessment' process is then reviewed to insure that data is valid and appropriate for assessment purposes. Tiered use designations are determined before data is assessed based on the attainment of the applicable biological criteria and/or an assessment of the habitat. Stream reaches are assigned the highest aquatic life use attained by both biological assemblages on or after November 28, 1975. Streams that do not attain the Exceptional or General Use for both assemblages undergo a Use Attainability Analysis (UAA) to determine if a lower use is appropriate. A Modified Use can be proposed if the UAA demonstrates that the General Use is not attainable as a result of legal human activities (e.g., drainage maintenance, channel stabilization) which are limiting the biological assemblages through altered habitat. Decisions to propose a new use are made through UAA workgroups which include watershed project managers and biology leads. The final approval to change a designated use is through formal rulemaking.

The next step in the aquatic life assessment process is a comparison of the monitoring data to water quality standards. Pre-assessments are then reviewed by either a biologist or water quality professional, depending on whether the parameter is biological or chemical in nature. These reviews are conducted at the workstation of each reviewer (i.e., desktop) using computer applications to analyze the data for potential temporal or spatial trends as well as gain a better understanding of any extenuating circumstances that should be considered (e.g., flow, time/date of data collection, or habitat).

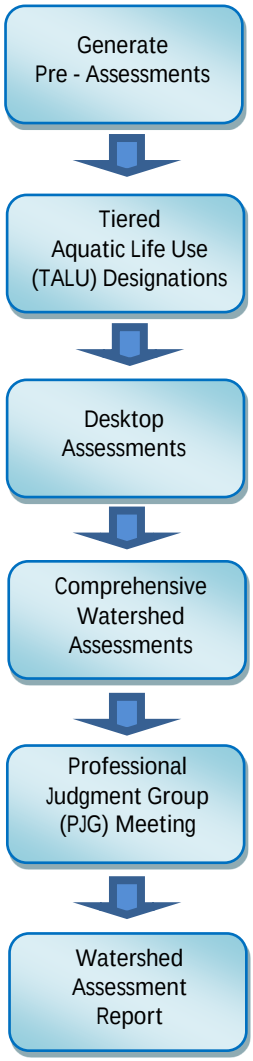

Figure 4. Flowchart of aquatic life use assessment process.

The next step in the process is a Comprehensive Watershed Assessment meeting where reviewers convene to discuss the results of their desktop assessments for each individual waterbody. Implementing a comprehensive approach to water quality assessment requires a means of organizing and evaluating information to formulate a conclusion utilizing multiple lines of evidence. Occasionally, the evidence stemming from individual parameters are not in agreement and would result in discrepant assessments if the parameters were evaluated independently. However, the overall assessment considers each piece of evidence to make a use attainment determination based on the preponderance of information available. See the *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for the Determination of Impairment 305(b) Report and 303(d) List* (MPCA 2012) http://www.pca.state.mn.us/index.php/view-document.html?gid=8601 for guidelines and factors considered when making such determinations.

The last step in the assessment process is the Professional Judgment Group meeting. At this meeting results are shared and discussed with entities outside of the MPCA that may have been involved in data collection or that might be responsible for local watershed reports and project planning. Information obtained during this meeting may be used to revise previous use attainment decisions (e.g., sampling events that may have been uncharacteristic due to annual climate or flow variation, local factors such as impoundments that do not represent the majority of conditions on the AUID). Waterbodies that do not

meet standards and therefore do not attain one or more of their designated uses are considered impaired waters and are placed on the draft 303(d) Impaired Waters List. Assessment results are also included in watershed monitoring and assessment reports.

Data management

It is MPCA policy to use all credible and relevant monitoring data to assess surface waters. The MPCA relies on data it collects along with data from other sources, such as sister agencies, local governments and volunteers. The data must meet rigorous quality assurance protocols before being used. All monitoring data required or paid for by MPCA are entered into EQuIS (Environmental Quality Information System), MPCA's data system and are also uploaded to the EPA's data warehouse. Data for monitoring projects with federal or state funding are required to be stored in EQuIS (e.g., Clean Water Partnership, CWLA Surface Water Assessment Grants and TMDL program). Many local projects not funded by MPCA also choose to submit their data to the MPCA in an EQuIS-ready format so that the monitoring data may be utilized in the assessment process. Prior to each assessment cycle, the MPCA sends out a request for monitoring data to local entities and partner organizations.

Period of record

The MPCA uses data collected over the most recent 10-year period for all water quality assessments. This time-frame provides a reasonable assurance that data will have been collected over a range of weather and flow conditions and that all seasons will be adequately represented; however, data for the entire period are not required to make an assessment. The goal is to use data that best represents current water quality conditions. Therefore, recent data for pollutant categories such as toxics, lake eutrophication and fish contaminants may be given more weight during assessment.

Watershed overview

The greater Lake of the Woods Watershed falls on the border of the USA and Canada. The majority of the drainage is in the Canadian provinces of Manitoba and Ontario, with a smaller area in north central Minnesota. For this report the data focuses on the watershed within Minnesota's borders. Fed by the mouth of the Rainy River, the Lake of the Woods Watershed is the northwest-most watershed in the Rainy River Basin. The watershed is heavily influenced by the former glacial lakes that were once abundant across this landscape (EPA, 2013). The glacial lake influence is now found in vast amounts of flat wetlands. This area is also rich in boreal forest vegetation. This description is most apparent on both the Northwest Angle and in the southernmost part of the Lake of the Woods Watershed.

The Minnesota portion of the Lake of the Woods Watershed is approximately 734,783 acres (NRCS, 2007), which includes the Northwest Angle, and a portion of Lake of the Woods. Landownership in the watershed is 25.3% US government (county, state, or federal), 9.5% tribal lands, and approximately 24% privately owned.

The Lake of the Woods lake itself, an immense lake covering over 950,000 acres, is a water of current and historical significance. The Lake is actually a collection of several distinct basins with varying water quality characteristics. In general, the southern basin is shallow and well mixed due to its large fetch, and is relatively productive due to the influence of Glacial Lake Agassiz. The northern portion, characterized by Precambrian geology with exposed shorelines, numerous bays and over 14,500 islands, is deeper and less productive. The Lake of the Woods drains a very large watershed (27,000 square miles), outletting to the Winnipeg River at Kenora, Ontario. Hydroelectric dams at the outlet have controlled lake elevations since the late 1800s. The Rainy River is the Lake's primary tributary, contributing about 75% of the inflow from most of the lake's drainage area; it enters Lake of the Woods in 4 Mile Bay, a shallow embayment near Baudette, Minnesota. The Rainy River, historically heavily impacted by discharge from industrial (pulp and paper) and domestic sewage facilities, is now a high-

quality resource. Most of the Lake drains a landscape dominated by forest and wetlands, including the Boundary Waters Canoe Area Wilderness, Quetico Provincial Park, and Voyageur's National Park. The lower portions of the Rainy River and the southern shore of Lake of the Woods have some land in agricultural production. The Lake of the Woods remains a premier fishing and tourism destination, with annual economic impact worth tens of millions of dollars.

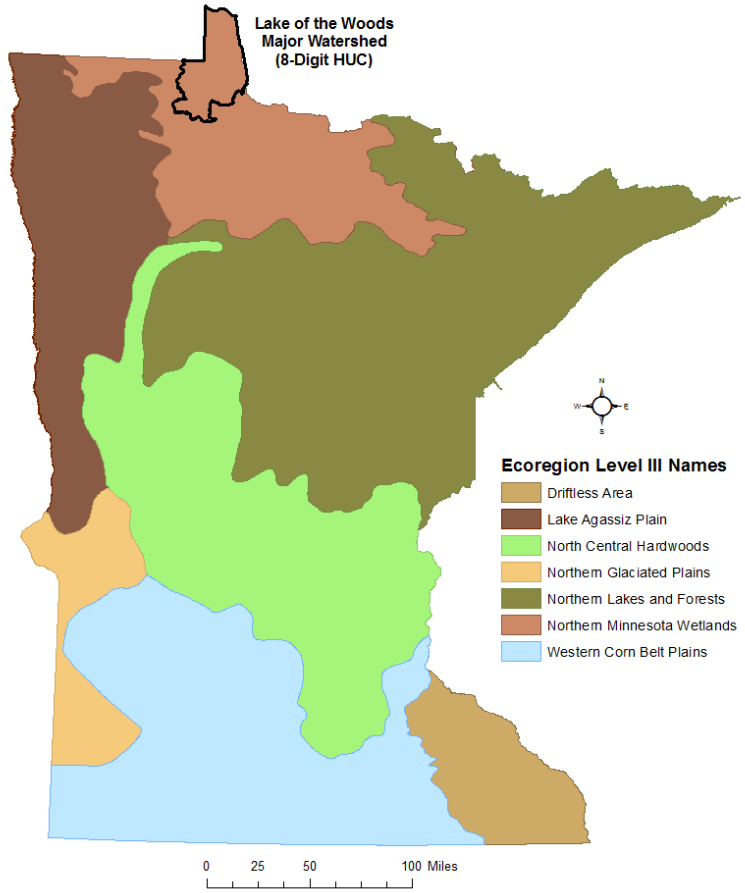

Figure 5. The Lake of the Woods Watershed is within the Northern Minnesota Wetlands ecoregion of north central Minnesota.

Land use summary

Like much of northern Minnesota, this region's history stems back long before Minnesota was a state. Lake of the Woods and the rivers that run into it provided travel routes for Tribal people, and eventually European fur traders. Trains later brought more immigrants to the area searching for jobs and land. In the early 1900s, large judicial ditches were dug to drain wetlands to make the land productive for farming (History of Lake of the Woods County). However, these ditches often failed. After a couple years of struggling with wet soils and a short growing season, most of the homesteaders left (MNopedia). Much of that land is now part of the Beltrami Island State Forest (MNopedia). Today the majority of farmland is located just south of the lake, as seen in Figure 8. Of the farms operated today, 76% are less than 1000 acres with an average farm size of 187 acres, and only 47% of the farmers rely on external income (NRCS, 2007).

During this same time when hopeful farmers were moving in, another industry already had a foothold in this region - commercial fishing (History of Lake of the Woods County, Dobie). Commercial fishing started on Lake of the Woods in the 1890s, and ended around 1985. A failing fishery was attributed to both fishing practices and paper mill sewage. Though the commercial fishing industry is no longer a large economic driver, recreational fishing still brings in tourists year-round.

Land use percentages seen in Figure 6 include Lake of the Woods. Percentages calculated by removing the lake acreage are recorded in Table 1. The largest difference is in the open water percentages moving from 41.38% to 0.40%. Both calculations agree that this region is sparsely populated with 1.33-2.33% of the land developed. Though the largest land use classification is wetlands, the second largest is rangeland and croplands (11.92-20.78%). The majority of the range and croplands are close to the southern edge of the lake; both the southern part of the watershed and the northwest angle are predominantly wetlands.

Table 1. Alternative land use percentages for the Lake of the Woods Watershed in Minnesota.

	Percentage including the Lake of the Woods	**Percentage excluding the Lake of the Woods**
Open Water	41.38	0.40
Developed	1.33	2.33
Barren/Mining	0.05	0.05
Forest/Shrub	2.72	4.62
Rangeland	5.30	9.19
Cropland	6.62	11.59
Wetland	42.58	71.82

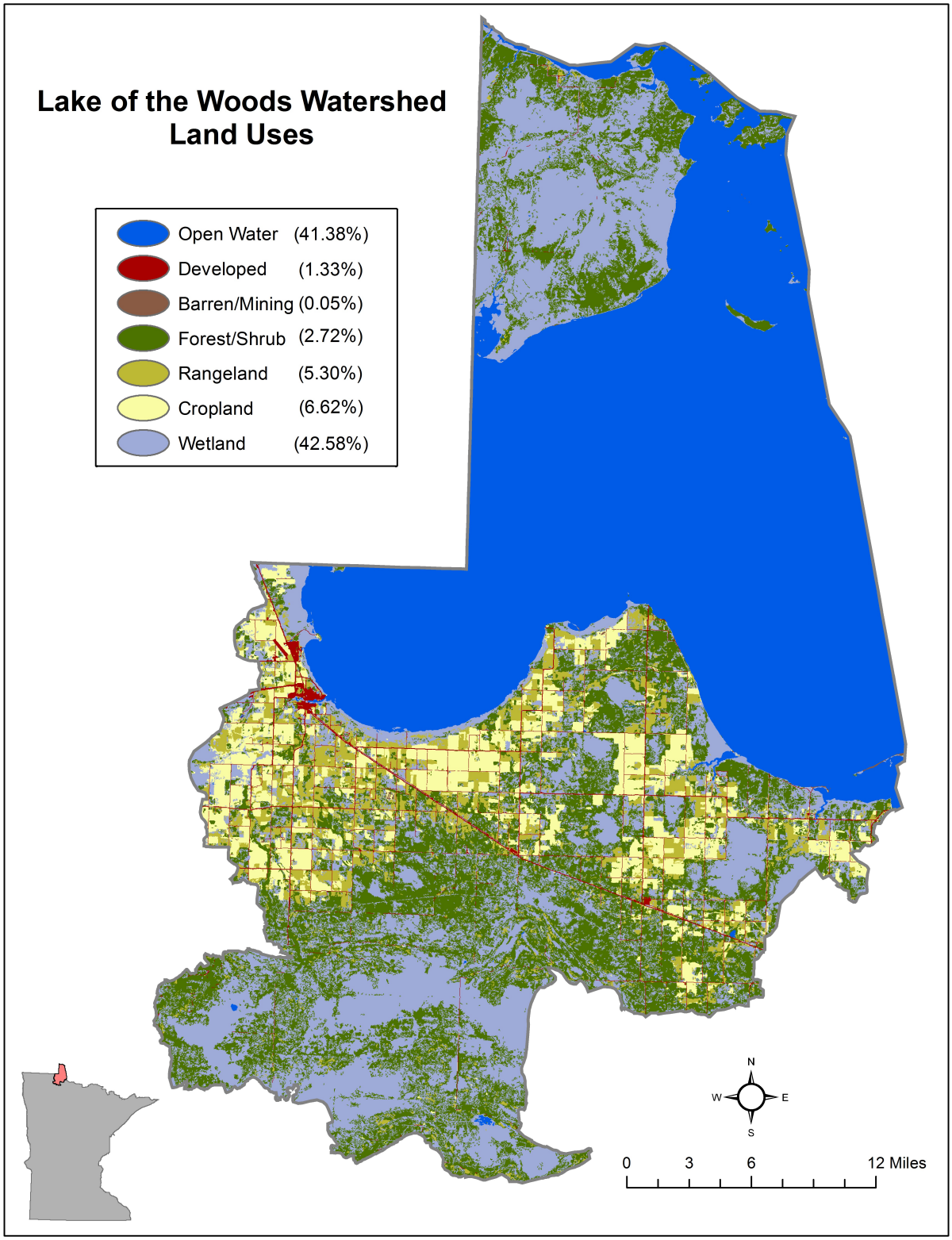

Figure 6. Land use in the Lake of the Woods Watershed.

Surface water hydrology

Unlike many 8-digit HUC watersheds that consist of many small streams flowing together to form one large river, the rivers in Lake of the Woods Watershed all flow into the Lake of the Woods at many different entry points. Five main rivers flow into the Lake of the Woods: the Warroad River, Willow Creek, West Branch Zippel Creek, South Branch Zippel Creek, and Bostick Creek.

The Warroad River has two main branches, the West Branch Warroad and the East Branch Warroad River. Both of these branches start in the southern wetlands and flow north-northwest. The two branches join and become the Warroad River about 1.5 miles south of the city of Warroad. The Warroad River then flows north until the city of Warroad, where it turns east and continues to flow through town until it meets the Lake. Between the Warroad River and Willow Creek, there are many small channelized reaches that flow north between fields before draining into the Lake. Willow Creek starts just south of the city of Roosevelt and flows northward for about 15 miles before it reaches the Lake of the Woods. The next major river to the east is the West Branch Zippel Creek. West Branch Zippel Creek starts 3 miles west of the city of Williams and flows mostly east northeast until it flows into Zippel Bay. South Branch Zippel Creek starts out just south of the city of Williams in a creek called Williams Creek, and flows northward until it also flows into Zippel Bay. Both Zippel Creeks are joined through a network of artificial channels making up the Bostick Creek Watershed. The headwaters for Bostick Creek are 5 miles southeast of the city of Williams. These headwater streams flow northward forming Canfield Creek. Shortly after crossing Highway 11, Canfield Creek is channelized and runs north through a wetland complex. Emerging from the wetland complex the ditch runs eastward, connecting with Bostick Creek. Bostick Creek then flows north east until it empties into the Lake of the Woods.

The Lake of the Woods Watershed contains a high ratio of modified streams. In Figure 8, 42.4% of the streams are considered altered or ditched. There is also a high percentage (33.6%) of streams that are impounded or have a non-definable channel. In this watershed many of these impounded or non-definable channels are through wetlands. Figure 7 it shows that the Lake of the Woods Watershed area is 60.8 to 65.2% impacted by altered streams.

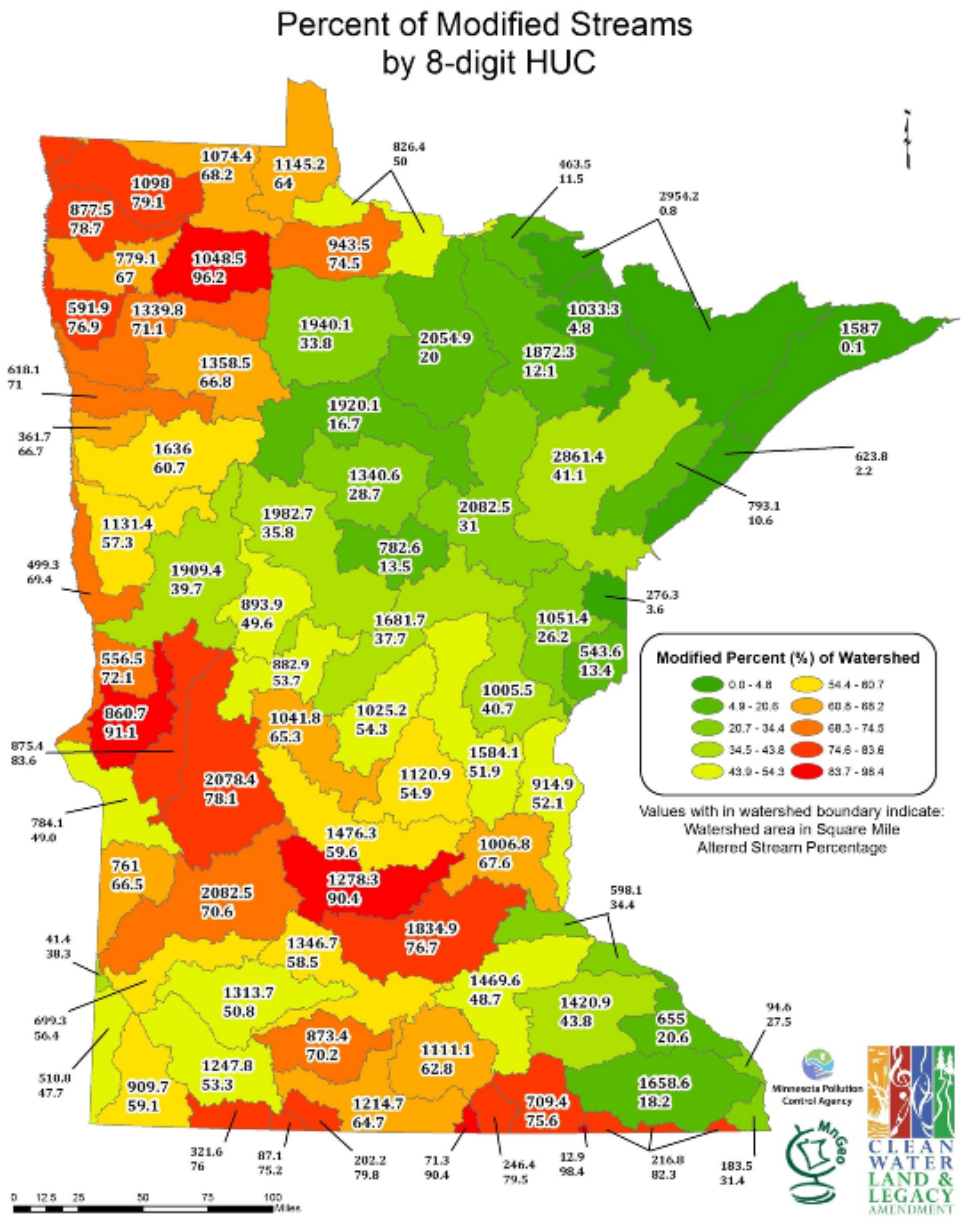

Figure 7. Map of percent modified streams by major watershed (8-HUC).

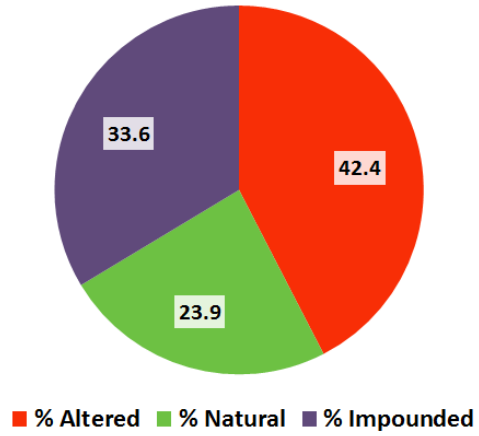

Figure 8. Comparison of natural to altered streams in the Lake of the Woods Watershed (percentages derived from the state-wide altered water course project).

Climate and precipitation

Minnesota has a continental climate, marked by warm summers and cold winters. The mean annual temperature for Minnesota is 4.5˚C; the mean summer temperature for the Lake of the Woods Watershed is 17.2˚ C, and the mean winter temperature is -15.6˚ C (Minnesota State Climatologists Office, 2003).

Precipitation is an important part of water input in a watershed. Figure 9 shows two representations of precipitation for calendar year 2012. On the left is total precipitation, showing the typical pattern of increasing precipitation toward the eastern portion of the state. According to this map, the Lake of the Woods Watershed area received 16 to 20 inches of precipitation in 2012. The display on the right shows the amount those precipitation levels departed from normal. For the Lake of the Woods Watershed area it shows that precipitation ranged from 4 to 10 inches below normal (Figure 9).

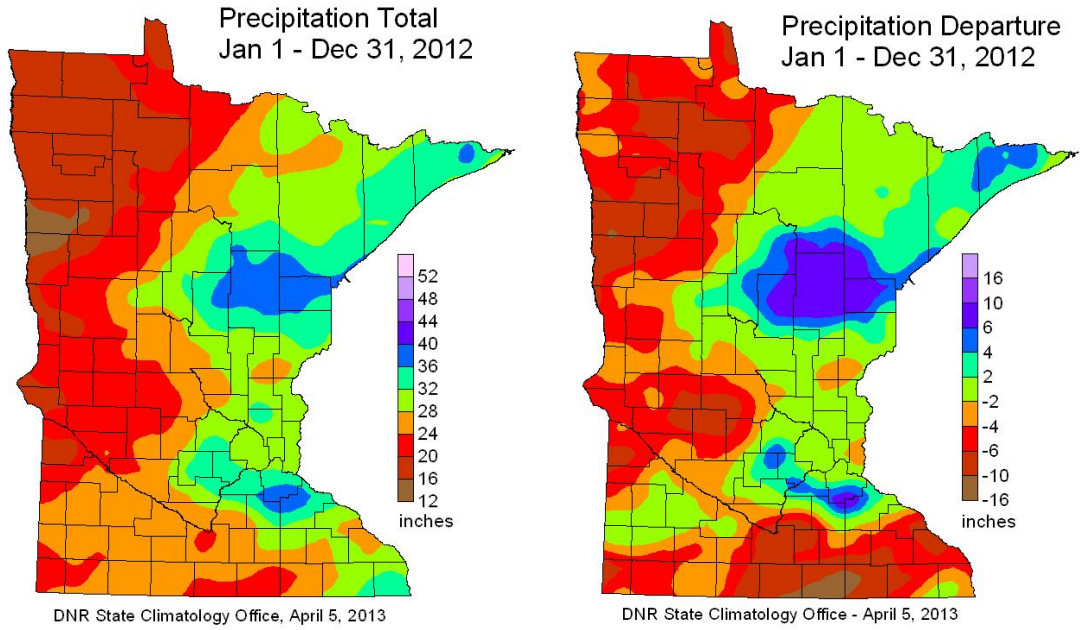

Figure 9. State-wide precipitation levels during the 2012 water year.

The Lake of the Woods Watershed is located in the north central precipitation region. Figure 10 and Figure 11 (below) display the areal average representation of precipitation in north central Minnesota for 20 and 100 years, respectively. An areal average is a spatial average of all the precipitation data collected within a certain area presented as a single dataset. These data are taken from the Western Regional Climate Center, available as a link on the University of Minnesota Climate website. Though rainfall can vary in intensity and time of year, rainfall totals in the north central region display no significant trend over the last 20 years.

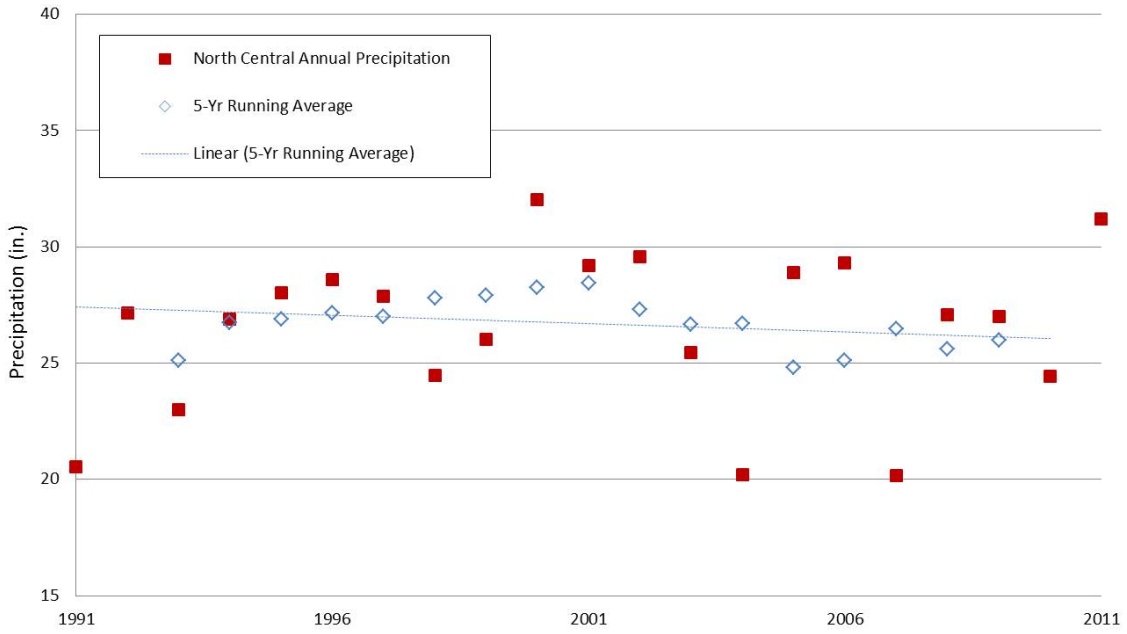

Figure 10. Precipitation trends in north central Minnesota (1991-2011) with five-year running average.

However, precipitation in north central Minnesota exhibits a statistically significant rising trend over the past 100 years (p=0.01). This is a strong trend and matches similar trends throughout Minnesota.

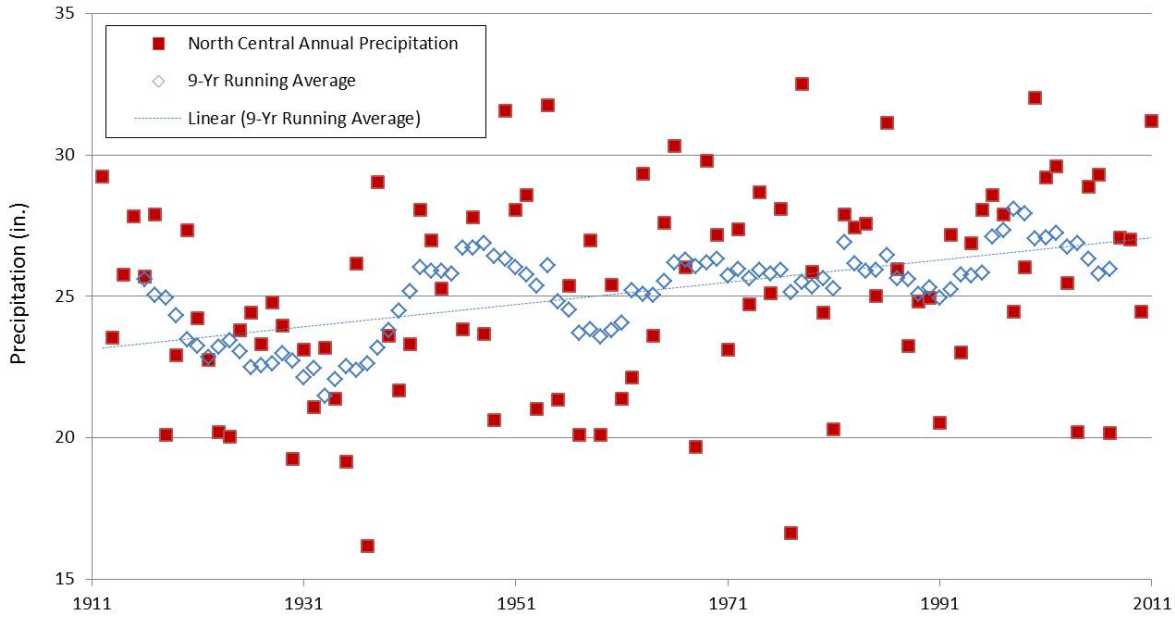

Figure 11. Precipitation trends in north central Minnesota (1912-2011) with nine-year running average.

Hydrogeology and groundwater quality

The Lake of the Woods Watershed is located in the Rainy River Basin within the northwest hydrogeologic region of Minnesota (Region 3). Like much of the state, this region was formed by the Des Moines Lobe, leaving quaternary deposits ranging from a few feet to several hundred feet (MPCA, 1999).

This region contains three main types of aquifers: surficial sand and gravel aquifers, buried drift aquifers, and cretaceous aquifers (Figure 12). These three aquifers are vital groundwater sources. The surficial sand and gravel aquifers consist of stagnation moraines, beach deposits, alluvial deposits, and outwash deposits left behind from the Des Moines lobe. These aquifers range from a few feet to over 30 feet, but many average approximately 20 feet thick. The two main aquifers that are included in this category are the Quaternary Water Table Aquifer and the Quaternary Buried Unconfined Aquifer. The buried drift aquifers are comprised of well-sorted sand and gravel deposited in bedrock valleys, alluvial channels, and outwash plains. These aquifers tend to be no greater than 30 feet thick and do not yield high groundwater quantities, so they are typically used for domestic use. The Cretaceous aquifers account for approximately 10% of Northwest Minnesota, primarily near the Red River of the North. These deposits consist of interbedded shale, siltstone, and sandstone and lay above the Precambrian rocks and are typically over 150 feet below land surface.

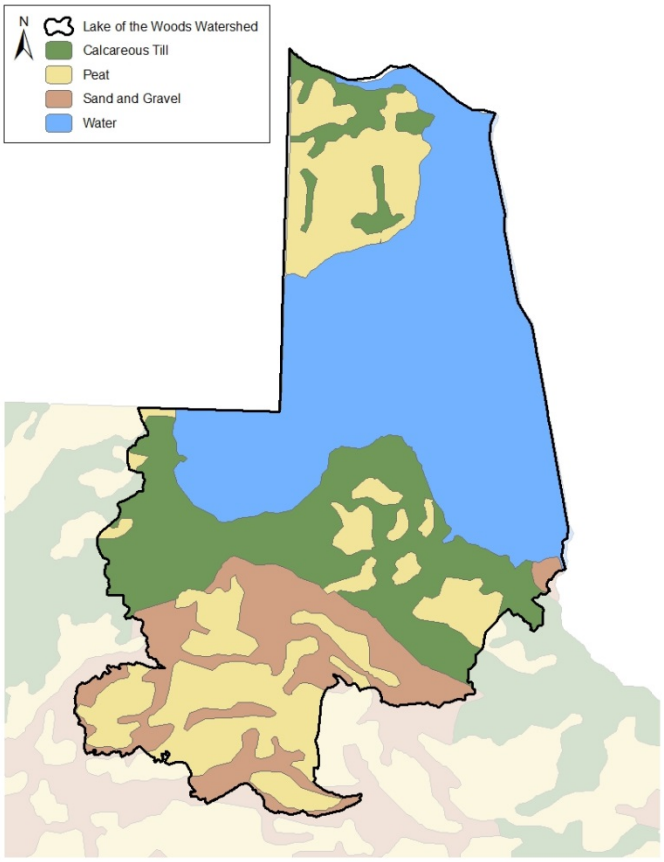

Figure 12. Quaternary geology, glacial sediments within the Lake of the Woods Watershed (GIS Source: MGS, 2010)

The Lake of the Woods Watershed lies at the intersection of two of Minnesota's six groundwater provinces: the Western Province and the Arrowhead Province. The majority of the watershed lies within the Western Province which is characterized by "clayey glacial drift overlying Cretaceous and Precambrian bedrock. Glacial drift and Cretaceous bedrock contain limited extent sand and sandstone aquifers, respectively" (MDNR, 2001). Features of the Arrowhead Province can be found in the

watershed as well. This province is characterized by Precambrian rocks, exposed at the surface or covered by a thin layer of drift (Figure 12). Groundwater here is typically found in faults and fractures (MDNR, 2001).

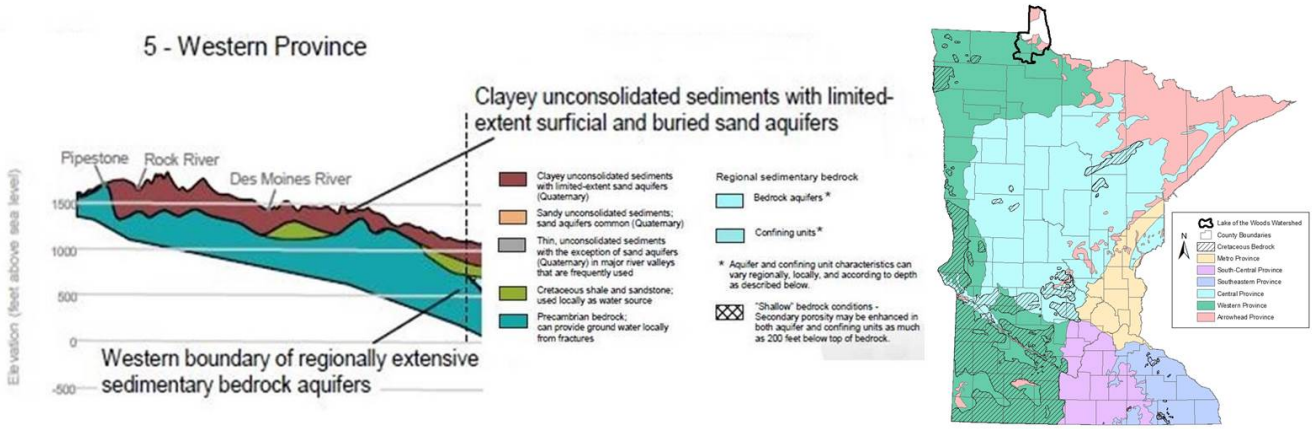

Figure 13. Western Province generalized cross section (Source: MDNR, 2001).

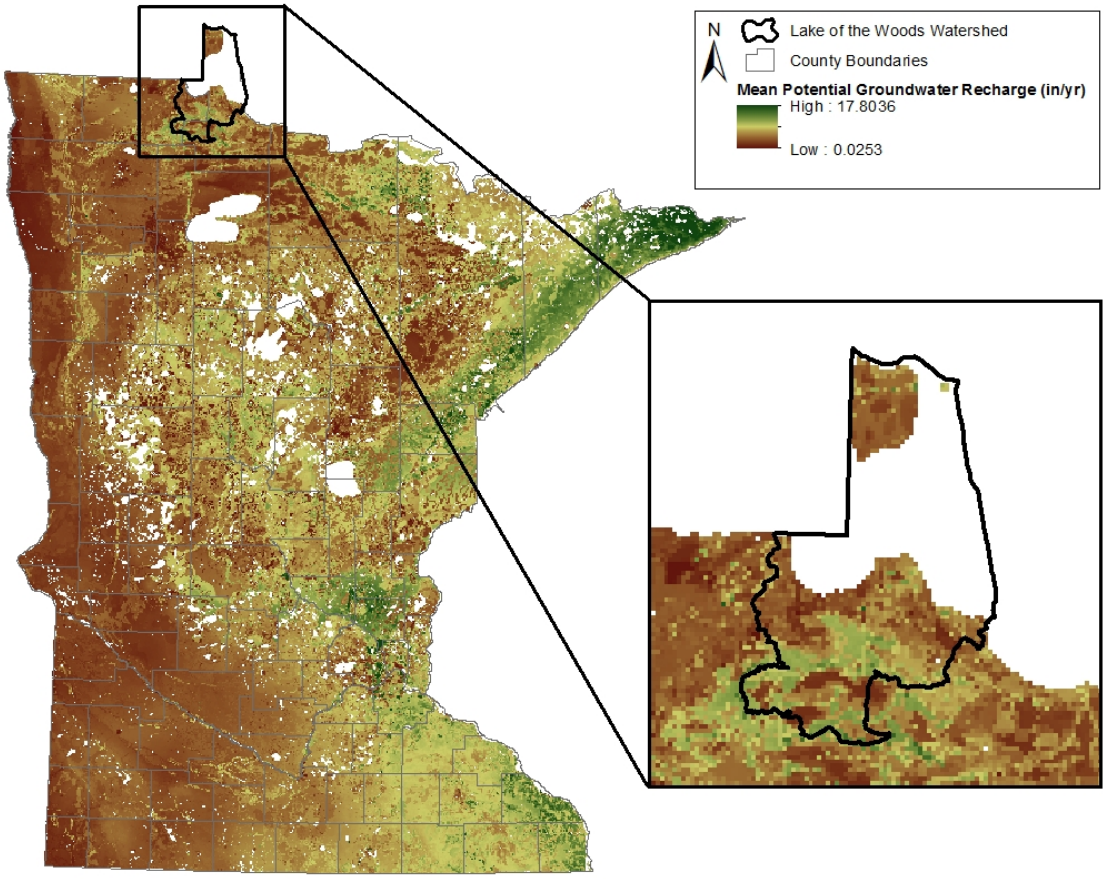

Figure 14. Average annual recharge rate to surficial materials in Lake of the Woods Watershed (1971-2000).

Groundwater recharge is one of the most important parameters in the calculation of water budgets, which are used in general hydrologic assessments, aquifer recharge studies, groundwater models, and water quality protection. Recharge is a highly variable parameter, both spatially and temporally, making accurate estimates at a regional scale difficult to produce. The MPCA contracted the U.S. Geological Survey to develop a statewide estimate of recharge using the SWB – Soil-Water-Balance Code. The result is a gridded data structure of spatially distributed recharge estimates that can be easily integrated into regional groundwater studies. The full report of the project as well as the gridded data files are available at: https://gisdata.mn.gov/dataset/geos-gw-recharge-1996-2010-mean

Recharge of these aquifers is important and limited to areas located at topographic highs, those with surficial sand and gravel deposits, and those along the bedrock-surficial deposit interface (Figure 14). Typically, recharge rates in unconfined aquifers are estimated at 20 to 25% of precipitation received, but can be less than 10% of precipitation where glacial clays or till are present (USGS, 2007). For Lake of the Woods Watershed, the average annual potential recharge rate to surficial materials ranges from 1.2 to 11.6 inches per year, with an average of 4.8 inches per year (Figure 15). The statewide average potential recharge is estimated to be 4 inches per year with 85% of all recharge ranging from 3 to 8 inches per year (Figure 16). When compared to the statewide average potential recharge, the Lake of the Woods Watershed receives a higher average and range of potential recharge, mostly likely attributed to the variability of the surficial sediment distribution of the area.

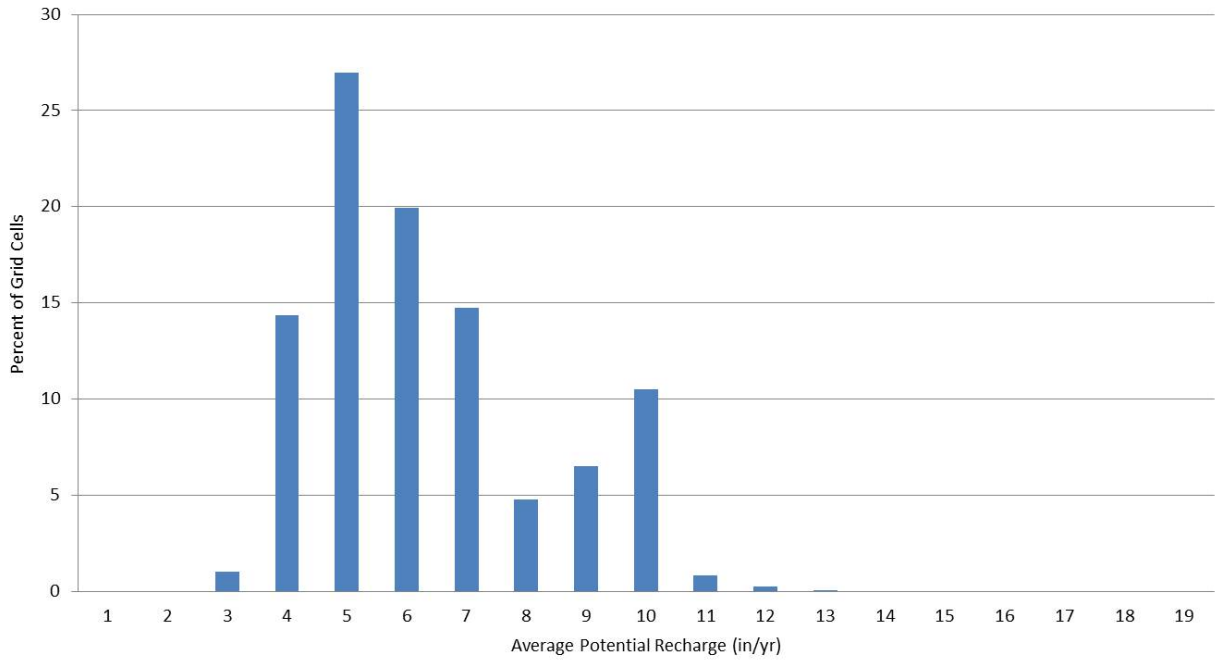

Figure 15. Average annual potential recharge rate percent of grid cells in the Lake of the Woods Watershed (1996-2010)

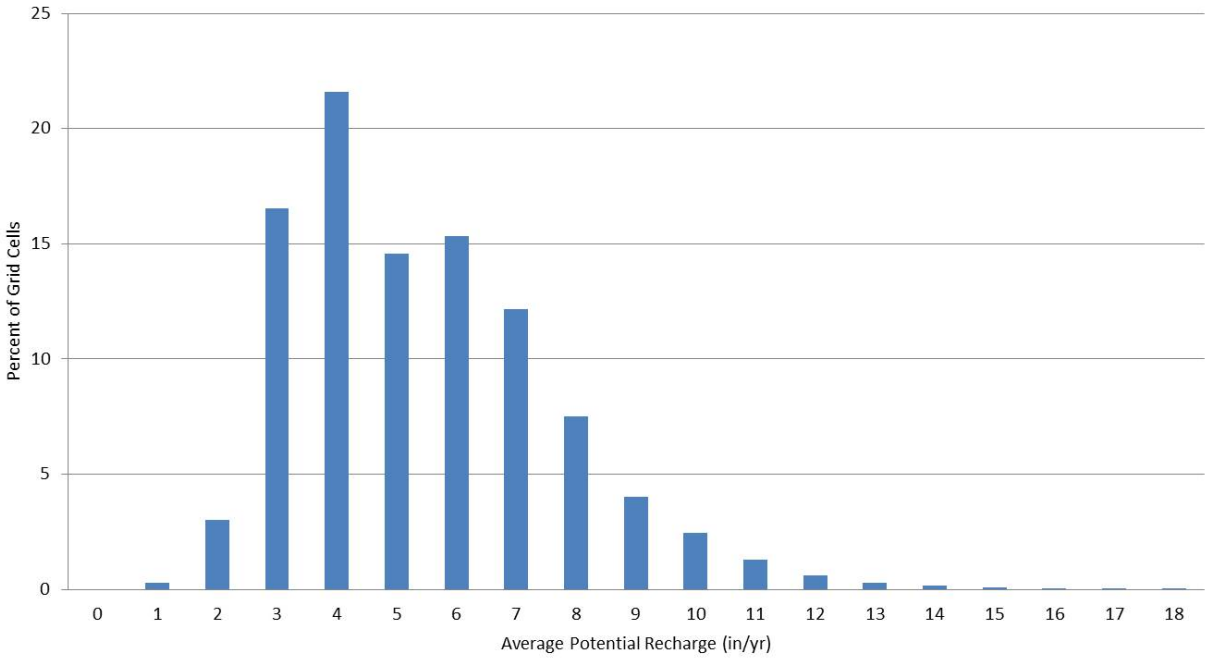

Figure 16. Average annual potential recharge rate percent of grid cells statewide (1996-2010)

Wetlands

Wetlands are a prevalent feature in the Lake of the Woods Watershed. There are an estimated 303,394 acres of wetland—or about 41% of the watershed area—according to National Wetlands Inventory (NWI) data (Figure 14). This coverage rate is higher than the statewide rate of 19% (Kloiber and Norris 213). Extensive peatlands occur along the southern margin of the Watershed and the Northwest Angle. The dominant wetland types are forested swamps and bogs, as well as open bogs that have a thick carpet of *Sphagnum* moss and are dominated by low shrubs.

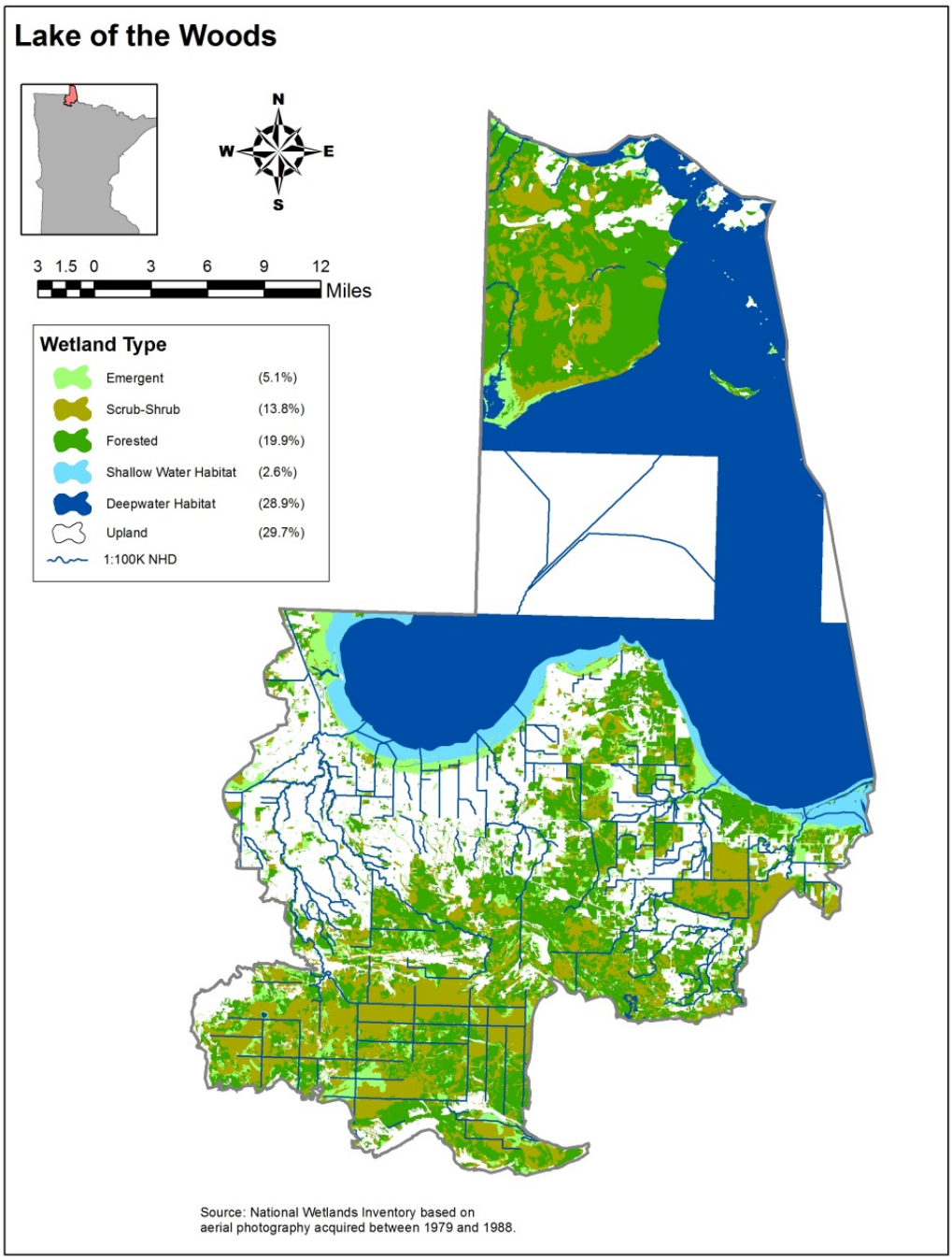

Figure 17. Wetlands and surface water in the Lake of the Woods Watershed. Wetland data is from the National Wetlands Inventory.

Prior to settlement, wetlands were even more prevalent in the watershed. Systematic attempts have been made to drain wetlands south of the Lake of the Woods. This drainage has apparently been largely successful within an approximate 10-mile radius of the southern margin of the Lake, where areas have been developed for agriculture (Figure 14). As wetland soil features persist after artificial drainage, soil survey data can be used to estimate historical wetland extent. Soil units mapped as Poorly and Very Poorly drained classes typically support wetlands when they are not artificially drained. Loss estimate can then be made by subtracting NWI totals (e.g., the best current wetland extent estimate) from the Poorly and Very Poorly drained totals (e.g., the best historical extent estimate). Unfortunately, complete soil survey data are available for only five of the seven sub-watersheds, which prohibit an accurate

historical wetland extent estimate for the watershed as a whole. Sub-watershed loss estimates, however, can be made where data are available (Figure 15). Both the Warroad River (72% loss) and Muskeg Bay (27% loss) sub-watersheds have lost substantial wetland acreage as they primarily occur within the developed area in the Watershed (Figure 15). Other sub-watersheds (such as the East and West Branch Warroad River) have also lost some wetlands but continue to support significant wetland extent at higher watershed positions.

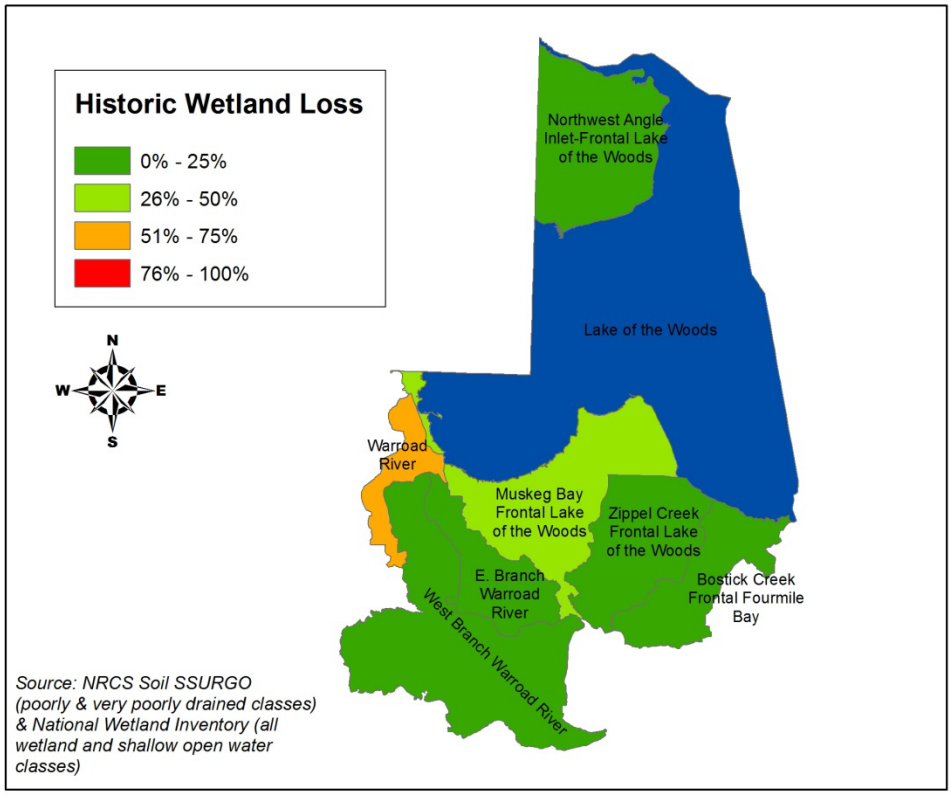

Figure 18. Historic wetland loss by sub-watershed in the Lake of the Woods Watershed. Soil survey data has not been completed for the Northwest Angle sub-watershed, but it was assumed wetland loss was < 25% given the minimal land development that has occurred there.

The predominant glacial lake plain landform (MNGS, 1997) has largely dictated the kinds of hydrogeomorphical (HGM) (Smith et al. 1995) functioning wetland types that are present in the Watershed. The extremely flat landscape that remained following Glacial Lake Agassiz had little capacity to drain surface water—promoting saturated soil conditions over expansive areas. Organic flat HGM type wetlands formed as peat accumulated vertically on saturated soils. The predominant water exchange in organic flat wetlands is through precipitation and evapotranspiration. As peat has low hydrologic conductivity, excess precipitation can slowly runoff via overland saturation flow along very low elevation gradients, providing high dissolved organic matter/low pH/low DO source water for streams (Acreman and Holden 2013). The majority of the natural stream channels in the watershed originate from saturation overland flow from these peatlands. Extensive ditching in the southern portion of the Watershed has likely augmented stream flow; however, because the hydrologic conductivity is low the peatlands remain largely unaffected. Conversely, it is likely that the wetlands that had formed in the developed portion of the watershed either had less peat depth or were the mineral flat HGM type (i.e., where the soil surface periodically dries out allowing organic material to decompose) and surface ditching was able to effectively drain the wetlands.

There are some special wetland features in the watershed of significance. The MDNR has documented wild rice populations on Lake of the Woods and the Bednar Impoundment located at the headwaters of the natural channel of the East Branch of the Warroad River. In addition, portions of the extensive peatlands are supported by upwelling groundwater and may have sufficient features to be considered calcareous fens. Calcareous fens are an uncommon wetland with alkaline (pH > 6.7) peat that support a number of rare plant species and are considered state Outstanding Resource Value Waters; Minn. R. ch. 7050 2008; https://www.revisor.leg.state.mn.us/rules/?id=7050). Currently, there are no designated calcareous fens in the watershed; however, favorable conditions exist at a number of locations including: the Winter Road Lake, Norris Camp, and Luxemberg Peatland Scientific and Natural Areas.

Watershed-wide data collection methodology

Watershed Pollutant Load Monitoring Network

Due to the small size and drainage areas of streams within the watershed, lack of road access, and backwater issues from Lake of the Woods, there are no WPLMN river or stream monitoring sites located within the Lake of the Woods Watershed.

Stream water sampling

Six water chemistry stations were sampled from May thru September in 2012 and again June through August of 2013, to provide sufficient water chemistry data to assess all components of the Aquatic Life and Recreation Use Standards. Following the IWM design, water chemistry stations were placed at the outlet of each aggregated 12-HUC subwatershed that was greater than 40 square miles in area (purple circles and green circles/triangles in (Figure 3). A Surface Water Assessment Grant (SWAG) was awarded to the Lake of the Woods and Roseau County SWCD. Appendix 2 identifies locations of stream water chemistry monitoring sites, See Appendix 1 for definitions of stream chemistry analytes monitored in this study.

Stream flow methodology

The MPCA and the MDNR joint stream water quantity and quality monitoring data for dozens of sites across the state on major rivers, at the mouths of most of the state's major watersheds, and at the mouths of some subwatersheds, are available at the MDNR/MPCA Cooperative Stream Gaging webpage at: http://www.dnr.state.mn.us/waters/csg/index.html.

The USGS maintains real-time streamflow gaging stations across the United States. Measurements can be viewed at http://waterdata.usgs.gov/nwis/rt

At this time, there is annual and monthly stream flow data for the Rainy River at Wheelers Point, Minnesota for 2012 and 2013. However, this is not sufficient data to make assertions on the stream flow trends.

Stream biological sampling

The biological monitoring component of the IWM in the Lake of the Woods Watershed was started during the summer of 2012. A total of 15 sites were newly established across the watershed and sampled. These sites were located near the outlets of most minor 14-HUC watersheds. In addition, 10 existing biological monitoring stations within the watershed were revisited in 2012. While data from the last 10 years contributed to the watershed assessments, the majority of data utilized for the 2014 assessment were collected in 2012. A total of 16 AUIDs were sampled for biology in the Lake of the Woods Watershed.

To measure the health of aquatic life at each biological monitoring station, IBIs, specifically fish and macroinvertebrate IBIs, were calculated based on monitoring data collected for each of these communities. A fish and macroinvertebrate classification framework was developed to account for natural variation in community structure which is attributed to geographic region, watershed drainage area, water temperature, and stream gradient. As a result, Minnesota's streams and rivers were divided into seven distinct warm water classes and two cold water classes, with each class having its own unique fish IBI and macroinvertebrate IBI. Each IBI class uses a unique suite of metrics, scoring functions, impairment thresholds, and confidence intervals (CIs) (For IBI classes, thresholds and CIs, see Appendix 4.1). IBI scores higher than the impairment threshold and upper CI indicate that the stream reach supports aquatic life. Contrarily, scores below the impairment threshold and lower CI indicate that the stream reach does not support aquatic life. When an IBI score falls within the upper and lower confidence limits additional information may be considered when making the impairment decision such as the consideration of potential local and watershed stressors and additional monitoring information (e.g., water chemistry, physical habitat, observations of local land use activities). For IBI results for each individual biological monitoring station, see Appendix 4.

Fish contaminants

Mercury and PCBs were analyzed in fish tissue samples collected from the Lake of the Woods and Warroad River Watershed. MPCA biomonitoring staff collected the fish from the Lake and the Warroad River in 2012. Minnesota MDNR fisheries staff collected all other fish (from previous years).

In addition, five sauger and five yellow perch from the Lake of the Woods were tested for perfluorochemicals (PFCs) in 2010. PFCs became identified as a contaminant of emerging concern in 2004 when high concentrations were measured in fish from the Mississippi River. Extensive statewide monitoring of lakes and rivers for PFCs in fish continued through 2010. After 2010, more focused monitoring for PFCs continued in known contaminated waters, such as the Mississippi River, several lakes in the Twin Cities Metropolitan Area, and some reservoirs in the Duluth area.

Captured fish were wrapped in aluminum foil and kept frozen until they were thawed, scaled (or skinned), filleted, and ground to a homogenized tissue sample. For mercury or PCBs analyses, homogenized fillets were placed in 125 milligram per liter (mL) glass jars with Teflon™ lids and kept frozen until thawed for lab analysis. The Minnesota Department of Agriculture (MDA) Laboratory performed all mercury and PCBs analyses of fish tissue. For PFCs, whole fish were shipped to AXYS Analytical Services Ltd in Sidney, British Columbia, Canada. AXYS performed the fish measurements and processing before analyzing the tissue samples for 13 PFCs. The PFC that primarily bioaccumulates in fish and is a known health concern for human consumption is perfluorooctane sulfonate (PFOS).

The Impaired Waters List is submitted every even-numbered year to the EPA for the agency's approval. MPCA has included waters impaired due to contaminants in fish on the Impaired Waters List since 1998. Impairment assessments for PCBs and PFOS in fish tissue are based on the fish consumption advisories prepared by the Minnesota Department of Health (MDH). If the consumption advice is to restrict consumption of a particular fish species to less than a meal per week because of PCBs or PFOS, the MPCA considers the lake or river impaired. The threshold concentration for impairment (consumption advice of one meal per month) is an average fillet concentration of 0.22 milligrams per kilogram (mg/kg) for PCBs and 0.200 mg/kg (200 parts per billion) for PFOS.

Before 2006, mercury in fish tissue was assessed for water quality impairment based on MDH's fish consumption advisory. An advisory more restrictive than one meal per week was classified as impaired for mercury in fish tissue. Since 2006, waterbodies have been classified as impaired for mercury in fish tissue if 10% of the fish samples (measured as the 90th percentile) exceed 0.2 mg/kg of mercury, which is a Minnesota's water quality standards for mercury. At least five fish samples per species are required to

perform this assessment and only the previous 10 years of data are used for statistical analysis. MPCA's Impaired Waters List includes waterways that were assessed as impaired prior to 2006 as well as more recent impairments.

PCBs in fish were intensively monitored in the 1970s and 1980s. High concentrations of PCBs were only a concern downstream of large urban areas in large rivers, such as the Mississippi River and in Lake Superior. Therefore, continued widespread, frequent monitoring of smaller river systems was not necessary. The current watershed monitoring approach includes screening for PCBs in representative predator and forage fish collected at the pour point stations in each major watershed.

Lake water sampling

Lake of the Woods is logistically challenging to monitor due to its large fetch, frequent high winds, navigational hazards, hydrological complexity, and cross border regulations. Therefore, water quality sampling over the years has been a cooperative effort between many agencies including the MPCA, MDNR, Lake of the Woods County SWCD, USGS, the Red Lake Nation, Ontario Ministry of Natural Resources, Ontario Ministry of the Environment and Climate Change, Environment Canada, and citizen volunteers. The MPCA led water quality sampling in 1999, 2005, 2006, and 2009 following standard lake assessment and sampling methodologies on five sites (four in the Minnesota Waters, and one on the Canadian side of Four Mile Bay). Under and MPCA contract, the USGS sampled several sites, including many in channels near the Northwest Angle, as part of the pre-impaired waters investigation to help define water and nutrient dynamics within the lake (Figure 16).

Figure 19. MPCA and USGS monitoring sites.

Groundwater monitoring

Groundwater quality

A baseline study conducted by the MPCA found that the median concentrations of most chemicals in the sand and gravel aquifers in this region were slightly higher, while iron and sulfate concentrations were

much higher when compared to similar aquifers statewide (MPCA, 1999). The results of this study also identified exceedances of drinking water criteria in the three different aquifers: cretaceous, surficial and buried sand and gravel.

The two factors that most heavily influence water quality were determined to be the presence of cretaceous bedrock and location. While water quality in cretaceous bedrock is typically poor, the location can dictate higher levels of contamination, such as higher arsenic concentrations in buried sand and gravel aquifers along stagnation moraines.

There is currently one MPCA Ambient Groundwater Monitoring well in the Lake of the Woods Watershed and there is not yet enough data collected from it to see trends in groundwater quality. Figure 17 displays the location of the well within the watershed.

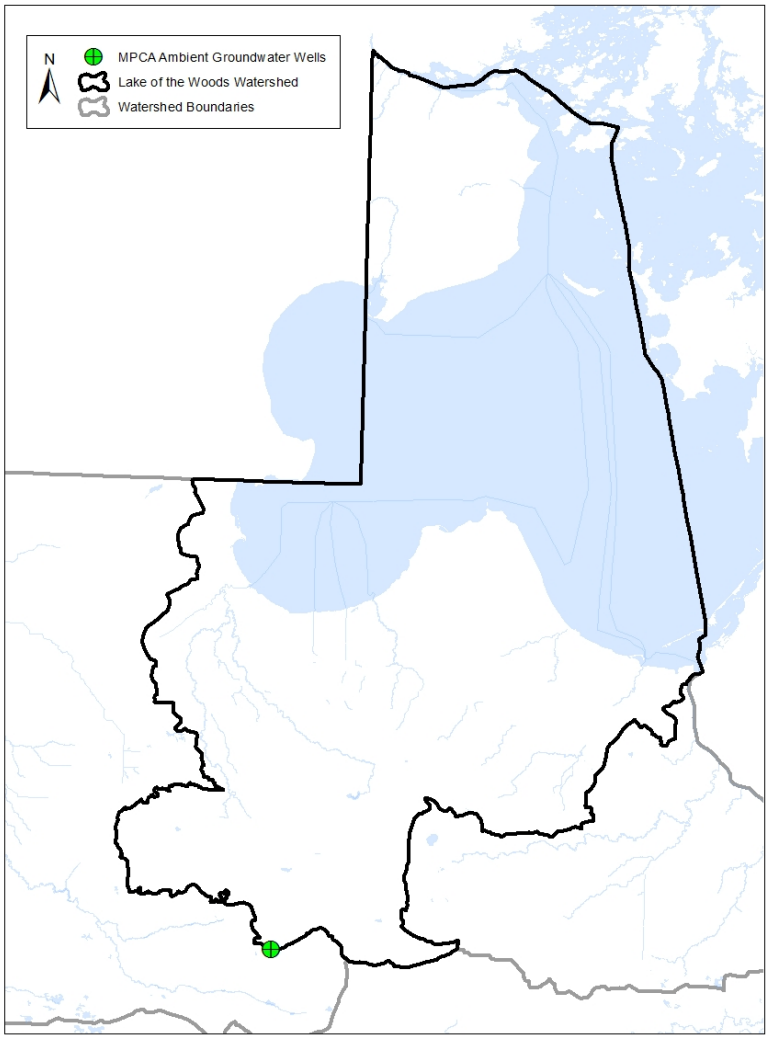

Figure 20. MPCA ambient groundwater monitoring well location within the Lake of the Woods Watershed.

The MDA monitors pesticides and nitrate on an annual basis in groundwater across agricultural areas in the state. The Lake of the Woods Watershed lies within MDA's Pesticide Monitoring Region 2 (PMR 2). However, due to the limited agricultural use and heavily forested areas, there is no groundwater monitoring currently done by the MDA for this region (MDA, 2014).

Another source of information on groundwater quality comes from the MDH. Mandatory testing for arsenic of all newly constructed wells has found that 10.4% of all wells statewide installed from 2008 to 2013 have arsenic levels above the maximum contaminant levels for drinking water of 10 micrograms

per liter (MDH). In northwest Minnesota, the majority of new wells are within the water quality standards for arsenic levels, but there are some exceedances (Figure 18).

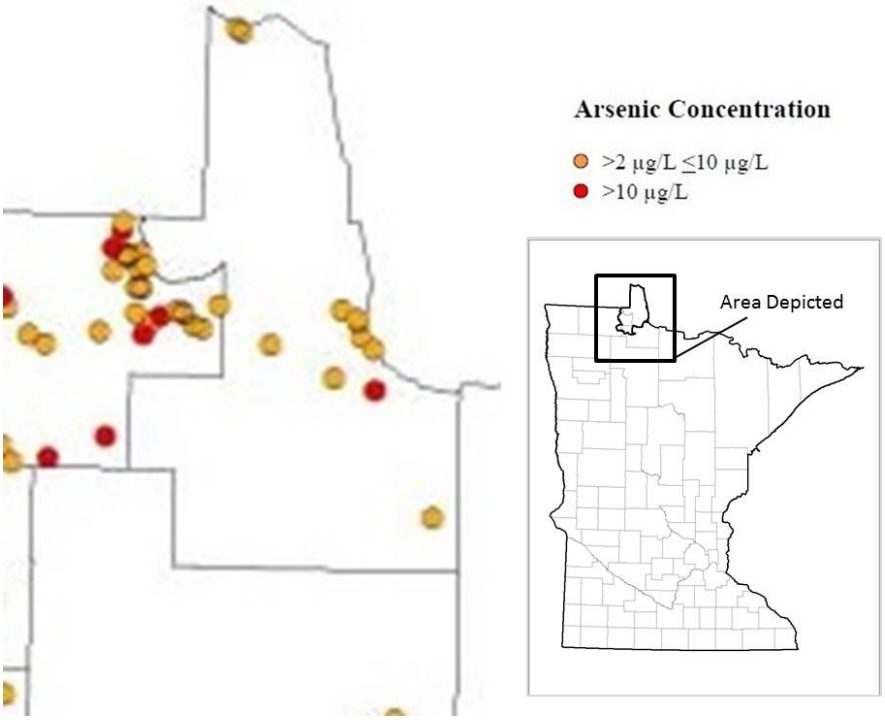

Figure 21. Arsenic occurrence in new wells in the Lake of the Woods area Minnesota (2008-2012) (Source: MDH, 2012).

Groundwater quantity

Monitoring wells from the MDNR Observation Well Network track the elevation of groundwater across the state. The elevation of groundwater is measured as depth to water in feet and reflects the fluctuation of the water table as it rises and falls with seasonal variations and anthropogenic influences.

There are no MDNR Observation Wells within the Lake of the Woods Watershed at this time.

Groundwater/surface water withdrawals

The MDNR permits all high capacity water withdrawals where the pumped volume exceeds 10,000 gallons/day or one million gallons/year. Permit holders are required to track water use and report back to the MDNR yearly. Information on the program and the program database are found at: http://www.dnr.state.mn.us/waters/watermgmt_section/appropriations/wateruse.html.

The changes in withdrawal volume detailed in this report are a representation of water use and demand in the watershed and are taken into consideration when the MDNR issues permits for water withdrawals. Other factors not discussed in this report but considered when issuing permits include: interactions between individual withdrawal locations, cumulative effects of withdrawals from individual aquifers, and potential interactions between aquifers. This holistic approach to water allocations is necessary to ensure the sustainability of Minnesota's groundwater resources.

The three largest permitted consumers of water in the state (in order) are municipalities, industry and irrigation. The withdrawals within the Lake of the Woods Watershed are mostly for municipal and private waterworks. Figure 19 shows locations of withdrawals from the watershed.

Figure 20 displays total groundwater withdrawals from the watershed from 1991-2011 are displayed below as blue diamonds with total surface water withdrawals as red squares. During this time period within the Lake of the Woods Watershed, groundwater withdrawals exhibit a statistically significant rising trend (p=0.001) while surface water withdrawals exhibits a less significant statistical trend (p=0.05).

Figure 22. Locations of permitted groundwater withdrawals in the Lake of the Woods Watershed.

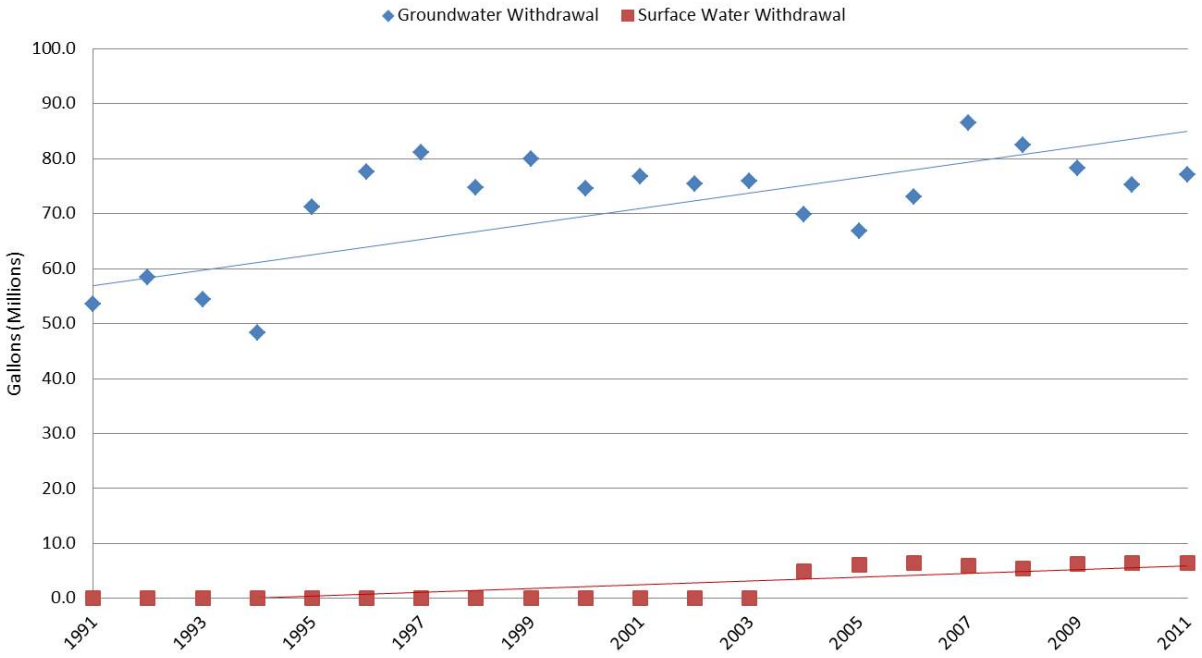

Figure 23. Total annual groundwater and surface water withdrawals in the Lake of the Woods Watershed (1991-2011).

Wetland monitoring

The MPCA is actively developing methods and building capacity to conduct wetland quality monitoring and assessment. Our primary approach is biological monitoring—where changes in biological communities may be indicating a response to human-caused stressors. The MPCA has developed macroinvertebrate and vegetation IBIs for depressional wetlands and the Floristic Quality Assessment (FQA) to assess vegetation condition in all of Minnesota's wetland types. For more information about the wetland monitoring (including technical background reports and sampling procedures) please visit the MPCA Wetland monitoring and assessment webpage.

The MPCA currently does not monitor wetlands systematically by watershed. Alternatively, the overall status and trends of wetland quality in the state and by major ecoregion is being tracked through probabilistic monitoring. Probabilistic monitoring refers to the process of randomly selecting sites to monitor; from which, an unbiased estimate of the resource can be made. The MPCA has recently published the results for an initial baseline survey of vegetation quality for all wetland types based on the FQA (MPCA 2015) and the overall survey results may provide a reasonable approximation of current wetland conditions in the watershed.

Individual subwatershed results

HUC-12 subwatersheds

Assessment results for aquatic life and recreation use are presented for each aggregated 12-HUC subwatershed within the Lake of the Woods Watershed. The primary objective is to portray all the fully supporting reaches and impairment listings within an aggregated 12-HUC subwatershed resulting from the multi-step assessment and listing process. (A summary table of assessment results for the entire 8-HUC watershed including aquatic consumption and drinking water assessments (where applicable) is included in Appendix 3). This scale provides a robust assessment of water quality condition at a practical

size for the development, management, and implementation of effective TMDLs and protection strategies. The graphics presented for each of the aggregated 12-HUC subwatersheds contain the assessment results from the 2014 Assessment Cycle as well as any impairment listings from previous assessment cycles. Discussion of assessment results focuses primarily on the 2012 IWM effort, but also considers available data from the last 10 years.

The proceeding pages provide an account of each aggregated 12-HUC subwatershed. Each account includes a brief description of the subwatershed and summary tables of the results for each of the following: a) stream aquatic life and aquatic recreation assessments; b) stream habitat quality c) channel stability; and where applicable d) water chemistry for the aggregated 12-HUC outlet; and e) lake aquatic recreation assessments. Following the tables are a narrative summary of the assessment results and pertinent water quality projects completed or planned for the subwatershed. A brief description of each of the summary tables is provided below.

Stream assessments

A table is provided, in each section, summarizing aquatic life and aquatic recreation assessments of all assessable stream reaches within the subwatershed (i.e., where sufficient information was available to make an assessment). Primarily, these tables reflect the results of the 2012 assessment process (2014 EPA reporting cycle); however, impairments from previous assessment cycles are also included and are distinguished from new impairments via cell shading (see footnote section of each table). These tables also denote the results of comparing each individual aquatic life and aquatic recreation indicator to their respective criteria (i.e., standards); these are determinations made during the desktop phase of the assessment process (see Figure 4 Figure 4). Assessment of aquatic life is derived from the analysis of biological (fish and macroinvertebrate IBIs), DO, turbidity, chloride, pH and un-ionized ammonia (NH3) data, while the assessment of aquatic recreation in streams is based solely on bacteria (Escherichia coli or fecal coliform) data. Included in each table is the specific aquatic life use classification for each stream reach: cold water community (2A); cool or warm water community (2B); or indigenous aquatic community (2C). Where applicable and sufficient data exists, assessments of other designated uses (e.g., Class 7, drinking water, aquatic consumption) are discussed in the summary section of each aggregated 12-HUC subwatershed, as well as in the Watershed-wide Results and Discussion section.

Stream habitat results

Habitat information documented during each fish sampling visit is provided in each aggregated 12-HUC subwatershed section. These tables convey the results of the Minnesota Stream Habitat Assessment (MSHA) survey, which evaluates the section of stream sampled for biology and can provide an indication of potential stressors (e.g., siltation, eutrophication) impacting fish and macroinvertebrate communities. The MSHA score is comprised of five scoring categories including adjacent land use, riparian zone, substrate, fish cover and channel morphology, which are summed for a total possible score of 100 points. Scores for each category, a summation of the total MSHA score, and a narrative habitat condition rating are provided in the tables for each biological monitoring station. Where multiple visits occur at the same station, the scores from each visit have been averaged. The final row in each table displays average MSHA scores and a rating for the aggregated 12-HUC subwatershed.

Stream stability results

Stream channel stability information evaluated during each macroinvertebrate sampling visit is provided in each aggregated 12-HUC subwatershed section. These tables display the results of the Channel Condition and Stability Index (CCSI) which rates the geomorphic stability of the stream reach sampled for biology. The CCSI rates three regions of the stream channel (upper banks, lower banks, and bottom), which may provide an indication of stream channel geomorphic changes and loss of habitat quality, which in turn may be related to changes in watershed hydrology, stream gradient, sediment supply, or

sediment transport capacity. The CCSI was recently implemented in 2008, and is collected once at each biological station. Consequently, the CCSI ratings are only available for biological visits sampled in 2010 or later. The final row in each table displays the average CCSI scores and a rating for the aggregated 12-HUC subwatershed.

Subwatershed outlet water chemistry results

These summary tables display the water chemistry results for the monitoring station representing the outlet of the aggregated 12-HUC subwatershed. This data along with other data collected within the 10-year assessment window can provide valuable insight on water quality characteristics and potential parameters of concern within the watershed. Parameters included in these tables are those most closely related to the standards or expectations used for assessing aquatic life and recreation. While not all of the water chemistry parameters of interest have established water quality standards, McCollor and Heiskary (1993) developed ecoregion expectations for a number of parameters that provide a basis for evaluating stream water quality data and estimating attainable conditions for an ecoregion. For comparative purposes, water chemistry results for the Lake of the Woods Watershed are compared to expectations developed by McCollor and Heiskary (1993) that were based on the 75th percentile of a long-term dataset of least impacted streams within each ecoregion.

Lake assessments

A summary of lake water quality is provided in the aggregated 12-HUC subwatershed sections where available data exists. For lakes with sufficient data, basic modeling was completed. The assessment results for Lake of the Woods are available in Appendix 3.2. Lake models and corresponding morphometric inputs can be found in Appendix 5.2.

Bostick Creek-Frontal Four Mile Bay Subwatershed HUC 0903000901-01

Located on the far eastern edge of the Lake of the Woods Watershed, this subwatershed is in Lake of the Woods County between the cities of Williams and Baudette. The main rivers are Canfield Creek and Bostick Creek. Canfield Creek is found in the southern half of the subwatershed flowing northward. Canfield Creek is directed by ditches through a wetland until the ditches emerge on the northern edge of the wetland and drain into Bostick Creek. Bostick Creek continues northward until it flows into Bostic Bay of Lake of the Woods, about three miles west of the mouth of the Rainy River. Land use in this subwatershed is dominated by wetland coverage at 69% and 22% combined crop and range land.

Table 2. Aquatic life and recreation assessments on stream reaches: Bostick Creek-Frontal Four Mile Bay Subwatershed. Reaches are organized upstream to downstream in the table.

AUID ***Reach Name***, *Reach Description*	Reach Length (miles)	Use Class	Biological Station ID	Location of Biological Station	Aquatic Life Indicators:							Aquatic Rec. Indicators		Aquatic Life	Aquatic Rec.
					Fish IBI	Invert IBI	Dissolved Oxygen	Turbidity	Chloride	pH	NH_3	Bacteria	Nutrients		
09030009-553, Unnamed creek, Unnamed cr to Canfield Cr	1.69	WWg					IF	IF		MTS				IF	NA
09030009-546, Canfield Creek, Unnamed cr to Unnamed cr	0.83	WWg					IF			MTS				IF	NA
09030009-540, Unnamed ditch, Canfield Cr to Unnamed ditch	2.63	WWg					IF	MTS		MTS				IF	NA
09030009-537, Bostick Creek, Headwaters to Lake of the Woods	3.76	WWg	12RN021	Upstream of CR 42nd Ave NW, 3 mi. W of Hacket	MTS		MTS	EXS	MTS	MTS	MTS	MTS		SUP	SUP
09030009-539, Unnamed ditch, Unnamed ditch to Bostick Cr	1.68	WWg					MTS	IF		MTS				IF	NA

Abbreviations for Indicator Evaluations: **MTS** = Meets Standard; **EXS** = Fails Standard; **IF** = Insufficient Information
Abbreviations for Use Support Determinations: **--** = No Data, **NA** = Not Assessed, **IF** = Insufficient Information, **SUP** = Full Support (Meets Criteria); **IMP** = Impaired (Fails Standards)
Key for Cell Shading: = existing impairment, listed prior to 2014 reporting cycle; = new impairment; = full support of designated use; = insufficient information.
Abbreviations for Use Class: **WWg** = warmwater general, **WWm** = Warmwater modified, **WWe** = Warmwater exceptional, **CWg** = Coldwater general, **CWe** = Coldwater exceptional, **LRVW** = limited resource value water

Table 3. Minnesota Stream Habitat Assessment (MSHA): Bostick Creek-Frontal Four Mile Bay Subwatershed.

# Visits	Biological Station ID	Reach Name	Land Use (0-5)	Riparian (0-15)	Substrate (0-27)	Fish Cover (0-17)	Channel Morph. (0-36)	MSHA Score (0-100)	MSHA Rating
1	12RN021	Bostick Creek	3	9	10	16	14	52	Fair
Average Habitat Results: *Bostick Creek-Frontal Four Mile Bay*			**3**	**9**	**10**	**16**	**14**	**52**	**Fair**

Qualitative habitat ratings

= Good: MSHA score above the median of the least-disturbed sites (MSHA>66)

= Fair: MSHA score between the median of the least-disturbed sites and the median of the most-disturbed sites (45 < MSHA < 66)

= Poor: MSHA score below the median of the most-disturbed sites (MSHA<45)

Table 4. Channel Condition and Stability Assessment (CCSI): Bostick Creek-Frontal Four Mile Bay Subwatershed.

# Visits	Biological Station ID	Stream Name	Upper Banks (43-4)	Lower Banks (46-5)	Substrate (37-3)	Channel Evolution (11-1)	CCSI Score (137-13)	CCSI Rating
1	12RN021	Bostick Creek	14	7	20	3	44	fairly stable
Average Stream Stability Results: *Bostick Creek-Frontal Four Mile Bay Subwatershed*			14	7	20	3	44	fairly stable

Qualitative channel stability ratings

= stable: CCSI < 27 = fairly stable: 27 < CCSI < 45 = moderately unstable: 45 < CCSI < 80 = severely unstable: 80 < CCSI < 115 = extremely unstable: CCSI > 115

Table 5. Outlet water chemistry results: Bostick Creek-Frontal Four Mile Bay Subwatershed.

Station location:	Bostic Creek, At CR 42nd Ave NW, 3 mi. W of Hacket
STORET/EQuIS ID:	S005-708
Station #:	0903000901-01, Bostick Creek-Frontal Four Mile Bay

Parameter	Units	# of Samples	Minimum	Maximum	Mean	WQ Standard[1]	# of WQ Exceedances[2]
Ammonia-nitrogen	ug/L	10	0.52	3.0	1.24	40	0
Chloride	mg/L	10	< 1	13.4	7.4	230	0
Dissolved Oxygen (DO)	mg/L	88	2.7	12.3	7.49	5	9
pH		91	7.25	8.35	7.8	6.5 - 9	0
Secchi Tube	cm	72	5	98	63	40	18
Total suspended solids	mg/L	60	< 1	271	17.8	15	8
Escherichia coli (geometric mean)	MPN/100ml	3	25	67	41	126	0
Escherichia coli	MPN/100ml	15	2.7	686	96	1260	0
Chlorophyll-a, Corrected	ug/L	0					
Inorganic nitrogen (nitrate and nitrite)	mg/L	10	0.033	0.12	0.08		
Kjeldahl nitrogen	mg/L	38	0.033	2.5	1.14		
Orthophosphate	ug/L	22	4	50	20		
Pheophytin-a	ug/L	0					
Phosphorus	ug/L	61	16	230	50		
Specific Conductance	uS/cm	91	16	597	451		
Temperature, water	deg °C	90	4.9	23.8	16.6		
Sulfate	mg/L	10	24	38	32		
Hardness	mg/L	10	5.2	314	256		

[1]Secchi Tube standards are surrogate standards derived from the total suspended solids (TSS) standard of 15 mg/L.

****Data found in the table above were compiled using the results from data collected at the outlet monitoring station in the Bostick Creek-Frontal Four mile Bay Subwatershed, a component of the IWM work conducted between May and September from 2004-2013. This specific data does not necessarily reflect all data that were used to assess the AUID.**

Summary

The Bostick Creek Subwatershed contains one fully assessable AUID. The Bostick Creek AUID contains one biological monitoring site (12RN021) along with co-located 10X water chemistry sampling. 12RN021 is on the mainstem of Bostick Creek downstream of County Road 70, 8 miles northeast of Williams. The fish sample did well against the IBI threshold for low gradient streams. Burbot and blacknose shiners, both sensitive species, were present in the sample. The most abundant fish found was yellow perch, ranging in size from two to eight inches (66-219 millimeters [mm]). Negatively, turbidity did not meet standards for aquatic life. Though turbidity did not meet standards, all other assessable indicators were satisfactory, so the AUID is listed as fully supporting aquatic life.

Habitat was evaluated with both MSHA and CCSI to gage habitat quality and stream channel stability. The MSHA was negatively impacted by limited changes in channel morphology and small substrate types. However, MSHA scored well for fish cover. CCSI was ranked fairly stable, losing points for poor substrate characteristics. Both MSHA and CCSI point to sedimentation as an issue for Bostick Creek, in part because Bostick is a low gradient stream with turbidity issues.

Water chemistry has been collected at this location for several projects, including the Zippel and Bostic Creek Assessments and a local River Watch program. Overall, the data indicates good water quality. Dissolved oxygen concentrations meet standards. However, there are sporadic periods of lower DO occurring during mid-summer low flows when DO falls below standards. This is a common occurrence for small low gradient streams like Bostic Creek. Nutrients, pH, and chloride concentrations were at expected levels, with no exceedances of standards. E. coli bacteria concentrations were consistently meeting standards, and indicated support of aquatic recreational use.

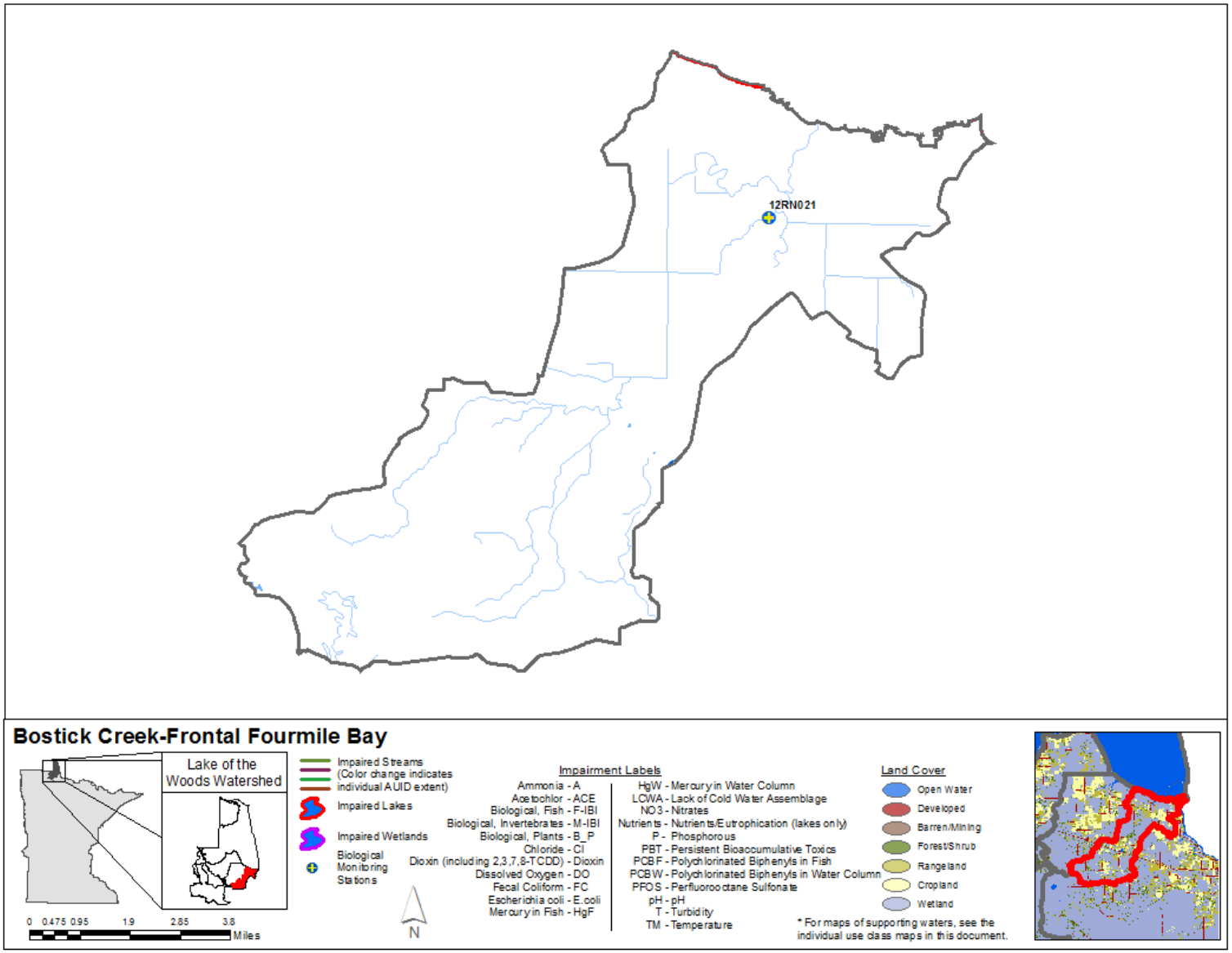

Figure 24. Currently listed impaired waters by parameter and land use characteristics in the Bostick Creek-Frontal Four Mile Bay Subwatershed.

Zippel Creek-Frontal Lake of the Woods Subwatershed HUC 0903000902-01

The Zippel Creek Subwatershed contains the rivers and streams that flow into Zippel Bay. Of these streams the two largest streams are West Branch Zippel Creek and East Branch Zippel Creek. Tomato Creek is the main tributary to West Branch Zippel Creek and Williams Creek is the main tributary to the East Branch. Tomato Creek and Williams Creek start in a large wetland south of Minnesota Highway 11 and flow northeasterly until they meet Zippel Bay.

Table 6. Aquatic life and recreation assessments on stream reaches: Zippel Creek-Frontal Lake of the Woods Subwatershed. Reaches listed upstream to downstream in the table.

AUID ***Reach Name***, *Reach Description*	Reach Length (miles)	Use Class	Biological Station ID	Location of Biological Station	Aquatic Life Indicators:							Aquatic Rec. Indicators:		Aquatic Life	Aquatic Rec.
					Fish IBI	Invert IBI	Dissolved Oxygen	Turbidity	Chloride	pH	NH_3	Bacteria	Nutrients		
09030009-516, Tomato Creek, Headwaters to T161 R34W S3, north line	3.13	CWg	05RN117	Upstream of Hwy 11, 3 miles W. of Williams	MTS	MTS	IF	IF		IF				SUP	NA
09030009-518, Tomato Creek, T162 R34W S34, south line to Unnamed cr	0.83	WWg	12RN017	Downstream of 24th St NW, 3 mi. NW of Williams	MTS	MTS	MTS	IF		MTS				SUP	NA
09030009-506, Zippel Creek, East Branch, Headwaters to Zippel Bay	7.08	WWg					IF	IF		MTS				IF	NA
09030009-529, County Ditch 1, Unnamed ditch to W Br Zippel Cr	1.48	WWg					MTS	MTS		MTS				SUP	NA
09030009-567, Unnamed creek, Headwaters to 70th Ave NW	2.71	WWm					IF			MTS				IF	NA
09030009-515, Zippel Creek, West Branch (County Ditch 1), Headwaters to Zippel Bay (Lake of the Woods)	6.03	WWg	12RN018	Upstream of 40th St NW, 6.5 mi. N of Williams	EXS	EXS	MTS	EXS	IF	MTS				IMP	NA
09030009-501, Williams Creek, Headwaters to Zippel Cr	12.73	WWg	10EM161, 12RN020	Upstream of 24th St NW, 3 mi. NE of Williams. Upstream of CR 12 about 6 mi. NE of Williams	EXS	EXS	IF	EXS	MTS	MTS	MTS	MTS		IMP	SUP

Abbreviations for Indicator Evaluations: **MTS** = Meets Standard; **EXS** = Fails Standard; **IF** = Insufficient Information

Abbreviations for Use Support Determinations: **--** = No Data, **NA** = Not Assessed, **IF** = Insufficient Information, **SUP** = Full Support (Meets Criteria); **IMP** = Impaired (Fails Standards)

Key for Cell Shading: = existing impairment, listed prior to 2014 reporting cycle; = new impairment; = full support of designated use; = insufficient information.

Abbreviations for Use Class: **WWg** = warmwater general, **WWm** = Warmwater modified, **WWe** = Warmwater exceptional, **CWg** = Coldwater general, **CWe** = Coldwater exceptional, **LRVW** = limited resource value water

Table 7. Minnesota Stream Habitat Assessment (MSHA): Zippel Creek-Frontal Lake of the Woods Subwatershed.

# Visits	Biological Station ID	Reach Name	Land Use (0-5)	Riparian (0-15)	Substrate (0-27)	Fish Cover (0-17)	Channel Morph. (0-36)	MSHA Score (0-100)	MSHA Rating
1	10EM161	Williams Creek	2.5	11	19.9	7	20	60.4	Fair
2	12RN020	Williams Creek	2.63	11	20.85	12	23	69.48	Good
3	05RN117	Tomato Creek	5	14	12.85	13.33	19	64.18	Fair
2	12RN017	Tomato Creek	3	12	10.5	11	16	52.5	Fair
1	12RN018	Zippel Creek, West Branch (County Ditch 1)	4	10	12.25	12	12	50.25	Fair
Average Habitat Results: *Zippel Creek-Frontal Lake of the Woods*			3.43	11.6	15.27	11.07	18	59.36	Fair

Qualitative habitat ratings
- = Good: MSHA score above the median of the least-disturbed sites (MSHA>66)
- = Fair: MSHA score between the median of the least-disturbed sites and the median of the most-disturbed sites (45 < MSHA < 66)
- = Poor: MSHA score below the median of the most-disturbed sites (MSHA<45)

Table 8. Channel Condition and Stability Assessment (CCSI): Zippel Creek-Frontal Lake of the Woods Subwatershed.

# Visits	Biological Station ID	Stream Name	Upper Banks (43-4)	Lower Banks (46-5)	Substrate (37-3)	Channel Evolution (11-1)	CCSI Score (137-13)	CCSI Rating
1	12RN020	Williams Creek	22	9	10	1	42	fairly stable
1	05RN117	Tomato Creek	19	20	17	3	59	moderately unstable
1	12RN017	Tomato Creek	15	17	30	3	65	moderately unstable
1	12RN018	Zippel Creek, West Branch (County Ditch 1)	16	13	11	3	43	fairly stable
Average Stream Stability Results: *Zippel Creek-Frontal Lake of the Woods subwatershed*			18	14.75	17	2.5	52.25	moderately unstable

Qualitative channel stability ratings = stable: CCSI < 27 = fairly stable: 27 < CCSI < 45 = moderately unstable: 45 < CCSI < 80 = severely unstable: 80 < CCSI < 115 = extremely unstable: CCSI > 115

Table 9. Outlet water chemistry results: Zippel Creek-Frontal Lake of the Woods Subwatershed.

Station location:	Williams Creek At CR 12, 5.5 mi. NE of Williams
STORET/EQuIS ID:	S000-906
Station #:	0903000902-01, Zippel Creek-Frontal Lake of the Woods

Parameter	Units	# of Samples	Minimum	Maximum	Mean	WQ Standard[1]	# of WQ Exceedances[2]
Ammonia-nitrogen	ug/L	11	1.25	2.5	1.68	40	0
Chloride	mg/L	11	3.3	10.1	6.3	230	0
Dissolved Oxygen (DO)	mg/L	118	3.0	16.3	9.49	5	11
pH		121	5.95	8.6	7.9	6.5 - 9	1
Secchi Tube	cm	61	28	99	73	40	24
Total suspended solids	mg/L	63	1	150	16.4	15	18
Escherichia coli (geometric mean)	MPN/100ml	3	34	71	49	126	0
Escherichia coli	MPN/100ml	15	13	191	60	1260	0
Chlorophyll-a, Corrected	ug/L	0					
Inorganic nitrogen (nitrate and nitrite)	mg/L	31	0.03	0.52	0.14		
Kjeldahl nitrogen	mg/L	61	0.31	1.6	0.81		
Orthophosphate	ug/L	23	4	70	20		
Pheophytin-a	ug/L	0					
Phosphorus	ug/L	59	20	250	50		
Specific Conductance	uS/cm	120	69	642	458		
Temperature, water	deg °C	120	0.07	25.5	14.7		
Sulfate	mg/L	11	3.79	16.5	8.1		
Hardness	mg/L	11	190	259	228		

[1]Secchi Tube standards are surrogate standards derived from the TSS standard of 15 cm.

****Data found in the table above were compiled using the results from data collected at the outlet monitoring station in the Zippel Creek-Frontal Lake of the Woods Subwatershed, a component of the IWM work conducted between May and September from 2004-2013. This specific data does not necessarily reflect all data that were used to assess the AUID.**

Summary

The Zippel Creek subwatershed contains eight assessable AUIDs. Four of these eight have biological data. The first AUID is designated coldwater, on Tomato Creek, while the others are designated warm water.

On the Tomato Creek headwaters AUID there is one biological monitoring station (05RN117), which was sampled in 2005, 2009, and 2012 for fish and for macroinvertebrates in 2005 and 2014. Fish samples scored well, containing sensitive cool water species including Pearl and Finescale Dace. The 2005 macroinvertebrate index of biological integrity score is six points below the coldwater general use threshold, the 2014 MIBI score is eight points above the general use threshold. The 2005 sample was collected during low water and not all habitats were adequately sampled, and therefore less weight is placed on this sample. Similarly, downstream Tomato Creek site 12RN017 met fish IBI thresholds, and contained a few cool water species. However, it had fewer cold water species and a higher number of tolerant species. Two additional macroinvertebrate monitoring sites were added in 2014, between 05RN117 and 12RN017, to evaluate where the stream transitioned from coldwater to warmwater. Coldwater macroinvertebrate taxa decreased the further downstream samples were collected, and it was decided that the use class designation split would be made at Highway 58.

Further downstream, on West Branch Zippel Creek, this next AUID contains one site (12RN018) with one visit in 2012. Here a large percentage of the fish sampled were central mudminnows, a tolerant species. Though the fish sample scored near the IBI threshold, this site did not meet standards due to the percentage of tolerant species in the sample. Macroinvertebrates collected at 12RN018 were dominated by snails, amphipods, and other tolerant taxa and scored well below the general use threshold.

On Williams Creek's one assessable AUID, there are two biological sites (10EM161, 12RN020). 10EM161 did not pass fish thresholds due to the dominance of tolerant species in the sample. 12RN020 was sampled twice for fish and both samples failed with 50 to 77% of fish sampled being tolerant species. 10EM161 was sampled for macroinvertebrates in 2010 and scored above the general use threshold, but 12RN020 scored well below the general use threshold and numerically dominated by tolerant taxa. Both West and East Branch show a trend of worsening biological conditions moving from the headwaters down to Zippel Bay.

The 10X water chemistry site for this subwatershed was on Williams Creek (County Ditch 1) at County Road 12, 5.5 miles northeast of the city of Williams (collocated with 12RN020). The site is within a ditched section of Williams Creek, and is located about 2 miles upstream from Zippel. This site has been sampled historically for several projects including the Lake of the Woods nutrient budget, and Bostic/Zippel Creek assessments. The DO dataset indicates impairment for aquatic life, with 18% of early morning samples not meeting (i.e., below) the 5 mg/L standard. Other parameters, such as unionized ammonia, chloride, and pH had no, or minimal, standard exceedances. Nutrients (N and phosphorus (P)) were at expected levels given the watershed's setting. E. coli bacteria concentrations were consistently meeting standards and indicated support of aquatic recreational use.

The overall habitat and stream stability ratings are fair and moderately unstable. Habitat scores were impacted by the sediment and channel morphology. Stream stability scores were most negatively impacted by upper bank stability and substrates. Both rankings are being impacted by sedimentation.

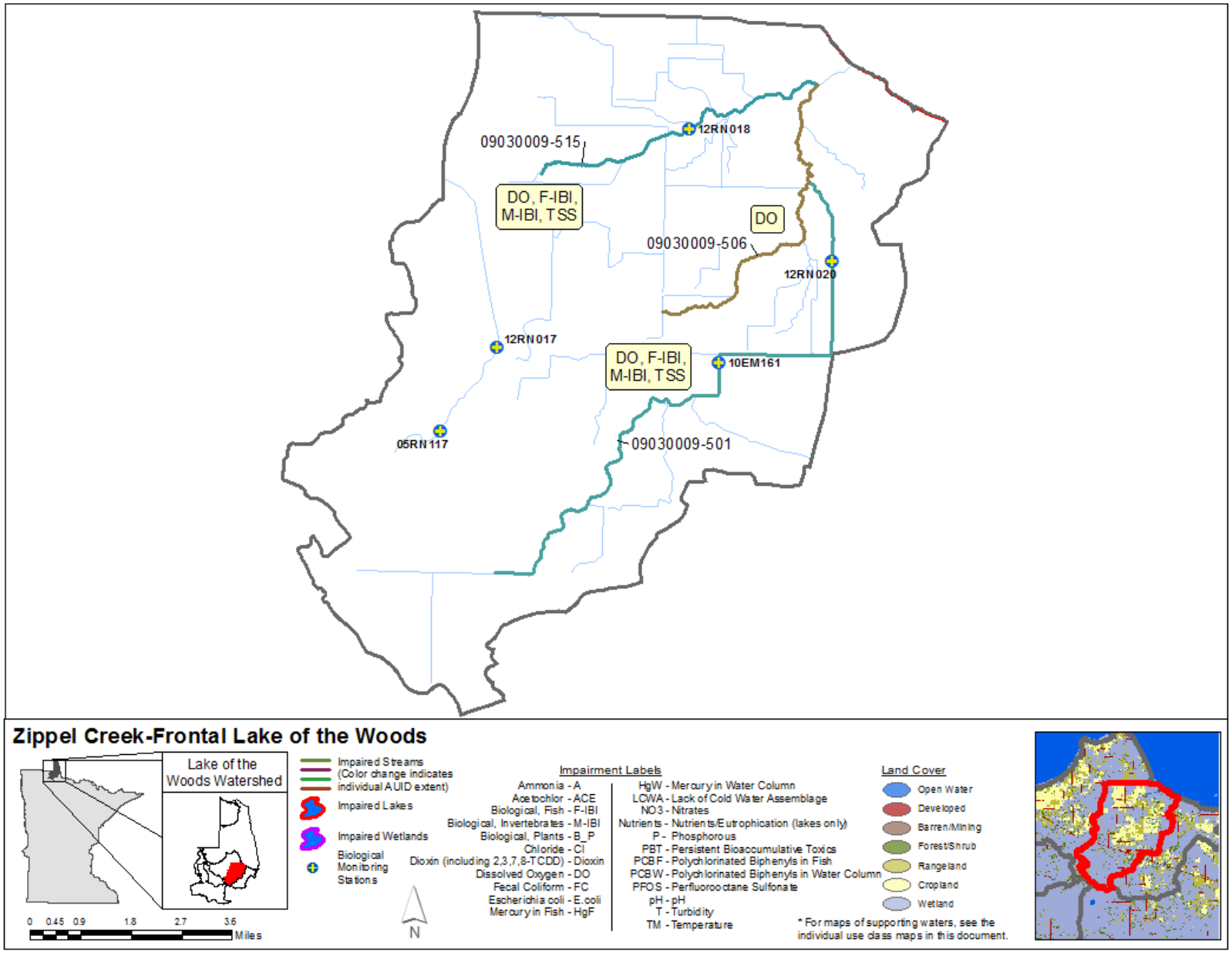

Figure 25. Currently listed impaired waters by parameter and land use characteristics in the Zippel Creek-Frontal Lake of the Woods Subwatershed.

Warroad River Subwatershed HUC 0903000903-01

The Warroad River Subwatershed is located in Roseau County, on the far western edge of the Lake of the Woods Watershed. The upper portion of the subwatershed originates in a large wetland complex within Beltrami Island State Forest, an area that was ditched in the early 1900s in an attempt at draining the landscape for agriculture. The Warroad River is the largest river within the Lake of the Woods Watershed. There are two branches, the east and west Branch, which flow north approximately 30 miles from its headwaters to the Lake of the Woods. The southern land use is primarily wetlands, but the northern portions are dominated by agricultural and urban land uses.

Table 10. Aquatic life and recreation assessments on stream reaches: Warroad River Subwatershed. Reaches are organized upstream to downstream in the table.

AUID *Reach Name*, *Reach Description*	Reach Length (miles)	Use Class	Biological Station ID	Location of Biological Station	Aquatic Life Indicators:							Aquatic Rec. Indicators		Aquatic Life	Aquatic Rec.
					Fish IBI	Invert IBI	Dissolved Oxygen	Turbidity	Chloride	pH	NH_3	Bacteria	Nutrients		
09030009-502, Warroad River, W & E Br Warroad R to Lake of the Woods	4.55	WWg	05RN116	Downstream of CR 5, just S. of Warroad	MTS		NA	IF	MTS	MTS	MTS	MTS		SUP	SUP

Abbreviations for Indicator Evaluations: **MTS** = Meets Standard; **EXS** = Fails Standard; **IF** = Insufficient Information
Abbreviations for Use Support Determinations: **--** = No Data, **NA** = Not Assessed, **IF** = Insufficient Information, **SUP** = Full Support (Meets Criteria); **IMP** = Impaired (Fails Standards)
Key for Cell Shading: = existing impairment, listed prior to 2014 reporting cycle; = new impairment; = full support of designated use; = insufficient information.
Abbreviations for Use Class: **WWg** = warmwater general, **WWm** = Warmwater modified, **WWe** = Warmwater exceptional, **CWg** = Coldwater general, **CWe** = Coldwater exceptional, **LRVW** = limited resource value water

Table 11. Minnesota Stream Habitat Assessment (MSHA): Warroad River Subwatershed.

# Visits	Biological Station ID	Reach Name	Land Use (0-5)	Riparian (0-15)	Substrate (0-27)	Fish Cover (0-17)	Channel Morph. (0-36)	MSHA Score (0-100)	MSHA Rating
2	**05RN116**	**Warroad River**	**3**	**10**	**12**	**14.5**	**18.5**	**58**	**Fair**
Average Habitat Results: *Warroad River Subwatershed*			**3**	**10**	**12**	**14.5**	**18.5**	**58**	**Fair**

Qualitative habitat ratings
= Good: MSHA score above the median of the least-disturbed sites (MSHA>66)
= Fair: MSHA score between the median of the least-disturbed sites and the median of the most-disturbed sites (45 < MSHA < 66)
= Poor: MSHA score below the median of the most-disturbed sites (MSHA<45)

Table 12. Channel Condition and Stability Assessment (CCSI): Warroad River Subwatershed.

# Visits	Biological Station ID	Stream Name	Upper Banks (43-4)	Lower Banks (46-5)	Substrate (37-3)	Channel Evolution (11-1)	CCSI Score (137-13)	CCSI Rating
1	05RN116	Warroad River	7	5	4	3	19	stable
Average Stream Stability Results: *Warroad River Subwatershed*			7	5	4	3	19	stable

Qualitative channel stability ratings = stable: CCSI < 27 = fairly stable: 27 < CCSI < 45 = moderately unstable: 45 < CCSI < 80 = severely unstable: 80 < CCSI < 115 = extremely unstable: CCSI > 115

Table 13. Outlet water chemistry results: Warroad River Subwatershed.

Station location:	Warroad River, Downstream of CR 5, just S. of Warroad
STORET/EQuIS ID:	S006-978
Station #:	0903000903-01, Warroad River

Parameter	Units	# of Samples	Minimum	Maximum	Mean	WQ Standard[1]	# of WQ Exceedances[2]
Ammonia-nitrogen	ug/L	10	0.43	1.29	0.78	40	0
Chloride	mg/L	10	1.33	3.2	2.3	230	0
Dissolved Oxygen (DO)	mg/L	164	3.5	11.9	8.9	5	3
pH		164	6.5	8.3	7.7	6.5 - 9	0
Secchi Tube	100 cm	19	32	97	80	40	5
Total suspended solids	mg/L	36	3	78	19	15	2
Escherichia coli (geometric mean)	MPN/100ml	3	31	63	51	126	0
Escherichia coli	MPN/100ml	15	14	139	58	1260	0
Chlorophyll-a, Corrected	ug/L	40	< 0.2	12	2.8		
Inorganic nitrogen (nitrate and nitrite)	mg/L	16	0.03	0.46	0.19		
Kjeldahl nitrogen	mg/L	42	0.54	1.39	0.91		
Orthophosphate	ug/L	26	< 3	30	10		
Pheophytin-a	ug/L	42	0.4	3.3	1.49		
Phosphorus	ug/L	42	20	170	50		
Specific Conductance	uS/cm	164	176	434	274		
Temperature, water	deg °C	164	3.4	23.4	12.9		
Sulfate	mg/L	10	< 3	3	< 3		
Hardness	mg/L	10	142	221	185		

[1]Secchi Tube standards are surrogate standards derived from the TSS standard of 15 cm.

****Data found in the table above were compiled using the results from data collected at the outlet monitoring station in the Warroad River Subwatershed, a component of the IWM work conducted between May and September from 2004-2013. This specific data does not necessarily reflect all data that were used to assess the AUID.**

Summary

This subwatershed has one assessable AUID, with one biological site near the town of Warroad on the Warroad River. Site 05RN116 was sampled for fish in 2005 and again in 2012. Both samples contained sensitive species such as silver lamprey and blacknose shiners, and scored well against the IBI threshold. However, during the 2012 sample fish tissues were collected to be analyzed for aquatic consumption analysis; results can be seen in Table 28. It was found that fish tissue collected from the Warroad River contained high mercury concentrations, resulting in an aquatic consumption impairment.

The 10X site for this subwatershed was collocated with 05RN116, on the Warroad River off 340th Street, 1 mile south of Warroad, and about 0.25 mile downstream from the confluence of the east and west branches. This site is approximately 4 river miles from the Lake of the Woods, and is free of backwater affects from the lake during most flow conditions. In addition to the IWM monitoring, this site was also sampled by the USGS for the Lake of the Woods pre-TMDL study. The robust dataset at this location indicates good water quality overall. Dissolved oxygen concentrations were sufficient, on average, to support aquatic life (some samples during a 2012 drought were not meeting standards, a common occurrence due to stagnant conditions). Nutrients (N and P) were at expected levels. E. coli bacteria concentrations were consistently meeting standards, and indicated support of aquatic recreational use.

Stream habitat and stream stability ratings are based on the 2012 visits for 05RN116. Habitat was rated fair because of fine sediments and limited changes in channel morphology, though it provided strong fish cover scores. Despite a higher percentage of fine sediments found in the habitat score, the stream channel rated as stable with good upper and lower bank stability.

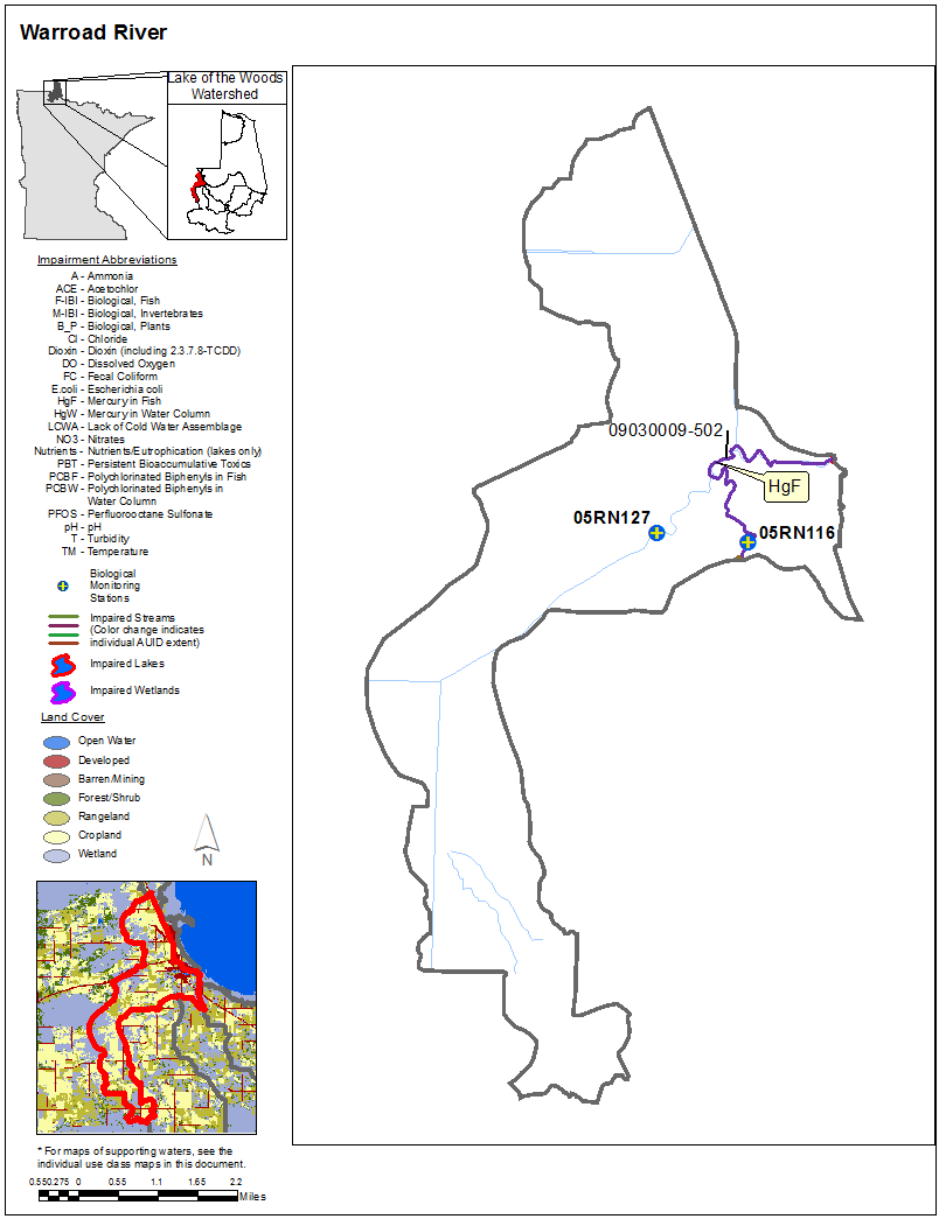

Figure 26. Currently listed impaired waters by parameter and land use characteristics in the Warroad River Subwatershed.

West Branch Warroad River Subwatershed HUC 0903000903-02

The West Branch Warroad River begins in a wetland area within the Beltrami Island State Forest, and flows about 30 miles to the confluence with the East Branch Warroad River just south of the town of Warroad. This subwatershed is split between both Roseau County in the north and Lake of the Woods County in the south. Similar to the previous subwatershed, the headwaters of the West Branch Warroad River Subwatershed begin in ditches of the Beltrami Island State Forest. The subwatershed also contains state natural areas including Winter Road Lake Peatland, Norris Camp Peatland, and Luxemburg Peatland. The predominant land uses for this subwatershed are 80% wetlands and 12% combined crop and range land.

Table 14. Aquatic life and recreation assessments on stream reaches: West Branch Warroad River Subwatershed. Reaches are organized upstream to downstream in the table.

AUID *Reach Name*, *Reach Description*	Reach Length (miles)	Use Class	Biological Station ID	Location of Biological Station	Aquatic Life Indicators:							Aquatic Rec. Indicators:		Aquatic Life	Aquatic Rec.
					Fish IBI	Invert IBI	Dissolved Oxygen	Turbidity	Chloride	pH	NH_3	Bacteria	Nutrients		
09030009-558, Unnamed ditch (Judicial Ditch 62), Headwaters to Unnamed ditch	1.72	WWg	12RN0081 4RN153	Upstream of Faunce-Butterfield Forest Rd, 10 mi. W of Faunce | Downstream of Faunce-Butterfield FR, 10 mi. W of Faunce	MTS	MTS	IF	IF		IF				SUP	NA
09030009-557, Unnamed creek, Headwaters to W Br Warroad R	3.08	WWg	12RN007	Upstream of Forest Rd, 10 mi. NE of Winner	MTS	MTS	IF	IF		IF				SUP	NA
09030009-533, Clausner Creek, Unnamed cr to Unnamed cr	1.76	WWg	12RN005	Upstream of CR 5, 8 mi. S of Warroad	MTS		IF	IF		IF				SUP	NA
09030009-503, Warroad River, West Branch, Headwaters to Warroad R	28.64	WWg	13RN001,12RN006,12RN004,05RN118	upstream of CR 134, 5 miles SW of Warroad | Downstream of CR 12, 6 mi. SW of Warroad | Upstream at CR 5, 11 mi. S of Warroad | Off forest road 13 miles south of Warroad	MTS	MTS	MTS	IF	MTS	MTS	MTS	EXS		SUP	IMP

Abbreviations for Indicator Evaluations: **MTS** = Meets Standard; **EXS** = Fails Standard; **IF** = Insufficient Information
Abbreviations for Use Support Determinations: **--** = No Data, **NA** = Not Assessed, **IF** = Insufficient Information, **SUP** = Full Support (Meets Criteria); **IMP** = Impaired (Fails Standards)
Key for Cell Shading: = existing impairment, listed prior to 2014 reporting cycle; = new impairment; = full support of designated use; = insufficient information.
Abbreviations for Use Class: **WWg** = warmwater general, **WWm** = Warmwater modified, **WWe** = Warmwater exceptional, **CWg** = Coldwater general, **CWe** = Coldwater exceptional, **LRVW** = limited resource value water

Table 15. MSHA: West Branch Warroad River Subwatershed.

# Visits	Biological Station ID	Reach Name	Land Use (0-5)	Riparian (0-15)	Substrate (0-27)	Fish Cover (0-17)	Channel Morph. (0-36)	MSHA Score (0-100)	MSHA Rating
2	12RN008	Judicial Ditch 62	5	13	11.75	13	20	62.75	Fair
1	14RN153	Judicial Ditch 62	5	11	10	12	15	53	Fair
1	12RN007	Unnamed Creek	5	14	20	15	23	77	Good
1	12RN005	Clausner Creek	3	13	10	12	11	49	Fair
2	13RN001	Warroad River, West Branch	5	15	20.3	13.5	32	85.8	Good
1	12RN006	Warroad River, West Branch	5	13.5	16.2	11	26	71.7	Good
1	12RN004	Warroad River, West Branch	4	14	15.3	14	24	71.3	Good
1	05RN118	Warroad River, West Branch	0	8	17.25	12	30	67.25	Good
Average Habitat Results: *West Branch Warroad River Subwatershed*			3.9	15.5	14.4	12.5	22.6	65.85	Fair

Qualitative habitat ratings

= Good: MSHA score above the median of the least-disturbed sites (MSHA>66)

= Fair: MSHA score between the median of the least-disturbed sites and the median of the most-disturbed sites (45 < MSHA < 66)

= Poor: MSHA score below the median of the most-disturbed sites (MSHA<45)

Table 16. CCSI: West Branch Warroad River Subwatershed.

# Visits	Biological Station ID	Stream Name	Upper Banks (43-4)	Lower Banks (46-5)	Substrate (37-3)	Channel Evolution (11-1)	CCSI Score (137-13)	CCSI Rating
1	12RN008	Judicial Ditch 62	14	15	26	3	58	moderately unstable
1	12RN007	Unnamed trib. to West Brach River	11	12	11	3	37	fairly stable
1	13RN001	West Branch Warroad River	10	9	6	3	28	fairly stable
1	12RN006	Warroad River, West Branch	18	15	12	2	47	moderately unstable
1	12RN004	Warroad River, West Branch	21	26	16	2	65	moderately unstable
Average Stream Stability Results: *West Branch Warroad River Subwatershed*			14.8	15.4	14.2	2.6	47	moderately unstable

Qualitative channel stability ratings

= stable: CCSI < 27 = fairly stable: 27 < CCSI < 45 = moderately unstable: 45 < CCSI < 80 = severely unstable: 80 < CCSI < 115

= extremely unstable: CCSI > 115

Table 17. Outlet water chemistry results: West Branch Warroad River Subwatershed.

Station location:	West Branch Warroad River, At CR 12, 6 mi. SW of Warroad						
STORET/EQuIS ID:	S004-289						
Station #:	0903000903-02, West Branch Warroad River						
Parameter	**Units**	**# of Samples**	**Minimum**	**Maximum**	**Mean**	**WQ Standard[1]**	**# of WQ Exceedances[2]**
Ammonia-nitrogen	ug/L	10	0.63	1.92	1.21	40	0
Chloride	mg/L	10	1.1	3.3	2.2	230	0
Dissolved Oxygen (DO)	mg/L	63	5.58	13.3	8.8	5	0
pH		59	6.8	8.2	7.8	6.5 - 9	0
Secchi Tube	cm	19	30	98	80	40	1
Total suspended solids	mg/L	10	2	18	6.7	15	1
Escherichia coli (geometric mean)	MPN/100ml	3	47	145	98	126	1
Escherichia coli	MPN/100ml	32	2	686	168	1260	0
Chlorophyll-a, Corrected	ug/L	0					
Inorganic nitrogen (nitrate and nitrite)	mg/L	10	0.07	0.24	0.13		
Kjeldahl nitrogen	mg/L	10	0.07	1.35	0.72		
Orthophosphate	ug/L	0					
Pheophytin-a	ug/L	0					
Phosphorus	ug/L	54	14	100	30		
Specific Conductance	uS/cm	65	14	578	331		
Temperature, water	deg °C	65	3.2	24.5	16.1		
Sulfate	mg/L	10	< 3	4.7	< 3		
Hardness	mg/L	10	2	319	197		

[1]Secchi Tube standards are surrogate standards derived from the TSS standard of 15 cm.

****Data found in the table above were compiled using the results from data collected at the outlet monitoring station in the West Branch Warroad River Subwatershed, a component of the IWM work conducted between May and September from 2004-2013. This specific data does not necessarily reflect all data that were used to assess the AUID.**

Summary

There are five assessable AUIDs on the West Branch Warroad River. Of the five, four have biological data. Sensitive fish species were found in many of the fish samples. Generally sites located on the larger West Branch Warroad River score better than headwater sites and smaller tributaries.

Furthest south in the headwaters, the southernmost AUID contains two sites (12RN008, 14RN153) on Judicial Ditch 62. Of the two sites 12RN008, was the only site sampled for fish. Sampled twice in 2012, both samples met the IBI threshold and contained cool water and sensitive fish species, such as finescale dace and pearl dace. The macroinvertebrate sample in 2012 showed signs of the drought and the IBI score did not do well, and a resample was attempted in 2014. In 2014, 12RN008 was non-sampleable due to beaver dams. Thus site 14RN153 was created just downstream of 12RN008, on the north side of Faunce Butterfield Road. The macroinvertebrate sample at 14RN153 scored above the general use threshold with many sensitive taxa.

After flowing through the ditched wetland complex, two branches form. One fork emerges from the west on an unnamed creek, and this fork contains site 12RN007. 12RN007 was sampled for both fish and macroinvertebrates in 2012, and scored well for both. The second fork that forms out of the wetland complex is the West Branch Warroad River. This is the beginning of the longest AUID, a 28.6 mile segment on the West Branch Warroad River containing four biological sites (13RN001, 12RN006, 12RN004, and 05RN118). Though all fish and macroinvertebrate samples scored well and contained intolerant taxa, scores were higher at sites further downstream. The final AUID is on Clausner Creek about 8 miles south of the city of Warroad. The one site on Clausner creek (12RN005) was sampled for fish in 2012. The site scored above the threshold and contained cool water and sensitive species. Throughout the subwatershed both fish and macroinvertebrates are doing well although larger streams consistently score higher than smaller headwater streams.

A mile downstream of the last biological site a 10X water chemistry station was established on the West Branch Warroad River at County Road 12, six miles southwest of the city of Warroad. Conventional water quality parameters, such as DO, pH, and chloride indicated good water quality, with no exceedances of standards. Nutrients (N and P) were at expected levels and were comparable to other area watersheds. Bacteria monitoring indicated an impairment of recreational use, due to exceedance of the monthly geometric mean standard; one summer month (July) had a geometric mean concentration of 145 colonies/100 mL, versus the standard of 126.

On average, the subwatershed habitat score is just above the “good” rating score. The biggest positive factor is the riparian condition. Many of the streams have a well-intact forested riparian buffer. The substrate and channel morphology are the top two factors that bring the score down. Similar to the biology, the sites on the West Branch Warroad River score better on average than headwaters and tributaries. The channel stability rating is at moderately unstable, but is only two points from being fairly stable. None of the factors seem to stand out as being exceptionally bad or good. However, the wetland nature of area probably contributes some to the fine sediments in the substrate score.

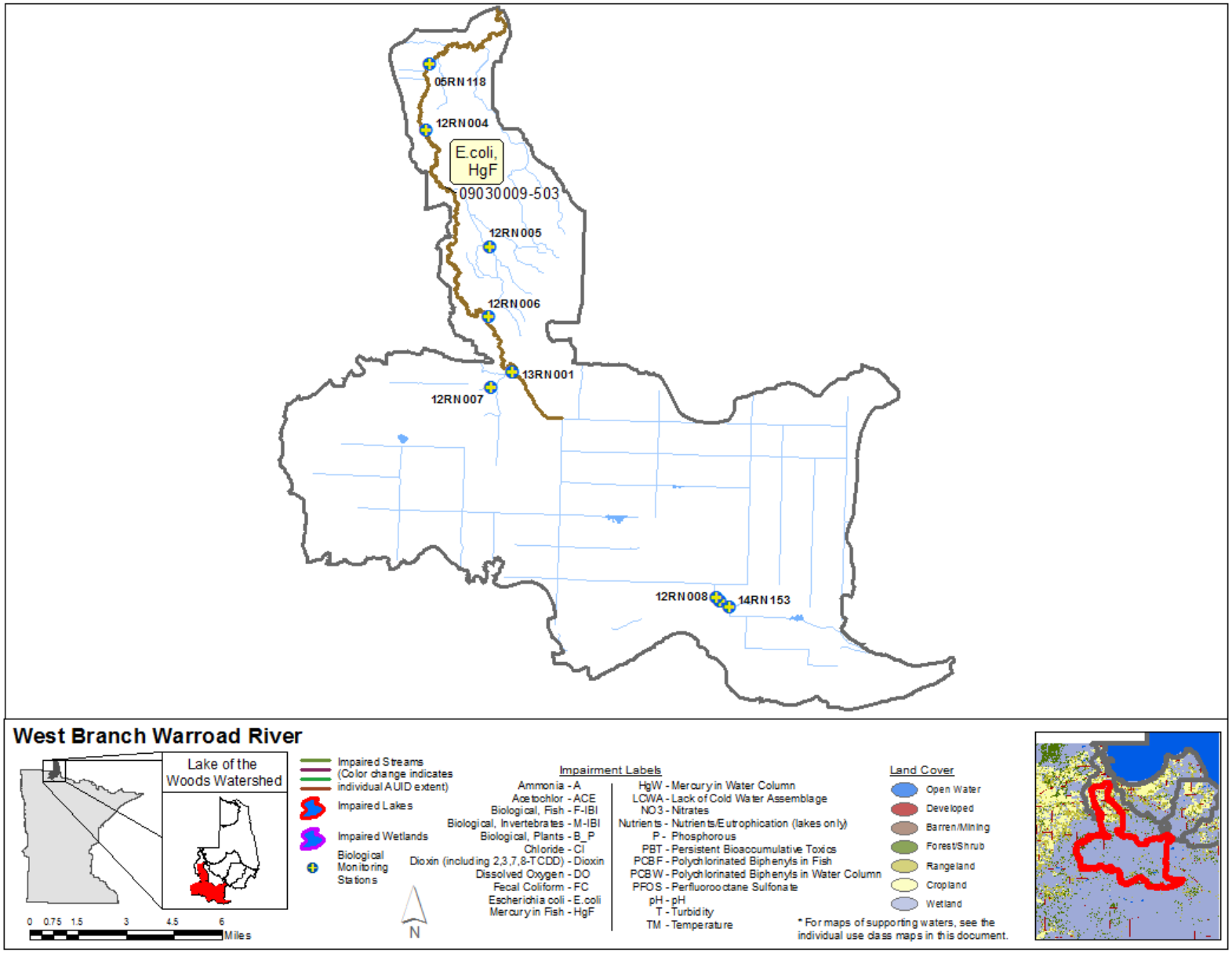

Figure 27. Currently listed impaired waters by parameter and land use characteristics in the West Branch Warroad River Subwatershed.

East Branch Warroad River Subwatershed HUC 0903000903-03

This subwatershed is largely located in Roseau County, with a small southern tip in Lake of the Woods County. The East Branch Warroad River originates in a forest/wetland area. It flows north about 30 miles, before joining with West Branch Warroad River to form the main stem of the Warroad River. Land use is dominated by wetland coverage at 76%, followed by 16% combined crop and range land.

Table 18. Aquatic life and recreation assessments on stream reaches: East Branch Warroad River Subwatershed. Reaches are organized upstream to downstream in the table

AUID ***Reach Name***, *Reach Description*	Reach Length (miles)	Use Class	Reach Length (miles)	Location of Biological Station	Aquatic Life Indicators:								Aquatic Rec. Indicators:		Aquatic Life	Aquatic Rec.
					Fish IBI	Invert IBI	Dissolved Oxygen	Turbidity	Chloride	pH	NH_3	Pesticides	Bacteria	Nutrients		
09030009-526, Unnamed ditch, Unnamed ditch to E Br Warroad R	3.15	WWg	05RN017	Upstream of CR 2, ~9.5 mi. SE of Warroad	MTS	MTS	IF			IF					SUP	NA
09030009-504, Warroad River, East Branch, Headwaters to Warroad R	33.72	WWg	05RN115 10EM017 12RN010	In Beltrami Island State Forest, 12 miles SE of Warroad | Upstream of CR 2, 8 mi. SE of Warroad | Upstream of CR 12, 5 mi. S of Warroad	MTS	EXS	MTS	IF	MTS	MTS	MTS		MTS		IMP	SUP

Abbreviations for Indicator Evaluations: **MTS** = Meets Standard; **EXS** = Fails Standard; **IF** = Insufficient Information
Abbreviations for Use Support Determinations: **--** = No Data, **NA** = Not Assessed, **IF** = Insufficient Information, **SUP** = Full Support (Meets Criteria); **IMP** = Impaired (Fails Standards)
Key for Cell Shading: = existing impairment, listed prior to 2014 reporting cycle; = new impairment; = full support of designated use; = insufficient information.
Abbreviations for Use Class: **WWg** = warmwater general, **WWm** = Warmwater modified, **WWe** = Warmwater exceptional, **CWg** = Coldwater general, **CWe** = Coldwater exceptional, **LRVW** = limited resource value water

Table 19. Minnesota Stream Habitat Assessment (MSHA): East Branch Warroad River Subwatershed.

# Visits	Biological Station ID	Reach Name	Land Use (0-5)	Riparian (0-15)	Substrate (0-27)	Fish Cover (0-17)	Channel Morph. (0-36)	MSHA Score (0-100)	MSHA Rating
3	05RN017	Trib. to Warroad River, East	3.75	10.83	14.33	8.67	16	53.58	Fair
2	05RN115	Warroad River, East Branch	5	11.50	17.55	15	25	74.05	Good
2	10EM017	Warroad River, East Branch	1.50	12	12.60	16	22	64.10	Fair
2	12RN010	Warroad River, East Branch	3.75	12.25	18.60	15	26	75.60	Good
Average Habitat Results: *East Branch Warroad River Subwatershed*			3.50	11.65	15.77	13.67	22.25	66.83	Good

Qualitative habitat ratings
= Good: MSHA score above the median of the least-disturbed sites (MSHA>66)
= Fair: MSHA score between the median of the least-disturbed sites and the median of the most-disturbed sites (45 < MSHA < 66)
= Poor: MSHA score below the median of the most-disturbed sites (MSHA<45)

Table 20. Channel Condition and Stability Assessment (CCSI): East Branch Warroad River Subwatershed.

# Visits	Biological Station ID	Stream Name	Upper Banks (43-4)	Lower Banks (46-5)	Substrate (37-3)	Channel Evolution (11-1)	CCSI Score (137-13)	CCSI Rating
1	10EM017	Warroad River, East Branch	27	32	24	4	87	severely unstable
1	12RN010	Warroad River, East Branch	18	26	14	3	61	moderately unstable
Average Stream Stability Results: *East Branch Warroad River Subwatershed*			22.5	29	19	3.5	74	moderately unstable

Qualitative channel stability ratings = stable: CCSI < 27 = fairly stable: 27 < CCSI < 45 = moderately unstable: 45 < CCSI < 80
= severely unstable: 80 < CCSI < 115 = extremely unstable: CCSI > 115

Table 21. Outlet water chemistry results: East Branch Warroad River Subwatershed.

Station location:	Warroad River, East Branch, At CR 12, 5 mi. S of Warroad						
STORET/EQuIS ID:	S004-295						
Station #:	0903000903-03, East Branch Warroad River						
Parameter	**Units**	**# of Samples**	**Minimum**	**Maximum**	**Mean**	**WQ Standard[1]**	**# of WQ Exceedances[2]**
Ammonia-nitrogen	ug/L	10	0.23	3.5	1.1	40	0
Chloride	mg/L	10	1.6	12.2	3.9	230	0
Dissolved Oxygen (DO)	mg/L	60	5.6	13.0	8.8	5	0
pH		56	7.0	8.2	7.8	6.5 - 9	0
Secchi Tube	cm	19	98	> 100	> 100	40	0
Total suspended solids	mg/L	10	2	5	3.7	15	0
Escherichia coli (geometric mean)	MPN/100ml	3	51	65	60	126	0
Escherichia coli	MPN/100ml	32	8.5	613	118	1260	0
Chlorophyll-a, Corrected	ug/L	0					
Inorganic nitrogen (nitrate and nitrite)	mg/L	10	0.08	0.15	0.12		
Kjeldahl nitrogen	mg/L	10	0.66	1.14	0.82		
Orthophosphate	ug/L	0					
Pheophytin-a	ug/L	0					
Phosphorus	ug/L	53	10	400	30		
Specific Conductance	uS/cm	61	192	634	344		
Temperature, water	deg °C	61	3.6	26.3	16.3		
Sulfate	mg/L	10	< 3	16	< 3		
Hardness	mg/L	10	153	363	216		

[1]Secchi Tube standards are surrogate standards derived from the TSS standard of 15 cm.

****Data found in the table above were compiled using the results from data collected at the outlet monitoring station in the East Branch Warroad River Subwatershed, a component of the IWM work conducted between May and September from 2004-2013. This specific data does not necessarily reflect all data that were used to assess the AUID.**

Summary

The East Branch Warroad subwatershed contains two assessable AUIDs with four biological sites. The smallest AUID located on the western border contains one biological site (05RN017) on an unnamed ditch. 05RN017 was sampled in 2005, 2012, and 2013. Samples in 2005 and 2013 did well against the fish IBI. In 2012, the fish sample did not pass IBI thresholds, likely influenced by a low flows that year. Macroinvertebrates scored well, but were only sampled in 2005.

The main AUID in this subwatershed is on the East Branch of the Warroad River. It contains sites 05RN115, 10EM017, and 12RN010 where fish samples scored above the general use threshold. Macroinvertebrate samples at 05RN115 failed to meet IBI thresholds in both 2005 and 2014. Downstream at 10EM017 samples taken in 2010 and 2012 scored poorly and were dominated by snails. 12RN010 was sampled twice in 2012; one sample was above the general use threshold and the other below. The numerous poor macroinvertebrate community scores indicate the East Branch of the Warroad River is showing signs of stress.

The 10X site for this subwatershed was located on County Road 12, five miles south of the city of Warroad. Water quality conditions, in general, were similar between the East and West Branch, except for lower bacteria counts in the East Branch. Water quality was good overall, and no individual samples exceeded water quality standards. The Warroad River has low concentrations of nutrients compared to other Lake of the Woods tributaries. E. coli bacteria concentrations were consistently meeting standards, and indicated support of aquatic recreational use.

On average, habitat and stream stability ratings in this subwatershed are good and moderately unstable. Habitat scores show that there is good fish cover and that much of the riparian area near the sites is intact. Stream stability scores were lowered by the upper and lower bank stability. Stability scores at 10EM017 are noticeably worse than the downstream site. Both banks were considered more unstable as was the stream bed or sediment. Comparably the habitat rating for 10EM017 was fair; again substrates brought the score down.

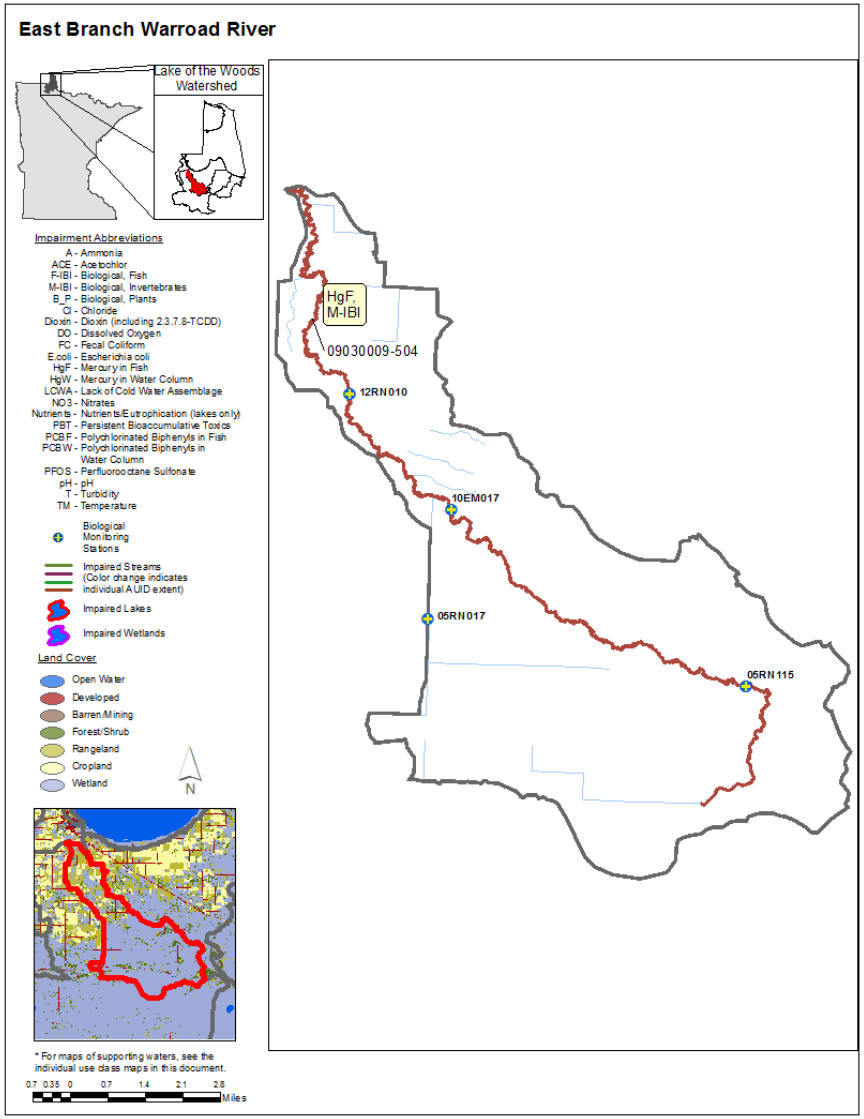

Figure 28. Currently listed impaired waters by parameter and land use characteristics in the East Branch Warroad River Subwatershed.

Muskeg Bay-Frontal Lake of the Woods Subwatershed HUC 0903000904-01

Centrally located within the Lake of the Woods Watershed, this subwatershed contains the city of Roosevelt, as well as portions of northern Warroad. The county line between Roseau and Lake of the Woods Counties splits this subwatershed in half. Willow Creek is the main tributary to Muskeg Bay between Rocky Point and the Warroad River. Willow Creek originates in a wetland area just south of the community of Roosevelt and flows north about 15 miles before draining into the Lake of the Woods. Agricultural land use is prominent in the watershed (38% overall), particularly in the northern portions where many ditch systems drain fields and flow into Lake of the Woods. Wetlands cover about 52% of the watershed, mostly within the headwaters or in the southern parts of the subwatershed.

Table 22. Aquatic life and recreation assessments on stream reaches: Muskeg Bay-Frontal Lake of the Woods Subwatershed. Reaches are organized west to east then upstream to downstream.

AUID ***Reach Name***, *Reach Description*	Reach Length (miles)	Use Class	Biological Station ID	Location of Biological Station	Aquatic Life Indicators:							Aquatic Rec. Indicators		Aquatic Life	Aquatic Rec.
					Fish IBI	Invert IBI	Dissolved Oxygen	Turbidity	Chloride	pH	NH_3	Bacteria	Nutrients		
09030009-560, County Ditch 20, Headwaters to Lake of the Woods	2.94	WWm	12RN012	Downstream of CR 12, 5 mi SE of Warroad	MTS	EXS	IF	IF		IF				IMP	NA
09030009-505, Willow Creek, Headwaters to Lake of the Woods	14.89	WWg	05RN188, 12RN015	11 miles SE of Warroad, upstream of County Road 140 | Upstream of CR 12, 10 mi. E of Warroad	EXS		EXS	IF	MTS	MTS	MTS	MTS		IMP	SUP
09030009-523, Unnamed ditch to Unnamed ditch	1.29	WWg	12RN016	Downstream of CR 17, 4 mi. SW of Arenson	EXS	EXS	IF	IF		IF				IMP	NA

Abbreviations for Indicator Evaluations: **MTS** = Meets Standard; **EXS** = Fails Standard; **IF** = Insufficient Information
Abbreviations for Use Support Determinations: **--** = No Data, **NA** = Not Assessed, **IF** = Insufficient Information, **SUP** = Full Support (Meets Criteria); **IMP** = Impaired (Fails Standards)
Key for Cell Shading: = existing impairment, listed prior to 2014 reporting cycle; = new impairment; = full support of designated use; = insufficient information.
Abbreviations for Use Class: **WWg** = warmwater general, **WWm** = Warmwater modified, **WWe** = Warmwater exceptional, **CWg** = Coldwater general, **CWe** = Coldwater exceptional, **LRVW** = limited resource value water

Table 23. MSHA: Muskeg Bay-Frontal Lake of the Woods Subwatershed.

# Visits	Biological Station ID	Reach Name	Land Use (0-5)	Riparian (0-15)	Substrate (0-27)	Fish Cover (0-17)	Channel Morph.	MSHA Score (0-100)	MSHA Rating
1	12RN012	County Ditch 20	1.25	9	15	8	7	40.25	Poor
1	05RN188	Willow Creek	3.50	14	12.25	16	17	62.75	Fair
2	12RN015	Willow River	2.75	12.75	10.50	9.50	17	52.50	Fair
5	12RN016	Unnamed ditch	0.90	9.60	15.72	12.40	20.20	58.82	Fair
Average Habitat Results: *Muskeg Bay-Frontal Lake of the Woods*			2.10	11.34	13.37	11.48	15.30	53.58	Fair

Qualitative habitat ratings

= Good: MSHA score above the median of the least-disturbed sites (MSHA>66)

= Fair: MSHA score between the median of the least-disturbed sites and the median of the most-disturbed sites (45 < MSHA < 66)

= Poor: MSHA score below the median of the most-disturbed sites (MSHA<45)

Table 24. CCSI: Muskeg Bay-Frontal Lake of the Woods Subwatershed.

# Visits	Biological Station ID	Stream Name	Upper Banks (43-4)	Lower Banks (46-5)	Substrate (37-3)	Channel Evolution (11-1)	CCSI Score (137-13)	CCSI Rating
1	12RN012	County Ditch 20	20	7	10	2	39	fairly stable
1	12RN015	Willow River	36	28	28	3	95	severely unstable
1	12RN016	Unnamed ditch	24	13	12	3	52	moderately unstable
Average Stream Stability Results: *Muskeg Bay-Frontal Lake of the Woods Subwatershed*			26.67	16	16.67	2.67	62	moderately unstable

Qualitative channel stability ratings

= stable: CCSI < 27 = fairly stable: 27 < CCSI < 45 = moderately unstable: 45 < CCSI < 80 = severely unstable: 80 < CCSI < 115 = extremely unstable: CCSI > 115

Table 25. Outlet water chemistry results: Muskeg Bay-Frontal Lake of the Woods Subwatershed.

Station location:	Willow Creek, At CR 12, 10 mi. E of Warroad						
STORET/EQuIS ID:	S004-293						
Station #:	0903000904-01, Muskeg Bay-Frontal Lake of the Woods						
Parameter	**Units**	**# of Samples**	**Minimum**	**Maximum**	**Mean**	**WQ Standard[1]**	**# of WQ Exceedances[2]**
Ammonia-nitrogen	ug/L	10	0.05	0.83	0.48	40	0
Chloride	mg/L	10	4.7	12	7.1	230	0
Dissolved Oxygen (DO)	mg/L	56	0.28	12.0	6.3	5	17
pH		52	6.7	8.0	7.5	6.5 - 9	0
Secchi Tube	cm	19	54	98	77	40	0
Total suspended solids	mg/L	10	2	9	5.1	15	0
Escherichia coli (geometric mean)	MPN/100ml	3	21	51	37	126	0
Escherichia coli	MPN/100ml	30	1	1553	117	1260	1
Chlorophyll-a, Corrected	ug/L	0					
Inorganic nitrogen (nitrate and nitrite)	mg/L	10	0.03	0.11	0.06		
Kjeldahl nitrogen	mg/L	10	0.99	1.47	1.2		
Orthophosphate	ug/L	0					
Pheophytin-a	ug/L	0					
Phosphorus	ug/L	49	10	310	140		
Specific Conductance	uS/cm	49	10	310	140		
Temperature, water	deg °C	58	2.9	25.6	15.5		
Sulfate	mg/L	10	< 3	3.8	< 3		
Hardness	mg/L	10	168	263	218		

[1]Secchi Tube standards are surrogate standards derived from the TSS standard of 15 cm.

****Data found in the table above were compiled using the results from data collected at the outlet monitoring station in the Muskeg Bay-Frontal Lake of the Woods Subwatershed, a component of the IWM work conducted between May and September from 2004-2013. This specific data does not necessarily reflect all data that were used to assess the AUID.**

Summary

The Muskeg Bay watershed contains four biological sites on three assessable AUIDs. The western most AUID is contains one site (12RN012) and is the only AUID in the watershed designated as modified use with assessable biological data. The fish collected at 12RN012 were able to score above the modified threshold. Macroinvertebrates scored below the modified threshold, resulting in aquatic life impairment. The modified use classification is a result of a TALU designation.

Further east the Willow Creek AUID contained two biological sites (05RN188 and 12RN015), each scoring poorly for fish, and was not sampled for macroinvertebrates. The Willow Creek site (05RN188) sample contained four fish species, three of which are tolerant. Further downstream on the Willow River site (12RN015), only four total fish were sampled. With two poorly scoring biological samples the Willow River AUID was found to have impaired aquatic life.

The eastern most AUID contains one site (12RN016) which was sampled for both fish and macroinvertebrates in 2014. Both biological communities failed to pass IBI thresholds. Of the five fish species collected, three species were tolerant. Those three tolerant species made up 75% of the total number of fish sampled at 12RN016. Similarly the macroinvertebrate sample was dominated by tolerant taxa. The Muskeg Bay Watershed is in poor biological health; of the three assessable AUIDs, none passed biological standards.

The 10X water chemistry site in the Muskeg Bay Subwatershed was located on Willow Creek at County Road 12, 10 miles east of the city of Warroad. Willow Creek was added to the Impaired Waters List in 2010 due to low dissolved oxygen (DO). Recent IWM monitoring confirms the impairment and poor water quality overall; 17 of 56 DO samples in the assessment cycle were below the 5 mg/L standard and some samples were very low (< 1 mg/L), representing a significant threat to aquatic life. Nitrogen and P concentrations were also comparably high; for example TP averaged 140 micrograms per liter (ug/L), nearly three times higher than other subwatersheds. *E. coli* bacteria concentrations were meeting standards overall, and indicated support of aquatic recreational use.

Habitat and channel stability for this subwatershed is rated as fair and moderately unstable respectively. 12RN012 has a habitat rating of poor, but a fairly stable channel rating. This channel morphology score reflects a ditched stream with a low amount of change in the streams bed and bank. Naturally a stream narrows and widens, and with that the depth will also change to accommodate stream flow. Ditches are modified to be one width and a consistent depth. This site's poor habitat score is a reflection of conditions common in a ditched or altered stream. On the Willow River AUID, biology is poor, habitat is fair, and the channel is rated as severely unstable. Both sampling locations have good riparian conditions and sufficient fish cover. However, both 05RN188 and 12RN015 are dominated by fine sediment types and are lacking changes in their channel morphology. 12RN015 is the only site with a channel stability rating on the Willow River AUID. 12RN015 has unstable upper banks and is dominated by fine substrates, giving a final rating of severely unstable. Eastwards, the AUID containing 12RN016 has fair habitat but is a moderately unstable stream. The habitat rating is being driven down by poor substrate variability and channel morphology, again relating to it being a ditched system.

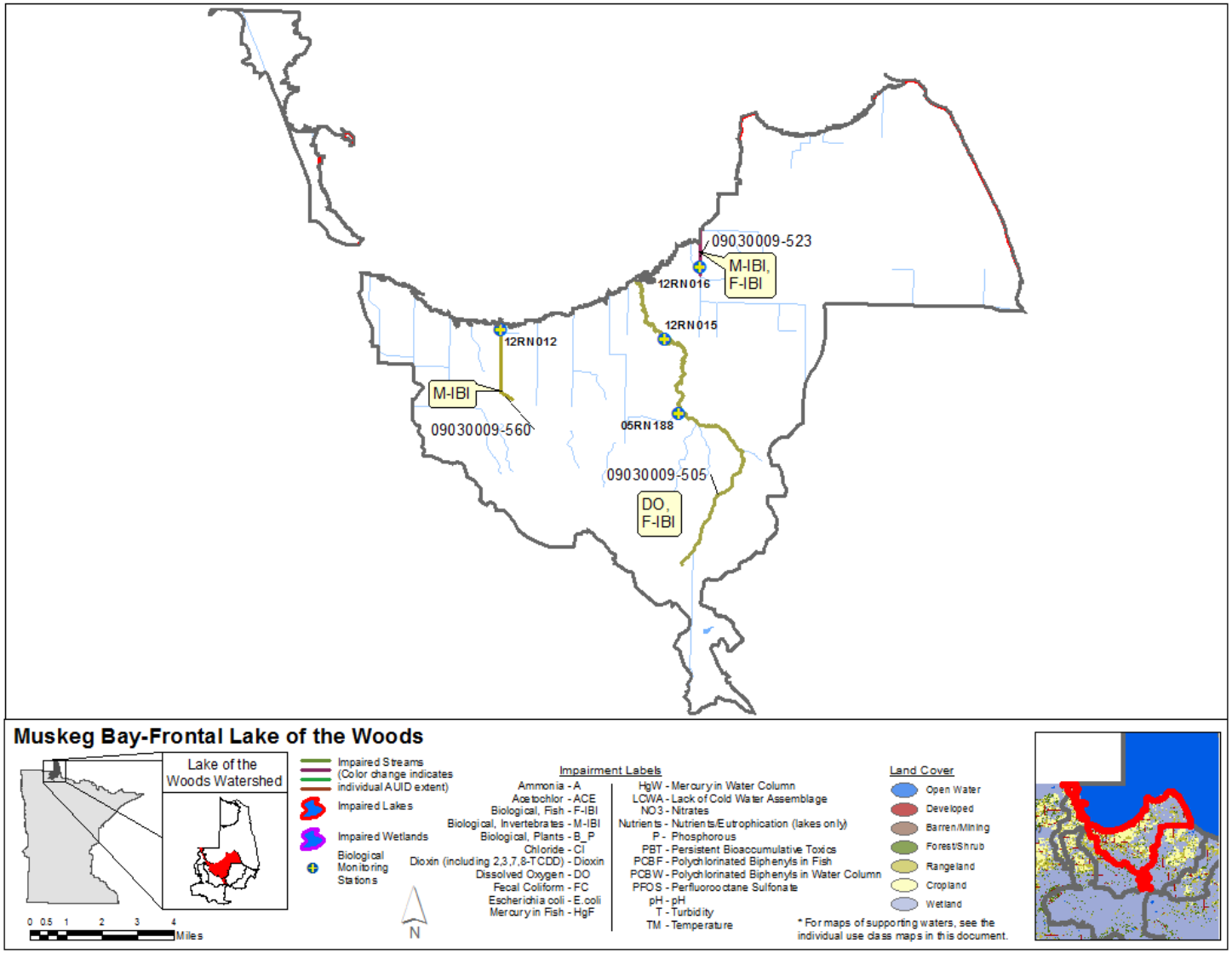

Figure 29. Currently listed impaired waters by parameter and land use characteristics in the Muskeg Bay – Frontal Lake of the Woods Subwatershed.

Northwest Angle Inlet-Frontal Lake of the Woods Subwatershed HUC 0903000905-01

The Northwest Angle is the northernmost part of Minnesota, and is primarily owned by the Red Lake Nation. The Angle is remote and dominated by wetlands. The remoteness of the Angle makes data collection difficult; the data that has been collected is in thanks to the Red Lake Nation. Though data was collected, there are no assessments done for this subwatershed at this time.

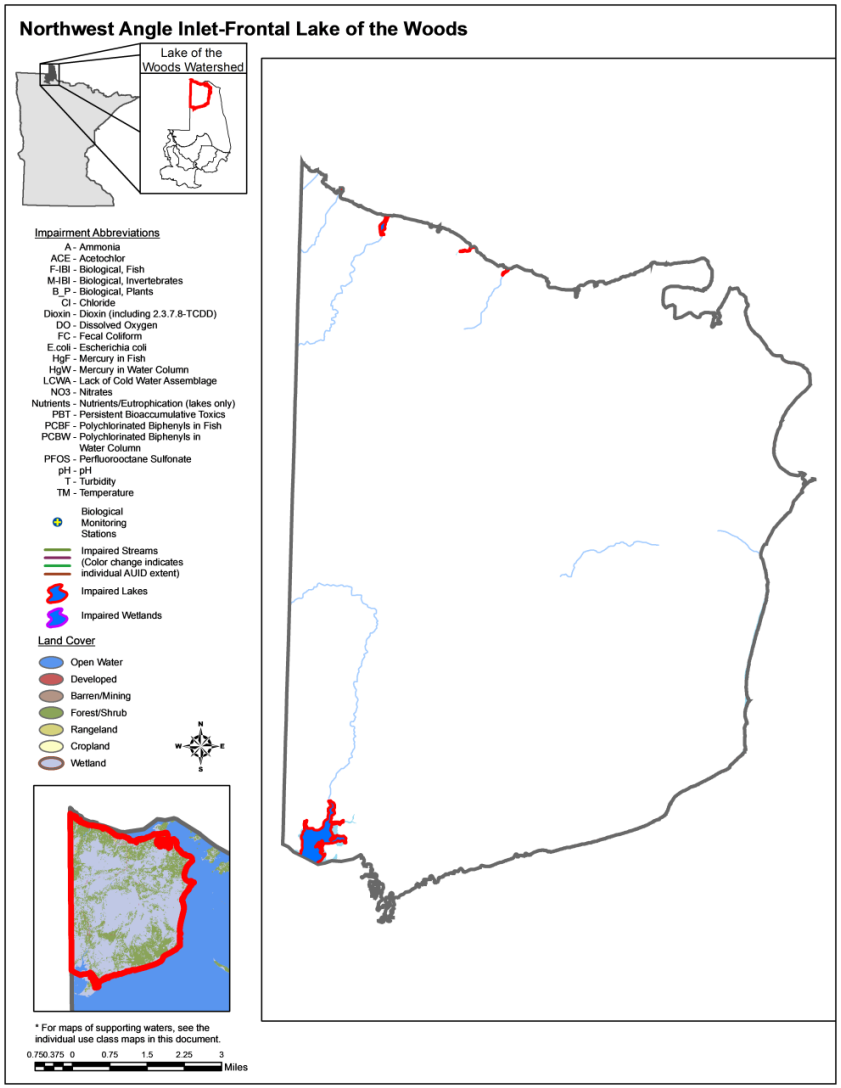

Figure 30. Currently listed impaired waters by parameter and land use characteristics in the Northwest Angle Inlet– Frontal Lake of the Woods Subwatershed.

Lake of the Woods Subwatershed HUC 0903000906-01

The Lake of the Woods, an immense lake covering over 950,000 acres, is a water of current and historical significance spanning the border between Minnesota and the Canadian provinces of Ontario and Manitoba (Figure 28). The Lake is actually a collection of several distinct basins with varying water quality characteristics. In general, the southern basin is shallow and well mixed due to its large fetch, and is relatively productive due to the historical influence of Glacial Lake Agassiz. The northern portion, characterized by Precambrian geology with exposed shorelines, numerous bays and over 14,500 islands, is deeper and less productive. The Lake of the Woods drains a very large watershed (27,000 square miles), outletting to the Winnipeg River at Kenora, Ontario. Hydroelectric dams at the outlet have controlled lake elevations since the late 1800s. The Rainy River is the Lake's primary tributary, contributing about 75% of the inflow and most of the lake's drainage area; it enters Lake of the Woods at Four Mile Bay, a shallow embayment near Baudette, Minnesota. The Rainy River, historically heavily impacted by discharge from industrial (pulp and paper) and domestic sewage facilities, is now a high quality resource. Most of the Lake drains a landscape dominated by forest and wetlands, including the Boundary Waters Canoe Area Wilderness, Quetico Provincial Park, and Voyageur's National Park. The lower portions of the Rainy River and the southern shore of the Lake of the Woods have some land in agricultural production. The Lake of the Woods remains a premier fishing and tourism destination, with annual economic impact worth tens of millions of dollars.

Lake of the Woods is logistically challenging to monitor due to its large fetch, frequent high winds, navigational hazards, hydrological complexity, and cross border regulations. Therefore, water quality sampling over the years has been a cooperative effort between many agencies including the MPCA, MDNR, Lake of the Woods County SWCD, USGS, the Red Lake Nation, Ontario Ministry of Natural Resources, Ontario Ministry of the Environment and Climate Change, Environment Canada, and citizen volunteers. The MPCA led water quality sampling in 1999, 2005, and 2006 following standard lake assessment and sampling methodologies on five sites (four in the Minnesota Waters, and one in Four Mile Bay). These datasets led the MPCA to declare the Minnesota portion of the Lake as impaired in 2008, due to exceedances of eutrophication criteria; in 2009 a TMDL study was initiated. This declaration, coupled with significant research and monitoring by our Canadian colleagues (including remote sensing) and anecdotal evidence by the public and resource managers, report increases in the number and severity of summer algal blooms Figure 29). This has brought considerable attention to water quality issues in the Lake of the Woods.

The International Joint Commission (IJC), a governing body created by the U.S. and Canada in 1909 that regulates shared water uses and investigates trans-boundary issues and solutions, has recently formed a new Board (International Rainy-Lake of the Woods Watershed Board) with the mandate to monitor ecosystem health in the Lake of the Woods Basin. The Board also petitioned the development of a Water Quality Plan of Study to better understand water quality issues in the Basin. The Plan of Study includes the following priority issues

- Nutrient enrichment and harmful algal blooms
- Aquatic invasive species
- Surface and groundwater contamination, including heavy metals and other contaminants
- Cross cutting factors of climate change and hydrologic regulation

The IJC and its study team have recently released the Plan of the Study, including 32 recommended projects to address challenges to the water quality in the basin, and strongly recommended that the U.S. and Canadian governments undertake all 32 projects at a cost of approximately $8.4 million dollars (International Joint Commission (2015)).

The most recent water quality assessment of the Lake of the Woods (including data from 2005-2014) continues to indicate impairment of recreational use and exceedances of the MPCA's nutrient criteria (Figure 31, Appendix 3.2). Monitoring to support the TMDL study has been expanded to several sites near the "outlet" of US waters near the Northwest Angle (Figure 16), conducted by the USGS and MPCA in 2009-2012, and the installation of a new USGS streamflow gage at Wheeler's Point at the outlet of Rainy River into Lake of the Woods.

Collaboration among resource agencies in the Lake of the Woods basin is a model within the IJC's jurisdiction. The MPCA and our Canadian colleagues have conducted independent monitoring of the Lake and evaluated water quality conditions in the southern basin, and found that the results were similar (Figure 31). The MPCA, Environment Canada, and other academic colleagues have estimated nutrient budgets for Lake of the Woods. Results have been comparable, and indicate that internal loading (i.e. recycling of nutrients from lake sediments) is a significant source of P to the lake (Figure 30). Additionally, recent research has shown that diatom-inferred P has increased in the Lake since the 1980s. This conclusion is counter to the documented improvement in Rainy River water quality in recent decades, via declines in nutrient loads discharged from major industrial facilities. A working hypothesis is that climate change is a key factor in the formation of the blue-green algal blooms, and that climate change may be masking the effects of upstream water quality improvements. It has been documented that Lake of the Woods had an increase in the length of ice-free period by 28 days between 1960 and 2010. Blue green algae can have a competitive advantage over other algal forms during warm weather and in the presence of abundant in-lake nutrients. Other cooperative monitoring efforts which have assisted and complemented the IJC Plan of Study and the Lake of the Woods TMDL include an expansion of tributary and lake monitoring by the Ontario Ministry of Environment and Climate Change, Environment Canada's Lake of the Woods Science Initiative, and the MPCA's IWM program.

Lastly, through the MPCA's eutrophication TMDL, several key projects are underway to understand the nature and extent of algal blooms in Lake of the Woods and appropriate restoration strategies:

- An assessment of internal loading rates, and its portion of the lake's TP budget
- Reconstruction of the lake's historical nutrient mass balance, to better understand historical conditions and the nature of the sediment pool of P in the lake
- Using paleolimnology techniques to determine water quality conditions pre-European settlement
- Updated water quality and flow-monitoring in the lake's Northwest Angle outlet channels
- An updated land-use map within the basin

For additional detail and specifics on the vast amount of research, monitoring and investigations on the Lake of the Woods, and its watershed, please refer to the Literature Cited (below). Tables summarizing the lake's assessment results, applicable lake water quality standards, and modeling results follow in the appendices. The Lake's 2014 water quality assessment results continue to show exceedance of the MPCA's eutrophication criteria and impairment of recreational use (Appendix 3.2).

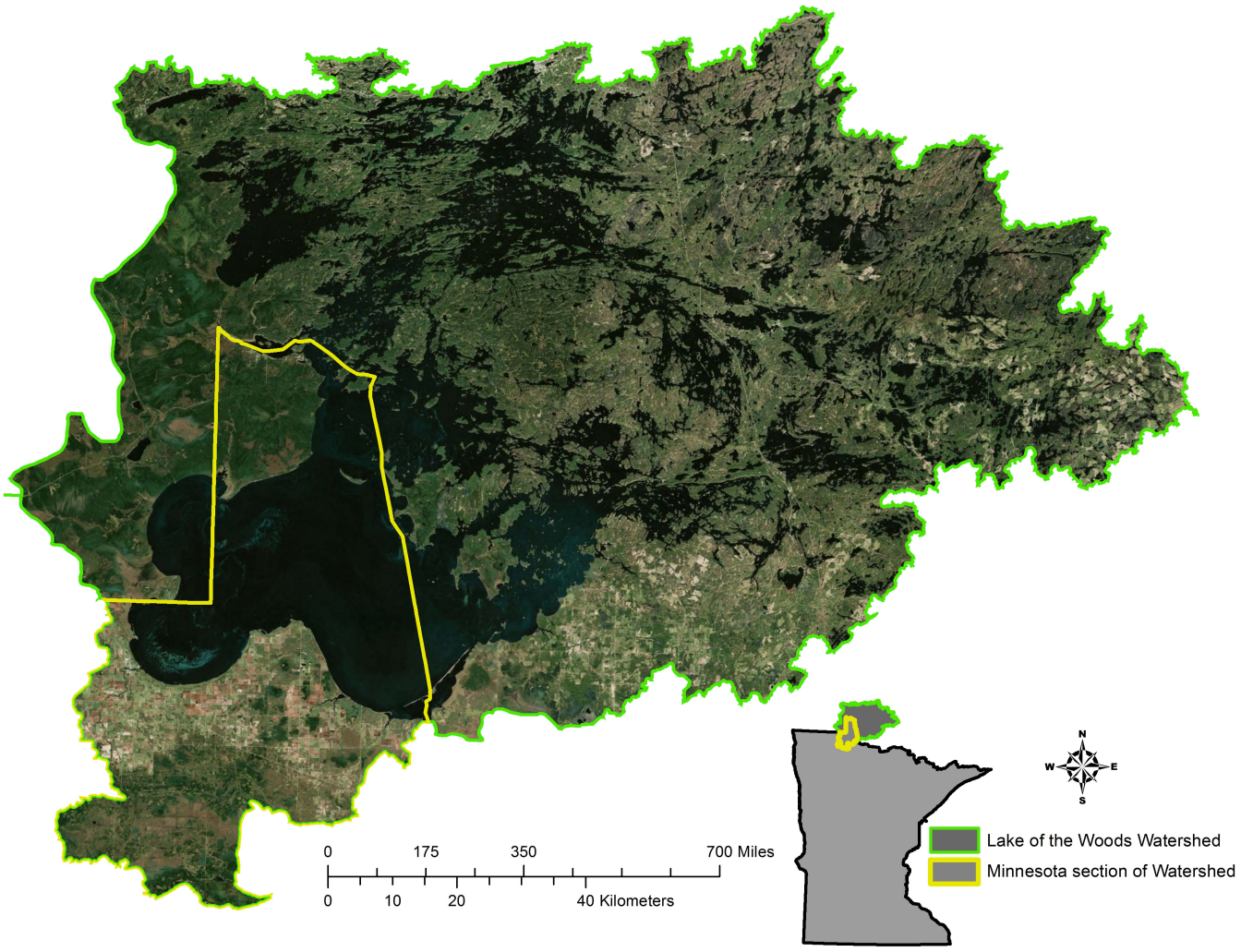

Figure 31. Entire Lake of the Woods direct Watershed.

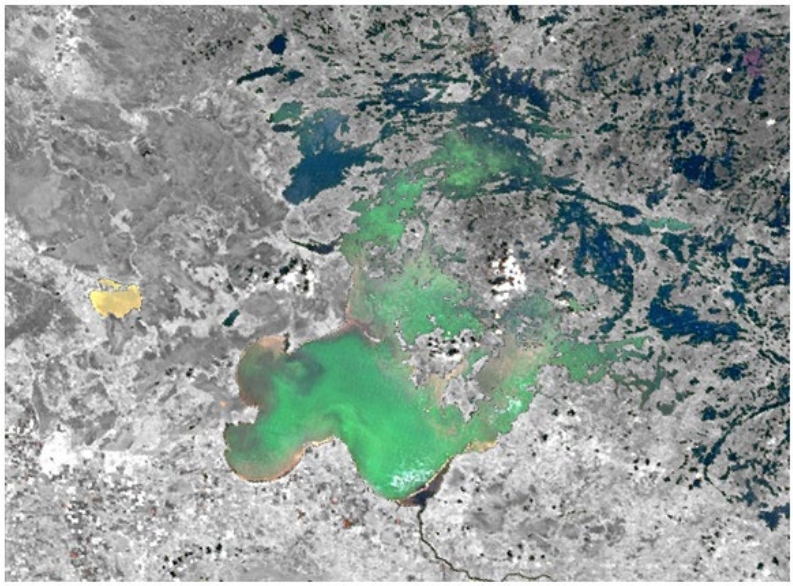

Figure 32. Lake of the Woods algae bloom, Aug. 2006.

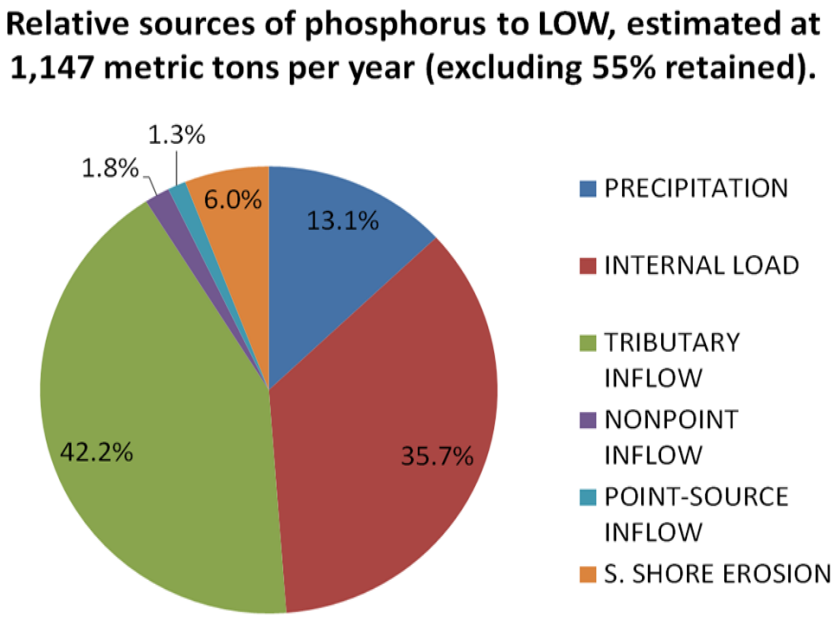

Figure 33. Preliminary TP budget to Lake of the Woods (MPCA, 2013).

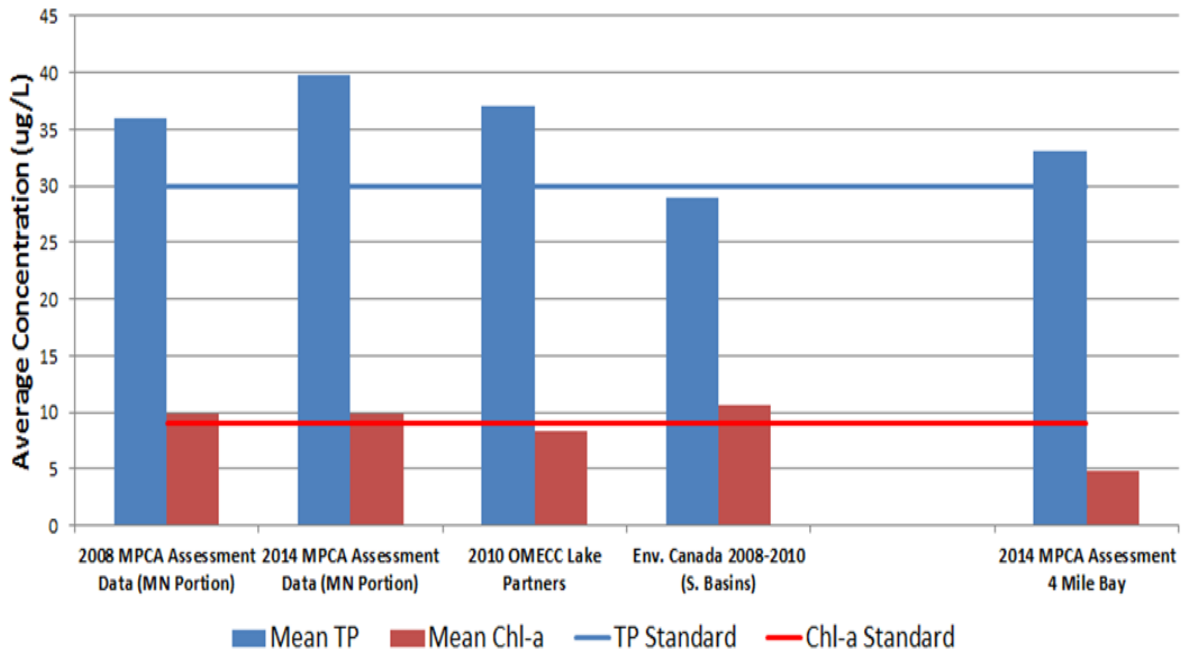

Figure 34. Lake of the Woods water quality summary, indicating exceedances of phosphorus and chlorophyll-a standards.

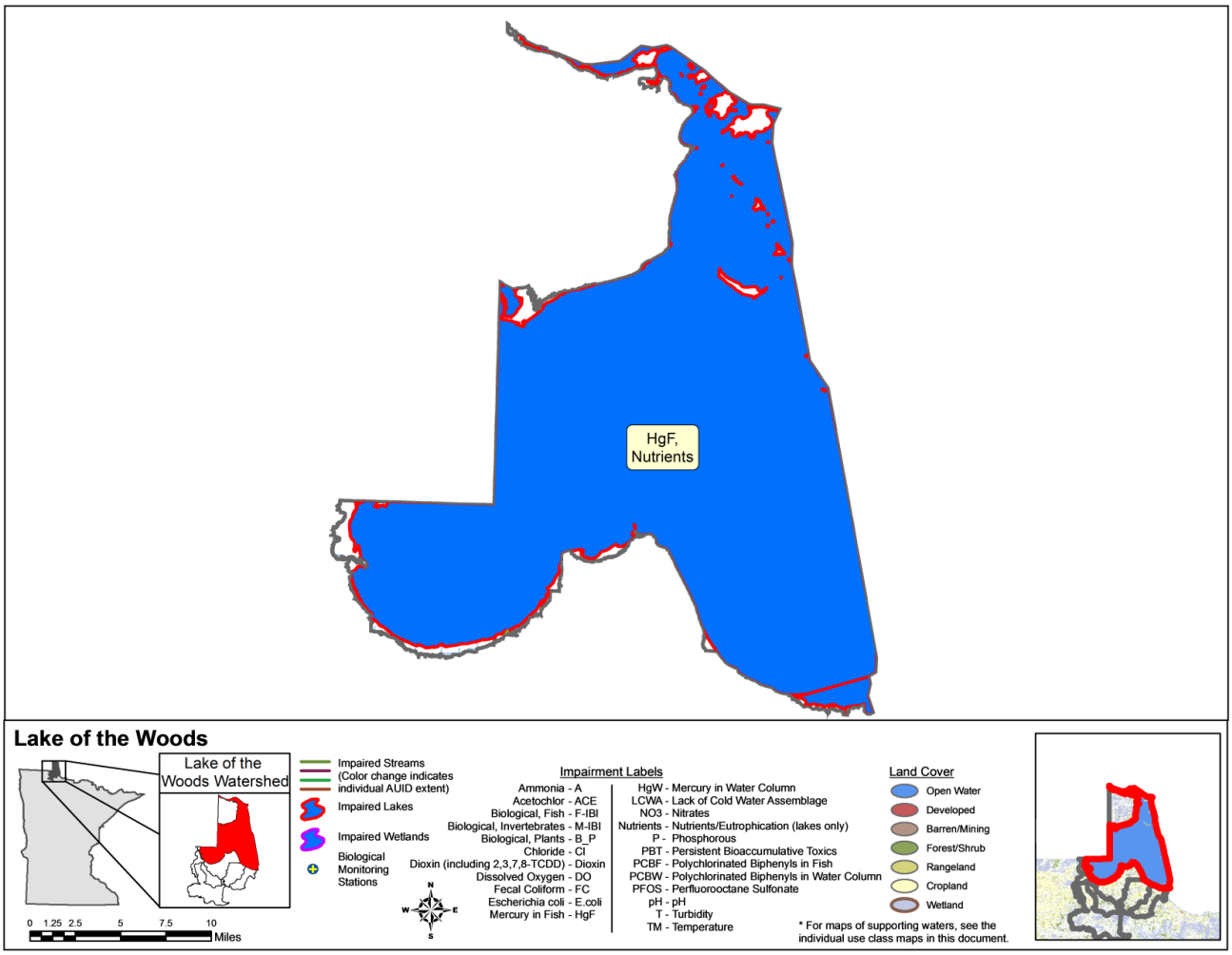

Figure 35. Currently listed impaired waters by parameter and land use characteristics in the Lake of the Woods Subwatershed.

Watershed-wide results and discussion

Assessment results and data summaries, grouped by sample type, are included below for the entire 8-HUC watershed unit of the Lake of the Woods. Summaries are provided for load monitoring data results near the mouth of the river, aquatic life and recreation uses in streams and lakes throughout the watershed, and for aquatic consumption results at select river and lake locations along the watershed. Additionally, groundwater monitoring results and long-term monitoring trends are included where applicable.

Following the results are a series of graphics that provide an overall summary of assessment results by designated use, impaired waters, and fully supporting waters within the entire Lake of the Woods Watershed.

Stream water quality

Sixteen of the 41 stream AUIDs were assessed (Table 26). Of the assessed streams, only 10 streams were considered to be fully supporting aquatic life and five streams were fully supporting aquatic recreation. Throughout the watershed, six AUIDs are non-supporting of aquatic life and one is non-supporting of aquatic recreation. A high percentage of AUIDs weren't assessed, but a large percentage of those AUIDs would not have been assessable due to the wetland nature of the Watershed.

Water quality is generally fair throughout the watershed. Where sampled, the most common issues are turbidity and poor biological communities. Nutrients often meet standards, with a few AUIDs experiencing higher than average concentrations. The one recreational impairment is due to high levels of E.coli found in the West Branch Warroad River.

Table 26. Assessment summary for stream water quality in the Lake of the Woods Watershed.

				Supporting		Non-supporting			
Watershed	**Area (acres)**	**# Total AUIDs**	**# Assessed AUIDs**	**# Aquatic Life**	**# Aquatic Recreation**	**# Aquatic Life**	**# Aquatic Recreation**	**Insufficient Data**	**# Delistings**
Lake of the Woods **HUC 8**	**731,247.35**	**57**	**16**	**10**	**5**	**6**	**1**	**41**	**0**
0903000906-01	313,397.10	0	0	0	0	0	0	0	0
0903000905-01	72,703.25	8	0	0	0	0	0	8	0
0903000901-01	40,657.62	11	1	1	1	0	0	10	0
0903000902-01	54,716.70	14	5	3	1	2	0	9	0
0903000903-01	19,253.76	3	1	1	1	0	0	2	0
0903000903-02	115,794.10	9	4	4	0	0	1	5	0
0903000903-03	34,709.03	3	2	1	1	1	0	1	0
0903000904-01	80,015.79	9	3	0	1	3	0	6	0

Lake water quality

The Lake of the Woods is the prominent water resource in the watershed. The lake is a prime recreational, fisheries, and economic resource. The Minnesota portion of the Lake of the Woods was declared impaired in 2008, due to exceedances of eutrophication criteria (high amounts of nutrients and algae). The most recent water quality assessments, as part of this watershed study, continue to indicate impairments for recreational use with nutrient and algae concentrations that are above the MPCA's criteria. An impaired waters study is currently underway to better understand the nature and extent of algae blooms in Lake of the Woods and develop appropriate restoration strategies. This work is being conducted with cooperation from numerous partner agencies and organizations, including the International Joint Commission's new Lake of the Woods Watershed Board.

Fish contaminant results

Nine fish species from the Lake and two from the Warroad River were tested for contaminants. A total of 305 fish were tested between 1970 and 2012. Fish species are identified by codes that are defined by their common and scientific names in Table 27.

Table 28 summarizes contaminant concentrations by waterway, fish species, and year. "No. Fish" indicates the total number of fish analyzed and "N" indicates the number of samples. The number of fish exceeds the number of samples when fish are combined into a composite sample. This was typically done for panfish, such as bluegill sunfish (BGS) and yellow perch (YP). Since 1989, most of the samples have been skin-on fillets (FILSK) or for fish without scales (catfish and bullheads), skin-off fillets (FILET).

The Lake and the Warroad River are listed as impaired due to mercury in fish and are covered under the statewide mercury TMDL.

A walleye collected from the lake in 2002 had the highest mercury concentration (0.815 mg/kg). It appears mercury levels have substantially declined in walleye since 2006, although they remain above the impairment threshold.

Most of the PCB concentrations in fish tissue were near or below the reporting limit. The notably high PCB concentration was 0.120 mg/kg in a lake sturgeon collected from the lake in 1990. No lake sturgeon have been tested for the contaminant since 1990.

Perfluorooctane sulfonate (PFOS) concentrations were below the reporting limit in five sauger and five yellow perch collected from the Lake of the Woods.

Overall, the fish contaminant results show PCBs have not been at levels of concern in the Lake of the Woods Watershed, whereas the mercury concentrations in fish tissue are relatively high in the lake and the Warroad River.

Table 27. Fish species codes, common names, and scientific names.

Species	Common Name	Scientific Name
BUR	Burbot (Eelpout)	Lota lota
CIS (HER)	Cisco (Lake herring)	Coregonus artedi
LST	Lake sturgeon	Acipenser fulvescens
NP	Northern pike	Esox Lucius
SAG	Sauger	Sander canadensis
SMB	Smallmouth bass	Micropterus dolomieu
WE	Walleye	Sander vitreus
WSU	White sucker	Catostomus commersoni
YP	Yellow perch	Perca flavescens

Table 28. Summary statistics of mercury and PCBs, by waterway-species-year.

WATERWAY	AUID	SPECIES[1]	YEAR	ANATOMY	NO. FISH	Length (in)			Mercury (mg/kg)				PCBs (mg/kg)			PFOS (mg/kg)		
						Mean	Min	Max	N	Mean	Min	Max	N	Mean	Max	N	Mean	Max
LAKE OF THE WOODS*	39000200	BUR	1972	WHORG					12	0.175	0.100	0.300						
		CIS	1970	PLUSK	2	13.1	12.7	13.5	2	0.120	0.090	0.150						
			2002	FILSK	5	12.8	12.8	12.8	1	0.055								
		LST	1990	FILSK	6	28.4	26.6	30.2	2	0.049	0.047	0.051	2	0.103	0.120			
		NP	1985	FILSK	8	24.3	22.4	26.2										
			1986	FILSK	19	23.6	21.3	26.9	4	0.430	0.310	0.520	4	< 0.05	< 0.05			
			1990	FILSK	9	30.2	28.5	32.8	3	0.260	0.230	0.320	3	0.029	0.037			
			1993	FILSK	11	22.9	17.9	28.6	3	0.307	0.200	0.450	3	0.012	0.015			
			1997	FILSK	6	26.8	23.5	31.5	6	0.168	0.140	0.220	2	< 0.01	< 0.01			
			2002	FILSK	4	30.8	24.6	39.5	4	0.315	0.196	0.475						
			2009	FILSK	12	22.3	19.4	29.0	12	0.197	0.083	0.331						
		SAG	1990	FILSK	13	14.5	11.2	16.3	3	0.210	0.140	0.270	3	< 0.01	< 0.01			
			1993	FILSK	5	10.5	10.5	10.5	1	0.230			1	< 0.01				
			1997	FILSK	10	13.2	12.4	14.2	10	0.136	0.110	0.170	1	< 0.01				
			2002	FILSK	5	13.5	11.9	17.3	5	0.260	0.171	0.504						
			2010	FILSK	5	11.6	10.0	12.8								5	< 4.76	< 5
		SMB	1993	FILSK	1	14.1			1	0.420			1	< 0.01				
		WE	1970	PLUSK	2	16.0	16.0	16.0	2	0.190	0.080	0.300						
			1985	FILSK	10	16.7	16.5	16.8										
			1986	FILSK	20	18.4	16.1	22.2	4	0.548	0.400	0.730	4	< 0.05	< 0.05			
			1990	FILSK	23	17.9	12.1	22.1	5	0.234	0.120	0.360	5	0.015	0.028			
			1993	FILSK	12	16.6	11.0	22.7	3	0.363	0.190	0.610	3	0.014	0.023			
			1997	FILSK	9	14.0	11.4	18.0	9	0.137	0.085	0.300	1	0.020				
			2002	FILSK	5	20.1	14.4	28.3	5	0.366	0.157	0.815						
			2009	FILSK	8	15.8	14.5	18.5	8	0.204	0.110	0.313						
			2012	FILSK	5	17.0	13.3	20.2	5	0.203	0.117	0.237						

			1990	FILSK	18	18.4	13.1	21.4	4	0.076	0.062	0.090	4	0.032	0.037			
			1993	FILSK	5	17.4	17.4	17.4	1	0.210			1	0.015				
			1997	FILSK	5	18.3	18.3	18.3	1	0.084			1	0.030				
		WSU	2002	FILSK	1	19.5			1	0.104								
		YP	1990	FILSK	10	8.2	8.2	8.2	1	0.060			1	< 0.01				
			1997	FILSK	8	9.7	9.7	9.7	1	0.170			1	< 0.01				
			2002	FILSK	6	10.7	10.7	10.7	1	0.145								
			2010	FILSK	5	8.9	7.5	10.0								5	< 4.87	< 5
			2012	FILSK	10	10.5	8.5	12.4	2	0.075	0.041	0.109						
WARROAD RIVER*	09030009-502, -503, -504	NP	2012	FILSK	5	17.9	15.3	21.3	5	0.222	0.188	0.254	2	<0.025	<0.025			
		WSU	2012	FILSK	5	15.2	10.5	18.5	5	0.146	0.079	0.255	2	<0.025	<0.025			

* Impaired for mercury in fish tissue as of 2012 Draft Impaired Waters List; categorized as EPA Class 4a for waters covered by the Statewide Mercury TMDL.

**Impaired for mercury and categorized as EPA Class 5 and requires a separate TMDL from the Statewide TMDL

1 Species codes are defined in Table FC1

2 Anatomy codes: FILSK – edible fillet, skin-on; FILET—edible fillet, skin-off; PLUG—dorsal muscle piece, without skin; WHORG—whole organism

Groundwater monitoring

The surficial geology of the Lake of the Woods Watershed is such that conditions for groundwater recharge are ideal in specific areas of surficial sand and gravel deposits. Preservation of these areas is critical to maintaining sufficient groundwater availability for consumptive use.

Wetland condition

Wetland vegetation quality is high in Minnesota—with approximately 67% of the statewide wetland extent in exceptional to good condition. Wetlands in exceptional-good condition have had few (if any) changes in expected native vegetation composition or abundance distribution. The high rates of exceptional-good condition at the statewide scale is being driven by the large proportion of wetlands (75%) that occur in the Mixed Wood Shield ecoregion, where there have been few human impacts and condition is largely intact. An estimated 64% of the wetland extent in the Mixed Wood Shield is in exceptional vegetation condition, with an additional 20% in good condition.

As the entire Lake of the Woods Watershed lies within the Mixed Wood Shield ecoregion, wetland vegetation quality in the Watershed is likely high overall. A single wetland survey site was located within the watershed at a large open bog and was in exceptional condition, helping to support this generalization. Any wetland quality impacts will likely be limited to areas immediately adjacent to artificial ditches or remaining wetlands within the developed areas of the watershed.

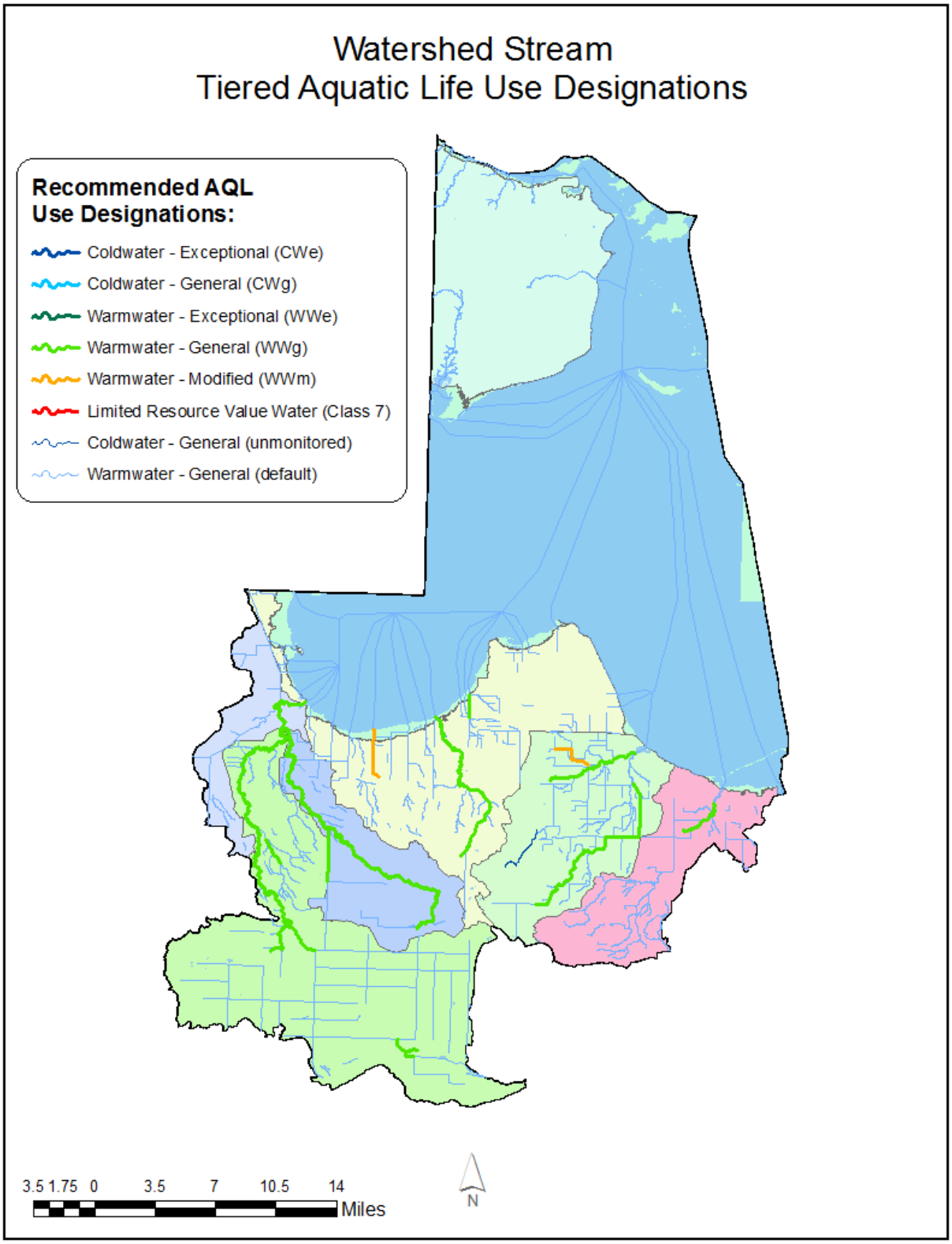

Figure 36. Stream TALU designations in the Lake of the Woods Watershed.

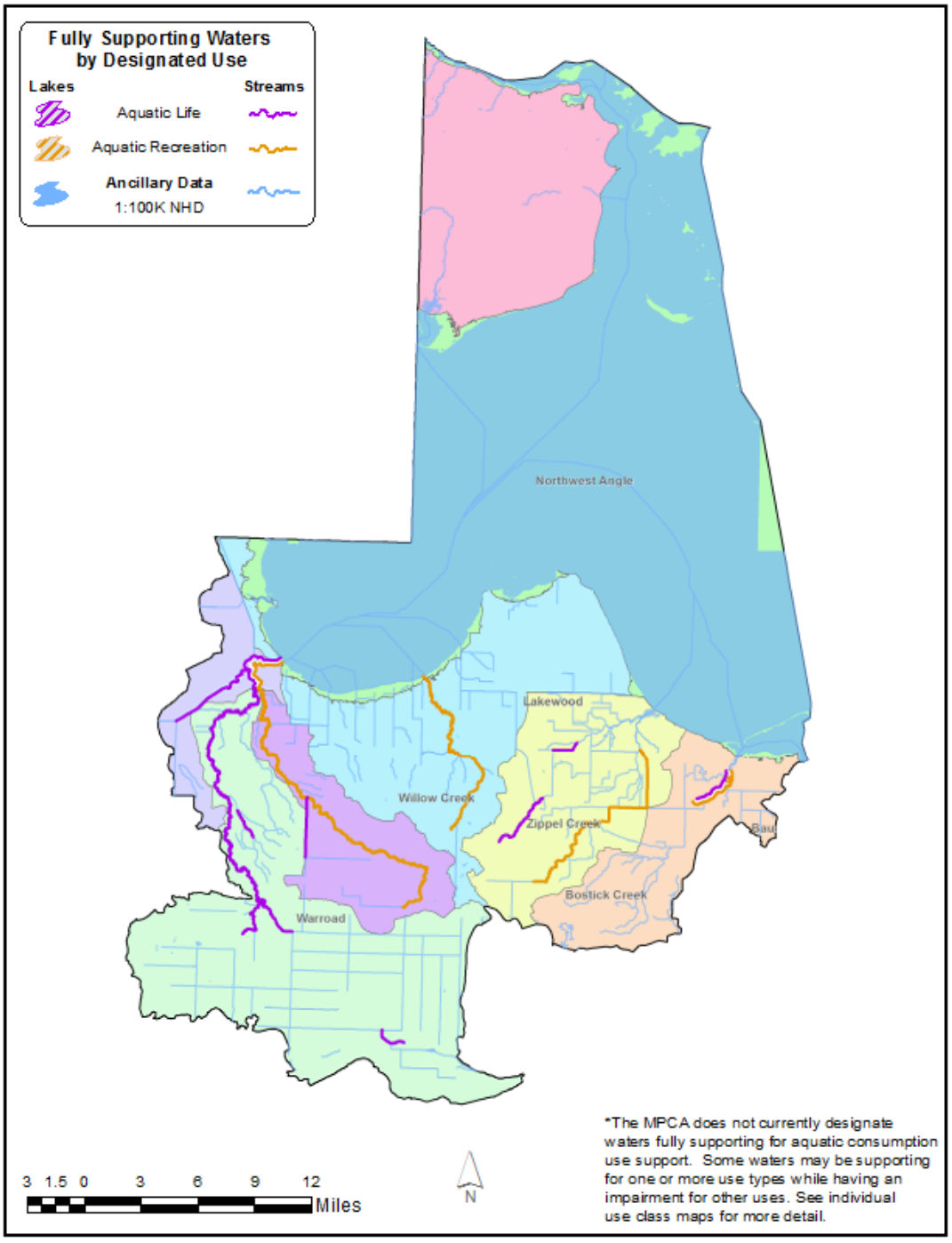

Figure 37. Fully supporting waters by designated use in the Lake of the Woods Watershed.

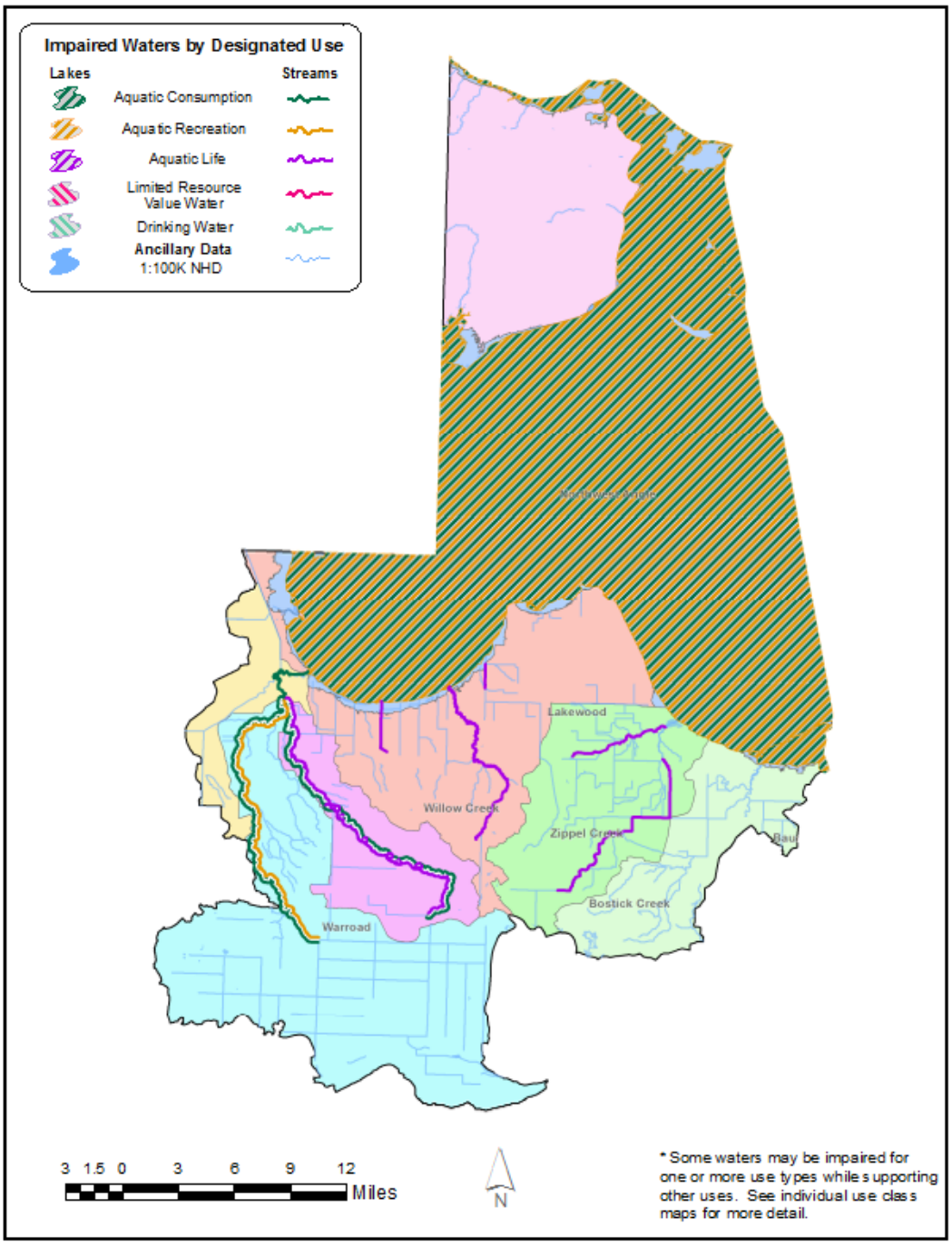

Figure 38. Impaired waters by designated use in the Lake of the Woods Watershed.

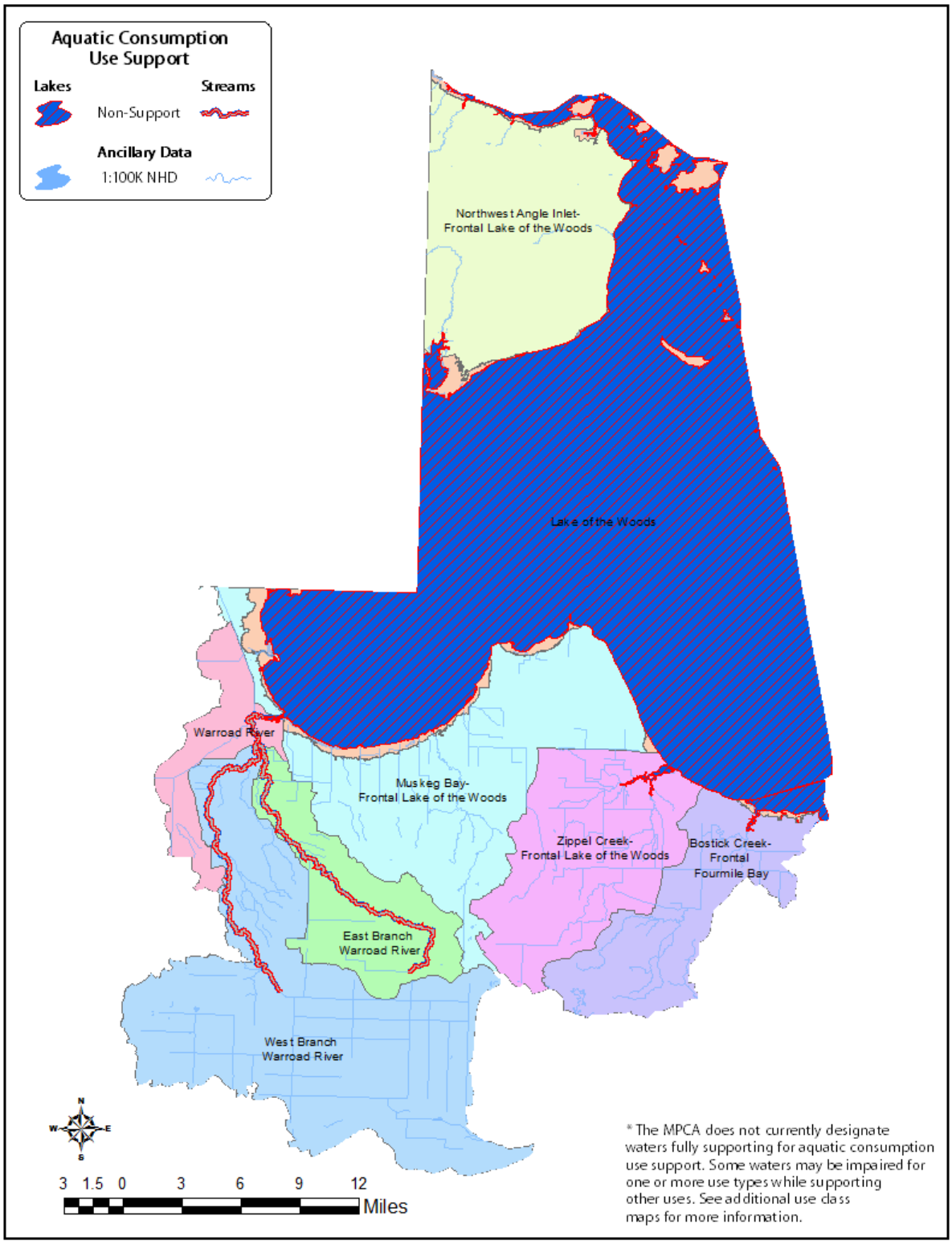

Figure 39. Aquatic consumption use support in the Lake of the Woods Watershed.

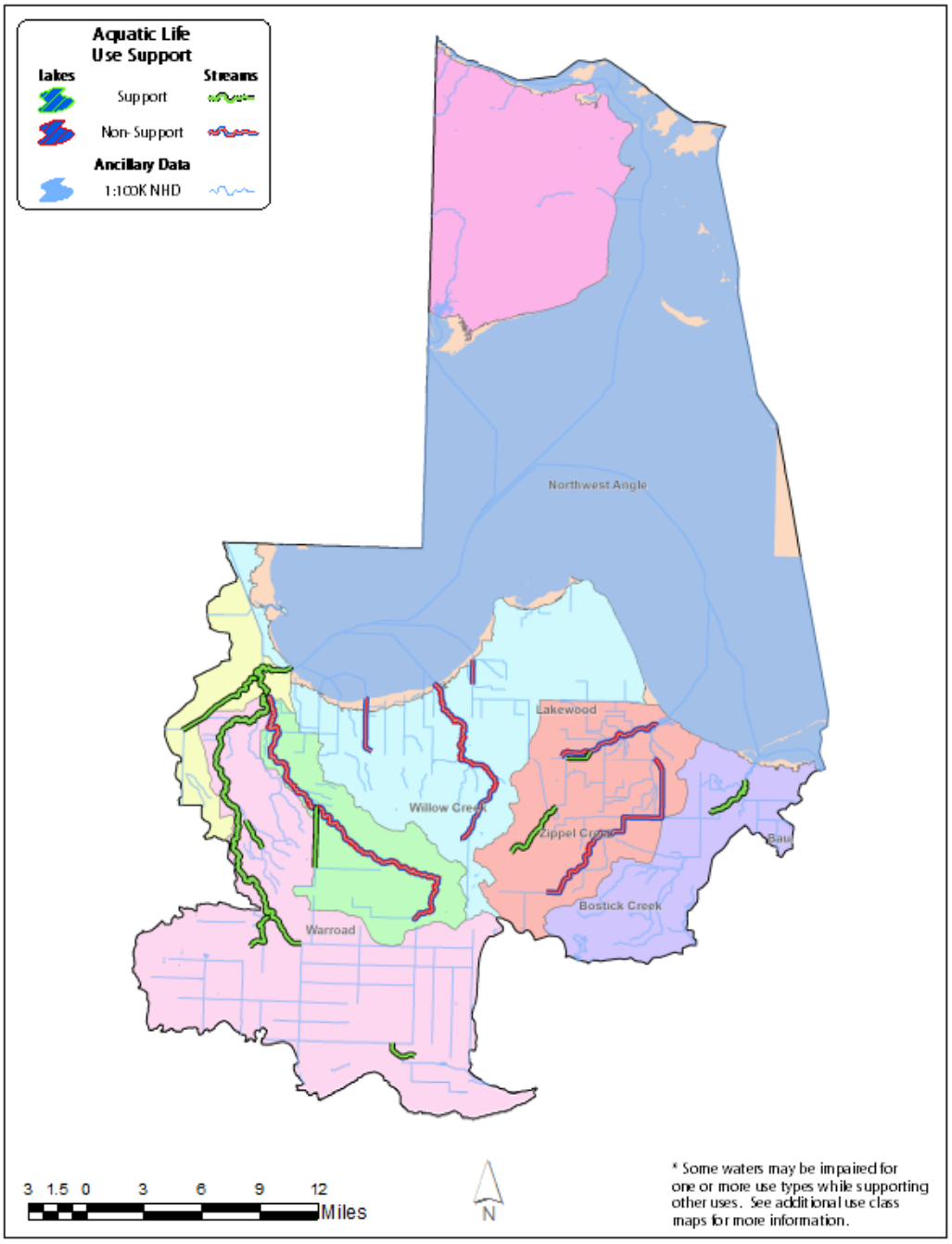

Figure 40. Aquatic life use support in the Lake of the Woods Watershed.

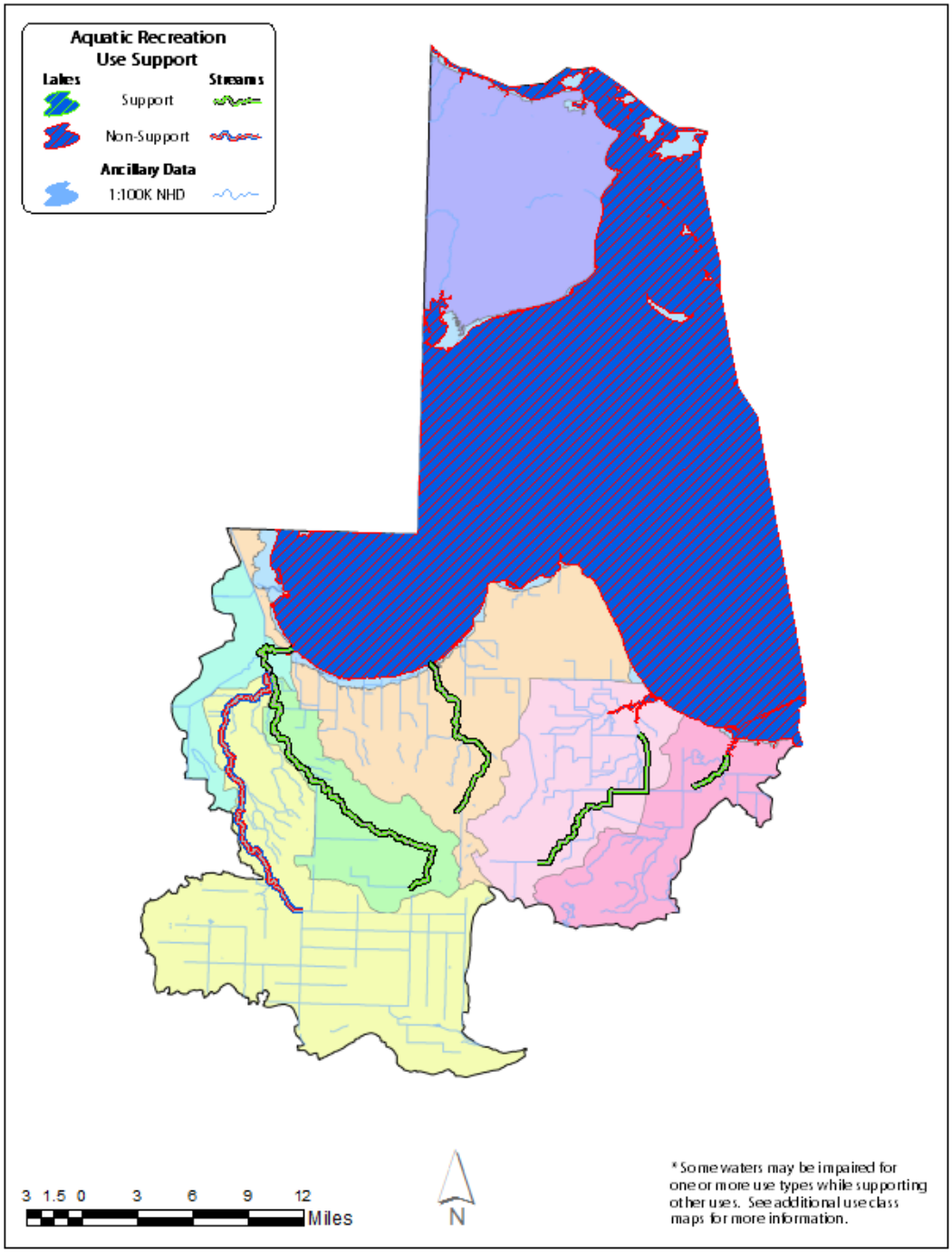

Figure 41. Aquatic recreation use support in the Lake of the Woods Watershed.

Summaries and recommendations

The Lake of the Woods Watershed is over 730,000 acres of the most northern part of Minnesota. The watershed is heavily influenced by the legacy of former glacial lakes, vast wetlands, boreal forest vegetation, and humans. Though the Lake of the Woods takes up about 41% of the total watershed area in Minnesota, 71% of the land is wetlands. Another 20% of the land is in agriculture, mostly found along the southern border of the lake. The remaining land is a mix of forests and city developments.

Streams

Biological monitoring showed a mixture of both tolerant and intolerant fish and macroinvertebrates throughout the Lake of the Woods Watershed. Watershed-wide intolerant fish species were slightly more likely to be sampled and at higher numbers than sensitive species. However, there were a fair number of sensitive species present. Consistently, IBI scores improved moving from headwater streams towards larger rivers. Nearly all of the subwatersheds contain stream impairments; the Bostick Subwatershed is the only one that does not. Impairments in the watershed include fish IBI, macroinvertebrate IBI, DO, TSS, E.coli, and mercury levels in fish tissue. MSHA overall is fair, with general strengths being intact riparian areas and instream fish cover. Channel stability was ranked as moderately unstable, though not many sites were scored. The top factors influencing stability were fine soft sediments and unstable upper banks.

Lakes

Restoration of water quality on Lake of the Woods will be difficult given the lake's nutrient sources. Recent research indicates that Lake of the Woods is slowly recovering, and that algal abundance peaked in the 1960s, corresponding to a peak in poor wastewater treatment practices from major industrial sources entering the Rainy River. However, the lake appears to be responding to climate change, making water quality recovery more complicated. Another complication is the changing agricultural practices. With added drainage, much of the watershed drains to the south shore, increasing the nutrient loading and endangering the slow progress being made on basin-wide nutrient reductions. This is compounded naturally by the Lake of the Woods' large size and shallow wind-swept southern basin that makes it behave like a shallow lake; therefore it readily recycles legacy P. The MPCA, and our numerous U.S. and Canadian governmental, tribal, and consulting partners are working to determine the nature and extent of algal blooms and to develop appropriate restoration strategies. The TMDL study is scheduled to be complete in 2016.

Groundwater

The surficial geology of the Lake of the Woods Watershed is such that conditions for groundwater recharge are ideal in specific areas of surficial sand and gravel deposits. Preservation of these areas is critical to maintaining sufficient groundwater availability for consumptive use.

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Appendix 1 - Water chemistry definitions

Dissolved oxygen (DO) - Oxygen dissolved in water required by aquatic life for metabolism. Dissolved oxygen enters into water from the atmosphere by diffusion and from algae and aquatic plants when they photosynthesize. Dissolved oxygen is removed from the water when organisms metabolize or breathe. Low DO often occurs when organic matter or nutrient inputs are high, and light inputs are low.

Escherichia coli (E. coli) - A type of fecal coliform bacteria that comes from human and animal waste. E. coli levels aid in the determination of whether or not fresh water is safe for recreation. Disease-causing bacteria, viruses and protozoans may be present in water that has elevated levels of E. coli.

Nitrate plus Nitrite – Nitrogen - Nitrate and nitrite-nitrogen are inorganic forms of N present within the environment that are formed through the oxidation of ammonia-nitrogen by nitrifying bacteria (nitrification). Ammonia-nitrogen is found in fertilizers, septic systems and animal waste. Once converted from ammonia-nitrogen to nitrate and nitrite-nitrogen, these species can stimulate excessive levels of algae in streams. Because nitrate and nitrite-nitrogen are water soluble, transport to surface waters is enhanced through agricultural drainage. The ability of nitrite-nitrogen to be readily converted to nitrate-nitrogen is the basis for the combined laboratory analysis of nitrate plus nitrite-nitrogen (nitrate-N), with nitrite-nitrogen typically making up a small proportion of the combined total concentration. These and other forms of N exist naturally in aquatic environments; however, concentrations can vary drastically depending on season, biological activity, and anthropogenic inputs.

Orthophosphate - Orthophosphate (OP) is a water soluble form of phosphorus that is readily available to algae (bioavailable). While orthophosphates occur naturally in the environment, river and stream concentrations may become elevated with additional inputs from waste water treatment plants, noncompliant septic systems and fertilizers in urban and agricultural runoff.

pH - A measure of the level of acidity in water. Rainfall is naturally acidic, but fossil fuel combustion has made rain more acid. The acidity of rainfall is often reduced by other elements in the soil. As such, water running into streams is often neutralized to a level acceptable for most aquatic life. Only when neutralizing elements in soils are depleted, or if rain enters streams directly, does stream acidity increase.

Specific Conductance - The amount of ionic material dissolved in water. Specific conductance is influenced by the conductivity of rainwater, evaporation and by road salt and fertilizer application.

Temperature - Water temperature in streams varies over the course of the day similar to diurnal air temperature variation. Daily maximum temperature is typically several hours after noon, and the minimum is near sunrise. Water temperature also varies by season as doe's air temperature.

Total Kjehldahl nitrogen (TKN) - The combination of organically bound N and ammonia in wastewater. TKN is usually much higher in untreated waste samples then in effluent samples.

Total Phosphorus (TP) - Nitrogen (N), phosphorus (P) and potassium (K) are essential macronutrients and are required for growth by all animals and plants. Increasing the amount of phosphorus entering the system therefore increases the growth of aquatic plants and other organisms. Excessive levels of Phosphorous over stimulate aquatic growth and resulting in the progressive deterioration of water quality from overstimulation of nutrients, called eutrophication. Elevated levels of phosphorus can result in: increased algae growth, reduced water clarity, reduced oxygen in the water, fish kills, altered fisheries and toxins from cyanobacteria (blue green algae) which can affect human and animal health.

Total Suspended Solids (TSS) – TSS and turbidity are highly correlated. Turbidity is a measure of the lack of transparency or "cloudiness" of water due to the presence of suspended and colloidal materials such as clay, silt, finely divided organic and inorganic matter and plankton or other microscopic organisms. The greater the level of TSS, the murkier the water appears and the higher the measured turbidity.

Higher turbidity results in less light penetration which may harm beneficial aquatic species and may favor undesirable algae species. An overabundance of algae can lead to increases in turbidity, further compounding the problem.

Total Suspended Volatile Solids (TSVS) - Volatile solids are solids lost during ignition (heating to 500 degrees C.) They provide an approximation of the amount of organic matter that was present in the water sample. ''Fixed solids'' is the term applied to the residue of total, suspended, or dissolved solids after heating to dryness for a specified time at a specified temperature. The weight loss on ignition is called ''volatile solids.''

Unnionized Ammonia (NH3) - Ammonia is present in aquatic systems mainly as the dissociated ion $NH4^{+}$, which is rapidly taken up by phytoplankton and other aquatic plants for growth. Ammonia is an excretory product of aquatic animals. As it comes in contact with water, ammonia dissociates into $NH4^{+}$ ions and ^{-}OH ions (ammonium hydroxide). If pH levels increase, the ammonium hydroxide becomes toxic to both plants and animals.

Appendix 2 - Intensive watershed monitoring water chemistry stations in the Lake of the Woods Watershed

Biological Station ID	STORET/ EQuIS ID	Waterbody Name	Location	12-digit HUC
12RN021	S005-708	Bostick Creek	At CR 42nd Ave NW, 3 mi. W of Hacket	0903000901-01
12RN020	S000-906	Williams Creek	At CR 12, 5.5 mi. NE of Williams	0903000902-01
05RN116	S006-978	Warroad River	Downstream of CR 5, just S. of Warroad	0903000903-01
12RN004	S004-289	Warroad River, West Branch	At CR 12, 6 mi. SW of Warroad	0903000903-02
12RN010	S004-295	Warroad River, East Branch	At CR 12, 5 mi. S of Warroad	0903000903-03
12RN015	S004-293	Willow Creek	At CR 12, 10 mi. E of Warroad	0903000904-01

Appendix 3.1 - AUID table of stream assessment results (by parameter and beneficial use)

AUID DESCRIPTIONS				USES							WATER QUALITY STANDARDS								
											Aquatic Life Indicators:							Aquatic Rec. Indicators:	
Assessment Unit ID (AUID)	Stream Reach Name	Reach Description	Reach Length (Miles)	Use Class	Aquatic Life	Aquatic Recreation	Aquatic Consumption	Drinking Water	303d listed impairments YEAR		Fish	Macroinvertebrates	Dissolved Oxygen	Turbidity	Chloride	pH	NH3	Bacteria	Nutrients
09030009-553	Unnamed creek	Unnamed cr to Canfield Cr	1.69	WWg	IF	NA							IF	IF		MTS			
09030009-546	Canfield Creek	Unnamed cr to Unnamed cr	0.83	WWg	IF	NA							IF			MTS			
09030009-540	Unnamed ditch	Canfield Cr to Unnamed ditch	2.63	WWg	IF	NA							IF	MTS		MTS			
09030009-537	Bostick Creek	Headwaters to Lake of the Woods	3.76	WWg	SUP	SUP					MTS		MTS	EXS	MTS	MTS	MTS	MTS	
09030009-539	Unnamed ditch	Unnamed ditch to Bostick Cr	1.68	WWg	IF	NA							MTS	IF		MTS			
Aggregated HUC 12: 0903000902-01 (Zippel Creek-Frontal Lake of the Woods)																			
09030009-516	Tomato Creek	Headwaters to T161 R34W S3, north line	3.13	CWg	SUP	NA					MTS	MTS	IF	IF		IF			
09030009-518	Tomato Creek	T162 R34W S34, south line to Unnamed cr	0.83	WWg	SUP	NA					MTS	MTS	MTS	IF		MTS			
09030009-506	Zippel Creek, East Branch	Headwaters to Zippel Bay	7.08	WWg	IF	NA							IF	IF		MTS			
09030009-529	County Ditch 1	Unnamed ditch to W Br Zippel Cr	1.48	WWg	SUP	NA							MTS	MTS		MTS			
09030009-567	Unnamed creek	Headwaters to 70th Ave NW	2.71	WWm		NA							IF			MTS			
09030009-515	Zippel Creek, West Branch (County Ditch 1)	Headwaters to Zippel Bay (Lake of the Woods)	6.03	WWg	IMP	NA			2015		EXS	EXS	MTS	EXS	IF	MTS			
09030009-501	Williams Creek	Headwaters to Zippel Cr	12.73	WWg	IMP	SUP			1996		EXS	EXS	IF	EXS	MTS	MTS	MTS	MTS	
Aggregated HUC 12: 0903000903-01 (Warroad River)																			
09030009-502	Warroad River, W & E Br Warroad R to Lake of the Woods	W & E Br Warroad R to Lake of the Woods	4.55	WWg	SUP	SUP	IMP		2014		MTS		NA	IF	MTS	MTS	MTS	MTS	

Full Support (FS); Not Supporting (NS); Insufficient Data (IF); Not Assessed (NA); Meets standards or ecoregion expectations (MT/MTS), Potential Exceedence (EXP), Exceeds standards or ecoregion expectations (EX/EXS).
Key for Cell Shading: = existing impairment, listed prior to 2015 reporting cycle; = new impairment; = full support of designated use.

AUID DESCRIPTIONS				USES							WATER QUALITY STANDARDS								
											Aquatic Life Indicators:							Aquatic Rec. Indicators:	
Assessment Unit ID (AUID)	Stream Reach Name	Reach Description	Reach Length (Miles)	Use Class	Aquatic Life	Aquatic Recreation	Aquatic Consumption	Drinking Water	303d listed impairments YEAR		Fish	Macroinvertebrates	Dissolved Oxygen	Turbidity	Chloride	pH	NH3	Bacteria	Nutrients
Aggregated HUC 12: 0903000903-02 (West Branch Warroad River)																			
09030009-558	Unnamed ditch (Judicial Ditch 62)	Headwaters to Unnamed ditch	1.72	WWg	SUP	NA					MTS	MTS	IF	IF		IF			
09030009-557	Unnamed creek	Headwaters to W Br Warroad R	3.08	WWg	SUP	NA					MTS	MTS	IF	IF		IF			
09030009-533	Clausner Creek	Unnamed cr to Unnamed cr	1.76	WWg	SUP	NA					MTS		IF	IF		IF			
09030009-503	Warroad River	Headwaters to Warroad R	28.64	WWg	SUP	IMP			2015		MTS	MTS	MTS	IF	MTS	MTS	MTS	EXS	
Aggregated HUC 12: 0903000903-03 (East Branch Warroad River)																			
09030009-526	Unnamed ditch	Unnamed ditch to E Br Warroad R	3.15	WWg	SUP	NA					MTS	MTS	IF			IF			
09030009-504	Warroad River, East Branch	Headwaters to Warroad R	33.72	WWg	IMP	SUP			2015		MTS	EXS	MTS	IF	MTS	MTS	MTS	MTS	
Aggregated HUC 12: 0903000904-01 (Muskeg Bay-Frontal Lake of the Woods)																			
09030009-560	County Ditch 20	Headwaters to Lake of the Woods	2.94	WWm	IMP	NA			2015		MTS	EXS	IF	IF		IF			
09030009-505	Willow Creek	Headwaters to Lake of the Woods	14.89	WWg	IMP	SUP			2010		EXS		EXS	IF	MTS	MTS	MTS	MTS	
09030009-523	Unnamed ditch	Unnamed ditch to Unnamed ditch	1.29	WWg	IMP	NA			2015		EXS	EXS	IF	IF		IF			

Full Support (FS); Not Supporting (NS); Insufficient Data (IF); Not Assessed (NA); Meets standards or ecoregion expectations (MT/MTS), Potential Exceedence (EXP), Exceeds standards or ecoregion expectations (EX/EXS).

Key for Cell Shading: = existing impairment, listed prior to 2014 reporting cycle; = new impairment; = full support of designated use.

Appendix 3.2 - Assessment results for lakes in the Lake of the Woods Watershed

Lake ID	Lake Name	County	HUC-12	Ecoregion	Lake Area (acres)	Max Depth (m)	Watershed Area (acres)	% Littoral	Mean depth (m)	AQR Support Status	AQL Support Status
39-0002-01	Lake of the Woods (Main Basin, MN Portion)	Lake of the Woods		NLF / NWM	687,000 *	N/A	14,702,661 *	7.3	5.9	NS	FS
39-0002-01	Lake of the Woods, Four Mile Bay	Lake of the Woods		NLF / NWM	7,907	3	13,828,703 *	100	2.5	NS	FS

Abbreviations:
FS – Full Support
NS – Non-Support
IF – Insufficient Information
N/A – Not Assessed

Key for Cell Shading: = existing impairment, listed prior to 2014 reporting cycle; = new impairment; = full support of designated use.
*These data were estimated by MPCA Staff. Morphometry includes data used in BATHTUB model, including all portions of LoW upstream of Northwest Angle Outlets
** From DNR Lake Finder

Appendix 4.1 - Minnesota statewide IBI thresholds and confidence limits

Class #	Class Name	Use Class	Exceptional Use Threshold	General Use Threshold	Modified Use Threshold	Confidence Limit
Fish						
1	Southern Rivers	2B, 2C	71	49	NA	±11
2	Southern Streams	2B, 2C	66	50	35	±9
3	Southern Headwaters	2B, 2C	74	55	33	±7
10	Southern Coldwater	2A	82	50	NA	±9
4	Northern Rivers	2B, 2C	67	38	NA	±9
5	Northern Streams	2B, 2C	61	47	35	±9
6	Northern Headwaters	2B, 2C	68	42	23	±16
7	Low Gradient	2B, 2C	70	42	15	±10
11	Northern Coldwater	2A	60	35	NA	±10
Invertebrates						
1	Northern Forest Rivers	2B, 2C	77	49	NA	±10.8
2	Prairie Forest Rivers	2B, 2C	63	31	NA	±10.8
3	Northern Forest Streams RR	2B, 2C	82	53	NA	±12.6
4	Northern Forest Streams GP	2B, 2C	76	51	37	±13.6
5	Southern Streams RR	2B, 2C	62	37	24	±12.6
6	Southern Forest Streams GP	2B, 2C	66	43	30	±13.6
7	Prairie Streams GP	2B, 2C	69	41	22	±13.6
8	Northern Coldwater	2A	52	32	NA	±12.4
9	Southern Coldwater	2A	72	43	NA	±13.8

Appendix 4.2 - Biological monitoring results – fish IBI (assessable reaches)

National Hydrography Dataset (NHD) Assessment Segment AUID	Biological Station ID	Stream Segment Name	Drainage Area Mi^2	Fish Class	Threshold	FIBI	Visit Date
Aggregated HUC 12: 0903000901-01 (Bostick Creek-Frontal Four mile Bay Subwatershed)							
09030009-537	12RN021	Bostick Creek	40.34	7	42	53.4	6/25/2012
Aggregated HUC 12: **0903000902-01 (Zippel Creek-Frontal Lake of the Woods)**							
09030009-516	05RN117	Tomato Creek	4.24	11	35	35	7/28/2005
09030009-516	05RN117	Tomato Creek	4.24	11	35	43.6	7/10/2012
09030009-518	12RN017	Tomato Creek	7.69	6	42	57.4	7/10/2012
09030009-515	12RN018	Zippel Creek, West Branch (County Ditch 1)	28.43	7	42	45.3	6/26/2012
09030009-501	10EM161	Williams Creek	18.91	6	42	38	6/23/2010
09030009-501	12RN020	Williams Creek	29.11	6	42	32.4	6/14/2012
09030009-501	12RN020	Williams Creek	29.11	6	42	28.2	7/12/2012
Aggregated HUC 12: 0903000903-01 (Warroad River)							
09030009-502	05RN116	Warroad River	235.47	5	47	63.4	9/21/2005
09030009-502	05RN116	Warroad River	235.47	5	47	55.8	7/26/2012
Aggregated HUC 12: 0903000903-02 (West Branch Warroad River)							
09030009-558	12RN008	Unnamed ditch (Judicial Ditch 62)	16.54	6	42	51.5	6/11/2012
09030009-558	12RN008	Unnamed ditch (Judicial Ditch 62)	16.54	6	42	43.8	7/11/2012
09030009-557	12RN007	Unnamed creek	35.86	6	42	64.9	6/27/2012
09030009-533	12RN005	Clausner Creek	2.25	6	42	53.7	6/12/2012
09030009-503	05RN118	Warroad River	162.88	5	47	68.2	9/14/2005
09030009-503	12RN004	Warroad River	160.65	5	47	65.5	6/28/2012
09030009-503	12RN006	Warroad River	142.72	5	47	58.7	6/26/2012
09030009-503	13RN001	Warroad River	140.51	5	47	53.3	7/31/2012

National Hydrography Dataset (NHD) Assessment Segment AUID	Biological Station ID	Stream Segment Name	Drainage Area Mi^2	Fish Class	Threshold	FIBI	Visit Date
Aggregated HUC 12: 0903000903-03 (East Branch Warroad River)							
09030009-526	05RN017	Unnamed ditch	140.51	6	42	65.2	6/22/2005
09030009-526	05RN017	Unnamed ditch	140.51	6	42	33.6	6/27/2012
09030009-526	05RN017	Unnamed ditch	140.51	6	42	42.6	6/18/2013
09030009-504	05RN115	Warroad River, East Branch	13.01	7	42	86.2	7/26/2005
09030009-504	05RN115	Warroad River, East Branch	13.01	7	42	86.8	8/27/2014
09030009-504	10EM017	Warroad River, East Branch	22.68	6	42	72.8	7/15/2010
09030009-504	10EM017	Warroad River, East Branch	22.68	6	42	61.8	6/27/2012
09030009-504	12RN010	Warroad River, East Branch	44.94	6	42	48.9	6/12/2012
09030009-504	12RN010	Warroad River, East Branch	44.94	6	42	59.4	6/27/2012
Aggregated HUC 12: 0903000904-01 (Muskeg Bay-Frontal Lake of the Woods)							
09030009-560	12RN012	County Ditch 20	10.32	7	15	38.2	6/26/2012
09030009-505	05RN188	Willow Creek	21.71	7	42	26.4	6/19/2006
09030009-505	12RN015	Willow Creek	25.11	6	42	0	7/10/2012
09030009-505	12RN015	Willow Creek	25.11	6	42	0.1	6/18/2013
09030009-523	12RN016	Unnamed ditch	11.85	6	42	24.9	8/27/2014

Appendix 4.3 - Biological monitoring results-macroinvertebrate IBI (assessable reaches)

National Hydrography Dataset (NHD) Assessment Segment AUID	Biological Station ID	Stream Segment Name	Drainage Area Mi^2	Invert Class	Threshold	MIBI	Visit Date
Zippel Creek - Frontal Lake of the Woods (0903000902-01)							
09030009-501	10EM161	Williams Creek	18.91	4	51	67.51	8/31/2010
09030009-501	12RN020	Williams Creek	29.11	3	53	42.26	7/31/2012
09030009-515	12RN018	Zippel Creek, West Branch (County Ditch 1)	28.43	4	51	36.30	7/31/2012
09030009-516	05RN117	Tomato Creek	4.24	8	32	26.24	8/15/2005
09030009-516	05RN117	Tomato Creek	4.24	8	32	41.09	8/27/2014
09030009-516	14RN150	Tomato Creek	4.59	8	32	22.75	8/26/2014
09030009-516	14RN151	Tomato Creek	7.59	8	32	22.90	8/26/2014
09030009-518	12RN017	Tomato Creek	7.69	4	51	24.90	7/31/2012
09030009-518	12RN017	Tomato Creek	7.69	4	51	49.79	8/26/2014
Warroad River (090300903-02)							
09030009-503	05RN118	Warroad River, West Branch	162.88	3	53	49.22	8/18/2005
09030009-503	05RN118	Warroad River, West Branch	162.88	3	53	75.28	9/14/2005
09030009-503	12RN006	Warroad River, West Branch	142.72	4	51	64.69	7/30/2012
09030009-503	12RN004	Warroad River, West Branch	160.65	4	51	57.66	8/1/2012
09030009-503	13RN001	West Branch Warroad River	140.51	3	53	54.59	7/31/2013
09030009-557	12RN007	Unnamed trib. to West Brach River	35.86	3	53	57.47	7/30/2012
09030009-558	12RN008	Judicial Ditch 62	16.54	4	51	39.33	7/30/2012
09030009-558	14RN153	Judicial Ditch 62	16.60	4	51	63.33	8/27/2014

National Hydrography Dataset (NHD) Assessment Segment AUID	Biological Station ID	Stream Segment Name	Drainage Area Mi^2	Fish Class	Threshold	FIBI	Visit Date
East Branch Warroad River (0903000903-03)							
09030009-504	05RN115	Warroad River, East Branch	13.01	3	53	50.62	8/16/2005
09030009-504	10EM017	Warroad River, East Branch	22.68	4	51	40.96	9/1/2010
09030009-504	12RN010	Warroad River, East Branch	44.94	3	53	50.54	8/1/2012
09030009-504	12RN010	Warroad River, East Branch	44.94	3	53	55.94	8/1/2012
09030009-504	10EM017	Warroad River, East Branch	22.68	4	51	44.33	8/1/2012
09030009-504	05RN115	Warroad River, East Branch	13.01	3	53	52.14	8/27/2014
09030009-526	05RN017	Trib. to Warroad River, East Branch	9.74	3	53	59.90	8/16/2005
Muskeg Bay – Frontal Lake of the Woods (0903000904-01)							
09030009-523	12RN016	Unnamed ditch	11.85	3	53	44.01	8/26/2014
09030009-560	12RN012	County Ditch 20	10.32	4	51	31.54	8/1/2012

Appendix 5.1 - Minnesota's ecoregion-based lake eutrophication standards

Ecoregion	TP µg/L	Chl-a µg/L	Secchi meters
NLF – Lake Trout (Class 2A)	< 12	< 3	> 4.8
NLF – Stream trout (Class 2A)	< 20	< 6	> 2.5
NLF – Aquatic Rec. Use (Class 2B)	< 30	< 9	> 2.0
NCHF – Stream trout (Class 2A)	< 20	< 6	> 2.5
NCHF – Aquatic Rec. Use (Class 2B)	< 40	< 14	> 1.4
NCHF – Aquatic Rec. Use (Class 2B) Shallow lakes	< 60	< 20	> 1.0
WCBP & NGP – Aquatic Rec. Use (Class 2B)	< 65	< 22	> 0.9
WCBP & NGP – Aquatic Rec. Use (Class 2B) Shallow lakes	< 90	< 30	> 0.7

Appendix 5.2 - MINLEAP model estimates of phosphorus loads for lakes in the Lake of the Woods Watershed

Lake ID	Lake Name	Obs TP (µg/L)	Modeled TP (µg/L)	Obs Chl-a (µg/L)	Modeled Chl-a (µg/L)	Obs Secchi (m)	Modeled Secchi (m)	Avg. TP Inflow (µg/L)	TP Load (kg/yr)	Background TP (µg/L)	%P Retention	Outflow (hm3/yr)	Residence Time (yrs)	Areal Load (m/yr)	Trophic Status
39-0002-01	Lake of the Woods (Main Basin, MN Portion) **MINLEAP - 2014 Assessment Dataset**	39	19	9.9	5	1.4	3.0	37	520,688	15	48	14,046	1.2	5.05	M / E
39-0002-01	Lake of the Woods, Four Mile Bay **MINLEAP 2014 Assessment Dataset**	33	33	4.8	11	0.9	1.9	35	450,988	20	5	12,875	0.06	397	M
39-0002-01	Lake of the Woods (Main Basin, MN Portion) **BATHTUB ****	33	34	7.7	9.5	1.4	1.3	68	517,624	---	55	15,171	1.06	5.5	M / E
39-0002-01	Lake of the Woods, Four Mile Bay **BATHTUB ****	32	34	4.7	13.3	0.9	0.8	35	458,661	---	0	12,956	0.006	404	M / E

Abbreviations: **H** – Hypereutrophic **M** – Mesotrophic --- No data
E – Eutrophic **O** – Oligotrophic

****** The BATHTUB results are deemed more robust because the Lake was segmented into basins, and included several metrics not modeled by MINLEAP such as internal loading, shoreline erosion, and point and non-point sources of phosphorus. Water quality inputs are 2010 averages provided by the USGS, monitoring was conducted under an MPCA contract; morphology was provided by partner agencies or estimated by MPCA staff.

Appendix 6 – Fish species found during biological monitoring surveys

Common Name	Quantity of Stations where Present	Quantity of Individuals Collected
black bullhead	2	331
black crappie	2	6
blacknose dace	19	1053
blacknose shiner	12	2440
brassy minnow	10	393
brook stickleback	22	1876
burbot	2	16
central mudminnow	32	1672
common shiner	19	1917
creek chub	19	1131
emerald shiner	1	2
fathead minnow	15	355
finescale dace	8	613
golden shiner	4	28
Iowa darter	12	137
johnny darter	20	480
lamprey ammocoete	10	174
logperch	10	48
northern brook lamprey	4	10
northern pike	16	162
northern redbelly dace	17	1954
pearl dace	15	645
pumpkinseed	1	4
rock bass	2	6
shorthead redhorse	1	1
silver lamprey	4	11
silver redhorse	4	13
spottail shiner	1	1
tadpole madtom	2	2
walleye	4	5
white sucker	24	1073
yellow perch	10	527
spottail shiner	1	1
tadpole madtom	2	2

Common Name	Quantity of Stations where Present	Quantity of Individuals Collected
walleye	4	5
white sucker	24	1073
yellow perch	10	527
spottail shiner	1	1
tadpole madtom	2	2
walleye	4	5
white sucker	24	1073
yellow perch	10	527

Appendix 7 – Macroinvertebrate species found during biological monitoring surveys

Taxonomic Name	Quantity of Stations where Present	Quantity of Individuals Collected
ACARI		
Acari	22	212
AMPHIPODA		
Amphipoda	3	9
Hyalella	17	535
COLEOPTERA		
Anacaena	5	26
Berosus	1	1
Coptotomus	1	3
Dineutus	2	3
Dubiraphia	25	409
Dytiscidae	6	11
Elmidae	5	32
Gymnochthebius	1	1
Gyrinus	6	41
Haliplidae	1	1
Haliplus	10	29
Helichus	3	7
Helophorus	4	6
Hydraena	17	64
Hydrobius	1	1
Hydrochus	1	1
Hydrophilidae	7	23
Hygrotus	2	2

Taxonomic Name	Quantity of Stations where Present	Quantity of Individuals Collected
Ilybius	2	2
Liodessus	5	9
Macronychus glabratus	1	1
Neoporus	2	3
Ochthebius	2	2
Optioservus	9	44
Peltodytes	1	1
Sanfilippodytes	1	2
Stenelmis	3	9
Tropisternus	1	1
DECAPODA		
Cambaridae	3	5
Orconectes	8	9
DIPTERA		
Ablabesmyia	22	99
Atrichopogon	1	1
Bezzia	3	9
Bezzia/Palpomyia	1	1
Brillia	10	16
Ceratopogonidae	2	3
Ceratopogoninae	9	30
Chironomini	5	10
Chironomus	6	13
Cladopelma	1	3
Cladotanytarsus	6	11
Conchapelopia	2	2
Corynoneura	10	20
Cricotopus	18	136
Cryptochironomus	3	3
Cryptotendipes	4	7
Culicidae	3	35
Culicoides	1	1
Dicranota	1	2
Dicrotendipes	12	125
Diplocladius cultriger	1	1
Dixa	2	6
Dixella	9	62

Taxonomic Name	Quantity of Stations where Present	Quantity of Individuals Collected
Dixidae	2	4
Dolichopodidae	1	1
Doncricotopus bicaudatus	1	1
Endochironomus	3	31
Ephydridae	6	10
Forcipomyiinae	1	4
Glyptotendipes	4	6
Hemerodromia	7	15
Heterotrissocladius	4	19
Labrundinia	13	37
Larsia	1	2
Limnophyes	8	14
Metriocnemus	1	2
Micropsectra	14	178
Microtendipes	17	175
Nanocladius	3	6
Natarsia	3	6
Nemotelus	1	1
Neoplasta	5	11
Nilotanypus	2	3
Nilothauma	5	15
Orthocladiinae	7	27
Orthocladius	7	60
Orthocladius (Symposiocladius)	4	9
Parachironomus	2	6
Parakiefferiella	8	20
Paralauterborniella nigrohalterale	2	2
Paramerina	9	28
Parametriocnemus	11	46
Paratanytarsus	19	186
Paratendipes	2	5
Phaenopsectra	15	59
Polypedilum	25	280
Probezzia	1	1
Procladius	13	55

Taxonomic Name	Quantity of Stations where Present	Quantity of Individuals Collected
Psectrocladius	3	8
Pseudochironomus	2	3
Rheocricotopus	4	7
Rheotanytarsus	14	169
Saetheria	1	1
Simuliidae	2	3
Simulium	10	192
Stempellina	1	1
Stempellinella	16	86
Stenochironomus	11	28
Tabanidae	2	4
Tanypodinae	12	75
Tanytarsini	11	40
Tanytarsus	22	338
Thienemanniella	7	15
Thienemannimyia	9	131
Thienemannimyia Gr.	17	199
Tipula	4	6
Tribelos	2	3
Tvetenia	3	25
Xylotopus par	8	14
Zavreliella	1	1
Zavrelimyia	1	1
EPHEMEROPTERA		
Acerpenna	3	16
Anafroptilum	2	7
Baetidae	4	5
Baetis	4	19
Baetis brunneicolor	2	28
Baetis flavistriga	2	10
Baetis intercalaris	1	1
Baetisca	1	1
Caenis	12	149
Caenis youngi	1	19
Caenis diminuta	6	66
Caenis hilaris	2	2
Callibaetis	4	23

Taxonomic Name	Quantity of Stations where Present	Quantity of Individuals Collected
Ephemera	2	4
Ephemerellidae	1	1
Eurylophella	3	3
Heptageniidae	4	23
Hexagenia	1	3
Hexagenia limbata	2	2
Labiobaetis	1	1
Labiobaetis frondalis	2	3
Labiobaetis propinquus	5	31
Leptophlebia	1	2
Leptophlebiidae	10	184
Maccaffertium	3	20
Maccaffertium vicarium	2	4
Plauditus	2	2
Procloeon	10	109
Pseudocloeon	2	154
Pseudocloeon propinquum	1	3
Stenacron	9	92
Stenonema	3	11
Tricorythodes	2	2
GASTROPODA		
Bulimnaea megasoma	1	1
Ferrissia	15	140
Fossaria	5	6
Gyraulus	7	45
Helisoma	2	2
Helisoma anceps	4	15
Hydrobiidae	5	156
Lymnaea	1	2
Lymnaea stagnalis	1	1
Lymnaeidae	2	2
Physa	18	422
Physella	4	15
Planorbella	3	3
Planorbidae	7	33
Planorbula	1	1
Promenetus	2	9

Taxonomic Name	Quantity of Stations where Present	Quantity of Individuals Collected
Pseudosuccinea	1	1
Stagnicola	6	13
HEMIPTERA		
Aquarius	1	2
Belostoma	2	2
Belostoma flumineum	4	5
Callicorixa	1	1
Corixidae	5	14
Gerridae	3	3
Hesperocorixa	1	1
Lethocerus	1	1
Merragata	1	3
Neoplea striola	3	45
Notonecta	3	5
Palmacorixa	1	2
Ranatra	2	2
Sigara	8	24
Trichocorixa	1	2
HIRUDINEA		
Hirudinea	11	36
Helobdella stagnalis	1	1
HYDROZOA		
Hydra	2	2
Hydrozoa	1	1
ISOPODA		
Caecidotea	1	48
LEPIDOPTERA		
Acentria	1	1
MEGALOPTERA		
Sialis	7	14
NEMATODA		
Nematoda	1	2
ODONATA		
Aeshna	12	18
Aeshnidae	5	12
Anax junius	1	2
Boyeria	3	9

Taxonomic Name	Quantity of Stations where Present	Quantity of Individuals Collected
Boyeria vinosa	1	3
Calopterygidae	4	23
Calopteryx	9	21
Calopteryx aequabilis	4	8
Coenagrionidae	7	109
Corduliidae	11	32
Enallagma	1	2
Epitheca canis	1	2
Gomphidae	1	1
Libellulidae	2	2
Neurocordulia	1	4
Somatochlora	4	5
OLIGOCHAETA		
Oligochaeta	25	170
PLECOPTERA		
Acroneuria	1	1
Acroneuria lycorias	3	7
Amphinemura	2	11
Attaneuria	1	3
Isoperla	1	7
Malenka	1	7
Paragnetina	1	2
Perlidae	1	1
Perlodidae	1	1
Pteronarcys	1	1
Taeniopteryx	1	9
TRICHOPTERA		
Brachycentrus	2	3
Brachycentrus numerosus	2	3
Ceraclea	6	13
Ceratopsyche	10	90
Ceratopsyche bronta	2	2
Ceratopsyche slossonae	2	52
Cheumatopsyche	16	169
Glossosomatidae	1	1
Glyphopsyche	1	1
Glyphopsyche irrorata	1	1

Taxonomic Name	Quantity of Stations where Present	Quantity of Individuals Collected
Helicopsyche	3	5
Helicopsyche borealis	9	67
Hydatophylax argus	2	4
Hydropsyche	4	20
Hydropsyche betteni	5	24
Hydropsychidae	7	22
Hydroptila	2	4
Lepidostoma	1	21
Leptoceridae	10	28
Limnephilidae	14	99
Lype diversa	1	4
Molanna	1	1
Mystacides	1	1
Nectopsyche	2	38
Nectopsyche diarina	1	1
Neureclipsis	2	3
Nyctiophylax	5	10
Nyctiophylax (Paranyctiophylax)	1	7
Oecetis	4	4
Oecetis avara	2	5
Oxyethira	1	2
Phryganeidae	5	19
Polycentropodidae	3	3
Polycentropus	4	4
Protoptila	1	2
Psychomyiidae	1	1
Ptilostomis	6	9
Pycnopsyche	4	4
Triaenodes	3	6
VENEROIDA		
Pisidiidae	20	260