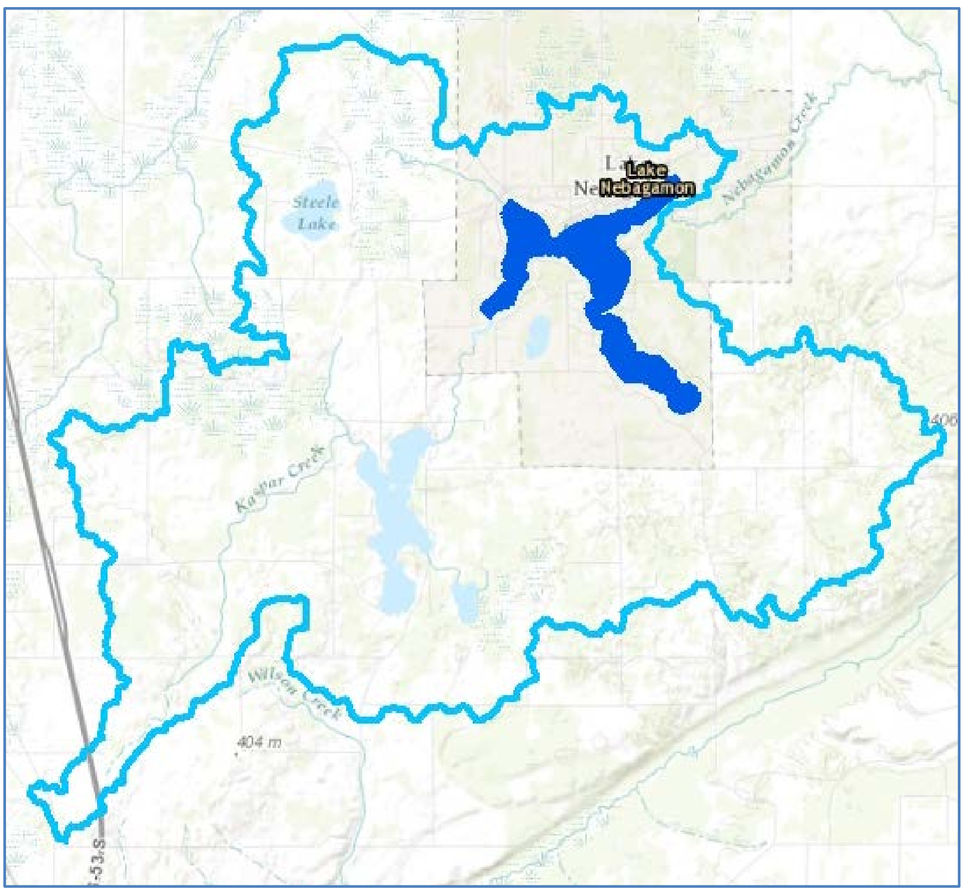
Comprehensive Management Plan for Lake Nebagamon

Wisconsin Department of Natural Resources
Lake Management Planning Program



Plan Approved

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1. Executive Summary

This document describes a plan for the long-term management of Lake Nebagamon. To enhance communication to the broadest range of audiences, this plan is structured such that the level of technical detail increases throughout the document. The Executive Summary is intended as a non-technical summary for all audiences. Sections 2 through 6 provide increased detail and background information to help the reader better understand the social and ecological components of the Lake Nebagamon ecosystem and rationale for different management recommendations. Appendices A through G are intended for more technical audiences and focus on an exhaustive presentation/discussion of the exiting data sets and management recommendations for different elements of the Lake Nebagamon ecosystem.

Successful management of Lake Nebagamon is dependent on an understanding of the relationship between the desired "use" of the lake and the physical, chemical, biological and social processes that shape the lake ecosystem. To this end, the plan is comprised of an assessment of 1) the use and value of Lake Nebagamon, 2) its current condition and the potential problems affecting it; and 3) the existing policies in place to protect it into the future.

To describe how Lake Nebagamon is used and valued by different groups, this plan was developed though collaborative input from the Nebagamon Lake Association, Lake Nebagamon Sanitary Sewer Commission, Red Cliff Natural Resources Department and Wisconsin Department of Natural Resources and informed by a user survey (administered by Northland College). Based on this process, it is obvious that Lake Nebagamon is an important ecological and social resource that is used and valued by different groups for different reasons. Across multiple questions in the survey, the majority of respondents highlighted the value of Lake Nebagamon as both a site for recreational activity and an important ecological resource that should be protected for the benefit of our natural world and use by future generations. From this process, a series of goals were developed to guide the management of Lake Nebagamon into the future.

1. Maintain Current Levels of Motorized and Non-motorized Use
2. Maintain Scenic Beauty of Lake Nebagamon
3. Protect and Restore Nearshore and Shoreline Habitat
4. Maintain Existing Water Levels and Hydrologic Processes
5. Maintain Existing Water Quality Conditions
6. Maintain Diverse Native Plant Communities
7. Maintain Diverse Native Fish Communities
8. Increase Walleye Population Densities
9. Maintain Access to Native American Fisheries and Fishing Sites

To achieve these goals, it was first necessary to assess the current conditions of the lake ecosystem. To this end, a two year study was conducted to summarize the existing data describing the health of Lake Nebagamon and develop new data sets to describe important processes throughout the ecosystem. Elements of Lake Nebagamon that were assessed include: Physical and Chemical Processes; Land Use and Runoff; Water Quality Conditions; Organisms and their Habitat; Invasive Species and Ecological Processes. From these studies, a number of important findings emerged.

Lake Nebagamon is a relatively healthy lake system and these conditions are created and sustained by a variety of ecological processes. The most significant elements of the Lake Nebagamon ecosystem that enable its conditions are the 1) diverse native communities of fish, plants and microscopic organisms (i.e., plankton) that make up the Lake Nebagamon food web and 2) the relatively limited levels of land use change (away from native vegetation) that exist throughout the watershed.

Despite its relatively healthy conditions, a number of potential problems are currently impacting, or have the potential to impact, the lake in the future. Water quality in Lake Nebagamon, although relatively stable, has likely degraded over the last 100 years, likely in response to historical changes in land use and increased levels of development along shoreland areas. Given the expected increases in population and changes in land use throughout the area, water quality has the potential to decline in the future—although anticipated changes would likely be small. Additionally, potential changes in land use, particularly in shoreline development have the potential to alter the availability and quality of nearshore habitat, as well as the aesthetics of the shoreline area. Although the biological communities within Lake Nebagamon are relatively diverse, changes in the fish community have been observed in recent years and a number of pathways exist that have the potential to result in invasive species introductions into the future.

A range of federal, tribal, state and local laws, rules and regulations are in place to protect Lake Nebagamon and its uses. However, existing policies do not adequately address all current and potential future problems that may affect the lake. The elements of the Lake Nebagamon ecosystem that are best protected by existing regulations are the potential impacts to water quality by any future pollutants discharged from municipal and/or industrial facilities and any artificial changes in water levels (increases or decreases). The elements of the Lake Nebagamon ecosystem that are least effectively protected are potential changes in shoreline habitat quality and aesthetics and the potential runoff of nutrients to the lake from future land uses with higher densities of urban/residential development.

The recommendations in this plan are based on a 1) comprehensive inventory and assessment of the existing uses for Lake Nebagamon, 2) current conditions of the lake and 3) existing policies that govern the protection and management of the lake. However, like all management plans, it is not possible to gather all of the data necessary to fully describe the relationship between human use and ecosystem health, or fully anticipate what future conditions will look like. As a result, the management recommendations are summarized in two forms: things that could (potentially should) be done now and things we should learn more about to make better informed decisions in the future.

Things that could be done now include:

1. Integrate updated climatological data sets into design standards for new development throughout the watershed.
    a. *Why? – Data used to historically size infrastructure do not reflect current rainfall patterns and more up-to-date data are available. Outdated data sets result in increased pollutant runoff to the lake.*

2. Continue and expand efforts to prevent, rapidly detect and respond to invasive species in Lake Nebagamon.
    a. *Why? – Current impacts from aquatic invasive species are minimal in Lake Nebagamon and preventative efforts are generally more effective than reactive efforts to manage invasive species.*

3. Implement efforts to formally designate areas of critical habitat to protect aquatic organisms throughout the lake.
    a. *Why? – Nearshore and shoreline areas in Lake Nebagamon are critical to the lake ecosystem and areas with the highest quality habitat are somewhat disconnected and isolated. Efforts to protect these areas will likely have a disproportionately high benefit to the long-term health of the lake.*

4. Implement efforts to restore areas of localized shoreland habitat degradation.
    a. *Why? – Shoreland habitat restoration and management represents the single largest opportunity for short-term improvement in lake condition and long-term protection of lake function. WDNR has a range of grant programs to facilitate shoreline restoration.*

5. Implement recurring monitoring programs that characterize user perceptions and water quality conditions over time.
    a. *Why? – User experiences and water quality conditions are primary drivers of management recommendations. Tracking changes over time will help evaluate the success of management efforts and identify potential future needs.*

Things we should learn more about:

1. Comprehensively evaluate the ability of local land use and zoning policies to effectively manage water quality and aesthetics in Lake Nebagamon into the future, with particular attention to the potential impact of anticipated future climate conditions.
    a. *Why? – Current land use and zoning policies are based on existing environmental conditions and may or may not be well suited to anticipated changes in climate and land use development.*

2. Locate and map important spawning grounds for different fish species and important sites for fish harvest by Native American tribal members to facilitate long-term protection.
    a. *Why? – Important spawning locations are currently undocumented and may be inadvertently affected by changes in development around the lake shoreline. Identification could help prevent potential impacts to fish spawning and conflict among users into the future.*

2. Introduction

Successful management of Lake Nebagamon is dependent on an understanding of the relationship between the desired "use" of the lake and the physical, chemical, biological and social processes that shape the lake ecosystem. Throughout this document the word "use" will be used to describe all of the potential ways in which people directly use (e.g., fishing and boating), interact with (e.g., wildlife observation) and value (e.g., a site for the conservation of species and native ecosystems) Lake Nebagamon.

Lake Nebagamon is used by different groups for different purposes. For example, some individuals may use the lake primarily for fishing or boating, while others (or perhaps the same individuals) may use the lake as a place for natural resource conservation or as a source of peace and relaxation. The Lake Nebagamon ecosystem supports each of these different uses through a combination of the physical, chemical, biological—and in some cases, social—processes that shape the lake ecosystem and experience of its users. For example, use of the lake as a fishery may be primarily based on the ability of the lake to support different species at different sizes and population densities, while use of the lake as a site for relaxation maybe primarily influenced by the number and type of watercraft on the lake.

Because different uses of Lake Nebagamon are dependent on different ecological and social processes, changes (often referred to as "stressors") that alter the lake ecosystem or its corresponding social conditions can undermine the ability of different groups to use the lake in the desired way. For example, changes in land use surrounding a lake may lead to decreased water quality, which may limit the utility of the lake for swimming (or other desired uses). Additionally, different uses of the lake may be in direct conflict with each other (often referred to as "incompatible uses"). For example, a desired use of the lake for increased motorized watercraft usage may be incompatible with a desired use of the lake as a site for relaxation and quiet interaction with the natural world.

Thus, to effectively manage Lake Nebagamon, it is necessary to:

1. Develop a series of goals that protect and/or restore the most highly valued uses for the lake by different user groups
2. Describe the conditions of the physical, chemical, biological and social processes that enable and sustain these different uses
3. Identify any potential stressors or use incompatibilities that limit the ability of different groups to use Lake Nebagamon in the desired way
4. Identify management options to protect and/or restore the desired use of the lake and reconcile any potential conflicts among user groups

To promote the health, management and restoration of lakes throughout the state, the Wisconsin Department of Natural Resources (WDNR) has developed a series of programs and funding sources. Through the WDNR Lake Programs, lake associations, local governments and a variety of other stakeholder groups can access technical resources and grant programs to enhance water quality, prevent and control invasive species introductions, restore shoreland habitat and develop local ordinances. This plan was enabled by funds from a WDNR Lake Planning grant (LPL-1484-13) and the Lake Nebagamon Sanitary Sewer Commission and developed collaboratively through volunteer contributions from the Nebagamon Lake Association and technical contributions from Northland College, WDNR and a range of different local, state, federal and tribal agencies.

2.1. Structure of the Plan

This plan is comprised of a series of sections that link the use, conditions and potential management option for the lake:

1) **Lake Uses and Users -** summarizes who primarily uses Lake Nebagamon and how it is used and valued by different groups

2) **Management Goals -** describes specific goals to protect and/or restore the ecological and social conditions necessary to sustain desired uses and values for Lake Nebagamon

3) **Lake Condition Assessment** - summarizes the historical and newly collected data that describe the conditions of the physical, chemical and biological processes that shape the Lake Nebagamon ecosystem

4) **Stressor Identification** - describes processes that are likely (now or in the future) to adversely affect the health of Lake Nebagamon

5) **Policy Analysis -** summarizes how effective the current rules and regulations are to address the stressors that are affecting (or likely to affect) Lake Nebagamon

6) **Management Recommendations -** summarizes potential actions to protect and restore Lake Nebagamon

7) **Appendices** - provided detailed assessments and management recommendations related to water quality, shoreland habitat, watershed land use, aquatic plants and invasive species and lake ecosystem dynamics

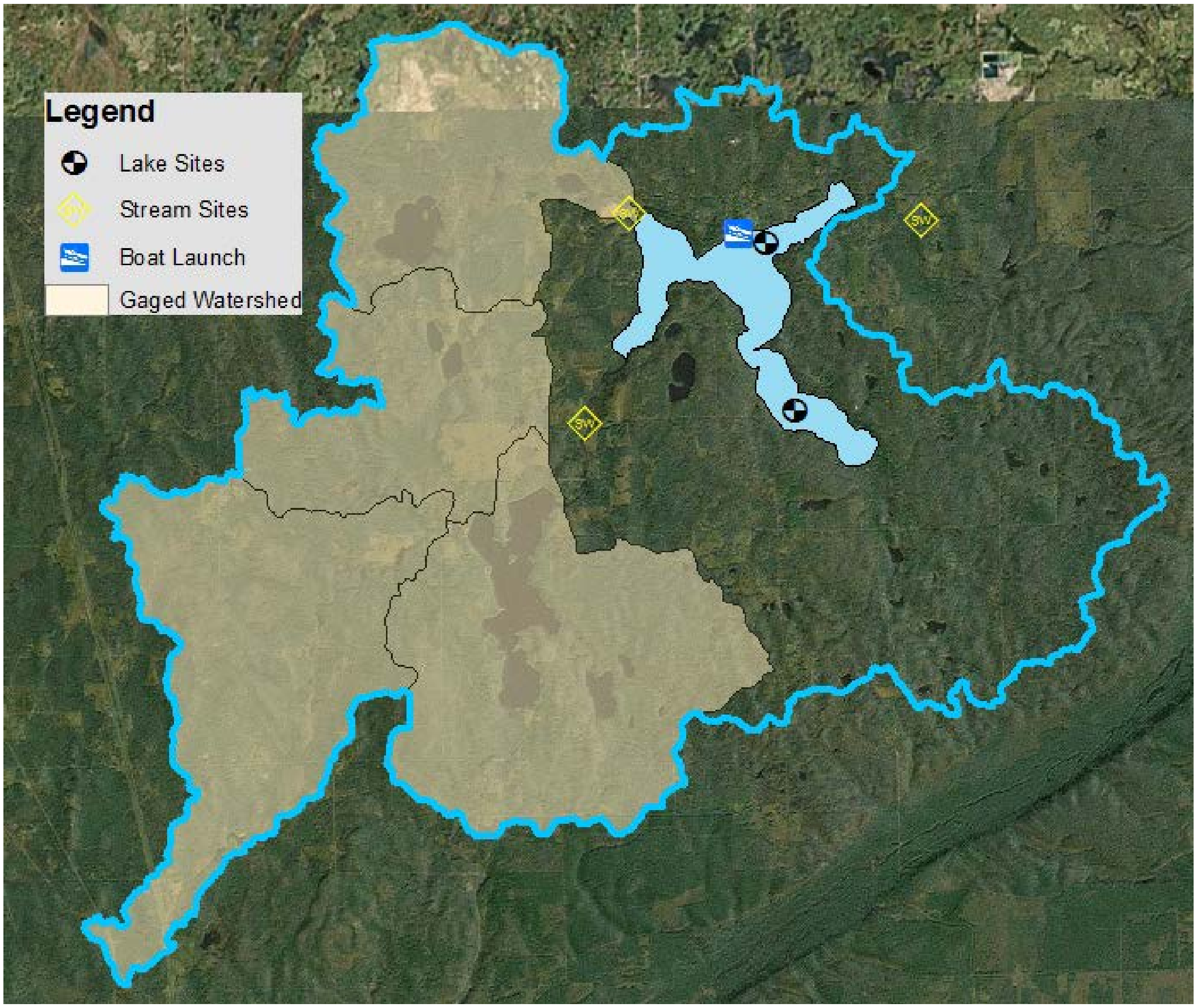

Figure 2.1. Lake Nebagamon and its watershed.

3. Lake Uses, Users and Access

Lake Nebagamon (WBIC Code – 2865000) is primarily used as a recreational and fishery resource by local residents, regional outdoor enthusiasts and Native American First Nations. Lake Nebagamon has one public and two undeveloped access points and one public beaches (Figure 1). Many residents and shoreland owners are actively involved in efforts to understand and protect the health of the lake. Lake Nebagamon has an active association (the Nebagamon Lake Association; http://nebagamonlakeassociation.com/) that hosts an annual lake association meeting and distributes quarterly newsletters to lakeshore property owners to increase awareness and understanding of emerging issues and ongoing management initiatives.

The Lake Nebagamon fishery supports both recreational and Tribal harvest. Three creel surveys have been conducted on Lake Nebagamon to assess recreational usage and harvest (Sand 2008). Results from these surveys suggest that recreational fishing pressure in Lake Nebagamon has declined over time. However, angler harvest of smallmouth bass has increased over time, potentially in response to increases in smallmouth bass densities. Species specific harvest rates are described in greater detail in Section 5.5.

3.1. Stakeholder Survey

To further assess the usage patterns and users of Lake Nebagamon, a stakeholder survey was conducted. The survey was structured to answer five main questions about the lake and it users:

1) How is Lake Nebagamon currently used?
2) Of these uses, which are most important and/or highly valued?
3) What are the general attitudes among lake users relative to different ecological elements and potential stressors to the lake system?
4) How important is Lake Nebagamon in the lives of different user groups?
5) What are the general value sets and beliefs that lake users likely base their actions on?

A census sample (i.e., the entire population) of households within one mile of the lakeshore of Lake Nebagamon was drawn from Douglas County records. After removing undeliverable surveys, duplicate landowners, or vacant properties, the final sampling size was 769 households or businesses. Surveys were delivered via mail using a modified Dillman method, where respondents were contacted prior to receiving their survey, sent the survey, and then sent a reminder if they did not return the survey within about a two week period. Surveys were sent out and received between August and September of 2014 with a 44.8 percent (or 330 surveys) response rate. Survey respondents generally represented the general population in the area. Average age of survey respondents was 61.8 years (ranging from 30 to 96), with an average income of $60,000-$99,000 per year. Of the respondents, ~60% were waterfront owners and 48% were year round residents.

Several trends emerged from the survey responses that highlight how different individuals and groups use and value the lake (Figure 3.1). Survey responses are summarized below with respect to the primary survey questions. Complete survey responses can be reviewed in Appendix A.

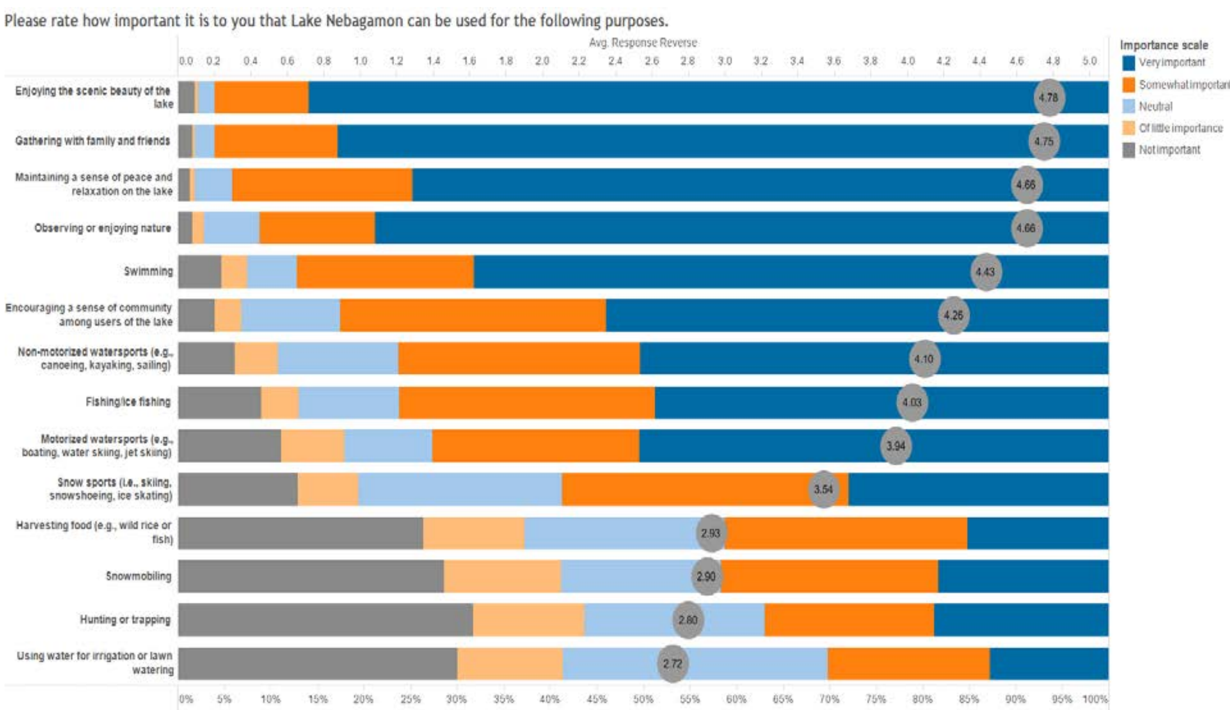

Figure 3.1. Most highly valued uses of Lake Nebagamon by survey respondents.

How is Lake Nebagamon currently used?
Lake Nebagamon is most heavily used as a recreational resource by survey respondents. Among these uses, observing nature, gathering with friends, boating and swimming were the most common activities. Fisherpersons, most typically fished walleye and sunfish, although many indicated an interest in more opportunity to catch walleye.

Which potential uses are most important and/or highly valued by different user groups?
Among the different potential uses of the lake, those that were most highly valued were: enjoyment of scenic beauty; gathering with family and friends; maintaining a sense of peace and relaxation; and observing and enjoying nature. Fishing and motorized boating were relatively highly valued by many individuals.

What are the general attitudes among lake users relative to different ecological elements and potential stressors to the lake system?
In general, most survey respondents described Lake Nebagamon as a relatively quiet, peaceful place that they care for deeply and are concerned that declines in its health would directly impact their wellbeing. Respondents generally preferred lake conditions that most closely reflect natural areas of little observable human disturbance.

How important is Lake Nebagamon in the lives of different user groups?
Lake Nebagamon is clearly an important part of the lives of those who use and interact with it. The majority of survey respondents indicated significant willingness to alter their behavior and/or financially contribute to enhance/protect the quality of the lake—in many cases, even if they were not likely to have opportunities to routinely use the lake.

What are the general value sets and/or beliefs that lake users likely base their actions on?
In general, survey respondents see Lake Nebagamon as a place to live and recreate and as an ecosystem that should be protected into the future for the sake of natural resource conservation and use by future generations. Respondents indicated a sense of responsibility for the long-term management/stewardship of the lake and a recognition that declines in the lake's health would adversely affect their wellbeing.

3.2. Use and Value Priorities

Based on results of the stakeholder survey and ongoing planning process, a series of priority uses for the Lake Nebagamon ecosystem were identified. The following values were used to development management goals to protect and/or restore the Lake Nebagamon ecosystem into the future.

- Aesthetics and scenic beauty
- Observation of the natural world
- Protection of the Lake Nebagamon ecosystem
- Relaxation and social gathering
- Boating (motor and non-motorized)
- Swimming
- Fishing

4. Management Goals

A series of goals were developed to protect and restore the ecological and social conditions that support the most highly valued uses and natural elements of the lake. Goals were developed through input from a user survey (described above) as well as a series of public and steering committee meetings. The scope and extent of planning meetings is described below.

4.1. Grant Development Meetings

In the year leading up to initiation of this planning project, two meetings were held with representatives from the Sanitary Sewer Commission and local government officials to develop the scope of work to be conducted. Drafts of the initial planning grant application were also reviewed by members of the NLA. From these initial meetings, concerns were raised about potential changes in water quality and the fishery, as well as the potential for invasive species introductions.

4.2. Public Meetings

In both 2013 and 2015, project summaries were presented at the NLA annual meeting. Presentations focused on current results and solicitation of input regarding potential management considerations for the lake. Comments from general lake association members were similar to that of the NLA board members and local elected officials—changes in the fishery and the potential for invasive species introduction were the primary concerns. Additionally, many members were appreciative and supportive of proactive steps to prevent any degradation in the lake.

4.3. Technical Team Meetings

Following the completion of field work in year one, a technical team meeting was held with representatives from Sanitary Sewer Commission, NLA and WDNR. Discussions at this meeting were focused on a review of new data and a preliminary conversation regarding potential management goals for the plan.

4.4. Draft Plan Review

Input from the stakeholder survey and planning meetings were integrated to develop a series of management goals for the plan. These goals (and the corresponding draft plan) were submitted for review by members of the NLA, WDNR, Douglas County and Red Cliff Tribe.

The goals that emerged from the stakeholder survey and public meetings are listed below:

- Maintain Current Levels of Motorized and Non-motorized Use
- Maintain Scenic Beauty of Lake Nebagamon
- Protect and Restore Nearshore and Shoreline Habitat
- Maintain Existing Water Levels and Hydrologic Processes
- Maintain Existing Water Quality Conditions
- Maintain Diverse Native Plant Communities
- Maintain Diverse Native Fish Communities
- Increase Walleye Population Densities
- Maintain Access to Native American Fisheries and Fishing Sites

5. Lake Condition Assessment

Lake Nebagamon is located in north central Douglas County (Figure 1.1). The lake conditions and processes that are necessary to support the desired uses identified above for Lake Nebagamon are influenced by a variety of physical, chemical and biological processes. This section describes the current conditions in and around Lake Nebagamon with respect to: Climate and Precipitation; Physical Habitat and Hydrologic Processes; Watershed Conditions; Water Quality Conditions; Biological Communities; and, Ecological Interactions.

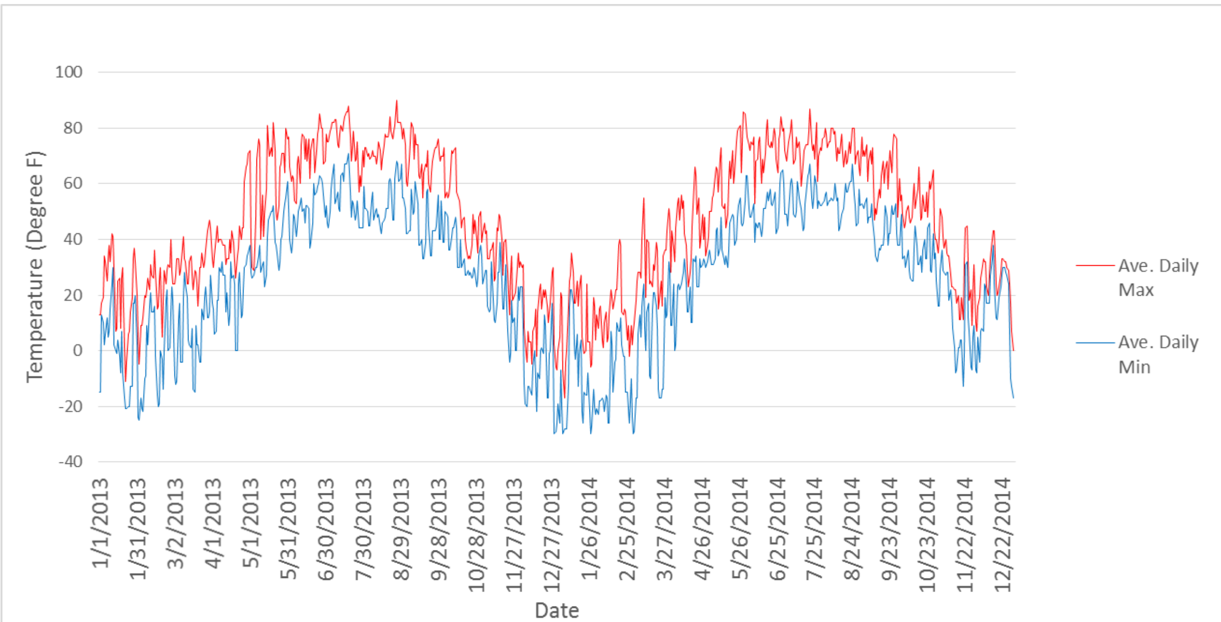

Figure 5.1. Minimum and maximum daily air temperatures through study period.

5.1. Climate and Precipitation

Climate in the Lake Nebagamon area is considered continental, but is moderately affected by the Lake Superior climate zone. Summer daily temperatures average 58.6 ^{o}F and winter daily temperatures average 24.6 ^{o}F. Annual precipitation averages 34.3 inches, most (68%) of which falls between April and September (Figure 5.1). Average seasonal snowfall is 68.1 inches. Historically, the 100-yr, 24-hour precipitation event was expected to yield ~5 inches and most engineering design throughout the area is based on the TP-40 values (Hershfield, 1963). However, precipitation recurrence intervals were recently updated in Atlas 14 (Perica et al. 2013) to account for increased spatial resolution in climatological data and account for any shifts in precipitation patterns over the last ~50 years.

Based on these updates, the 100-year, 24-hr precipitation event in the Lake Nebagamon area is now expected to yield 6.75 inches (a ~26% increase). However, the Atlas 14 precipitation estimates have only recently become available and have not been incorporated into engineering design and watershed planning work.

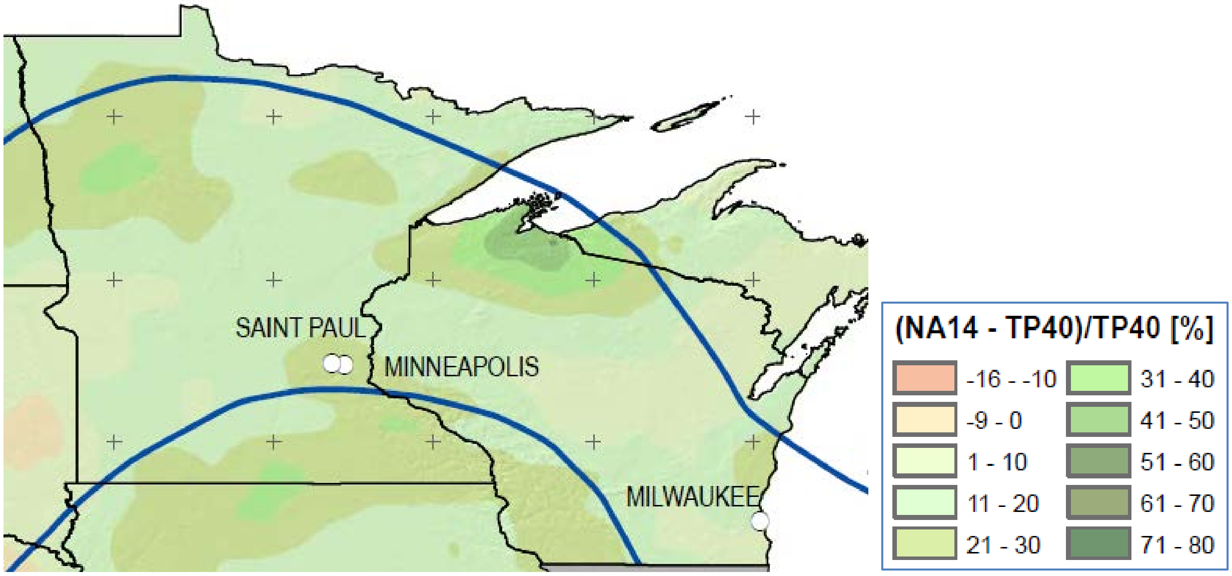

Figure 5.2. A comparison of the percent change in the 100-year, 24-hour precipitation events between the Atlas 14 and TP 40 publications. Adopted from Atlas 14 (Perica et al. 2013).

Additional changes in precipitation and atmospheric temperatures are anticipated throughout the region as a part of global climate change. As part of the Wisconsin Initiative on Climate Change Impacts (WICCI; http://www.wicci.wisc.edu/) as series of studies were conducted across Wisconsin to assess existing, and project future, climatically driven changes in environmental conditions. The major findings of this multi-year assessment (as is related to lake management) are that precipitation patterns are likely to become more intense and less frequent (i.e., increased potential for both drought and flooding) and that annual average temperatures are likely to increase. Evidence suggests that some of these changes may already be occurring, but that the rates of climate change are likely to increase into the future.

5.2. Physical Habitat and Hydrologic Processes

Physical habitat in Lake Nebagamon is shaped by a combination of the local geology, topography, landscape position of the lake and nearshore land use. Different species of plants and animals in lakes require different habitat types and conditions. As a result, lakes that retain the greatest diversity of habitat types often sustain the highest levels of biological diversity and support the widest range of uses. Although many habitat types are most easily viewed as a static "snapshot" of the lake (e.g., how many down trees are in the water), the relative occurrence of different habitat types is highly dependent on many dynamic processes (e.g., range of high and low water levels) that are less easily perceived in a snapshot.

Geology

Geology throughout the Lake Nebagamon watershed was primarily created by glacial activity ~9,500 to 23,000 ybp. As such, much of the existing geology is dominated by glacial till and outwash (Figure 5.3). Soils are comprised of a range of hydrologic soil groups, with A and B groups dominating upland areas and C and D groups dominating nearshore areas. In general, soils have high infiltration rates which facilitate groundwater flow to the lake.

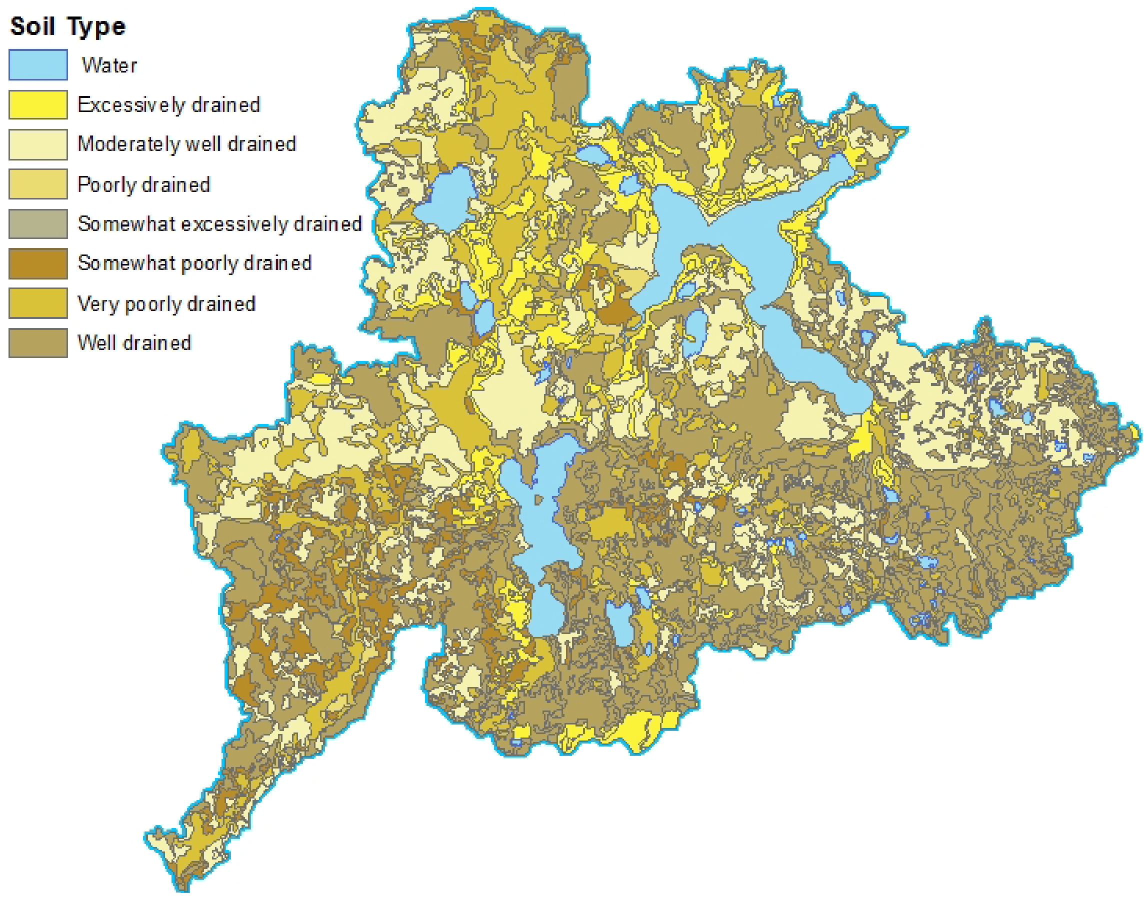

Figure 5.3. Distribution of soil groups throughout Lake Nebagamon watershed. Based on Natural Resource Conservation Service (NRCS) SURRGO soil classifications.

Bathymetry
Lake Nebagamon is a 986 acre, drainage-based lake with a maximum depth of 56 feet and an average depth of 20 feet (Figure 5.4). The Lake Nebagamon basin is irregularly shaped with a series of long, narrow and bays. Despite its long, narrow basin shape, the maximum fetch in the lake is 2.1 miles (in the northern basin).

Hydrologic Processes
The volume of water in a lake is determined by its bathymetry and the relative inputs and losses (outputs) of water to and from the surrounding atmospheric, groundwater and surface water systems (Figure 5.5). The relative influence of these different systems varies among lakes, and within each specific lake, as the rate and timing of precipitation vary throughout the season. The relationship between the different inflow and loss process in the lake (i.e., its water budget) is heavily influenced by its landscape position (Figure 5.6). In general, groundwater and atmospheric systems are the most important drivers of hydrologic processes in lakes that have a high landscape position (i.e., headwater and/or seepage lakes). As lakes exist further downstream in a watershed system, the more important surface water becomes as an input and loss mechanism. Thus, hydrologic processes in lakes with the lowest landscape position are dominated by the influence of surface water inflow and outflows.

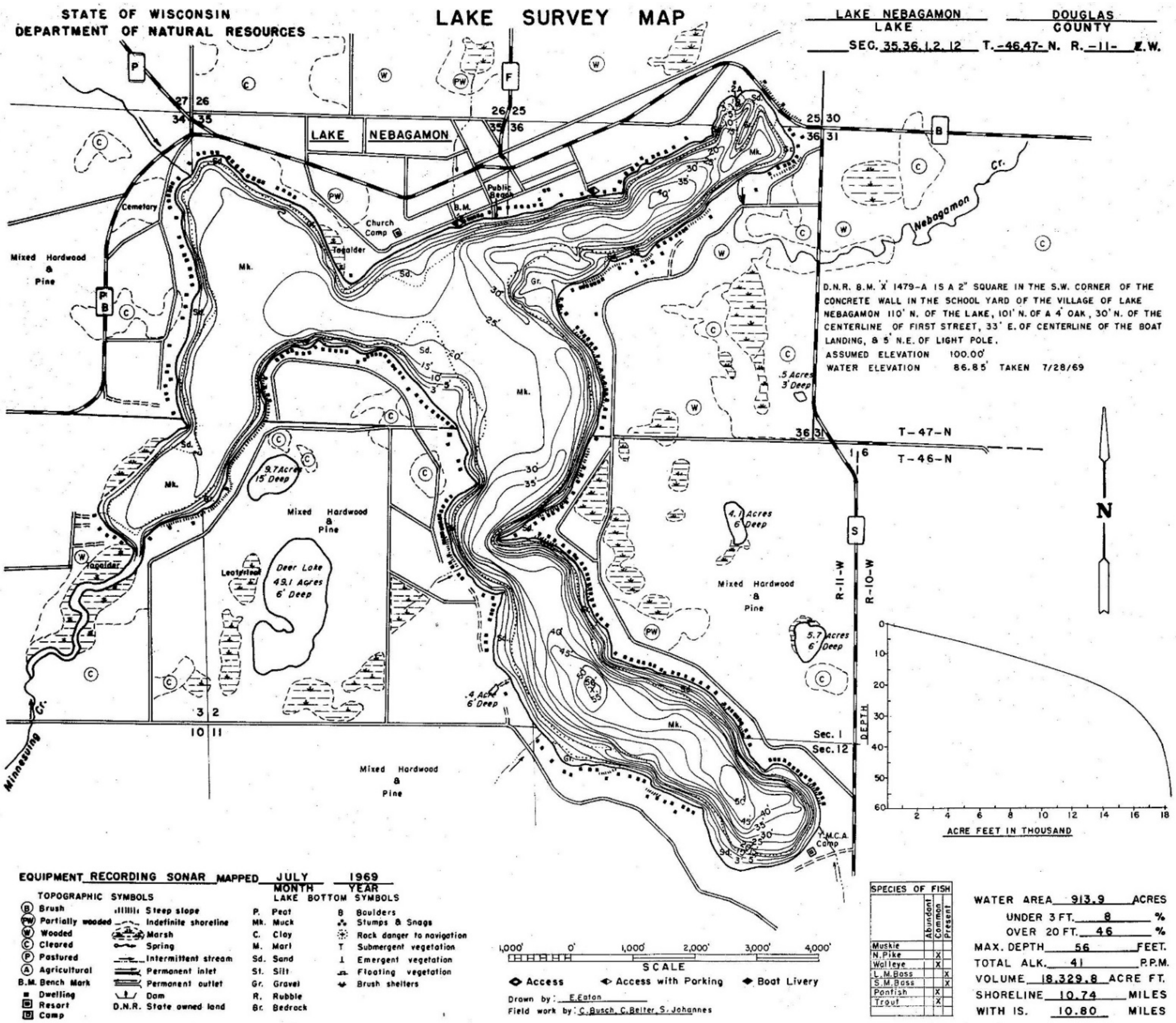

Figure 5.4. Bathymetry of Lake Nebagamon.

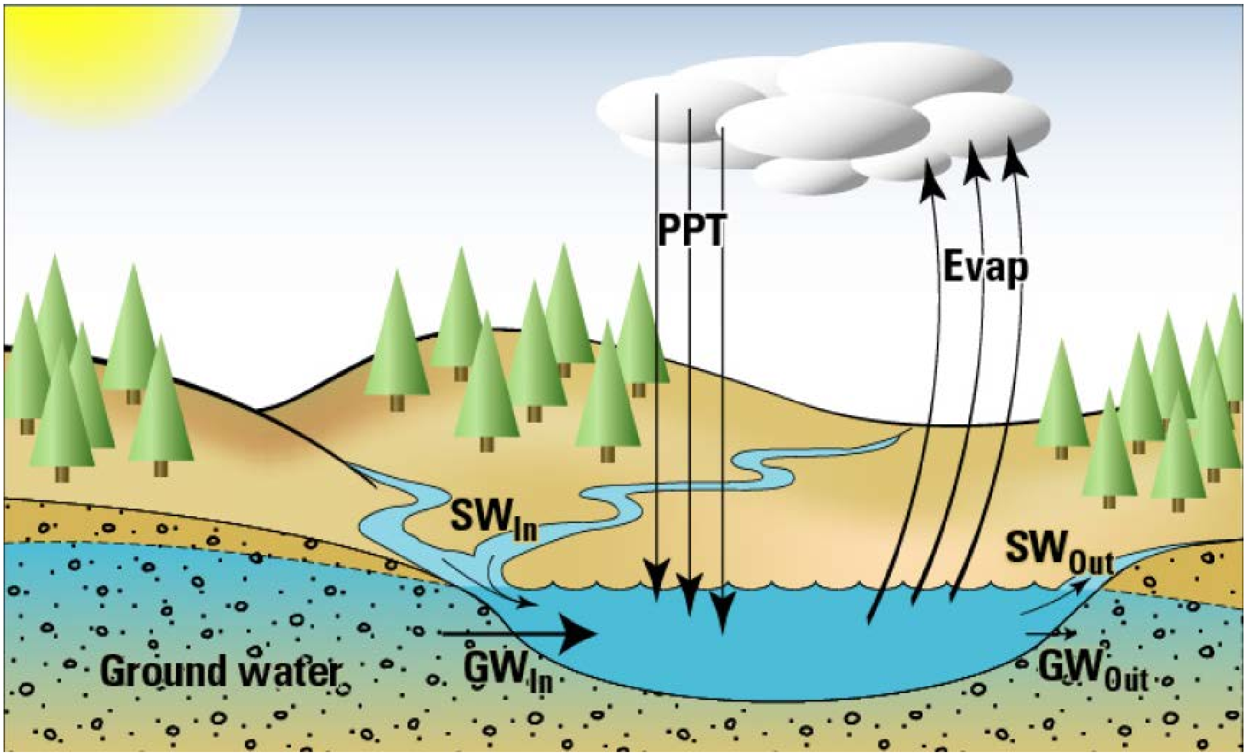

Figure 5.5. Conceptual schematic describing the surface water (SW), groundwater (GW). Precipitation (PPT) and evaporation (Evap) that determine lake levels (adopted from Krohelski, 2003).

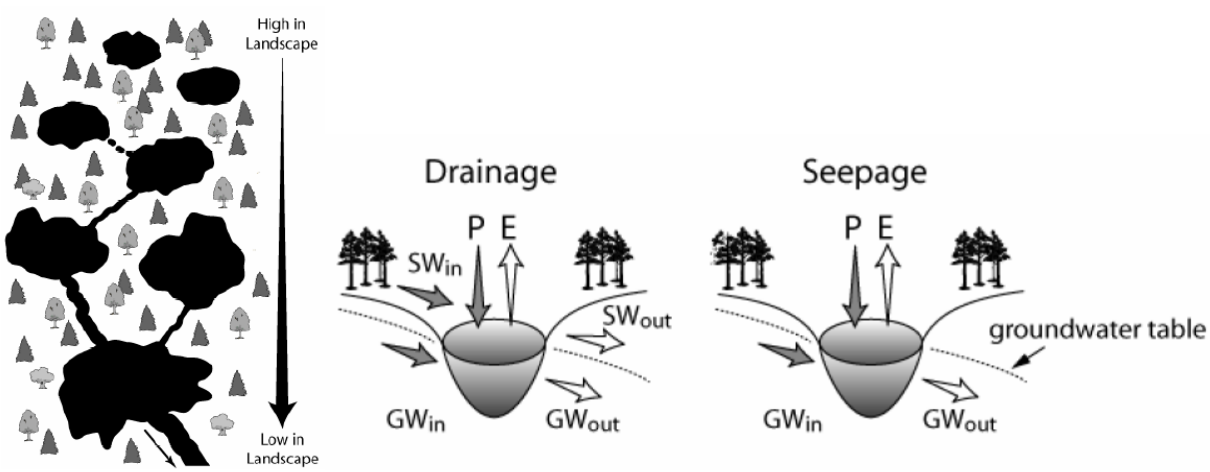

Figure 5.6. Conceptual diagram of "landscape position" and the differences in hydrologic processes between drainage and seepage lakes. Modified from Magnuson et al. 2006.

Water Level Fluctuation
Lake levels fluctuate on annual and multi-year time scales. In northern Wisconsin, lake levels are generally highest following spring snow melt and rain and lowest in late summer, fall and winter. Throughout any given year, water levels rise and fall in response to the size and timing of precipitation events. Across years (potentially decades), lake levels maintain different points of equilibrium—in drought years, water levels are generally lower, while in wet years, lake levels are generally higher. Over time, different high water events leave marks on the shoreline that designate the Ordinary High Water (OHW) mark, which has important regulatory and management implications (see Section 7.1 for additional detail).

Water level fluctuation is critical to the health of a lake because it is often a primary process that creates conditions that favor diverse biological communities. Different species (particularly aquatic plants) are better adapted to wetter or dryer conditions—and some are generalists across this range. As water levels fluctuate, no particular species becomes dominant and the biological communities are pushed toward a state of greater diversity that corresponds to different water levels throughout the lake. Similarly, as water (and ice) levels fluctuate, shoreline sediments erode away to an "angle of repose", where erodible soils gradually transition to the water's edge and sediments are anchored by vegetative root structures. When water levels are held constant (particularly at higher levels), the dynamic processes that promote biotic diversity are reduced and rates of shoreline erosion can become increased through wind and wave erosion and "ice-jacking" events (biological diversity in lakes is described in greater detail below).

Stratification and Mixing
Most deep lakes (>15 feet) in northern Wisconsin develop distinct layers throughout the summer (and occasionally winter) months (i.e., stratification; see Figure 5.7). Water is most dense (and heaviest) at a temperature just above freezing. As ice and snow melt in the spring, the "heaviest" water in the lake is at the surface—as this heavy water sinks to the bottom, the lake becomes well mixed (i.e., it "turns overs"). In this mixed condition, the temperature and chemistry of the water is essentially uniform from top to bottom. As the lake warms throughout the summer, the surface waters increase in temperature faster than deep water, which often results in the development of three layers that have distinct temperature and chemical profiles. Surface waters (or the epilimnion) are generally warmer and have higher oxygen concentrations. Bottom waters (or the hypolimnion) are generally colder and have lower oxygen concentrations. Middle waters (often referred to as the metalimnion or thermocline) generally represent a transition from surface to bottom conditions.

Stratification and turnover are key drivers of lake ecosystems. Over the course of a year (or millennia) nutrients wash into lakes (often attached to sediment particles) and gradually sink to the bottom. As a result, nutrients tend to accumulate in lake sediments over time. When lakes turn over, nutrients that have settled toward the bottom can be resuspended and made available to stimulate aquatic plant growth (particularly algae). As a lake stratifies, the metalimnion creates a functional barrier between the surface and bottom waters that tends to trap nutrients at the bottom of the lake and minimize the diffusion of oxygen from the atmosphere down into deeper waters. Thus, over the summer, oxygen concentrations tend to decrease in the deep waters (relative to the surface waters).

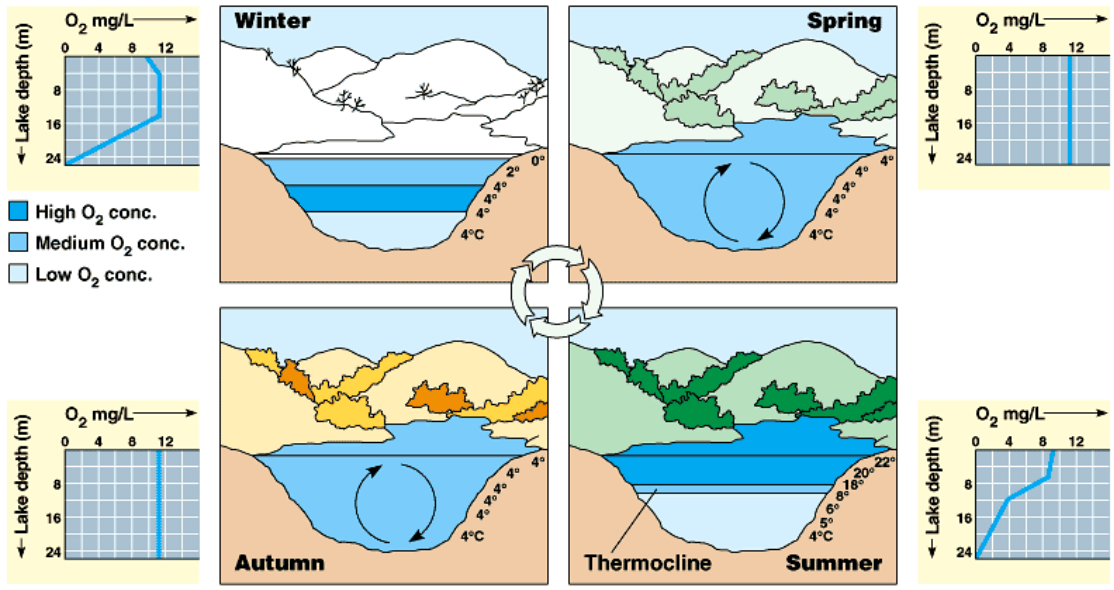

Figure 5.7. Conceptual schematic of the processes of turnover and stratification and the resulting water quality conditions.

Low oxygen conditions can directly affect a wide range of chemical and biological processes in lake ecosystems. Most directly, low oxygen conditions can result in localized "fish kills" if oxygen levels fall below a critical threshold. Perhaps more importantly, low oxygen conditions along the bottom sediments change the chemical environment from one of oxidizing conditions to one of reducing conditions. And, this shift in chemical conditions, often facilitates the release of phosphorus (once trapped in the sediments) back into the water column, where it can potentially be used by different organisms (algae in particular). Although low oxygen conditions can have some negative impacts to lake dynamics (e.g., fish kills and nutrient release), there is a significant body of evidence that suggest that episodic fish-kills may be an important component of the long-term stability of a lake (particularly in a shallow lake), see Section 5.4 for further discussion.

Shoreland Habitat

The area of transition between the terrestrial and aquatic worlds is often collectively referred to as shoreland habitat. However, shoreland habitat is often broken up into three distinct zones for purposes of lake management (Figure 5.8). The upland zone represents lands that are very rarely, if ever, inundated by water (management of this area is discussed in detail in Section 5.3). The in-lake (or littoral zone) represents the region of the lake where sunlight can penetrate down to the sediments, and rooted plants can grow. The transition zone, or shoreline, is a region of the lake that is rarely (but occasionally) inundated by water, but is linked to the in-lake zone through the processes of erosion, runoff and tree fall.

Coarse woody debris (CWD) is a critical habitat component in the nearshore ecosystems of lakes throughout northern Wisconsin. Shoreline trees fall into lakes as a result of natural die-off and wind and storm events. Once in the lake, this CWD has the potential to remain underwater for decades. In undistributed lake systems, the density of CWD in nearshore areas is often as high as 800 pieces of CWD per kilometer of shoreline. CWD serves as habitat to fish and invertebrates through a variety of processes, and loss of CWD has been shown to dramatically (and rapidly) alter the structure and function of lake ecosystems.

Figure 5.8. Conceptual diagram of the different habitat zones at the land water interface in a lake. Adopted from WDNR Healthy Lakes Implementation Plan, 2014.

Historical Conditions
Historically, relatively little was known about physical habitat and processes in Lake Nebagamon. Prior to this study, no data-sets had been developed to describe physical habitat in Lake Nebagamon.

New Data Collection
To better characterize shoreland habitat in Lake Nebagamon, shoreline and in-lake habitat conditions and the processes of stratification and turnover were characterized over the two year study period. Shoreline and nearshore habitat were quantified using methods described by the Environmental Protection Agency (USEPA, 2007). Following this method, sample transect points were identified at 20 locations around the lakeshore. At each transect, data were collected to describe the habitat conditions and level of disturbance in upland, shoreline and littoral zones of the lake using a series of semi-quantitative ranking criteria. Stratification and turnover processes were assessed following methods outlined by USEPA (2007). Vertical profiles of dissolved oxygen, temperature conductivity and pH were collected at one meter increments every two weeks from two sites that represent the deepest hole in the north and south basin of the lake. In addition to these internal processes, inflows to and outflows from Lake Nebagamon were measured over the two years study, and periods of base flow (and a variety of landscape measurements) were used to develop a water budget for the lake. A more detailed summary of methods, results and management considerations for shoreland habitat and hydrologic processes are provided in Appendices B and C.

Summary Results – Water Budget
Because of its location in the watershed, a substantial land area drains to Lake Nebagamon (Figure 1.1). As such, Lake Nebagamon is classified as a drainage lake. Results from this assessment confirm this drainage-based classification. Throughout most of the year (except spring) tributary discharge is the dominant source of water to the lake (Figure 5.9). In the spring, as snow melts and early season rains are most intense, the majority of water in Lake Nebagamon comes from watershed runoff. However, as the summer progresses, groundwater becomes increasingly

important. These results highlight the significance of tributary discharge and outflow as part of the Lake Nebagamon ecosystem.

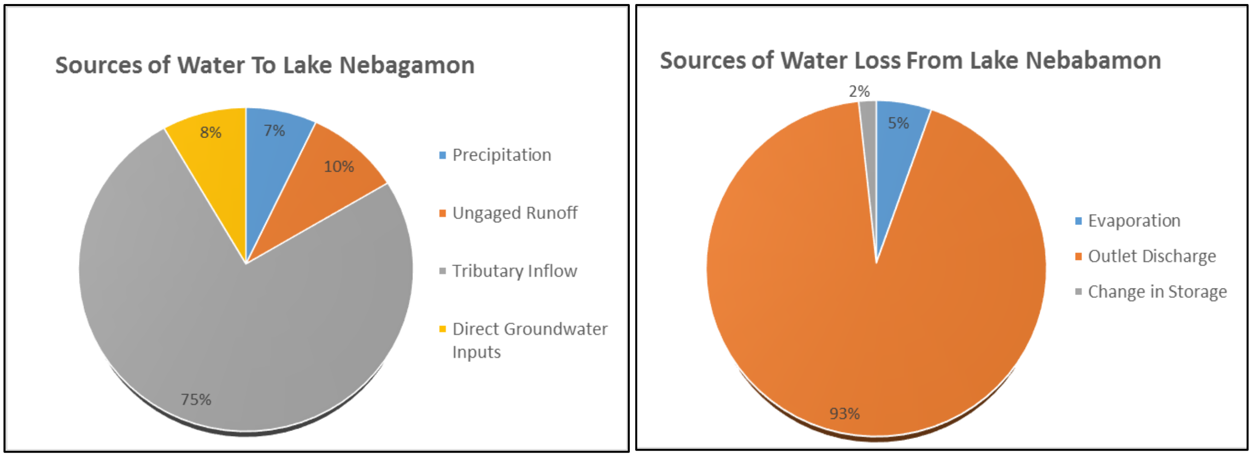

Figure 5.9. Sources of water into and out of Lake Nebagamon.

Summary Results – Physical Processes

Like most regional lakes, Lake Nebagamon mixes twice each (e.g., Figure 5.10) and develops distinct stratification throughout the summer. Because of this stratification, dissolved oxygen concentrations in the bottom waters (particularly in the southern basin) remained particularly low (often below 1 mg/L) throughout much of the summer. These low oxygen concentrations do not appear to be directly affecting fish and other living organisms throughout the lake (no fish kills were observed over this time period), but they are likely influencing the release of phosphorus from the sediments (discussed further in Section 5.4).

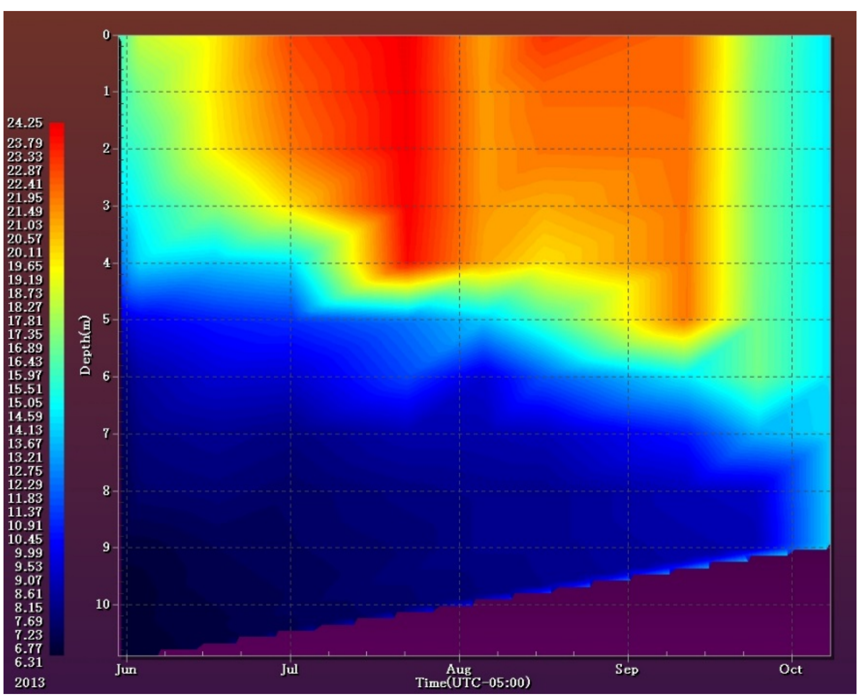

Figure 5.10. Seasonal thermal stratification in Lake Nebagamon in the north basin (2013). Red colors represent warmer waters.

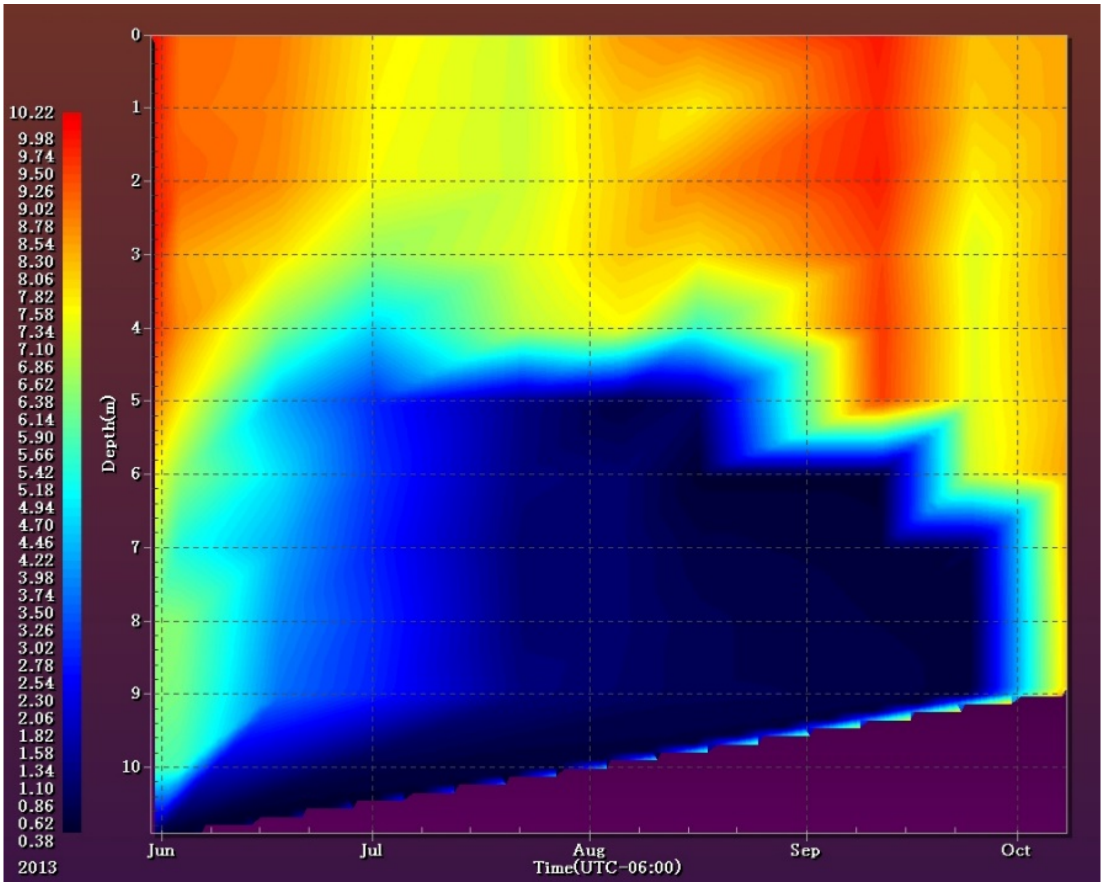

Figure 5.11. Vertical profiles of oxygen concentrations in Lake Nebagamon (north basin). Red colors indicate the areas of highest oxygen concentration.

Summary Results – Shoreland and Critical Habitat

Shoreland habitat is of moderate to low quality in Lake Nebagamon (Figure 5.12). In general, the areas of the lake that contain the highest quality shoreland habitat are located along the northern and southern shorelines. Across the lake, upland, transition and in-lake zones are generally similar in quality, although the in-lake zone has been slightly more impacted by human development. Areas that contain the highest density and diversity of floating and emergent vegetation (and likely serve as the most critical habitat for aquatic organisms) are generally located in protected embayments on the north and south end of the lake. Not surprisingly, the areas of highest quality in-lake habitat are often adjacent to the areas of highest quality upland/shoreline habitat. Given the relatively impacted condition of the shoreland areas in Lake Nebagamon, shoreland restoration efforts are a critical element of long-term protection and management of the lake system.

Summary Conclusions – Physical Habitat and Processes

Physical processes in Lake Nebagamon are consistent with other lakes throughout the region. Much of the condition of the Lake Nebagamon ecosystem is likely driven by the quality of the shoreline habitat and the influence of tributary runoff. Long-term management of Lake Nebagamon should include strategies for shoreline restoration and watershed land use management. Strategies for habitat protection and restoration are described in detail in Appendix C.

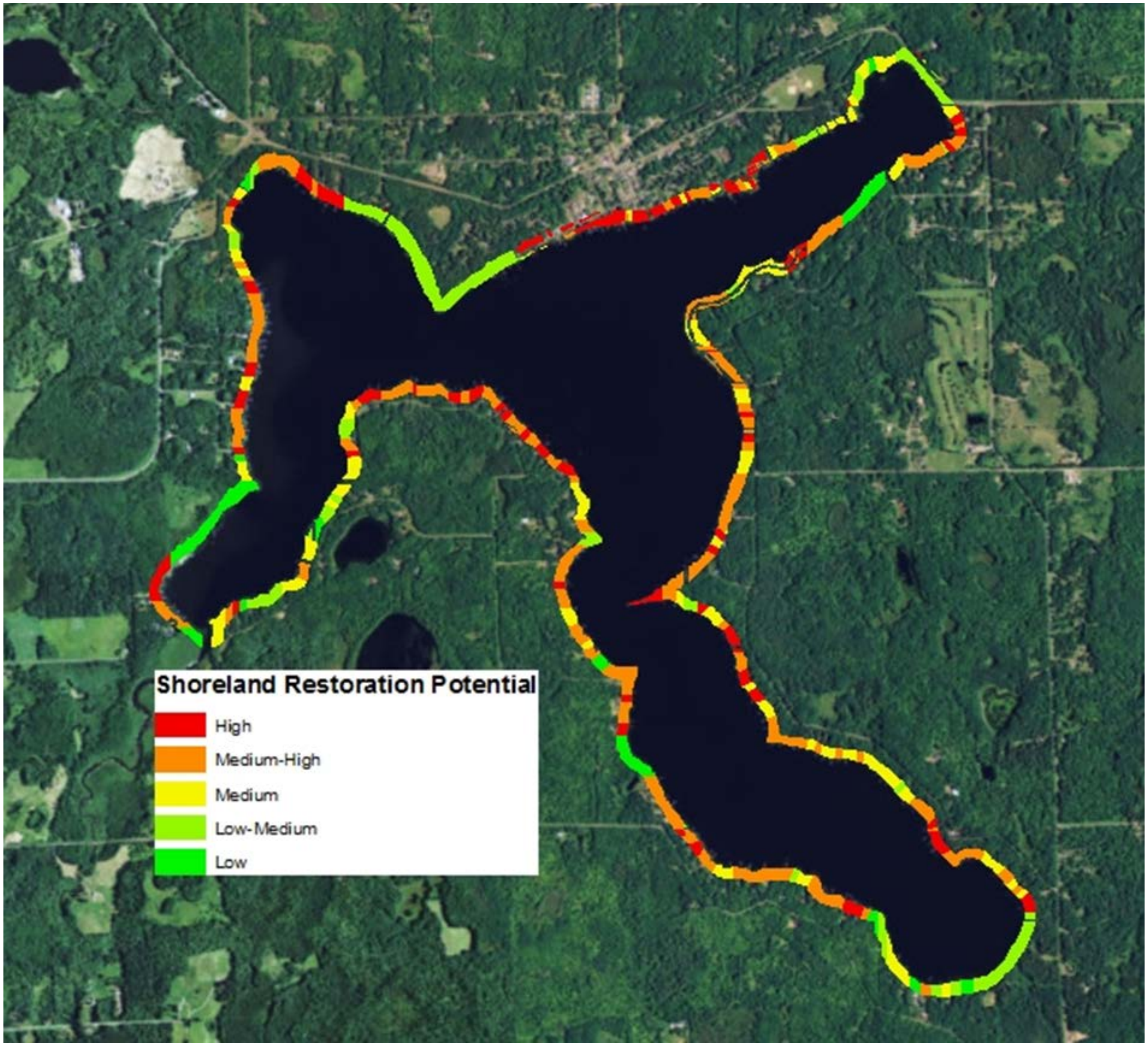

Figure 5.12. Locations of highest quality shoreland habitat, 2013.

5.3.Watershed Conditions and Processes

Lakes are ultimately a product of their watershed (or lakeshed) conditions. In northern Wisconsin, most lakes were formed by some glacial event. Following their formation after the last glacial maxima (~15,000 ybp), most all lakes in this region have been accumulating sediments and nutrients that have runoff from their upland watershed following snow-melt and precipitation events (Figure 5.13). As a result, the sediment—and more importantly, nutrient concentrations—in lakes generally increases over time (the chemical and biological effect of nutrient and sediment loading to lakes is described below in Section 5.4).

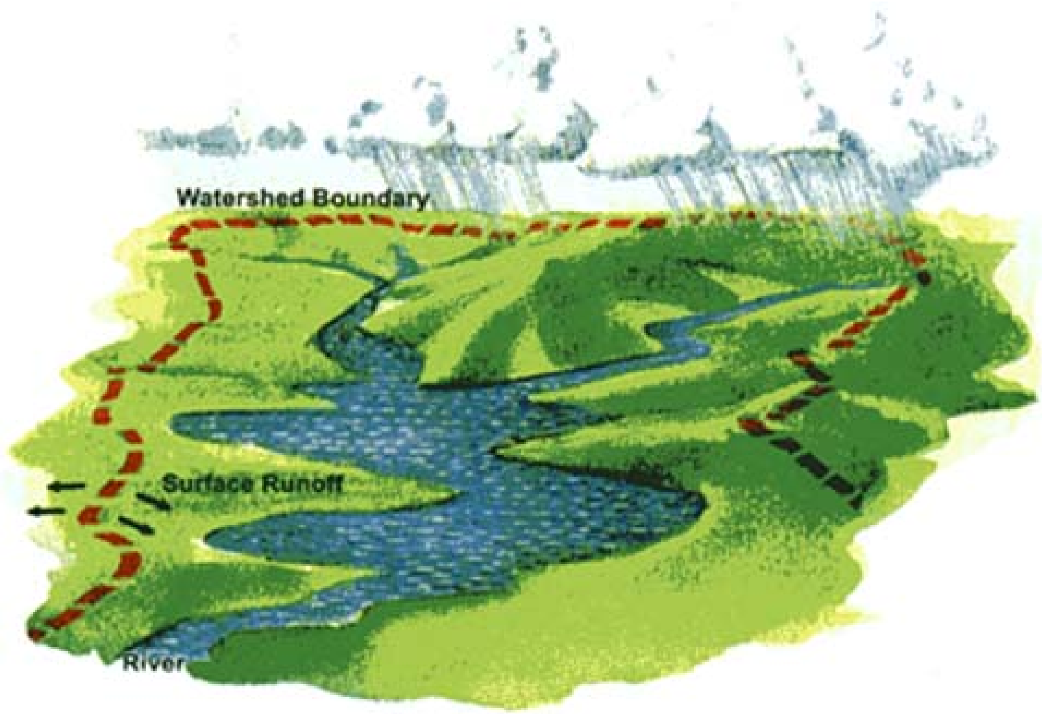

Figure 5.13. Conceptual diagram of the land area that contributes water to a lake—often referred to as the watershed, or lakeshed.

The rate of nutrient (particularly phosphorus) and sediment delivery to a lake is determined by its watershed position, regional precipitation patterns, soil characteristics, topography and the surrounding watershed land use. Of these attributes, land use is typically the only one that can be controlled through management activities and is often a primary consideration in the long-term management of a lake.

In general, as land cover is converted from a native vegetative community to an altered state, the rates of overland water flow and erosion increase. Consequently, rates of groundwater recharge decrease, while rates of phosphorus runoff increase (as well as additional pollutants). Additionally, if the “new” land use increases nutrient and/or sediment application rate (e.g., via fertilizer application or the erosion of exposed sediments), rates of pollutant delivery can be further increased. Changes in rates of nutrient and sediment delivery from different land uses and/or land covers are often described as an annual, unit-area load (i.e., the number of pounds/acre/year of phosphorus that are likely to wash into a lake from different land use types).

To proactively manage lake ecosystems, it is important to understand the relationship between land cover and land use. Land cover describes the current conditions of a particular land area (e.g., a forest vs. a residential development). Land use describes how people are currently and/or plan to use a particular land area in the future. Land use is often driven by local zoning ordinances. For example, a parcel of land can be zoned for low density residential developed, but covered primarily by a forest. Because different land covers can have different impacts on a lake (particularly with respect to water quality), it is important to understand the current land cover and how, based on zoning, land cover will likely change in the future.

Historical, Current and Future Land Cover and Use

The transition of land cover types was summarized and projected based on historical, current and anticipated future land uses throughout the watershed. Historical land uses were estimated by examining archived satellite imagery and land cover surveys. Current land uses are based on a combination of the 2011 data from the National Land Cover Dataset (NLCD) and the parcel specific shoreland habitat assessments. Projections of anticipated future land uses were based on zoning conditions specified in the comprehensive plans for the Village of Lake Nebagamon. Details of the land use assessment are described in Appendix D.

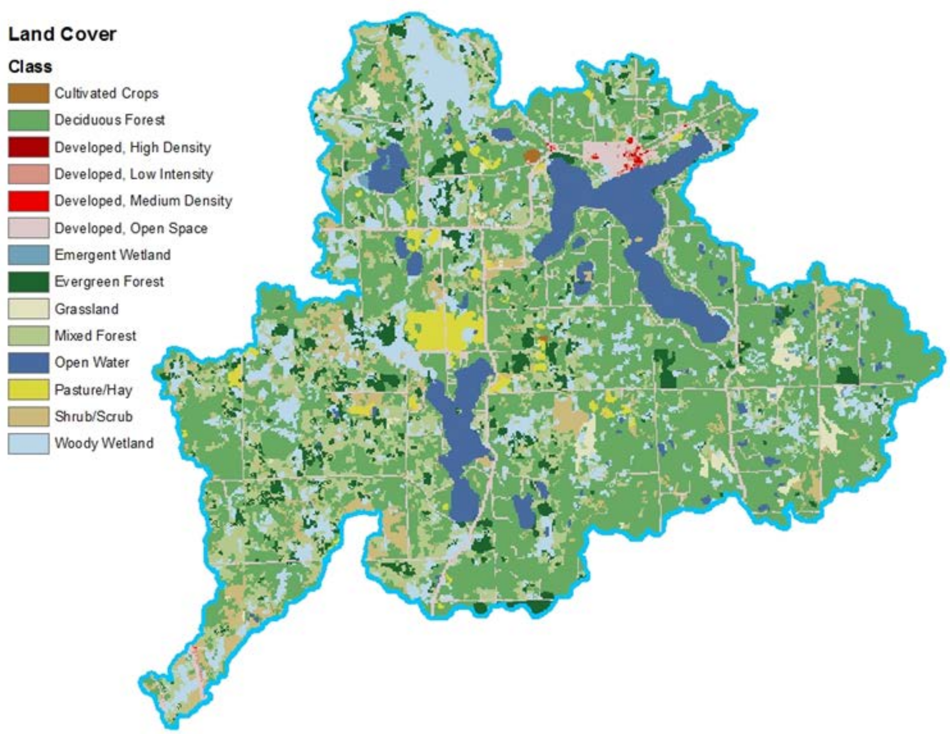

Figure 5.14. Land cover throughout the Lake Nebagamon watershed and surrounding shoreland areas.

Summary Results – Land Use

Land cover throughout the watershed has significantly shifted since the mid-1800s and is anticipated to continue to change in the coming years (Figures 5.14 and 5.15). Historically, sugar maple and yellow birch dominated much of the north and western lake shore, while white, jack and red pine dominated much of the south and eastern lake shore. Over time, the relative abundance of coniferous species has declined and has been replaced by mixed forests and small amounts of urban and agricultural lands. As the permanent and seasonal population in the area continues to grow, land cover throughout the watershed is expected to become more dominated by low and medium density urban development.

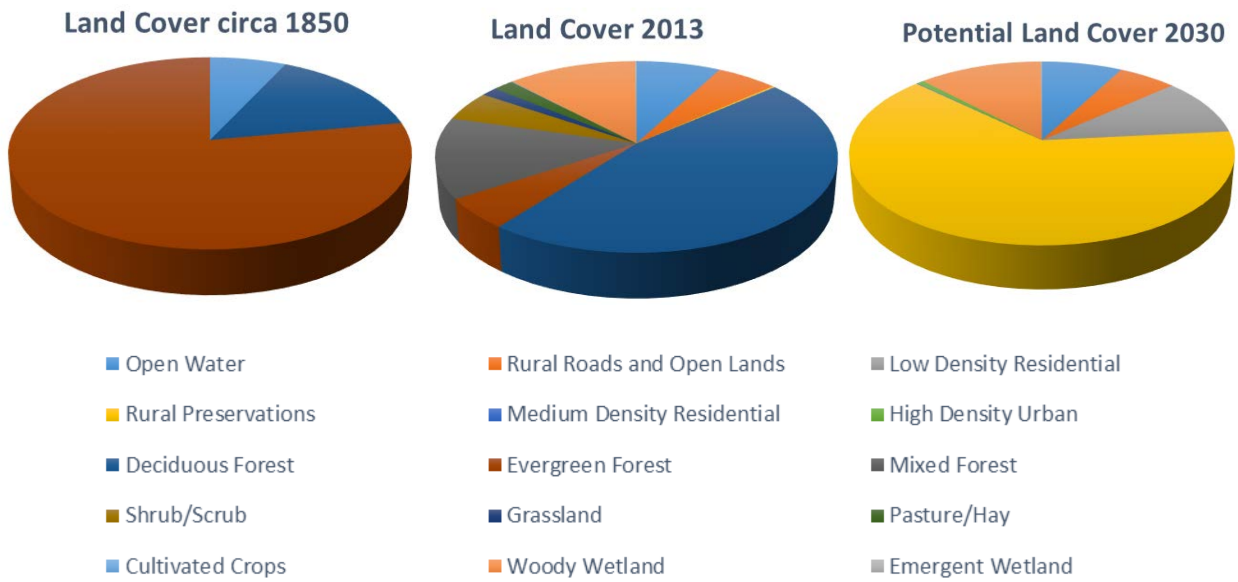

Figure 5.15. Land cover change throughout the Lake Nebagamon watershed.

Historical, Current and Future Watershed Nutrient Loads
Based on historical, current and anticipated future land use and land cover information, corresponding annual nutrient loads to Lake Nebagamon were calculated. Total acreages of different land covers were multiplied by a corresponding expected annual pound/acre/year phosphorus runoff value. Phosphorus runoff to the lake was then summarized as an annual load from each land use type.

Summary Results – Watershed Nutrient Export
As might be expected, as land throughout the watershed becomes increasingly covered by different types of urban land uses, phosphorus runoff to the lake is likely to increase (Table 5.1). Based on these changes, annual phosphorus runoff to the lake has likely increased by approximately 72% percent over pre-development conditions. If the Lake Nebagamon watershed is fully developed according to existing zoning and land use policies, phosphorus runoff to the lake has the potential to increase by an additional 15 percent by 2030.

Shoreland Septic Systems
To calculate phosphorus runoff to Lake Nebagamon from septic systems, the total number of septic systems from privately owned shoreline parcels was multiplied by an expected per capita annual phosphorus discharge value and scaled depending on the likely number of users and seasonality of usage. Because no comprehensive inventory of septic system types exists, estimate were based on values observed in similar systems, and as such, results should be interpreted in general terms.

Table 5.1. Potential sources of phosphorus from different land uses in the Lake Nebagamon watershed.

Potential Phosphorus Source	Annual TP Loads			Estimated Annual Phosphorus Loads to Lake Nebagamon					
				Historical (1856)		Current (2013)		Potential Future (2030)	
	Minimum	Maximum	Most Likely	Units	TP Load	Units	TP Load	Units	TP Load
Agriculture Lands	(lbs./acre/yr)			Acres	lbs.	Acres	lbs.	Acres	lbs.
Cultivated Crops	0.5	3	1	0	0	21	21	0	0
Pasture/Hay	0.1	3	1	0	0	472	472	0	0
Urban Lands	(lbs./acre/yr)			Acres	lbs.	Acres	lbs.	Acres	lbs.
Rural Roads and Open Lands	0.1	0.5	0.3	0	0	1412	424	3896	1169
Developed, Rural Residential	0.05	0.25	0.1	0	0	53	5	15911	1591
Developed, Medium Density	0.3	0.8	0.5	0	0	17	9	22	11
Developed, High Density	1	2	1.5	0	0	2	2	175	263
Forest and Grasslands	(lbs./acre/yr)			Acres	lbs.	Acres	lbs.	Acres	lbs.
Deciduous Forest	0.05	0.2	0.09	5360	732	11679	1589	0	0
Evergreen Forest				2010		1314		0	
Mixed Forest				766		3412		0	
Shrub/Scrub				0		1250		0	
Grassland	0.01	0.25	0.17	0	0	373	63	0	0
Wetland	0.01	0.01	0.01	191	2	3012	30	3012	30
Permitted Sources	(lbs./source/yr)			Sources	lbs.	Sources	lbs.	Sources	lbs.
None	-	-	-	-	-	-	-	-	-
Non-permitted Sources (lbs./system)	(lbs./systems/yr)			Systems	lbs.	Systems	lbs.	Systems	lbs.
*Septic Systems	1.1	1.8	1.5	0	0	359	164	610	278
Relative Changes in Phosphorus Load					**Total**	**%**	**Total**	**%**	**Total**
Total Watershed Load					**734**	**72%**	**2615**	**15%**	**3064**
Permitted/Non-permitted Source Load					**0**	**100%**	**164**	**41%**	**278**
Total Phosphorus Loads					**734**	**74%**	**2779**	**17%**	**3342**
Per Acre Phosphorus Load					**0.03**	**72%**	**0.10**	**15%**	**0.12**

Table 5.2. Potential septic system contributions of phosphorus to Lake Nebagamon

Time Period	Residency	Number of Septic Systems	Number of Users per System	Seasonal Ratio	Soil Retention	Export (lbs/capita years)			Load (lbs/year)		
						Low	High	Average	Low	High	Average
Current Conditions	Full-time	90	2.5	1	0.3	1.1	1.8	1.5	74	121	**101**
	Seasonal	187	2.5	0.3	0.3	1.1	1.8	1.5	46	76	**63**
	Total	**359**	**2.5**	**0.65**	**0.3**	**1.1**	**1.8**	**1.5**	**120**	**197**	**164**
Addition of 150	Full-time	152	2.5	1	0.3	1.1	1.8	1.5	126	206	**171**
	Seasonal	317	2.5	0.3	0.3	1.1	1.8	1.5	79	128	**107**
	Total	**610**	**2.5**	**0.65**	**0.3**	**1.1**	**1.8**	**1.5**	**204**	**334**	**278**
Removal of 100	Full-time	65	2.5	1	0.3	1.1	1.8	1.5	53	87	**73**
	Seasonal	135	2.5	0.3	0.3	1.1	1.8	1.5	33	55	**45**
	Total	**259**	**2.5**	**0.65**	**0.3**	**1.1**	**1.8**	**1.5**	**87**	**142**	**118**
Removal of 150	Full-time	52	2.5	1	0.3	1.1	1.8	1.5	43	70	**59**
	Seasonal	109	2.5	0.3	0.3	1.1	1.8	1.5	27	44	**37**
	Total	**209**	**2.5**	**0.65**	**0.3**	**1.1**	**1.8**	**1.5**	**70**	**114**	**95**

Summary Results – Septic Systems
Under current conditions, 359 privately owned shoreline parcels draining to Lake Nebagamon use septic systems. Of these, most (~52%) are seasonal residences. Based on these parameters, the annual load of phosphorus to Lake Nebagamon from septic systems is approximately 164 lbs/year (Table 5.2). Given the current zoning ordinances relative little shoreline development is expected into the future. Removal of 100 to 150 septic systems through use expansion of a sanitary sewer system has the potential to reduce annual phosphorus runoff by between 46 and 69 lbs/year (less than 1% of the total phosphorus budget for the lake).

Summary Conclusions – Watershed Conditions
Watershed delivery of phosphorus to Lake Nebagamon has likely increased over time in response to land use/land cover change. Most of this increase in phosphorus is likely as a result of changes in land cover and a smaller percentage is potentially attributable to septic system discharge. If future land use planning/zoning scenarios are realized, it is likely that phosphorus runoff to Lake Nebagamon will increase by a relatively moderate amount. Given the land use development guidelines in place, future land uses have the potential to increase phosphorus runoff to the lake by approximately 20%. Given the limited data available to describe the current condition/use of septic systems and the uncertainty underlying the realization of future land use scenarios, these estimates should only be used to inform general watershed planning.

5.4. Water Quality Conditions

Water quality in Lake Nebagamon is influenced by a combination of processes in the lake and its surrounding watershed. In general, short-term changes in water quality are often attributable to in-lake processes, while long-term trends in lake condition are often attributable to changes in watershed conditions. Although a wide range of biotic and abiotic factors shape water quality conditions in lakes, the primary driver of water quality conditions in lake ecosystems is their nutrient concentration (particularly for phosphorus).

As described above, as lakes "age" their nutrient concentration generally increases (Figure 5.16 and 5.17). This process of lake aging is generally referred to as eutrophication. Most lakes in northern Wisconsin were created by glaciation and began their existence as low-nutrient, oligotrophic lakes. Oligotrophic lakes are characterized by deep, cold clear water with relatively little plant growth and fish communities that are dominated by trout, cisco and perch. As nutrients and sediments wash into the lake each year and nutrient concentrations increase, the lake becomes more productive (i.e., more plants grow) and the composition of the biological communities shift. Mesotrophic lakes are characterized by increased aquatic plant growth, somewhat warmer, shallower water, with reduced water clarity and fish communities that are dominated by perch, smallmouth bass, walleye and pike. As the lake continues to age and increase in nutrient concentration, the biological communities continue to shift toward more eutrophic conditions. Eutrophic lakes are warmer and shallower and characterized by dense aquatic plant communities and relatively warmer, more turbid waters that are dominated by sunfish, largemouth bass and perch. As lake depth continues to decrease through sedimentation and nutrient concentrations continue to increase, the lake become hypereutrophic and ultimately transitions into a bog and/or wetland ecosystem. Each stage in this nutrient-driven evolution of a lake is often referred to as a trophic state.

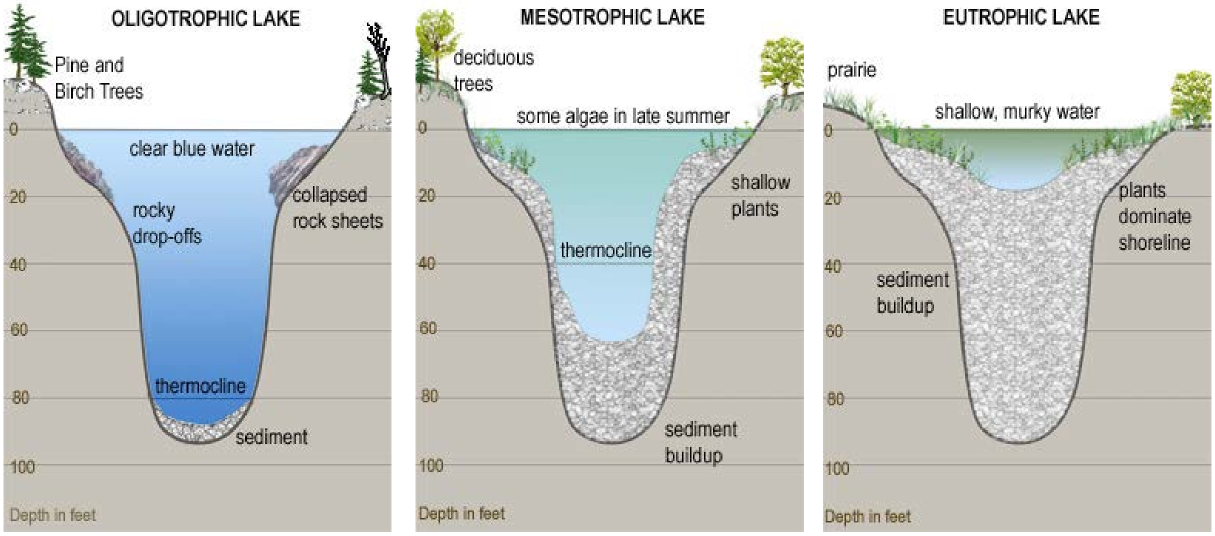

Figure 5.16. Conceptual diagram of the structure of different lake classifications. Adopted from http://rmbel.info/lake-trophic-states-2/.

Because oligotrophic lakes are relatively deep, nutrients and sediments that settle out to the bottom of the lake are generally isolated from biological productivity. As such, water clarity and biological productivity in oligotrophic lakes are primarily influenced by "new" nutrients and sediment that wash in on an annual basis (often referred to as the "external load"). As the lake becomes warmer and shallower, wind mixing and aquatic plant growth and decomposition become more important drivers of water clarity, such that in eutrophic lakes, phosphorus release from sediments and sediment (re)suspension can be the most important drivers of water clarity (often referred to as the "internal load"). Because this stratification also can result in oxygen depletion, nutrients, particularly phosphorus, can be released back to the water column as the chemical processes in the sediments shift to a "reducing" system in the presence of low oxygen conditions. If stratification in the lake is consistently present throughout the year, soluble phosphorus in the deep water remains relatively isolated from the algal communities in the surface water. However, if the depth of stratification is shallow (i.e., sunlight can penetrate through it) or the stratification is periodically broken up wind, wave or current-driven mixing, soluble phosphorus can be released in pulses to the surface waters, resulting in increased algal blooms.

In lakes of all trophic states, water clarity is further influenced by food web interactions. The predominant driver of water clarity in most lakes is phytoplankton (algae) growth (and in lesser instances, suspended sediments). Although phytoplankton growth is predominantly driven by phosphorus concentrations, the density of phytoplankton is further influenced by the rate of phytoplankton consumption (i.e., grazing) by zooplankton. As such, many lakes which have high phosphorus concentrations also have relatively high water clarity, as a result of zooplankton grazing of phytoplankton. Because zooplankton grazing of phytoplankton is such an important driver of water clarity, any processes in the lake that affects the diversity and relative abundance of zooplankton can have an indirect effect on water clarity. In particular, any changes in the fish community that increase the relative abundance of planktivorous fish (e.g., sunfish) can have secondary impacts on water clarity (e.g., as sunfish populations increase, water clarity often decreases in response to reduced zooplankton abundance, particularly in shallow, more eutrophic lakes.) Food web interactions are described in greater detail below (see Section 5.4).

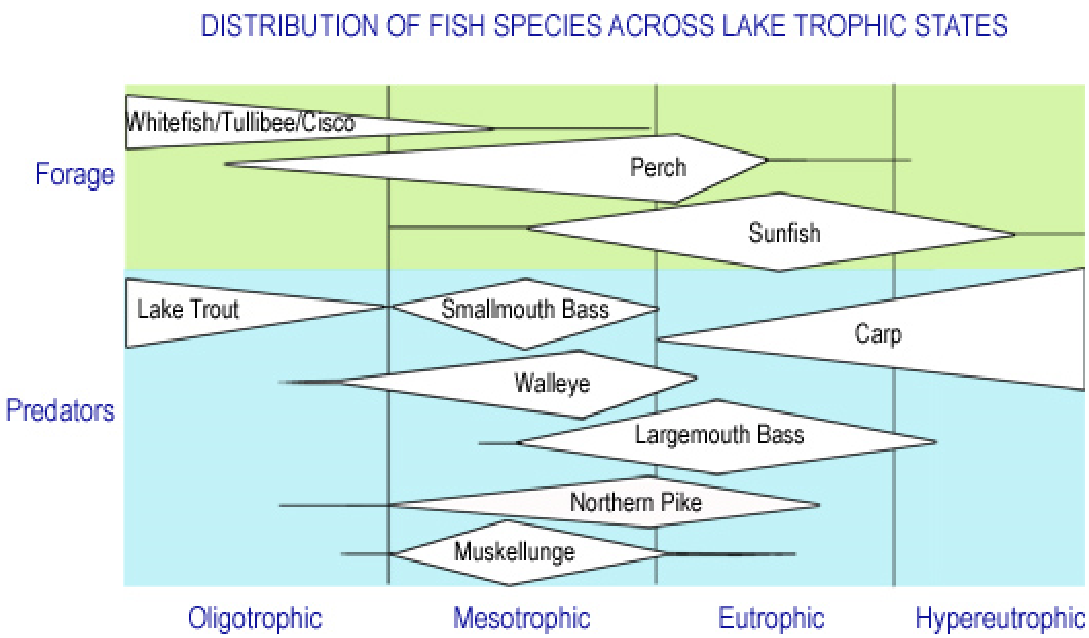

Figure 5.17. Conceptual diagram of the different fish communities that often inhabit lakes of different trophic conditions. Adopted from http://rmbel.info/fish-distribution/.

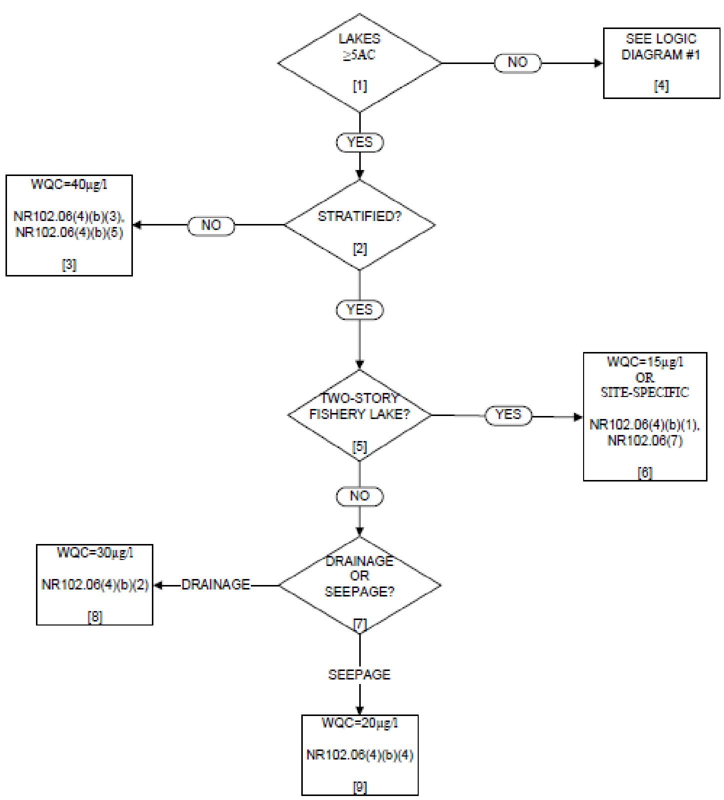

Figure 5.18. Total phosphorus water quality standards for lakes in Wisconsin.

Managing Water Quality Conditions
Because of the importance of water quality process on in-lake conditions and the complexity of these interactions, the management of a lake is often highly dependent on the measurement of different parameters that are taken to characterize the trophic state of a lake. The three most commonly measured water quality parameters in lake management are total phosphorus (TP; a measure ofs nutrient conditions in the lake), Chlorophyll-a (Chl-a; a measure of algal densities) and Secchi depth (a measure of water clarity). These parameters (individually or combined) are also often used to calculate a Trophic State Index (TSI) that describes the relative trophic state of the lake (e.g., oligotrophic vs. eutrophic).

Historical Water Quality Conditions
Water quality in Lake Nebagamon has been monitored over different periods and by different agencies since 1973. All data for this section were accessed through the WIDNR Surface Water Information Management System (SWIMS) or the corresponding lake website (http://dnr.wi.gov/lakes/lakepages/LakeDetail.aspx?wbic=2865000). The most detailed water quality study for Lake Nebagamon was conducted as part of a WDNR Lake Planning Grant (LPL-093) from 1992-1994 (USGS, 1992; 1993; 1994). Results from this study suggested that 1) relatively little difference exists between the three lobes of the lake in terms of water quality and 2) Lake Nebagamon had somewhat lower water clarity than similar regional lakes. Additionally, WDNR collected inflow and outflow data on a monthly basis (for nutrients) at two sites in 1973 and 1974 and in-lake data as part of the Baseline Monitoring Program 2004.

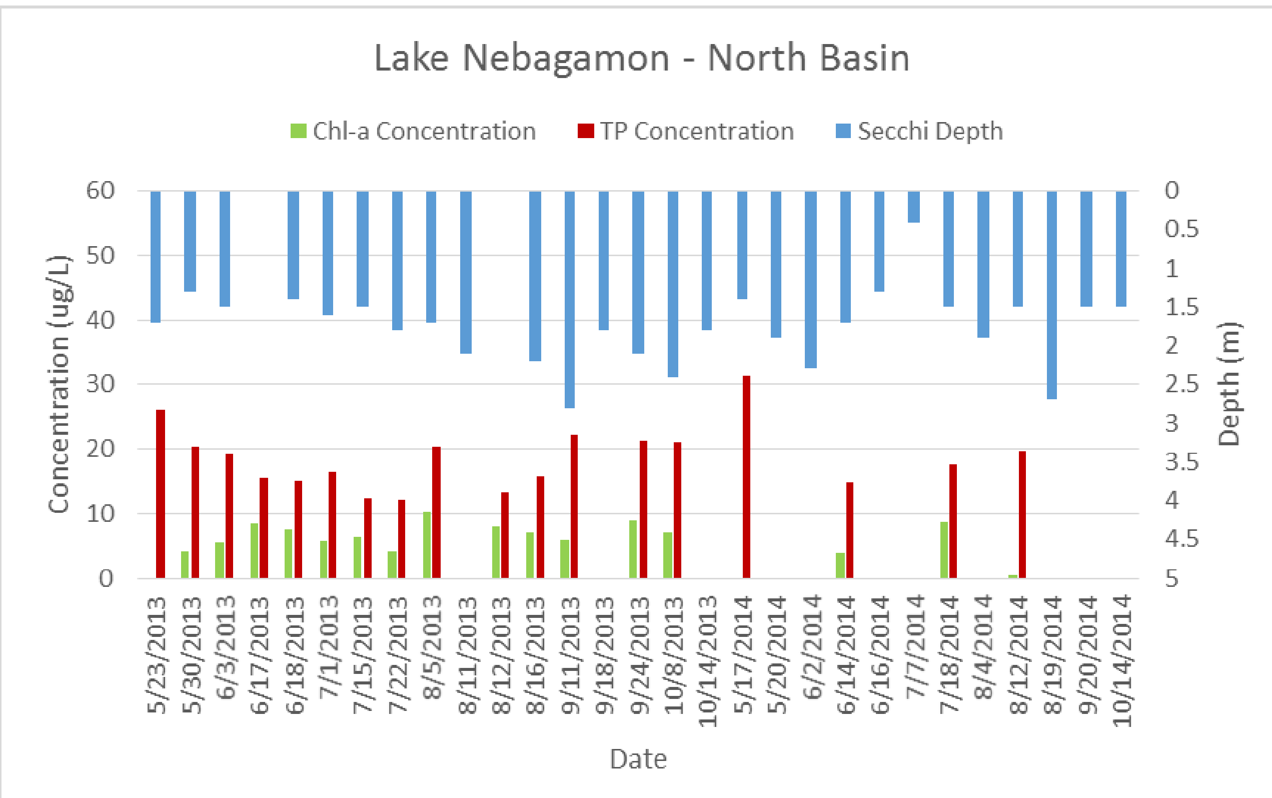

Figure 5.19. Average annual water quality trends in Nebagamon (2013-2014).

The majority of the recent water quality data have been collected through the CLMN. Through this program, volunteers have collected data at one primary site since 1986. Volunteers have generally collected samples once per month from June to September at the deepest point in the sampling location. Samples have been analyzed to measure total phosphorus and Secchi depth in surface waters and temperature and dissolved oxygen throughout a vertical profile at one meter intervals. Water quality measurements have primarily focused on Secchi depth and, to a lesser extent, total phosphorus in surface waters.

The combination of the water quality data suggests that Lake Nebagamon has an average phosphorus concentrations of ~ 19 ug/L, an average Secchi depth of 8 feet, a Secchi Trophic State Index (TSI) of 47.3 and a total phosphorus TSI of 46.5 (Figures 5.19 and 5.20). Lake Nebagamon is currently classified as a mesotrophic lake. In general, the existing data suggest that water quality has decreased over the last 100 years, but that current water quality conditions are relatively stable.

New Data Collection
To supplement the existing water clarity and nutrient data (summarized above), a more intensive water quality assessment was conducted from 2013-2014. As part of this study, samples were collected at two sites in the north and south basins every two weeks from May-October. At each site, water quality was described by supplementing Secchi depth measurements with Chl-a data, as well as profile measurements of temperature, pH, dissolved oxygen, conductivity, total phosphorus, soluble reactive phosphorus and total nitrogen. Details of the intensive water quality sampling are described in Appendix B.

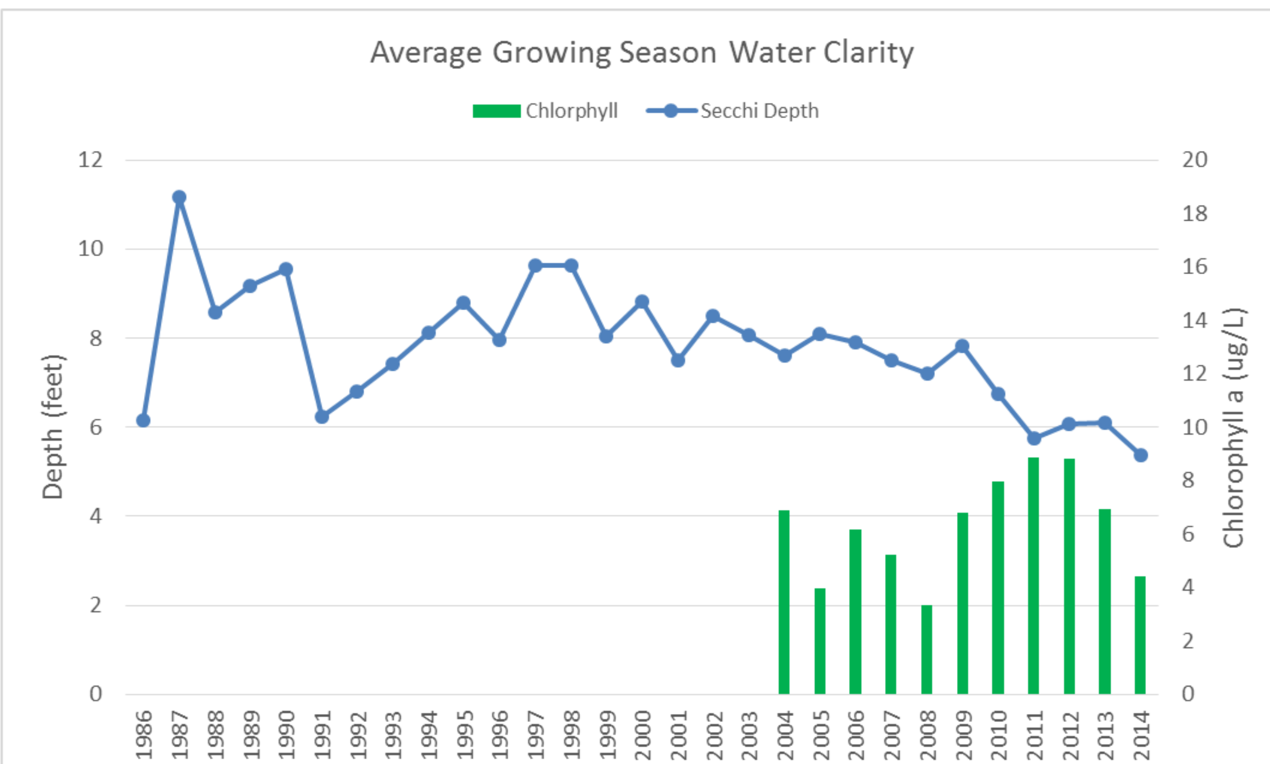

Figure 5.20. Historical trends in Secchi depth in Lake Nebagamon.

Summary Results – Water Quality
Results from this work suggest that water quality in Lake Nebagamon meets state water quality standards. Total phosphorus, chlorophyll and Secchi depth measurement all indicated that Lake Nebagamon is meeting water quality standards and is accurately classified as a mesotrophic lake.

Nutrient concentrations throughout the depth profile samples are of interest in Lake Nebagamon. Although surface water phosphorus concentrations in Lake Nebagamon, concentrations of phosphorus in the hypolimnion are often elevated, likely as a result of low oxygen conditions (Figure 5.21).

Summary Results – Lake Nutrient Budget
Within Lake Nebagamon, the majority of the external phosphorus load originates from watershed runoff (Figure 5.22). Most of this watershed loading of phosphorus occurs as part of spring snowmelt and rainfall. Approximately 56% of the phosphorus delivered to the lake from external sources is discharged through the outlet to the Nebagamon Creek. Additional "internal" sources and loss processes are discussed in Appendix G.

Summary Conclusions – Water Quality Conditions
Water quality conditions in Lake Nebagamon are consistent with those expected for a mesotrophic lake. Because a relatively high percentage of annual phosphorus is retained in Lake Nebagamon, it is likely that internal cycling of phosphorus is a key element of the lake ecosystem.

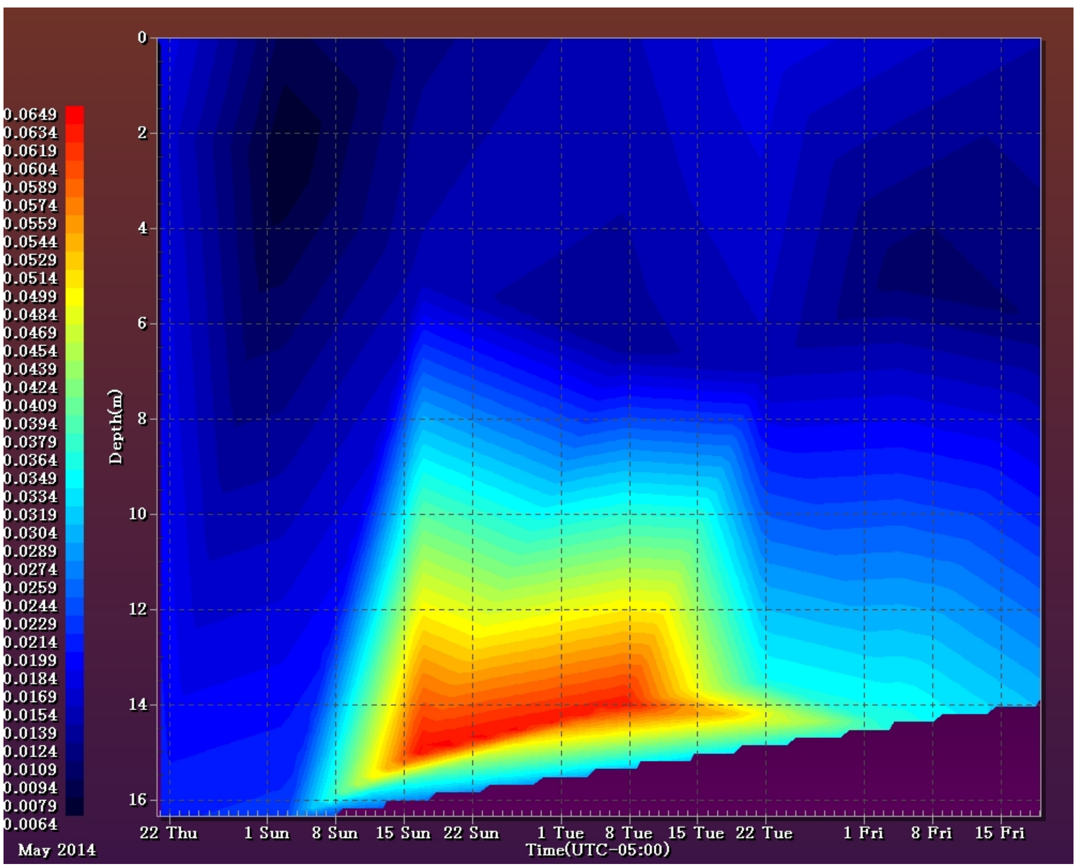

Figure 5.21. Seasonal profiles of total phosphorus concentrations in Lake Nebagamon (north basin).

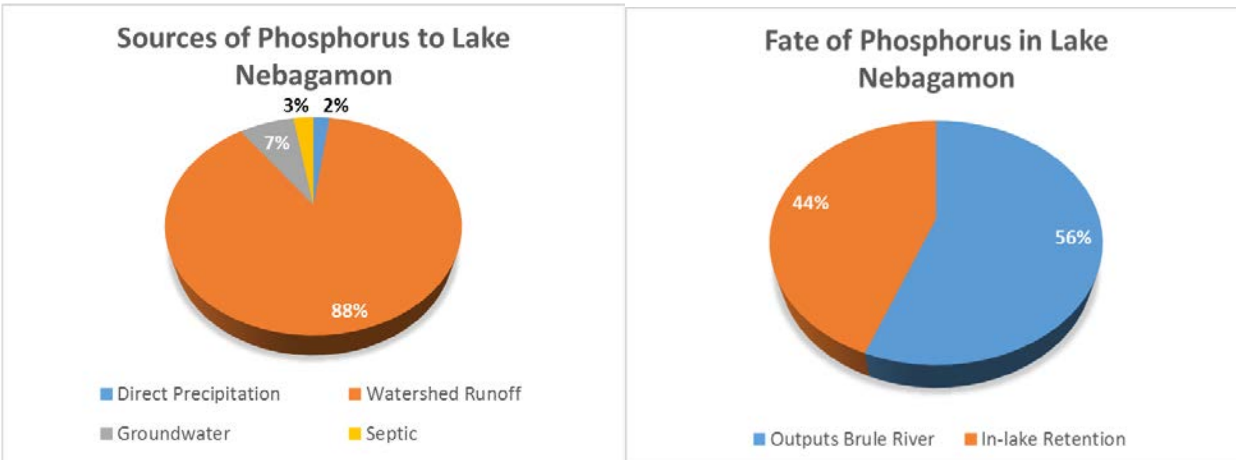

Figure 5.22. External phosphorus budget in Lake Nebagamon.

5.5.Biological Communities

Biological communities within a lake ecosystem are structured by a range of physical, chemical and biological processes. Biological communities are fundamentally structured by physical and chemical processes described above. In general, nutrient levels and water temperature define the range of species that can exist within in a lake system and the diversity of the sediment and habitat types and physical processes (e.g., water level fluctuation) determine diversity of species that are likely to coexist within the lake. However, within these physical/chemical ecosystem boundaries, a range of biological interactions (i.e., competition and predation) further shape the structure and function of lake ecosystems. In addition, some biological processes and feedback mechanisms can influence the underlying physical/chemical processes that shape lake conditions.

Species Diversity

The diversity of species in lakes is fundamentally driven by the diversity of habitat types present throughout the lake ecosystem over the course of time. Species within a lake are continually in competition with each other for the limited food and habitat resources throughout the system. Over time, different species have coevolved to utilize different food and habitat resources in such a way that minimizes the competition among species and maximizes the competition within a particular species. This "evolutionary history" of competition among and within species is a primary mechanism that maintains the diversity of species and genetic variability within species, and these process often lead to the establishment of rare species that are specially adapted to unique local conditions. Species diversity is also generally viewed an important element of the long-term resilience of lake ecosystems (i.e., diverse biological communities are more likely to be resistant to change and recover after large scale disturbances, like drought or flooding).

Species diversity can be influenced through a variety of process. The introduction of species into a lake that does not share an evolutionary history of competition that uniquely exists within each lake can dramatically alter levels of species diversity. Introduced species (e.g., invasive species) often do not have natural predators (natural predator species are often more poorly adapted to feed on species that they have not historically encountered) and are often able to outcompete many native species for local resources (particularly in a lake system that is already being impacted by additional stresses like elevated nutrients). Alternatively, some introduced species (e.g. rusty crayfish or cladphora) affect species diversity by modifying relative habitat abundance or redistribution resources within a lake. Similarly, species diversity and the relative abundance of different species can be altered through a variety of food web processes.

Food Web Processes

Lake ecosystems are a mosaic of species that are in continuous fluctuation in response to the availability of different food sources. The food web in most lakes throughout northern WI can be viewed as a combination of primary producers (algae and rooted plants), primary consumers (zooplankton and grazing invertebrates), secondary consumers (planktivorous and insectivorous fish), tertiary consumers (picivorous fish) and quaternary consumers (fish eating birds/mammals and people). Changes in the abundance of any of species at these different trophic levels often results in a change at all other levels in the food web (often referred to as a "trophic cascade"; Figure 5.23). As such, a change in the abundance of top predators can have a cascading effect that results in shifts benthic invertebrate density and/or water quality conditions, or vice versa.

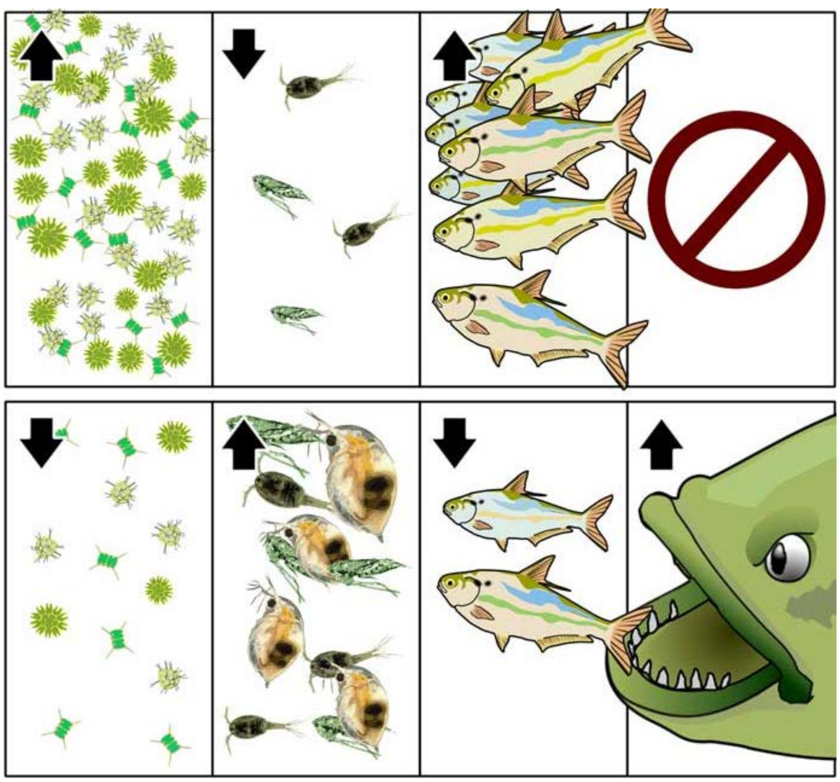

Figure 5.23. Conceptual diagram of the relationship between food web interactions and water clarity. Adopted from http://www.lmvp.org/Waterline/fall2005/topdown.htm.

Food web interactions can also be described with respect to the type of food that is primarily, or preferentially, being consumed by different organisms. For example, a predatory fish may have the ability to feed on many different prey types, but may preferentially feed on one or two species. If the relative abundance of the preferred food-type decreases, this can cause the same predator to shift feeding preferences to different food types—which can result in a cascade effect throughout the food web. Similarly, there may be one or more species that utilize a particular food-type within a lake ecosystem. For example, young bluegills are often the predominant consumers of zooplankton in lake ecosystems. If/when bluegill populations decline (potentially in response to low oxygen conditions, or winter kill), the food web can rapidly restructure, such that zooplankton abundance rapidly increases and algal abundance rapidly decreases. In fact, these shifts can be so rapid and pronounced that lakes that were once considered "impaired" due to poor water quality may now be considered relatively healthy, in a time span of one to two years.

Managing Biological Communities
Because of the importance of species diversity in the long-term resilience of a lake and the ability of changes in species abundance to cascade throughout the food web, lake management often focuses on an assessment of the relative abundance, population trends and trophic interaction among species. To this end, lake managers often rely on measurements of species richness, diversity, and population trends in plankton, aquatic plant and fish populations, as well as the physical and chemical processes that support them.

Historical Data
The majority of the data that exists to describe the biological communities in Lake Nebagamon are related to fisheries and invasive species. Fisheries management work in Lake Nebagamon has been ongoing since 1936 and is well described in the most recent WDNR fisheries report (Sand, 2008). Base on this report, the fish community has been dominated by walleye (*Sander vitreus)*, northern pike (*Esox Lucius)*, smallmouth bass (*Micropterus dolomieui)*, yellow perch (*Perca flavescens)*, black crappie (*Pomoxis nigromaculatus)* and white sucker (*Catostomus commersoni)*.

In the 1960s, attempts were made to establish a two-tiered brown trout fishery; however these efforts were abandoned due to poor productivity. Since the 1980s, management efforts have focused on the walleye fishery, with a population goal of three adult walleye per acre. Management of the mixed (sport and tribal) walleye fishery of Lake Nebagamon, have primarily focused on periodic stock assessments, stocking and habitat enhancement. Despite the ongoing efforts, the walleye population has continued to decline, while at the same time densities of smallmouth bass have increased. The 2008 DNR fishery report highlighted the need for a comprehensive lake management plan that, "should, 1) develop strategies for identifying, protecting and enhancing sensitive aquatic and shoreland habitats, 2) implement self-help water quality monitoring and provide mechanisms for control of satellite exotic infestations, and 3) provide an educational and interactive forum for environmentally sensitive shoreland living." Beyond the existing fishery data, relatively little information historically existed to describe different elements of the biological communities in Lake Nebagamon.

New Data Collection
To supplement the existing data, a series of new data sets were developed to characterize phytoplankton, zooplankton and aquatic plant communities. Aquatic plant communities in Lake Nebagamon were sampled in year one of this project using a point intercept methodology described by Hauxwell, et al. (2010). Aquatic plant data were analyzed to characterize relative species abundance, invasive species distribution, species diversity and Floristic Quality. All aquatic plant survey results were geospatially processed to inform the identification of critical habitat areas throughout the lake (see Section 5.1 above). Phytoplankton and zooplankton communities were sampled monthly during year two of this project. All plankton data were collected following standard plankton tow methods outlined by the USEPA (2007) and analyzed to characterize the relative abundance of major taxonomic groups and taxa that are known to be key indicators of lake health. Details of collection procedures, data analysis and results are described in Appendix E (aquatic plants) and Appendix F (plankton). Additionally, the presence of Rare, Threatened and

Endangered species in the Lake Nebagamon area was quantified by working with WDNR staff to conduct a Township Level query of the Natural Heritage Inventory (NHI) database.

Summary Results – Plankton
Plankton communities in Lake Nebagamon are highly variable, depending on the time of year (Figure 5.24 and 5.25). Over the course of any given summer, the total density of phytoplankton was quite variable, while zooplankton densities are quite stable. Over the course of the summer, the relative abundance of different phytoplankton groups change. In general, diatoms dominated phytoplankton communities in mid and late summer and blue green algae were relatively consistent throughout the year. Zooplankton communities are generally dominated by rotifers throughout the year, with copepods becoming more abundant later in the season.

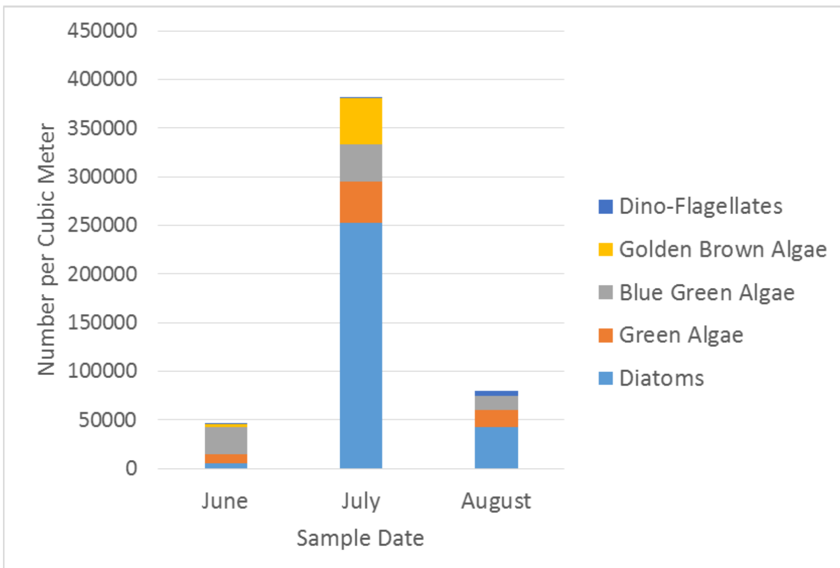

Figure 5.24. Seasonal variation in relative phytoplankton abundance in Lake Nebagamon in 2014.

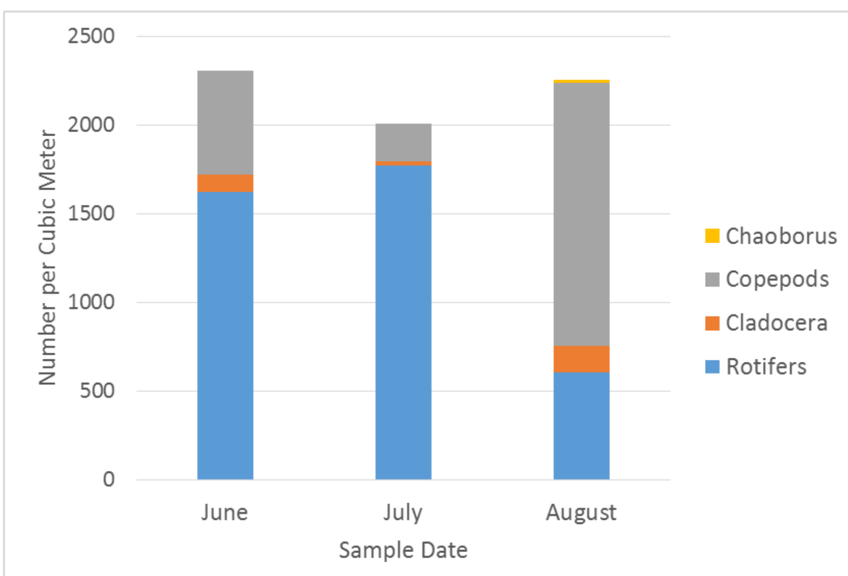

Figure 5.25. Seasonal variation in relative zooplankton abundance in f Lake Nebagamon in 2014.

Summary Results – Aquatic Plants

Lake Nebagamon contains a robust and diverse aquatic plant community (Figure 5.26). Throughout this study, 35 species were identified. The majority of plants were observed growing between 1 and 11 feet, with a maximum depth of 26 feet. The diversity and richness of species also varied among sites within the lakes, with some individual rake pulls not collecting any plants and other collecting up to eleven individual species. In general, the areas of highest species richness were in protected bays at the northern and southern end of the lake. For details of the aquatic plant community assessment, see Appendix F.

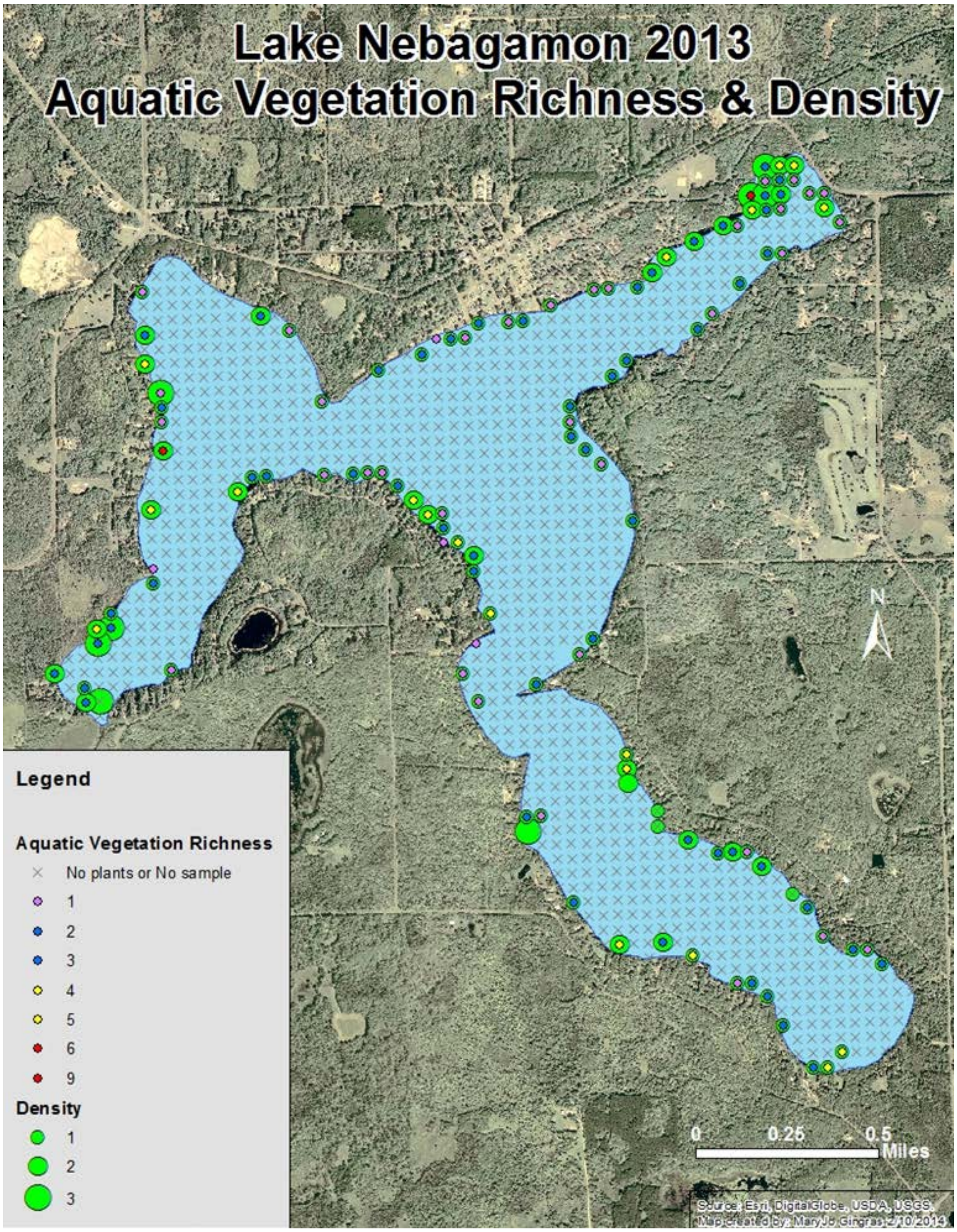

Figure 5.26. Density and species richness of aquatic plants throughout Lake Nebagamon.

Summary Results – Invasive Species
No invasive plant species have been detected throughout the Lake Nebagamon ecosystem. The only non-native species detected in the Lake Nebagamon are Chinese mystery snail (*Bellamya chinensis*), Japanese knotweed (*Fallopia japonica*), purple loosestrife (*Lythrum salicaria*) and rusty crayfish (*Orconectes rusticus*).

Summary Results – Rare, Threatened and Endangered Species
Thirteen rare, threatened and endangered species exist within the townships surrounding the Lake Nebagamon watershed (Table 5.3). The specific location of each species is kept confidential by the WDNR Endangered Resources staff, but it is unlikely that any of these species is an obligate resident within Lake Nebagamon (i.e., lake management decisions will likely not affect these species).

Table 5.3. Species of special interest throughout the Lake Nebagamon watershed

Scientific Name	Common Name	WI Status	Group
Regulus calendula	Ruby-crowned Kinglet	SC/M	Bird
Tympanuchus phasianellus	Sharp-tailed Grouse	SC/H	Bird
Falcipennis canadensis	Spruce Grouse	THR	Bird~
Northern dry-mesic forest	Northern Dry-mesic Forest	NA	Community
Northern mesic forest	Northern Mesic Forest	NA	Community
Alder thicket	Alder Thicket	NA	Community~
Hardwood swamp	Hardwood Swamp	NA	Community~
Northern wet-mesic forest	Northern Wet-mesic Forest	NA	Community~
Somatochlora forcipata	Forcipate Emerald	SC/N	Dragonfly~
Callitriche hermaphroditica	Autumnal Water-starwort	SC	Plant~
Calypso bulbosa	Calypso Orchid	THR	Plant~
Parnassia palustris	Marsh Grass-of-Parnassus	THR	Plant~
Ranunculus lapponicus	Lapland Buttercup	END	Plant~

Summary Conclusions – Biological Communities
Biological communities throughout the Lake Nebagamon ecosystem are somewhat variable. Aquatic plant and plankton communities are diverse and robust and the only invasive species detected are Chinese mystery snail (*Bellamya chinensis*), Japanese knotweed (*Fallopia japonica*), purple loosestrife (*Lythrum salicaria*) and rusty crayfish (*Orconectes rusticus*). Fish communities are generally consistent with those expected in mesotrophic lakes like Lake Nebagamon.

5.6. Ecological Interactions

To understand the interactions among different components of the Lake Nebagamon ecosystem, it is necessary to develop a framework that relates physical, chemical and biological processes. To this end, ecological interactions were assessed in Lake Nebagamon through the use of the AQUATOX simulation program. AQUATOX simulates the relationship between nutrient runoff, water quality and food web interactions. Different AQUATOX simulations were used to assess the potential impacts of future land use on water quality and the relative importance of food web processes in the long-term stability of the Lake Nebagamon ecosystem.

Summary Results and Conclusions – Ecological Interactions

Model simulations suggest that water quality changes resulting from future land use scenarios are likely to be relatively small. However, model simulation of the ecosystem suggest that internal nutrient dynamics are quite complex and that additional data are likely necessary to fully understand water quality dynamics in Lake Nebagamon. Given the uncertainty about both the ecosystem processes and the future land use conditions, management of Lake Nebagamon should emphasize routine monitoring and assessment to track water quality conditions over time and clarify uncertainties surrounding food web dynamics.

Table 5.4. Water quality changes potentially resulting from future land use/nutrient loading scenarios

Land Use Condition	Total Phosphorus Load (Pounds/year)	Water Quality Conditions			
		TP (ug/L)	Chl-a (ug/L)	Secchi (m)	TSI
Historical (~1850)	734	12.0	5.7	3.2	39.5
Monitored Data (2013)	2779	18.7	6.9	1.8	46.8
Current Model Predictions (2013)		19.7	6.7	1.7	45.5
Future (2030)	3342	22.3	8.6	1.3	51.0

6. Stressor Identification and Analysis

A range of stressors have the potential to impacts lake ecosystems and their use (Table 6.1) by altering the fundamental physical, chemical and biological processes that sustain lake conditions and/or creating social conditions that favor one use over another. For example, increased phosphorus runoff from altered land use can be an ecological stressor to lakes by decreasing water clarity and altering the structure of the food web and fishery. Similarly, increased boat traffic can be a social stressor to lakes by limiting potential use of the lake for quiet, solitude and relaxation. This section describe the current, and potential future, impact of different stressors on the desired uses of Lake Nebagamon identified in the goal setting process (see Section 3).

Five categories of stressors were identified to have the theoretical potential to limit the desired uses identified for the Lake Nebagamon ecosystem: hydrologic alteration, habitat loss, pollutant runoff and deposition, biological community modification and use incompatibility. Within these five general stressor classifications, the potential impact of 17 specific stressor-types were evaluated within the Lake Nebagamon ecosystem.

Table 6.1. Summary of the sources and impacts of stressors potentially impacting Lake Nebagamon.

Stressors	Primary Impacts	Potential Sources
Hydrologic Alteration		
Surface Water Alteration	Increases in rates of runoff to a lake can increase shoreline erosion and nutrient runoff. Decreases in runoff and/or water diversion can result in reduced water levels and nearshore habitat alteration.	Impervious surfaces, irrigation and/or drinking water removal
Groundwater Alteration	Increased groundwater withdrawal can result in lower summer water levels, increased water temperatures and loss of shoreline habitat	Increased well usage
Water Level Modification	Artificial water level control in lakes can increase shoreline erosion and minimize water level fluctuations necessary for maintaining diverse aquatic plant communities	Outlet control structures
Habitat Loss		
Nearshore/Shoreline	Loss of nearshore/shoreline habitat can negatively affect fish, invertebrate and aquatic plant communities as well as in crease rates of nutrient runoff and invasive species introduction	Upland vegetation removal, shoreline riprap, increased dock densities
Thermal Restrictions	Changes in temperature profiles and distributions can alter the range and distribution of fish and invertebrates, generally toward communities that are dominated by warm water specialists	Thermal discharges, climate change
Spawning Substrate	Loss of spawning substrate is species dependent (based on preferred spawning substrate) and generally leads to a reduced population density of affected species. Common habitat types include, rocks and cobble, course sand, vegetation, coarse woody debris	Sedimentation, dredging, woody debris removal, thermal restriction
Pollutant Runoff and Deposition		
Agricultural	Increased rates of agricultural runoff can lead to increased nutrient and sediment levels in lakes and an increase in the natural process of eutrophication	Increased erosion, nutrient application
Industrial wastewater	Increased rate of industrial discharge can alter temperature profiles in lakes and increase contaminant and nutrient levels in lakes, depending on the nature of the discharge	New facilities or increase discharge from existing facilities
Municipal wastewater	Increased rates of industrial discharge can lead to increased nutrient (and to a lesser extent, contaminant) levels in lakes and an increase in the natural process of eutrophication	New facilities or increase discharge from existing facilities
Septic Systems	Increased rates of industrial discharge can lead to increased nutrient (and to a lesser extent, contaminant) levels in lakes and an increase in the natural process of eutrophication	New systems or increase discharge from existing systems (i.e., failures)
Urban	Increased rates of industrial discharge can lead to increased nutrient, sediment, and contaminant levels in lakes and an increase in the natural process of eutrophication	Increased impervious surfaces, unmaintained stormwater infrastructure
Contaminant Deposition	Deposition of mercury, lead, pesticides and organic pollutants can negatively impact fish and wildlife reproduction and limit human consumption.	Atmospheric, runoff or direct deposition depending on contaminant
Biological Community Modification		
Non-native Species Introduction	Introduction of non-native species can alter biological communities, often leading to a reduction in species diversity and disproportionately high densities of the introduced species.	Boat transport, stormwater, ornamental gardens, wildlife
Species Incompatibility	Introduction of native species at levels above their natural carrying capacity can alter food web structure and have secondary impacts on ecological processes	Stocking
Overharvest	Harvest at levels above a reproductive replacement rate can lead to localized extinctions of different species and result in tropic cascade alterations in the lake ecosystem	Commercial and/or recreational harvest
Use Incompatibility		
Ecological Incompatibility	Uses that alter fundamental ecological processes may ultimately undermine the characteristics of the lake that are most highly used and valued	Limited monitoring, management and/or regulatory capacity
Use Based Incompatibility	Preferred uses by one group that negatively affect the ability of another group use the resource in a preferred manner may lead to conflict and require mitigation	Limited monitoring, management and/or regulatory capacity
Intergenerational Use	Existing uses that do not currently limit the desired use of the lake but create a trajectory in which the same use (or different use) may not be an option to future generations	Limited monitoring, management and/or regulatory capacity

6.1. Stressor Analysis

To describe the relative impact of different stressors on the Lake Nebagamon ecosystem, individual stressors (see Table 6.1) were evaluated based on their ability to limit achievement of the identified management goals for the lake. The impact of each stressor was ranked based on its likely impact on the current conditions of the lake. Stressors were ranked by Northland College lake assessment staff using a four point scale (Table 6.2).

Table 6.2. Criteria used to rank the relative impact of different potential stressor throughout the Lake Nebagamon ecosystem

Level of Stressor Impact	Definitions
Low	Unlikely to be affecting use of the lake and attaiment of mangement goals
Medium	Potentially affecting use of the lake and attaiment of mangement goals, now and into the future
High	Likely to be affecting use of the lake and attaiment of mangement goals, now and into the future
Not Applicable (NA)	Management goal not theoretically affect by the specific stressor

Within the Lake Nebagamon ecosystem, relatively few stressors are negatively impacting its current use (Table 6.3). However, several management goals are partially affected by different stressors and several stressors have the ability to limit the desired use of the lake in the future. The relative impact of these different stressors are summarized below according to each management goal:

<u>Goal 1 – Maintain Current Levels of Motorized and Non-motorized Use</u>
Current levels of motorized and non-motorized use appear consistent with the ecological conditions and user experiences on Lake Nebagamon. However, given the potential for increased shoreline development, it is possible that watercraft usage may increase in the future. Most survey responses highlighted interest in maintaining or limiting watercraft densities.

<u>Goal 2 – Maintain Scenic Beauty of Lake Nebagamon</u>
The scenic beauty of Lake Nebagamon is generally consistent with user expectations. Most survey respondents indicated that lake aesthetics did not limit their use and/or enjoyment of Lake Nebagamon. It is unclear how much of this aesthetic beauty is driven by shoreline development. But, given the potential changes in shoreline development that are possible under future zoning conditions, it is possible that lake aesthetics will change in the future.

<u>Goal 3 – Maintain Existing Water Levels and Hydrologic Processes</u>
In general, the hydrologic processes in Lake Nebagamon are relatively undisturbed. Water levels at the outlet are moderately controlled and the lake receives runoff from a minimal amount of imperious surface. Given the potential for increased development throughout the watershed, and in the shoreline areas in particular, it is possible that both overland and groundwater flow to the

lake may be altered under future land use conditions. However, the full extent of these potential changes is unclear.

Goal 4 – Protect and Restore Nearshore, Shoreline and Critical Habitat
Nearshore and shoreline habitat in Lake Nebagamon are in moderate to poor condition, although some localized areas of high quality habitat are present. However, given the potential for changes in shoreline development, it is possible that nearshore, shoreline and critical habitat may continue to be altered in the future.

Goal 5 – Maintain Existing Water Quality Conditions
Water quality conditions in Lake Nebagamon are consistent with state standards for mesotrophic lakes. Although water quality has likely declined in Lake Nebagamon since the mid-1800s, it is unlikely that existing pollutant sources are currently impacting the Lake Nebagamon ecosystem in a way that limits the desired uses. However, given the potential for altered land use, shoreline development and climate driven shifts in water temperature and pollutant runoff, it is possible that water quality may decline in Lake Nebagamon in the future.

Goal 6 – Maintain Diverse Native Plant Communities
Native aquatic plant communities are diverse and robust. As such, it is unlikely that existing ecological stressors are negatively impacting this element of the ecosystem. However, given the potential changes in use and shoreline development and difficulty in adequately monitoring all potential pathways for invasive plant species, introductions are possible in the future.

Goal 7 – Maintain Diverse Native Fish Communities
Fish communities in Lake Nebagamon are generally consistent with those expected in mesotrophic lakes. However, stocked walleye do not appear to establish significant resident populations. Secondary impacts, if any, of stocked fish are unclear in Lake Nebagamon.

Goal 8 – Increase Walleye Population Density
Walleye recruitment has been historically limited in Lake Nebagamon. Population enhancement efforts have primarily focused on stocking and habitat enhancement. However, walleye densities (although consistent with other regional lakes) are lower than the state goal of three adults per acre.

Goal 9 – Maintain Access to Native American Fisheries and Fishing Grounds
Access by Native American tribal members to traditional fisheries and fishing grounds is currently unimpeded. However, given the potential for shoreline development it is possible that access to traditional fishing ground may be impeded in the future.

Table 6.3. Analysis of the potential ability to impair the desired uses for Lake Nebagamon.

Management Goals for Lake Nebagamon	Potential Stressors and Level of Impairment: Hydrologic Alteration			Habitat Loss			Pollutant Runoff and Deposition						Biological Community Modification			Use Incompatibility			Comments and Analysis
	Surface Water Alteration	Groundwater Alteration	Water Level Modification	Nearshore/Shoreline	Thermal Restrictions	Spawning Substrate	Agricultural	Industrial	Municipal	Septic Systems	Urban	Contaminant Deposition	Non-native Species	Species Incompatibility	Overharvest	Ecological Incompatibility	Use Based Incompatibility	Intergenerational Use	
1 - Maintain Levels of Motorized and Non-motorized Use	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	1	2	Desired recreational usage patterns are currently unimpaired by ecological stressors or incompatible uses.
2 - Maintain Scenic Beauty of Lake Nebagamon	1	1	1	3	1	1	1	1	1	1	2	1	1	1	1	1	1	2	Scenic beauty of the Lake Nebagamon is moderately impaired through shoreland development, but has the potential to decline in the future in response to shoreline habitat loss and urban runoff.
3 - Maintain Existing Water Levels and Hydrologic Processes	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	2	Hydrologic processes are generally unimpaired.
4 - Protect and Restore Shoreline, Nearshore and Critical Habitat	1	1	1	3	1	1	1	1	1	1	2	1	1	1	1	1	1	2	Nearshore and shoreline habitat are heavily impacted and have the potential to decline in the future in response to shoreline development and habitat loss.
5 - Maintain Existing Water Quality Conditions	1	1	1	2	1	1	1	1	1	1	2	1	1	1	1	1	1	2	Water quality is generally unimpaired, but has the potential to decline in the future in response to urban runoff.
6 - Maintain Diverse Native Aquatic Plant Communities	1	1	1	3	1	1	1	1	1	1	2	1	1	1	1	1	1	2	Aquatic plant communities are generally unimpaired, but have the potential to delcine in the future response to shoreline habitat loss and urban runoff.
7 - Maintain Diverse Naive Fish Communities	1	1	1	1	2	1	1	1	1	1	2	1	1	2	2	1	2	2	Fish communities are generally unimpaired, but may be beginning to shift in response to thermal restrictions, urban/septic system runoff.
8 - Increase Walleye Population Densities	1	1	1	3	2	2	1	1	1	1	1	1	1	2	1	2	2	2	Native walleye reproduction is limited. Future catches are highly dependent on stocking.
9 - Maintain Access to Tribal Fisheries	1	1	1	2	1	2	1	1	1	1	1	1	1	1	1	1	2	2	Access to nearshore fishing grounds to Tribal members is critical. Access currently not affected, but may be in the future in response to increased shoreline development.
Cumulative Stressor Ranks	**8**	**8**	**8**	**18**	**10**	**10**	**8**	**8**	**8**	**8**	**14**	**8**	**8**	**10**	**9**	**10**	**12**	**18**	

7. Policy Summary and Analysis

To mitigate and prevent the impacts of the different stressors described above, a range of existing rules, regulations and management activities have been developed and implemented by different management units and stakeholder groups surrounding Lake Nebagamon. The existing policies are summarized below:

7.1. Existing Policies and Management Activities

Public Access and Recreation

Public use and access to water resources throughout Wisconsin are protected and managed under the Public Trust Doctrine. Under the Public Trust Doctrine, all navigable waterways are commonly owned by all citizen of Wisconsin. As such, the state (generally through the WDNR) is obligated to protect the public's right to use "waters of the state" for transportation, consumptions, recreation and scenic beauty. Wisconsin law affords riparian land owners special privileges adjacent to their private property, but is required under Supreme Court decision to manage water resource primarily for public use and secondarily for private use. Public use of state waters are managed and protected through a variety of mechanisms described below.

Water Quality

Water quality in Lake Nebagamon is managed through a series of federal, state and local regulations as well as a range of volunteer efforts. The federal Clean Water Act (CWA) is the primary law that sets regulations for water quality. In Wisconsin, the regulatory authority for the CWA has been delegated to the WDNR, which has in turn delegate some of this responsibility to different local governmental units. The CWA sets the minimum for water quality standards, but different state and local rules and regulations can require more stringent water quality protection measures. Under the CWA, WDNR is required to 1) develop water quality standards, 2) assess the condition of water resources based on these standards, and 3) restore all waterbodies not meeting established water quality standards. Implementation of the CWA is achieved through a series of programs within the WDNR. Details of these programs are described below.

Under the Water Quality Standards program, WDNR reviews and revises water quality standards on a triennial basis. Every two (even) years, existing data sets are compared to water quality standards as part of the Water Condition Assessment and Reporting process at WDNR http://dnr.wi.gov/topic/SurfaceWater/assessments.html. To assess water quality conditions in different waterbodies, the WDNR follows the Wisconsin Consolidated Assessment and Listing Methodology (WisCALM) process, which specifies the criteria for data to be used in an assessment as well as the conditions under which data would be interpreted as evidence of a water quality impairment. When a waterbody has been identified as not meeting standards, or impaired, it is placed on the WDNR impaired waters (or 303d) list. Although routine water quality assessments occur, the ability to conduct a full "condition assessment" for a lake is often limited by the availability of appropriate data sets.

When a waterbody is placed on the impaired waters list, the CWA stipulates that a study must be conducted to identify and reduce the pollutant of concern. The process/study that is required for all impaired waterbodies is called a Total Maximum Daily Load (TMDL). Once a waterbody is listed as impaired, WDNR has 15-years to develop/finalize a TMDL or provide evidence as to why the waterbody should be delisted. Following the development of a TMDL and approval by EPA, local governmental units and potential pollutant sources are responsible for implementing activities to reduce pollutant loads to the impaired waterbody, and this work is generally completed as part of different regulatory/permitting processes.

Runoff and Pollutant Management
The primary program through which pollutant runoff/discharge into lakes (and other waterbodies) is regulated is through the Wisconsin Pollutant Discharge Elimination System (WPDES). All entities that discharge different potential pollutants into a waterbody (e.g., wastewater facilities, industrial plants, municipal stormwater systems, confined animal feeding operations…etc.) are required to obtain WPDES permits. Through the WPDES system, discharges from regulated facilities are required to meet different environmental standards, depending the nature of the discharge and the waterbody being discharged into.

Although the WPDES program is intended to regulate pollutant runoff from all wastewater and industrial discharges, confined animal feeding operations and urban stormwater, different thresholds must be met before a permit is required. Potential point-sources of pollution that are below the WPDES permit thresholds are not regulated unless specific local regulations and/or ordinances exist. Currently, stormwater from urban lands in the Village of Lake Nebagamon is not regulated as part of the WPDES program because the population in these towns is below 5000 (see Comprehensive Planning Law).

All other more diffuse (non-point) potential sources of runoff and pollution (particularly agricultural runoff, http://dnr.wi.gov/topic/Nonpoint/) are regulated through NR 151, and/or local ordinances/zoning requirements. In particular, NR 151 regulates erosion and nutrient runoff through a series of agricultural performance standards and manure management prohibitions. Statewide efforts to manage nonpoint source pollution are described in the 2011-2015 plan. In addition to these agricultural standards, use of fertilizers containing phosphorus in urban areas was banned in 2009 (unless warranted by a soil test).

Comprehensive Planning Law
Wisconsin's comprehensive planning law requires land use plans to be developed (among other items) by local units of government and requires that future land use development be consistent with these stated land uses. Zoning ordinances can then be further used to regulate different aspects of land development (e.g., stormwater and nutrient runoff). Beyond areas zoned for shoreland development, stormwater and nutrient management is not prescribed in existing land use plans for the Village of Lake Nebagamon.

Antidegradation
The CWA also requires that WDNR establish and implement an "antidegradation" policy to prevent the degradation of water resource as a result of future activities and develop special protections for the state's highest quality waters. This antidegradation provision is implemented through Chapter NR 207 of the Wisconsin Administrative Code. Through NR 207 any "new" (initiated after March 1st, 1989) potential pollutant discharges must first demonstrate justification of the new or increased discharge prior to permit issuance. Additionally, WDNR is required to identify Outstanding Resource Waters (ORWs) and Exceptional Resource Water (ERWs). In Wisconsin, ORWs and ERWs are designated by WDNR and listed in Chapter NR 102 of the Wisconsin Administrative Code. Once listed in NR 102, these waterbodies are managed to a higher standard, such that no new discharges are allowed to decrease water quality, except in unusual circumstances. Lake Nebagamon is not considered an ORW or ERW.

Chemical Contaminants
Some pollutants are regulated outside the traditional frameworks for point and nonpoint sources described above. The two chemical where this is most applicable to lake management are mercury and lead. Mercury deposition in lakes is primarily regulated by the Clean Air Act, and, in 2015, Mercury and Air Toxics Standards (MATS), both of which are expected to continue to reduce mercury deposition to lakes. However, since much of the mercury deposition in Wisconsin originates from emissions outside of the US, a continuing strategy to reduce mercury exposure is though consumption advisories from the Wisconsin Health Department (http://dnr.wi.gov/topic/fishing/consumption/). Many historical sources of lead have been addressed through different regulations (e.g., gasoline additives, and waterfowl shotgun shell pellets). Currently, the primary source of lead in lakes is fishing tackle (and to a lesser degree ammunition) and most efforts to reduce lead introduction to lakes are based on voluntary tackle buy-back programs (e.g., Get-the-lead-out, http://dnr.wi.gov/topic/fishing/fishhealth/gettheleadout.html). Elevated mercury concentrations in fish (specifically walleye) have been a recurring challenge in Lake Nebagamon.

Shoreland Habitat
Shoreland and nearshore habitat is generally regulated through county and/or local zoning ordinances. The WDNR has set minimum standards for shoreline and floodplain zoning (WDNR 2005). However, many counties and Villages have adopted local regulations that require more stringent regulations than the WDNR minimum standards. Shoreland zoning regulation only apply to areas above the Ordinary High Water (OHW) mark. The Village of Lake Nebagamon has a shoreland zoning ordinance that requires a 150 foot minimum for all shoreland lots.

Nearshore habitat is additionally regulated through Section 404 of the CWA http://water.epa.gov/lawsregs/guidance/cwa/dredgdis/ . Section 404 is administered by the US Army Corps of Engineers and regulates the dredge and/or fill of material to and from surface water and wetlands. Modification of nearshore areas in which permanent structures are placed and/or lake beds are disturbed require 404 permits. Additionally, docks and piers are regulated in Wisconsin under NR 326—which requires specific standards for all dock, piers and wharfs constructed after 2012.

Pursuant to NR 1.06 areas of Critical Habitat (generally in nearshore areas) can be designated by WDNR if they have Public Right Features and/or Sensitive area. Critical Habitat designation then requires that new developments and/or shoreline modifications me an additional set of more restrictive/protective standards.

Aquatic Plants and Invasive Species
Aquatic plants and invasive species are primarily managed through NR 19, 40, 107 and 109. NR 19 requires the drainage of all water from boats and associated equipment prior transportation. NR 40 makes it illegal to possess and/or transport any aquatic plants on highway systems. NR 107 regulates the control of aquatic nuisance plants using chemical treatment. NR 109 regulates manual and mechanical removal of aquatic plants from nearshore area from areas greater than 30 feet in width.

Wetlands
Modification of wetland habitat is primarily regulated at federal and state levels of government. Wetlands are primarily regulated through Section 404 of the CWA. Section 404 is administered by the US Army Corps of Engineers and is intended to provide a no-net-loss of wetland (function).

Under this law, projects potentially impacting wetlands are reviewed and permitted to 1) avoid wetland impacts where possible, 2) minimize the extent of any necessary wetland impacts and 3) mitigate any losses. Federal review only applies to "navigable" wetlands. In addition to these federal regulations, NR 187 establishes minimum standards for shoreland and wetlands zoning and local zoning codes also often require different setback distances from wetlands.

Fisheries

Fisheries in Lake Nebagamon are managed through selective stocking and harvest regulations that occur through a number of tribal, state and local programs. Stocking programs are determined by deliberations between tribal and state biologists and related to user demand, ecological need/constraints and available funding. Harvest regulations are determined on a species-by-species basis and through a process that integrates Tribal treaty rights, recreational fishing usage and biological constraints within any given system. For most game species (other than walleye) harvest limits are based on generalized state-wide standards developed by the WDNR. The combined walleye fishery in Lake Nebagamon (tribal and recreational angling) is managed through by a "safe harvest" system (http://dnr.wi.gov/topic/fishing/ceded/managing.html).

Safe harvest is based on the total allowable catch (TAC) for a lake. TAC is the total number of adult walleye that can be taken from a lake by tribal and recreational fishermen without endangering the population. Safe harvest is calculated as a percentage of TAC, taking into account the variability in population estimates. Safe harvest is calculated each year for all walleye lakes in the Ceded Territory. If a recent adult walleye population estimate is available for Lake Nebagamon, it is used to set safe harvest. If no current population estimate is available, a more conservative approach for estimating the population is used. Safe harvest limits are set so there is less than a 1-in-40 chance that more than 35% of the adult walleye population will be harvested in any given lake by the combined efforts of tribal and recreational fishermen.

However, population estimates cannot be conducted on every lake in the Ceded Territory in a single year and estimates that are more than two years old may no longer accurately reflect the walleye population in a lake. For lakes where there is not a population estimate less than two years old available, a statistical model is used to calculate safe harvest, based on the size of the lake and the primary recruitment source of walleye in the lake (natural reproduction or stocking). The model results in more conservative safe harvest limits than those set using recent population estimates.

The six Chippewa tribes of Wisconsin are legally able to harvest walleyes using a variety of high efficiency methods, but spring spearing is the most frequently used method. In spring each tribe declares how many walleyes and muskellunge they intend to harvest from each lake. Harvest begins shortly after ice-out, with nightly fishing permits issued to individual tribal spearers. Each permit allows a specific number of fish to be harvested, including one walleye between 20 and 24 inches and one additional walleye of any size. All fish that are taken are documented each night with a tribal clerk or warden present at each boat landing used in a given lake. Once the declared harvest is reached in a given lake, no more permits are issued for that lake and spearfishing ceases.

Rare, Threatened and Endangered Species

Rare, threatened and endangered species are primarily regulated though WDNR administration of the Endangered Species Act. Through this process, WDNR develops and updates lists of species considered rare, threatened and/or endangered. As the species are identified throughout the state, they are added to the Natural Heritage Inventory (NHI) Database. Once listed, different species and their associated habitats are afforded a broader range of protections, and different land development activities are required to obtain permits that require review of the NHI database to assess the potential for impacts to protected species. See NR 27 and 29 for additional details.

7.2. Policy Analysis

To characterize the ability of different policies to mitigate and/or prevent potential stressor impacts in the Lake Nebagamon ecosystem, the scope/implementation capacity of each policies was compared against each individual stressor (Table 7.2). Each stressor-policy combination was assessed based on the ability of the policy to mitigate/prevent stressor impacts to the lake. Policy-based management of different stressors were relatively ranked on a scale of 0 to 4 (Table 7.1). Policy evaluations were based on professional judgement by Northland College staff and faculty and reviewed by stakeholder groups.

The effectiveness of different policies, rules, regulations to prevent and/or mitigate the impacts of different stressors is highly variable. Potential impacts from some stressors are likely to be almost entirely prevented by some policies under current and future conditions, while some stressors are relatively poorly mitigated/prevented by any policies. Stressors that are best regulated through different policies include water level modification, industrial runoff and municipal runoff. Stressors that are least effectively regulated by current policies are spawning habitat loss, polluted runoff from urban and agricultural lands and recreational use incompatibilities.

The primary limitations across all policies is a lack of ability to 1) account for anticipated future conditions and 2) reconcile potential use/ecological incompatibilities. Many policies effectively protect the Lake Nebagamon ecosystem under current land use and climate scenarios. However, given the potential (arguable likelihood) that both land use and climate will continue to change into the future, it is important to account for these potential changes through educational, planning and regulatory tools.

Table 7.1. Definitions level(s) of stressor mitigation/prevention provided by different policies

Level of Stressor Mitigation/Prevention	Definitions
Excellent	Policy likely to effectively mitigate/prevent stressor impacts under current and potential future conditions
Good	Policy mostly mitigates/prevents stressor impacts but may not under site specific and/or potential future conditions
Fair	Policy partially mitigates/prevents stressor impacts
Poor	Policy unlikely to mitigate/prevent stressor impacts
Policy Not Applicable	Policy not intended to mitigate/prevent stressor impacts

Table 7.2. Summary of policy coverage of current and potential stressors to Lake Nebagamon (part I).

Stressors to be Mitigated	Existing Policies																	Cumulative Protection	Comments and Analysis
	USACE	USEPA	Tribes	WDNR					WDNR			Douglas County		Village of Lake Neb.	NLA		NA		
	Section 404 of Clean Water Act	Clean Air Act and MATS Rule	Treaties of 1837 and 1842	NR 102 - Water Resource Designation	NR 207 Antidegradation	NR 109 and 107 - Aquatic Plants	WPDES Program	303 Surface Water Program	NR 151 - Ag. Standards	NR 40 - Invasive Species	NR 115 - Shoreland Zoning (State Minimums)	Septic System Permitting	Shoreland Zoning	Comprehensive Plans and Zoning	WDNR, Clean Boats, Clean Waters (Voluntary)	WDNR, Healthy Lakes Initiative (Voluntary)	WDNR, Invasive Species Control (Voluntary)		
Pollutant Runoff and Deposition																			
Agricultural Runoff	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	2	Agricultural runoff is unlikely to affect Lake Nebagamon, as current zoning regulations call for less than 1% of future lands to be used for agricultural purposes.
Industrial Runoff	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	4	Industrial runoff is unlikely to impact Lake Nebagamon into the future, as current land uses to not allow for industrial development and industrial effluents are well regulated by the WPDES program.
Municipal Wastewater	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	4	Municipal wastewater is unlikely to affect Lake Nebagamon, as no effluents currently (or are planned to) discharge to Lake Nebagamon and municipal effluents are well regulated by the WPDES program.
Septic Systems	0	0	0	0	0	0	0	2	0	0	0	3	0	0	0	0	0	3	Septic systems have a moderate potential to negatively affect Lake Nebagamon in the future. Current septic regulations require relatively high standards, but the large potential increase in septic systems that could result from future zoning plans could have a cumulative impact on the lake. Current monitoring efforts are likely poorly suited to detect potential impacts from septic systems.
Urban Runoff	0	0	0	0	0	0	2	2	0	0	2	0	3	0	0	2	0	3	Urban runoff has a moderate potential to impact Lake Negagamon in the future. Stormwater management is required for all shoreland parcels, but relatively little stormwater management is required for parcels outside of the shoreland areas. Current stormwater policies do not account for anticipated changes in precipitation from climate change.
Contaminant Deposition	0	3	0	0	0	0	3	2	0	0	0	0	0	0	0	0	0	3	The primary contaminants to the lake (mercury and lead) are currently (or will be in the near future) well managed through federal regulations and volunteer efforts.
Use Incompatibility																			
Ecological Incompatibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	Relatively few policies are in place to reconcile the potential ecological incompatibility of the recreational uses for Lake Nebagamon.
Use-based Incompatibility	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	3	No policies/processes are in place to reconcile potential use incompatibilities among different user groups, particularly with respect to access to Tribal spearing grounds.
Intergenerational Incompatibility	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	3	No policies/processes are in place to reconcile potential use incompatibilities across generations.
Maximum Policy Benefit	14	3	4	15	15	10	13	16	2	2	7	5	9	12	2	8	2		

Table 7.3. Summary of policy coverage of current and potential stressors to Lake Nebagamon (part II).

Stressors to be Mitigated	Existing Policies: USACE	USEPA	Tribes	WDNR					WDNR			Douglas County		Village of Lake Neb.	NLA		NA	Cumulative Protection	Comments and Analysis
	Section 404 of Clean Water Act	Clean Air Act and MATS Rule	Treaties of 1837 and 1842	NR 102 - Water Resource Designation	NR 207 Antidegradation	NR 109 and 107 - Aquatic Plants	WPDES Program	303 Surface Water Program	NR 151 - Ag. Standards	NR 40 - Invasive Species	NR 115 - Shoreland Zoning (State Minimums)	Septic System Permitting	Shoreland Zoning	Comprehensive Plans and Zoning	WDNR, Clean Boats, Clean Waters (Voluntary)	WDNR, Healthy Lakes Initiative (Voluntary)	WDNR, Invasive Species Control (Voluntary)		
Hydrologic Alteration																			
Surface Water Modification	4	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	3	Existing policies are relatively well suited to protect surface water alterations in the Lake Nebagamon watershed. The primary activity that has the most potential to alter surface water processes in Lake Nebagamon is land use change throughout the watershed.
Groundwater Modification	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	3	Existing policies are well suited to protect against large scale groundwater withdrawals from Lake Nebagamon, but less well suited to protect against the potential cumulative impacts individual well development over time. Groundwater recharge is not protected.
Water Level Modification	4	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	3	Water levels are relatively unaffected in Lake Nebagamon.
Habitat Loss																			
Nearshore/Shoreline	3	0	0	2	2	3	0	0	0	0	2	2	3	3	0	2	0	3	Future shoreline habitat loss in Lake Nebagamon is moderately protect. Under current policies, the nearshore and shoreline areas are unlikely to change into the future.
Critical Habitat	3	0	0	2	2	3	0	0	0	0	2	0	3	3	0	2	0	3	Critical habitat is somewhat protected by existing shoreline zoning and dredge and fill permits. However, Critical Habitat areas have not been formalized throughout the lake for specific protections
Spawning Substrate	0	0	0	2	2	2	0	0	0	0	2	0	0	2	0	0	0	2	Spawning substrate is poorly documented throughout Lake Nebagamon. It is likely that much of the important spawning habitat will be somewhat protected by existing shoreland zoning and permitting processes. However, without full understanding of the extend of habitat conditions, the effectiveness of current policies is uncertain.
Biological Community Modification																			
Non-native Species	0	0		0	0	2	0	0	0	2	0	0	0	0	2	2	2	2	Non-native species introduction is moderately prevented through existing polices. Laws exist to prevent invasive species transportation, but complete monitoring and enforcement are limited. Most management of existing invasive species is dependent on volunteer effort.
Species Incompatibility	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	Current policies are moderately well prepared to minimize the potential impacts of native species introductions (e.g., stocking).
Overharvest	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	Current policies are moderately well prepared to prevent overharvest of fish from Lake Nebagamon. Current data suggest that harvest of walleyes is beyond a sustainable level.
Maximum Policy Benefit	14	3	4	15	15	10	13	16	2	2	8	5	9	12	2	8	2		

8. Management and Monitoring Recommendations

In general, because of the relatively good quality of the Lake Nebagamon ecosystem, management activities should focus on proactive planning to prevent any future degradation of the lake system and the development of routine monitoring systems to detect any changes in ecosystem condition and/or user experiences early on. However, significant opportunities exist to enhance the quality of the lake system through shoreland restoration and management efforts.

Goal 1 – Maintain Current Levels of Motorized and Non-motorized Use
Maintenance of existing levels of watercraft usage is most likely to be affected by the potential for increased access to the lake from the higher densities of shoreland properties likely to be encountered under future land use scenarios. There is no particular policy/process in place to manage this potential transition. However, ongoing monitoring of user experience and perception may help to proactively manage any use conflicts that arise in the future. User experience and perception could by monitored by routine administration of the user survey used in the study. Future surveys should expand the use of metrics to more holistically capture and describe the attributes of Lake Nebagamon that contribute to positive user experiences.

Goal 2 – Maintain Scenic Beauty of Lake Nebagamon
Maintenance of existing aesthetics of Lake Nebagamon is most likely to be affected by the potential for increased shoreline development and recreational use of the lake that could be encountered under future land use scenarios. The primary regulatory process governing shoreland development is the Lake Nebagamon Village Zoning rules. While these zoning rules strive to balance recreational access, environmental quality and lake aesthetics, it is unclear how these development patterns will affect the aesthetic value of Lake Nebagamon for current and future users. Ongoing monitoring of user experience and perception may help proactively manage any changes is aesthetic value of the lake that arise in the future. User experience and perception could by monitored by routine administration of the user survey used in the study. Future surveys should expand the use of metrics to more holistically capture and describe the attributes of Lake Nebagamon that contribute to the aesthetic elements of the Lake Nebagamon ecosystem.

Goal 3 – Maintain Existing Water Levels and Hydrologic Processes
Maintenance of existing water levels and hydrologic processes is likely to be primarily affected by changes in land use surrounding the lake. Potential water level changes are highly regulated through a variety of mechanisms. However, changes in runoff process of surface and groundwater are less fully regulated. Projected changes in land use throughout the watershed are expected to increase levels of impervious surfaces and the potential for increased groundwater extraction. Increased impervious surfaces in shoreland area are relatively well regulated through shoreland zoning ordinances, but cumulative impacts of shoreland development and groundwater extraction from individual wells are less clearly regulated. Given the likelihood that climate change will lead to increased rainfall intensity, it is important that engineering design standards incorporate (and periodically update) the most current hydrologic model input files to accurately size stormwater management practices and other infrastructure.

Goal 4 – Maintain Existing Water Quality Conditions
Water quality in Lake Nebagamon is regulated and protected through a variety of rules and policies. However, not all relevant/necessary policies apply to the Lake Nebagamon watershed. The primary mechanism for water quality management in Lake Nebagamon is through the WDNR

implementation of the Clean Water Act 303 program. However, current water quality monitoring efforts (necessary to implement the 303 program) are insufficient to track changes in the condition of the lake. Using a monthly water quality sampling regime, it will take approximately 10 years of continuous monitoring to detect a change in average phosphorus concentrations of 15% — and 20% for Secchi transparency (summarized in NPS, 2008). Additionally, because the municipal areas potentially contributing runoff to Lake Nebagamon are all less than 5000 people, they are exempt from the storm sewer system regulations required in larger communities. In the absence of these regulations, local zoning ordinances are potentially insufficient to fully mitigate increased nutrient loads to Lake Nebagamon likely to be encountered under future land use scenarios.

Increased septic system densities potentially developed under future shoreland zoning guidelines will also likely increase phosphorus discharge to Lake Nebagamon. Current county zoning ordinances require routine monitoring and maintenance of septic systems. However, current regulations do not consider potential cumulative impacts of relatively dense septic system development along shoreland areas. Future on-site wastewater designs should prioritize use of holding tank systems over conventional and mound systems (although this recommendation is potentially in conflict with the Douglas County permitting).

Potential future changes in water quality in Lake Nebagamon may be potentially prevented through altered stormwater management and ongoing water quality monitoring. To manage runoff from future development it will be important to develop both water quality and quantify performance standards for land use conversion and regulatory thresholds that are consistent with future development.

Climate change should also be incorporated into future planning. Given the anticipated changes in both water temperature and runoff potential in future climate scenarios, it is critical that all engineering design and land use plans reflect anticipated future hydrologic conditions. This will need to be accomplished through cumulative effect modeling of different land use scenarios, but can also be enhanced through adoptions (and recurring revision of) hydrologic design standards. Current NWS, Atlas 14 rainfall data should be incorporated into design standards as soon as possible.

Goal 5 – Protect and Restore Nearshore, Shoreline and Critical Habitat

The two primary factors that may likely to lead to degradation of shoreland and critical habitat around Lake Nebagamon are shoreland development and a lack of official critical habitat designation. Nearshore and shoreline habitat are most effectively protected through the 404 permitting process of the USACE and the Village of Lake Nebagamon shoreland zoning requirements. While the shoreland zoning requirements provide the most comprehensive levels of protection for shoreland habitats, current zoning requirements do not consider cumulative impacts of multiple individual developments.

Officially designating areas of Critical Habitat in Lake Nebagamon would also enhance protection of in-lake areas. This study identified areas of potential critical habitat around the lake, but stopped short of delineating these areas and seeking special designation as critical habitat. Critical habitat designation would enhance protection of these areas by requiring additional protection if/when any shoreline development or modification occurs in the future.

Goal 6 – Maintain Diverse Native Plant Communities
Maintenance of diverse native plant communities is likely to be primarily impacted by potential future introductions of invasive species. A range of potential invasive species introduction pathways exist for Lake Nebagamon. Given the current levels of access and development, the potential introduction pathways do not represent an immediately critical concern. However, if use and access to Lake Nebagamon (particularly though increased shoreline development) increase as planned, the probability of invasive species introduction increases.

Prevention of future invasive species can be achieved by both the management of the lake and education/interaction with its users. Wisconsin laws prohibit transportation of aquatic plants on vehicles and trailers. However, while this law is a deterrent for invasive species introduction, it cannot achieve a level of 100% containment. In fact, most efforts to prevent/respond to invasive species introductions are voluntary. The NLA currently supports (Clean Boats Clean Waters) CBCW inspections at the primary landing at the north end of the lake. However, one of the primary invasive species pathways to lakes (riparian introduction) is currently not considered as part of enforcement and/or volunteer efforts. Future invasive species control efforts should focus on increased outreach to riparian landowners and boat launch users.

Beyond prevention, activities to monitor and respond to any potential invasive species introductions could be expanded and formalized. Ongoing prevention activities, could be coupled with the development of an Early Detection, Rapid Response Plan to prepare for any potential future species introductions. Similarly, site-specific monitoring should be combined with routine inventories of the entire aquatic plant community to characterize any changes that may be resulting from related stressors like climate change and/or shoreline development (both of which can increase the probability that introduced species become invasive).

Goals 7-8 – Fish Community and Fishery Management
Goals 7-8 all described desired potential states for fish communities and the Lake Nebagamon fishery. All management recommendations for these goals are to be provided by the WDNR fisheries program.

Goal 9 – Maintain Access to Native American Fisheries and Fishing Grounds
Current access to the walleye fishery and seasonal spearing grounds is not impeded, but has the potential to be impacted through shoreline development into the future. Identification and protection of important walleye spawning and tribal member spearing grounds is a critical element in the long-term protection of treaty fishing rights.

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10. Appendix A – Use and Value Survey

Introduction

This report summarizes the results from the stakeholder use and value assessment survey. Given the important role that people play in the use and condition of the Lake Nebagamon ecosystem, it is critical to characterize how different user groups use and value Lake Nebagamon. Results from this survey were used to inform the development of management goals for Lake Nebagamon.

Methods

Survey construction

One of the primary goals of the Lake Nebagamon grant is to implement a stakeholder survey to describe the values, uses and behaviors that shape the use and management of Lake Nebagamon. As a result, a group of faculty and student researchers from Northland College constructed the survey between 2012-2014 as the primary mechanism to capture stakeholder values, attitudes, uses and behaviors. A resource sociologist with the Wisconsin Department of Natural Resources and members of the Lake Nebagamon Sanitary Sewer Commission vetted the final instrument. The final survey is divided into six parts covering a variety of topics including:

(1) participant demographic information,
(2) property information,
(3) participant uses of the lake,
(4) importance of these uses,
(5) participant attitudes toward the lake and its uses, and
(6) general values of the participants.

Sampling strategy and sampling frame

A census sample (i.e., the entire population) of households within one mile of the lakeshore of Lake Nebagamon was drawn. The initial sampling frame included 769 households. After removing undeliverable surveys, duplicate landowners, or vacant properties, the final sampling frame was 736. Surveys were delivered via mail using a modified Dillman method where respondents were contacted prior to receiving their survey, sent the survey, and then sent a reminder if they did not return the survey. Researchers from Northland College collected surveys during the months of August, September, and October of 2014 and ended up with a 44.8 percent (n=330) response rate.

Results

Participants

Survey respondents range in age from 30 to 96 years old with the average age being 61.8 years old. Approximately 63.4 percent of respondents were male; the other 36.6 percent were female. Education levels vary from high school diplomas to graduate and professional degrees, of which approximately 32.6 percent have graduate or professional degrees (see Table 1). Respondents most commonly identify with the income range of $60,000 to $99,000 (see Table 2).

Property Description

The average number of years that respondents have owned property in the Lake Nebagamon area is 27.5 years with the range being 1 years to 100 years. Approximately 59.7 percent of respondents own waterfront property on Lake Nebagamon (see Table 3), and 52 percent of the respondents are not full time residents (see Table 4).

Participation with the Lake Nebagamon Association
Only 45.3 percent of respondents are current members of the Lake Nebagamon Lake Association (see Table 5), and 60.8 percent of respondents report that they never attend lake association meetings (see Table 6).

Participant Uses of Lake Nebagamon
In the section of the survey on participant uses of Lake Nebagamon, respondents were asked: "how often do you participate in the following activities on or adjacent to Lake Nebagamon?" The activities included observing nature, gathering with friends, boating, swimming, canoeing, hiking, fishing, picnicking, cross country skiing, snowshoeing, hunting, snowmobiling, sailing, jet skiing, and ice skating (Figure 1). Participants could choose how often they participate from never (gray), 1-5 times per year (peach), 5-11 times per year (light blue), 1-3 times per month (orange), and weekly or more (dark blue). The circle on each line indicates the average response for all respondents for each question. The matrix is organized in a way that puts the activities in descending order from the activities done most often at the top the top of the matrix and those done least often at the bottom.

The activities that occur most commonly include observing nature, gathering with friends or family, boating, and swimming. These four activities all had a mean score above 3 (i.e., more than 6 times per year). The most common activities, observing nature and gathering with friends or family, have not only the highest mean scores but also both have a majority of respondents (68.2 percent and 58.0 percent, respectively) identify that they engage in this activity monthly or more. The next two most common activities – boating and swimming – had approximately 40 percent of the respondents identify that they do this activity monthly or more when in season.

The activities with the least participation were sailing or windsurfing, ice skating, snowshoeing, cross-country skiing, snowmobiling, and jet skiing with the majority of people (i.e., over 75 percent on each indicator) never participating. A majority of respondents (67.2 percent) also identify as never engaging in hunting or trapping on or around Lake Nebagamon.

Hiking, canoeing or kayaking, fishing and picnicking were also favorable activities, with 52 to 62 percent participation. On the indicators - hiking, canoeing or kayaking, and fishing – between 30 and 35 percent of respondents did identify that they do these activities monthly or more when in season. Picnicking tended to waver to only a couple times of the year rather than several times in a month.

Importance of Uses on Lake Nebagamon
The second section of the survey asked participants: "Please rate how important it is to you that Lake Nebagamon can be used for the following purposes." The activities identified in this section were similar – and in some cases identical – to the indicators included in the frequency of use activities. The specific items participants were asked to rate included: enjoying scenic beauty, gathering with family and friends, maintaining sense of peace and relaxation, observing or enjoying nature, swimming, non-motorized watersports, encouraging sense of community among users of the lake, fishing/ice fishing, motorized watersports, non-motorized snow sports, harvesting food, snowmobiling, hunting or trapping, using water for irrigation or lawn (Figure 2). Participants could choose from "not at all important" (gray), "of little importance" (peach), "neutral" (light blue),

“somewhat important” (orange), and “very important” (dark blue). The circle on each line indicates the average response for all respondents for each item in the matrix. The matrix is organized in a way that puts the activities with the higher average, or activities found to be more important, at the top and those found to be least important at the bottom.

The activity most important to people was enjoying the scenic beauty of the lake, with almost the entire sample, approximately 96 percent, identifying the activity as very important (85.9 percent) or important (10.0 percent). The next three items – gathering with friends and family, maintaining a sense of peace and relaxation, and observing or enjoying nature – also had a majority of respondents (96.0 percent, 94.5 percent, and 91.3 percent, respectively) identify these activities as very important or important. Together, these top four items all relate to the intrinsic value and enjoyment of Lake Nebagamon. A majority of respondents also identified “encouraging a sense of community among users of the lake” as very important (54.0 percent) or important (28.5 percent). Like the top four items, this indicator also falls outside of the typically utilitarian uses of Lake Nebagamon.

Still identified by a majority of respondents as very important or important, the next cluster of indicators all have to do using the lake for recreational purposes. Over 87 percent identified swimming as very important or important. This is followed by a majority of respondents identifying non-motorized watersports (76.4 percent), fishing or ice fishing (76.2 percent), and motorized watersports (72.6 percent) as very important or important. Dropping slightly but still a majority approximately 59 percent of respondents identified non-motorized snow sports as very important or important.

Less than half of the respondents identified the remaining four items as either very important or important. Despite being lower on average, all four indicators tended to have an even distribution across response categories with two having a slight positive skew toward these activities being important, and two of the items having a slight negative skew toward seeing these activities as of little importance or not important. Just under 40 percent of respondents identified harvesting food (e.g., wild rice or fish) as of little important or not important compared to a little over 40 percent choosing very important or important. A similar distribution can be seen with snowmobiling (41.1 percent of little importance/not important versus 41.7 percent very important/important). Approximately 43 percent of respondents identified hunting or trapping as of little importance or not important whereas 36.9 percent selected very important or important. The lowest indicator – using water for irrigation or lawn watering – had 41.3 percent choosing of little importance or not important compared to 30.3 percent selecting very important or important.

Participant Attitudes of Lake Nebagamon and Its Uses

In the third section of the survey, respondents were asked: “Please indicate the extent to which you AGREE or DISAGREE with each of the following statements.” Respondents were asked to rate a series of twenty-two items related to objects such as: land, plants, water quality, shoreline, boats, other users, and development (Figure 3). Participants could choose from “strong disagree” (gray), “disagree” (peach), “undecided” (light blue), “agree” (orange), and “strongly agree” (dark blue). The circle on each line indicates the average response for all respondents for each item in the matrix. The matrix is organized in a way that puts the attitudes with the higher average, or the items that respondents tended to have a stronger agreement with, at the top and those items participants tended to have a stronger disagreement at the bottom.

Similarly to both use and importance items found in the previous sections, the indicators that deal with the intrinsic value of Lake Nebagamon rise to the top. In fact, the three of the top four items are relate to the intrinsic value of the lake including: Lake Nebagamon being a peaceful place to be, maintaining peace and quiet on the lake, and enjoying a view of nature from the water. The highest rated item, Lake Nebagamon is a peaceful place to be, had over 87 percent of the respondents agree or strongly agree with this statement. The other two indicators – maintaining peace and quiet and view of nature from the lake – also had a majority of respondents agree or strongly agree with these statements (76.3 percent and 71.9 percent respectively). When taken with the fifth highest (out of twenty-two) rated item – "I am concerned that if the health of the lake declines, it could decrease my property value" – nearly 68 percent of respondents agree or strongly agree with this statement. Despite intrinsic value being one of the most important parts of Lake Nebagamon, respondents also suggested they have a financial stake in the health of the lake.

The second highest rated item (with 81.3 percent agree or strongly agree) – "Property owners and permanent renters care about water quality" – and the seventh highest rated item (with 50.5 percent agree or strongly agree) – "Property owners and permanent renters are more respectful of the lake than visiting users" – deal with whether respondents agree or disagree with statements of how much other users care and respect the lake. Coupled together, most of the respondents agree that users regardless of relationship to Lake Nebagamon are respectful when utilizing it[1] but definitely have a more favorable opinion of property owners and permanent renters.

Rounding out the top rated items, a majority of respondents (over 64 percent) agree or strongly agree with the statement about their individual actions having a significant impact on the lake. This particular item suggests that respondents feel their actions whether good or bad do affect the health and wellbeing of Lake Nebagamon. When asked about their attitude toward motorized boats, respondents were split on concern over the possibility of increased erosion – with a mean score of 2.67 (which is close to the midpoint of the scale, labeled as "undecided", but slightly skewed toward not worry about erosion due to boat traffic). Approximately 46.2 percent disagree or strongly disagree, 29.8 percent are undecided, and the remaining 24 percent agree or strongly agree. When taken in combination with "I prefer motorized watersports (e.g., boating or jet skiing) to non-motorized sports (e.g., kayaking)," the sample does seem to favor non-motorized sports with approximately 46.6 percent of respondents preferring non-motorized to approximately 24.5 percent who prefer motorized. About 69 percent of the respondents disagree or strongly disagree with the idea that "There are too many boating restrictions (e.g. wake, motor size) on Lake Nebagamon" – compared to only 2.2 percent who agree or strongly agree with this statement. Regardless of preference and feeling about possibility of erosion, respondents seemed to feel boating restrictions were not too stringent.

A smaller proportion but still a majority of respondents (approximately 67.5 percent) disagree or strongly disagree with the statement that "The lake is crowded by boat traffic" compared to 14.7 percent who agree or strongly agree. This sentiment is also reflected in another questions related to crowdedness where respondents were asked about to rate the statement "There are too many homes on the lake." Approximately 45.4 percent chose either disagree or strongly disagree versus 27.3 percent who agree or strongly disagree. The remaining 27.3 percent of respondents were

[1] Most respondents felt Lake Nebagamon has either improved (25.2 percent) or stayed about the same (35.7 percent) when asked about whether the quality of the water has "improved," "stayed about the same," or "worsened." Approximately 14 percent stated it has worsened. A sizeable proportion of respondents (25.2 percent)selected the "I don't know" option.

undecided. Taken together, respondents generally did not see boat traffic nor current number of homes on the lake as contributing to overcrowding.

Approximately 63 percent – and a mean score of 2.28 – of participants selected that they disagree or strongly disagree with the statement "I would prefer to have more people living in and around Lake Nebagamon." A majority of participants (63 percent) also disagree or strongly disagree with the statement that "There is too much access to Lake Nebagamon for non-residents." Only 11.6 percent of respondents agree or strongly agree and the remaining 25.4 percent are undecided. Despite having more negative attitudes about further increasing the population of people in and around Lake Nebagamon, respondents did not have negative attitudes about increasing access to the lake for other users and felt indifferent or positive about the current number of homes as well as the amount of boat traffic on the lake.

Respondents did not seem to have either strong positive or negative attitudes toward aquatic vegetation. When asked to rate "Aquatic plans improve the appearance of the lake," 35.1 percent agree or strongly agree, 28.2 percent disagree or strongly disagree, and 36.7 percent are undecided. When asked how aquatic plants influenced their experiences when recreating on the lake, again, respondents did not seem to have either strong positive or negative attitudes. For example, when asked about concerns over density of aquatic plants affecting recreational activity, 56.9 percent of respondents strongly disagree or disagree with the statement: "Aquatic vegetation is too dense for recreational activity (e.g. swimming and boating)." Approximately 24.9 percent of respondents were undecided while only 18.2 percent agree or strongly agree with this statement. Likewise, when asked specifically about algae and swimming, respondents again are distributed somewhat evenly across response categories with a mean score of 3.07 (just above the mid-point of three and slightly skewed toward being concerned with algae). Approximately 39.3 percent of respondents selected that they agree or strongly agree compared to 33.8 percent who disagree or strongly disagree. The remaining 23.9 percent selected undecided.

Respondents were asked to rate their level of agreement on a variety of indicators related to preference of lakeshore practices. On the three items about personal preference – "I prefer the appearance of landscaped shorelines," "Having a grass lawn leading down to the lake's shore is better than natural vegetation," and "Untouched natural vegetation in and around the lake is unattractive" – respondents tended to slightly favor non-landscaped shorelines. For example, approximately 29.9 percent stated a personal preference for landscaped shorelines compared 40.7 percent of respondents who do not. Similarly, 21.7 percent of respondents thought a grass lawn leading down to the waterfront is better than natural vegetation compared to a slight majority at 52.9 percent who did not. Approximately 69.9 percent of respondents disagree or strongly disagree with the statement that untouched natural vegetation in and around the lake is unattractive. Despite having a slight preference for manicured shorelines, a sizable majority did not have a negative attitude toward untouched natural vegetation. Finally, when asked about whether they think other property owners around the lake have a preference for lawns/landscape over natural vegetation, just over 46 percent of respondents said they thought others around the lake prefer lawns, 15.9 percent thought others prefer natural vegetation, and 37.7 percent were undecided.

Finally, a sizable majority of respondents – over 80.1 percent – and the lowest overall mean score (1.96) did not have a problem with the smell of the lake.

Participant Attitudes of Lake Nebagamon Management
In this section of the survey, respondents were asked: "Please indicate the extent to which you AGREE or DISAGREE with each of the following statements." Respondents were asked to rate five items related to management of the Lake Nebagamon fishery (Figure 4). Participants could choose from "strong disagree" (gray), "disagree" (peach), "undecided" (light blue), "agree" (orange), and "strongly agree" (dark blue). The circle on each line indicates the average response for all respondents for each item in the matrix. The matrix is organized in a way that puts the attitudes with the higher average, or the items that respondents tended to have a stronger agreement with, at the top and those items participants tended to have a stronger disagreement at the bottom.

Overall, the respondents, on average are mostly undecided but tend to have a negative skew towards the quality of the management of Lake Nebagamon. Just under 40 percent of the respondents are undecided about whether or not the Wisconsin Department of Natural Resources is effectively managing the fishery of Lake Nebagamon while approximately 30.2 percent disagree or strongly disagree and 30. 6 percent agree or strongly agree. Respondents seem to be similarly undecided (32.7 percent) with a slight negative skew (36.9 percent disagree or strongly disagree) towards the tribal management of the fishery. On average, respondents feel that Lake Nebagamon is worse than other lakes in the area (42.3 percent) or they are undecided (40.5 percent). A similar finding can be seen with a 41.3 percent of respondents selecting that they disagree or strongly disagree with the statement "Fishing tournaments enhance the quality of the lake." Another sizeable proportion of respondents chose that they were undecided at 38.2 percent. The majority of respondents, about 66.9 percent, do not think that there is excessive recreational fishing on Lake Nebagamon.

Angler Attitudes of Lake Nebagamon Fishery
In this section of the survey, only the respondents who self-identified as anglers (n=162) completed this section. Respondents were asked: "Please indicate the extent to which you AGREE or DISAGREE with each of the following statements" (Figure 5). The matrix above is arranged in the same way as the previous two sections with respondents being asked to rate seven items related to fishing on Lake Nebagamon. Participants could choose from "strong disagree" (gray), "disagree" (peach), "undecided" (light blue), "agree" (orange), and "strongly agree" (dark blue). The circle on each line indicates the average response for all respondents for each item in the matrix. The matrix is organized in a way that puts the attitudes with the higher average, or the items that respondents tended to have a stronger agreement with, at the top and those items participants tended to have a stronger disagreement at the bottom.

Of the respondents who fish on Lake Nebagamon the majority (65 percent) consider themselves to be experienced anglers. According to about 68.2 percent of the respondents the most important aspect of fishing on Lake Nebagamon is interacting with the natural world. Whereas only approximately 40 percent of respondents felt that the social interaction with others while fishing was the most important. The respondents appear to be generally dissatisfied with the fish they are able to catch in Lake Nebagamon. More than half of the respondents (approximately 52 percent) show that the species and size of the fish they are able to catch are unsatisfactory. This is compared to only 31 percent (species) and 26 percent (size) of respondents who identified that they are satisfied with the fish they are able to catch. The lowest rated item, number of fish they can catch, had 60.8 percent of anglers claim they are unsatisfied.

When the respondents were asked what species of fish they typically fish for and which they would most like fish for (Table 5 and Table 6), 50 percent or more typically fish for Walleyes, Crappies, Sunfish/Bluegill, and Smallmouth Bass. Some anglers typically fish for Northern Pike (45 percent) and Largemouth Bass (28 percent). Though very few typically fish for Trout, Muskies, or White fish in Lake Nebagamon. The respondents had similar answers for what they would like to fish. Though there is an overwhelming majority (85.9 percent) that would like to fish for Walleye. Wanting to fish for Crappies, Sunfish/Bluegill, or Smallmouth Bass falls between 65.9 percent and 40.1 percent. The less common fish that anglers would like to fish for include Northern Pike, Largemouth Bass, Trout, Muskie, and Whitefish in order from highest percent response to lowest.

Participant Willingness to Protect Lake Nebagamon

In this section of the survey, respondents were asked: "The following items are meant to gauge your willingness to participate in certain activities concerning Lake Nebagamon. Your responses are hypothetical and will not indicate any actual commitment to these activities. How willing would you be to…?" (Figure 6). On the six items in the matrix, participants could choose from "extremely unwilling" (gray), "somewhat unwilling" (peach), "somewhat willing" (orange), and "extremely willing" (dark blue). The circle on each line indicates the average response for all respondents for each item in the matrix. The matrix is organized in a way that puts the items respondents are more willing to do at the top and those they are less willing to do toward the bottom.

The majority of respondents would be willing to participate in protecting Lake Nebagamon by attending to an educational event (almost 80 percent), changing how they manage their personal property (70 percent), many are even willing to limit their use of the lake in order to protect it (65 percent), and volunteer (70 percent). Though most respondents are willing to assist in these ways, the majority, about 70 percent, are unwilling to offer any financial support through taxes and fees.

Participant Values

In the final section of the survey, respondents were asked: "We would like you to tell us your views on various issues. For each statement, please select the circle nearest the statement you most agree with. Selecting the circle furthest left indicates total agreement with the left-hand statement; the circle furthest right indicates total agreement with the right-hand statement. The circles in between indicate varying levels of agreement. The middle circle suggests you have similar levels of agreement with both statements." The matrix asks respondents to evaluate eleven different sentence pairings on a variety of values. The circle on each line indicates the average response (from 1-7) for all respondents for each item in the matrix (Figure 7).

The first item on the matrix asked respondents whether they see their Lake Nebagamon property as primarily a financial investment or a place to live and recreate. The majority of respondents chose values closer to a place to recreate. In fact, 81.7 percent of respondents selected numbers 5, 6, or 7 suggesting respondents overwhelmingly saw their Lake Nebagamon property as a place to live and recreate. When taken in combination with whether respondents feel most closely connected to Lake Nebagamon community or another community, as can be seen in from the overall mean score of 3.6, respondents are equally distributed across the scale. Roughly 47.8 percent identified feeling connected to the community surrounding Lake Nebagamon – as indicated by circling 1, 2, or 3 on the scale – compared to 29.3 percent of respondents who felt most connected with some other community – as indicated by circling 5, 6, or 7 on the scale.

When asked to choose between whether changes in the health of Lake Nebagamon affect the respondents overall well-being, respondents tended to feel changes to the lake would affect their well-being. A majority (61 percent) of respondents choose either 1, 2, or 3 while an additional 20.8 percent chose the middle number 4. Although we cannot say for certain, because many respondents tended to identify with the property as a place to live and recreate over a financial investment, one can assume that some of these changes are more than just financial in nature.

Most respondents saw appropriate management of Lake Nebagamon being for the "conservation of the natural ecosystem" over "managed primarily for human uses". Approximately 43 percent of participants chose managing the lake for the conservation of the natural ecosystem versus 23 percent who tended to lean toward management for human uses. This sentiment is not, however, reflected in the percent of participants who tend to agree more with the statement that the natural environment should be protected from human activity with 28.7 percent falling toward protecting from human activity, 31.9 percent in the middle, and 39.4 percent leaning toward utilization for human needs and growth. When asked where respondents fell on whether they felt more closely aligned with managing the lake for future generations versus for current users, 47.9 percent of respondents suggested they thought the lake should be managed for the needs of future generations versus 23.5 percent who identified more closely with managing for current users. Roughly, 26.8 percent of respondents chose the middle point.

Additionally, a large majority of respondents felt that it was appropriate for human intervention to help maintain a healthy lake (70.2 percent) rather than not intervene (8.5 percent) and felt that individuals (37.9 percent) – not government (27.5 percent) – should be primarily responsible for managing the lake. Participants did, however, suggest limitations on what people should be able to do regardless of whether they own property; 25.7 percent tended to lean toward individuals having cart blanche to develop their property versus 60.2 percent who suggested constraint and imposing limitations on an individual's ability to develop their property. Finally, respondents tended to give priority to those who live in and around the lake (60.6 percent) more say in its management over all users of Lake Nebagamon (23.9 percent).

Table 10.1. Property Location

How would you best describe your property?	
Waterfront on Lake Nebagamon	59.7%
Non-waterfront	37.8%
Waterfront on a different lake	2.5%

Table 10.2. Participant Residency

How would you best describe your residency?	
Year round	48.0%
Full time in summer	14.5%
Other	14.5%
Full time in summer and more throughout the year	9.5%
Weekends throughout the year	7.1%
Weekends only in summer	6.5%

Table 10.3. Nebagamon Lake Association Membership

What is your affiliation with the Nebagamon Lake Association?	
Never been a member	46.3%
Current member	45.3%
Former member	8.4%

Table 10.4. Lake Association meeting attendance

How often do you attend Lake Association meetings?	
Never	60.8%
Every few years	22.2%
Annually	11.4%
More than once a year	5.7%

Table 10.5. Species typically fished for.

What species do you typically fish for in Lake Nebagamon?	
Walleye	77.7%
Crappie	70.3%
Sunfish/Bluegill	64.3%
Smallmouth Bass	52.7%
Northern Pike	45.6%
Largemouth Bass	28.7%
Trout	10.4%
Muskie	2.9%
Whitefish	1.7%

Table 10.6. Species most like to fish for.

What species would you most like to fish for in Lake Nebagamon?	
Walleye	85.9%
Crappie	65.9%
Sunfish/Bluegill	44.0%
Smallmouth Bass	40.1%
Northern Pike	35.7%
Largemouth Bass	30.9%
Trout	28.0%
Muskie	8.3%
Whitefish	7.7%

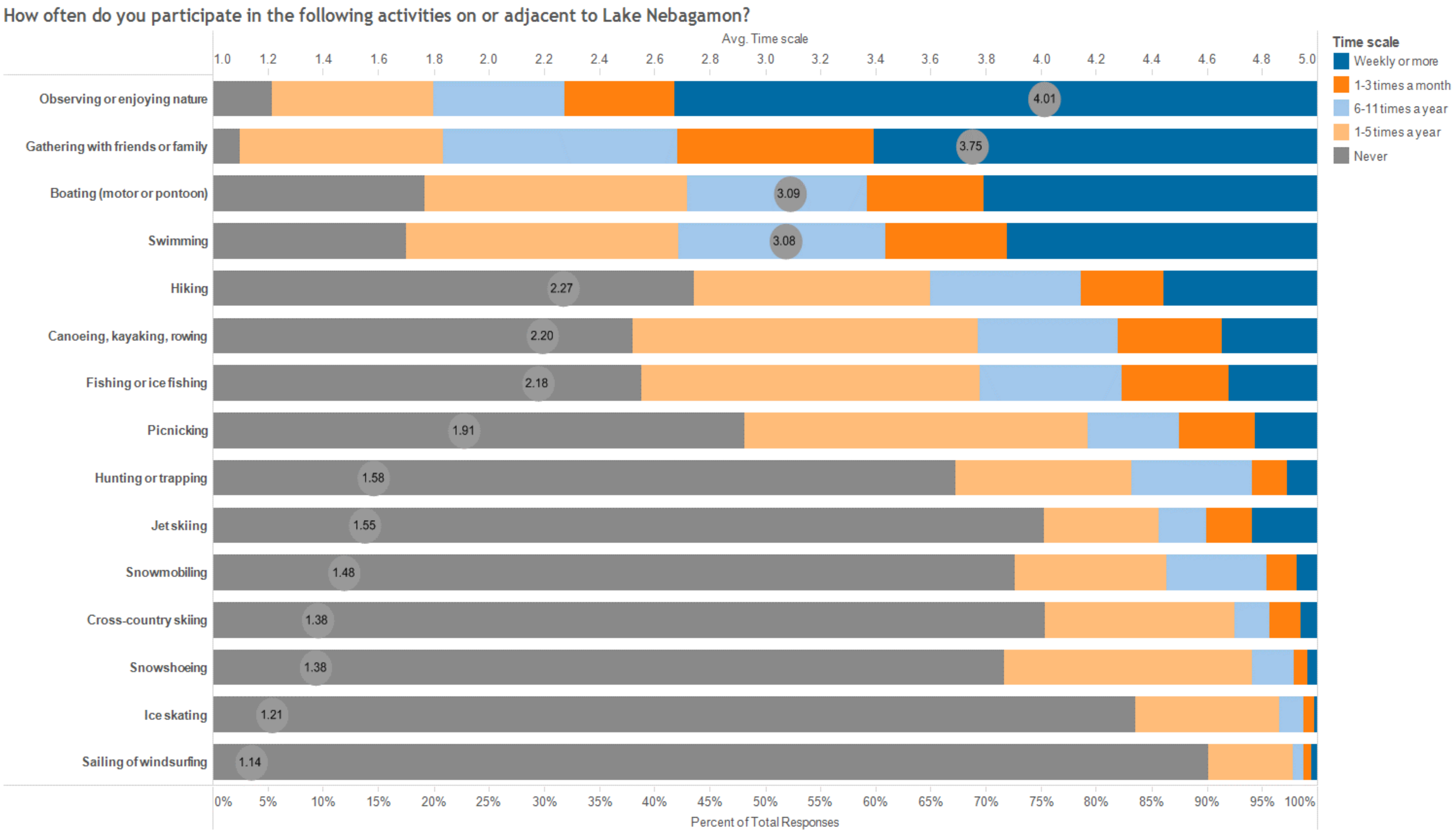


Figure 10.1. Participant Uses of Lake Nebagamon

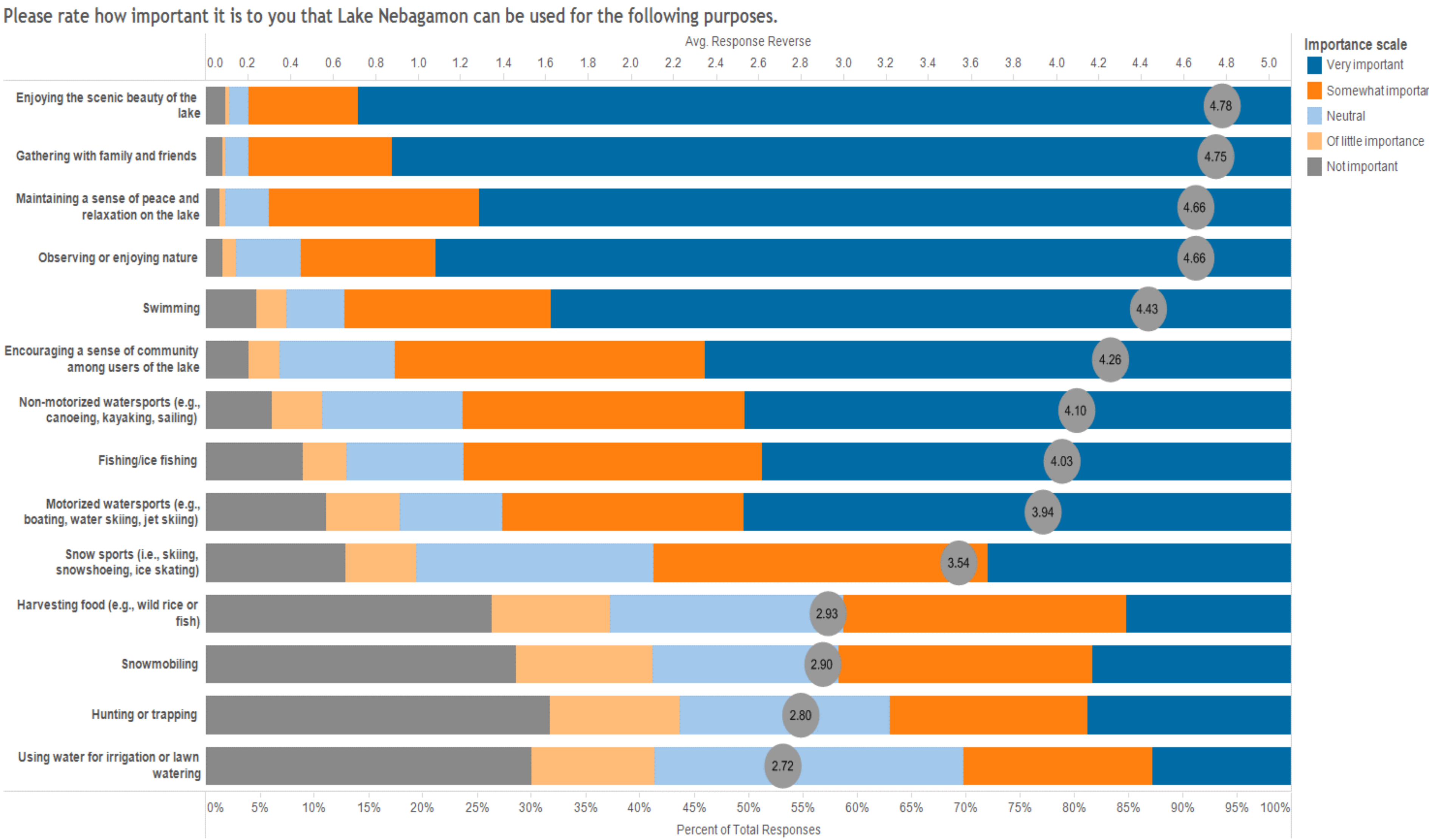


Figure 10.2. Importance of Uses on Lake Nebagamon

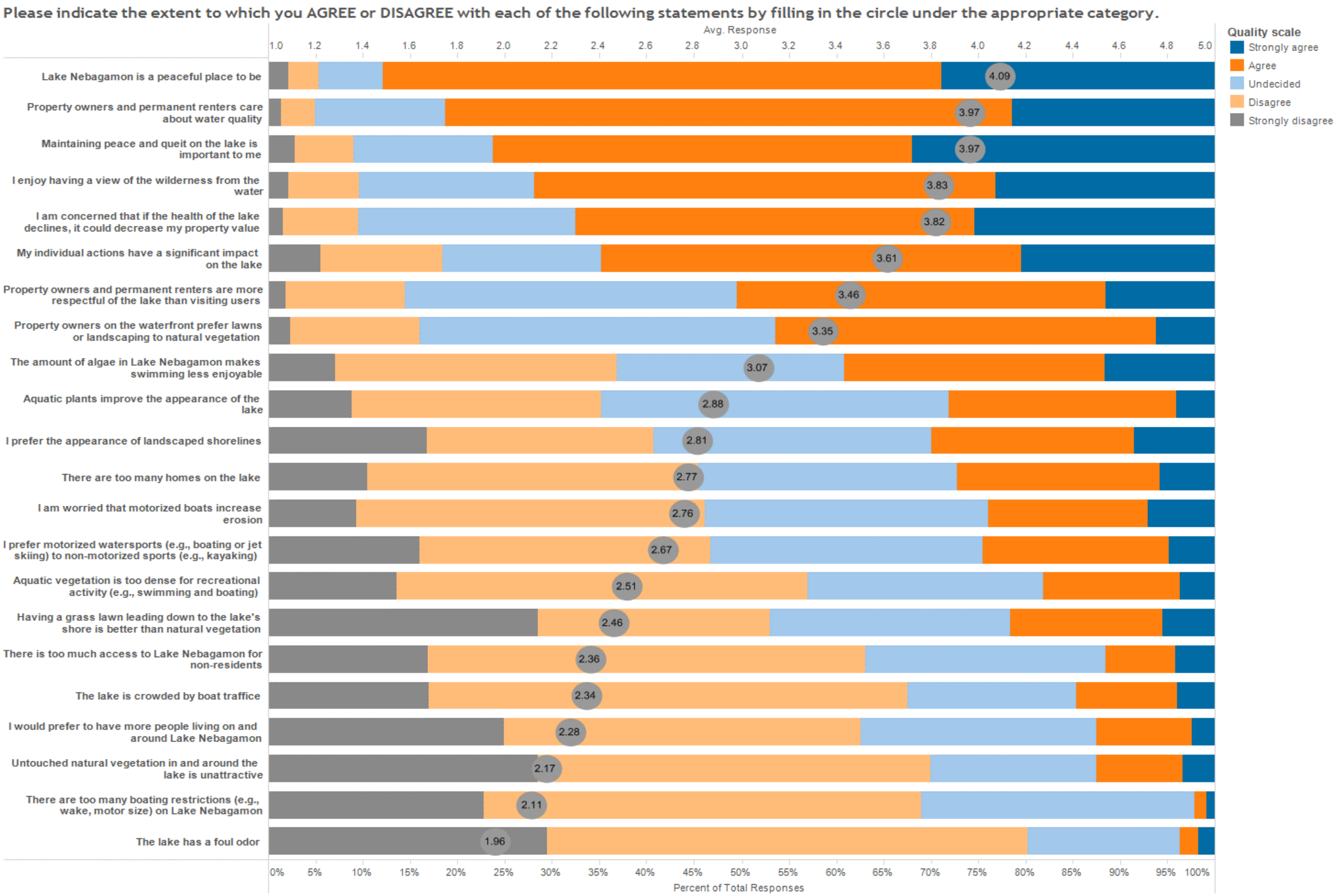


Figure 10.3 Participant Attitudes of Lake Nebagamon and Its Uses

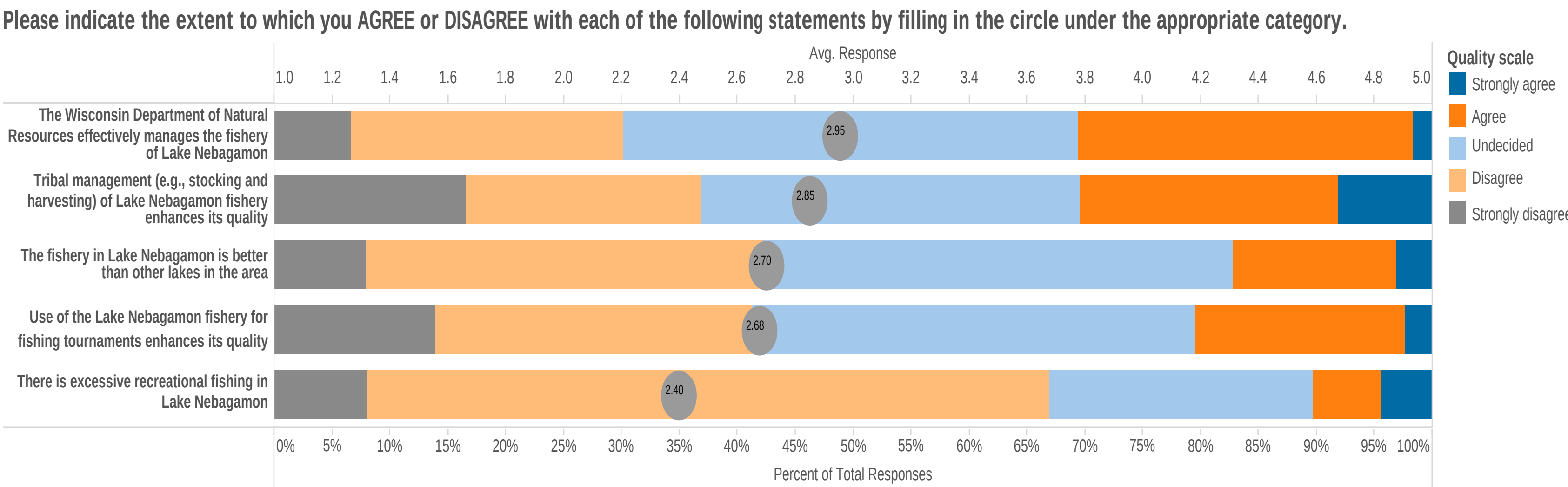


Figure 10.4. Participant Attitudes of Lake Nebagamon Management

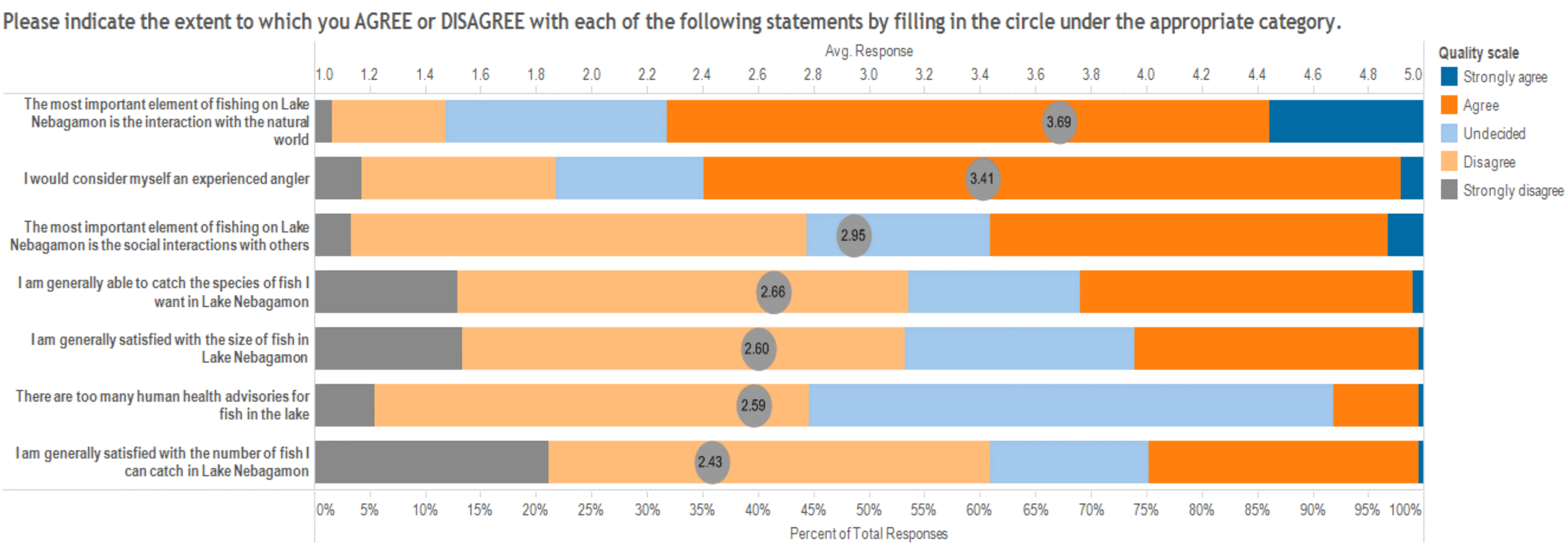


Figure 10.5 Angler Attitudes of Lake Nebagamon Fishery

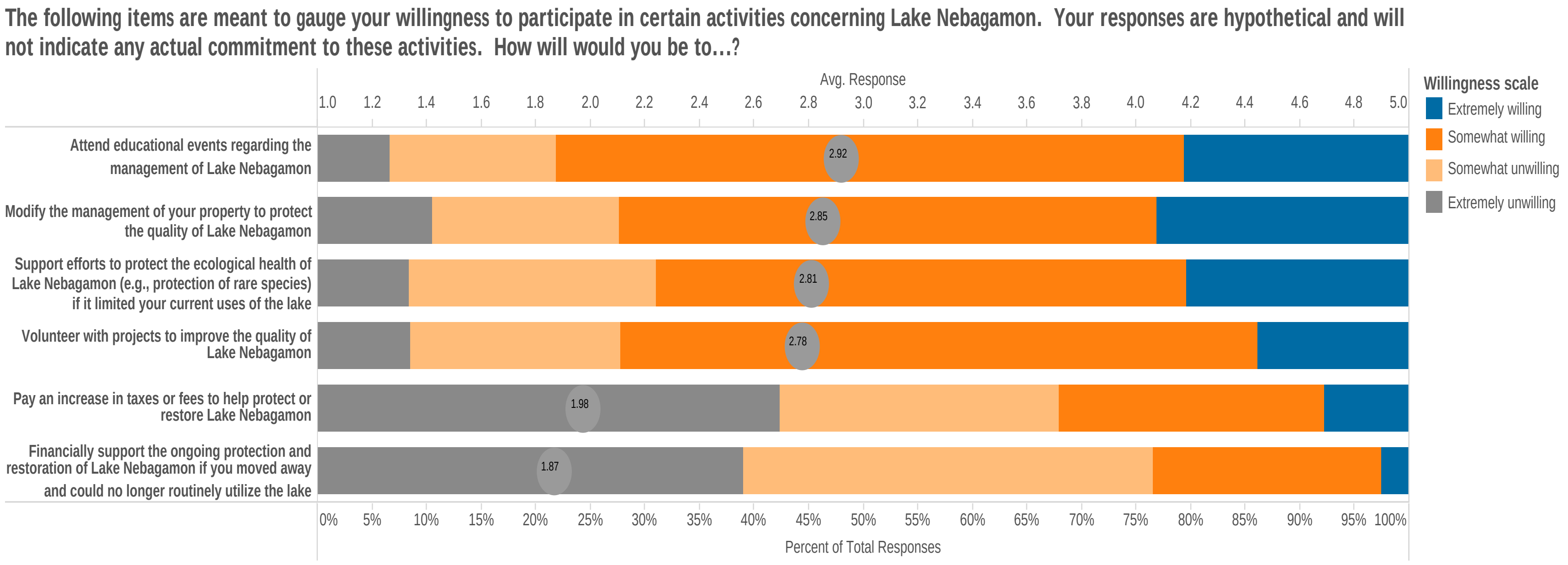


Figure 10.6 Participant Willingness to Protect Lake Nebagamon

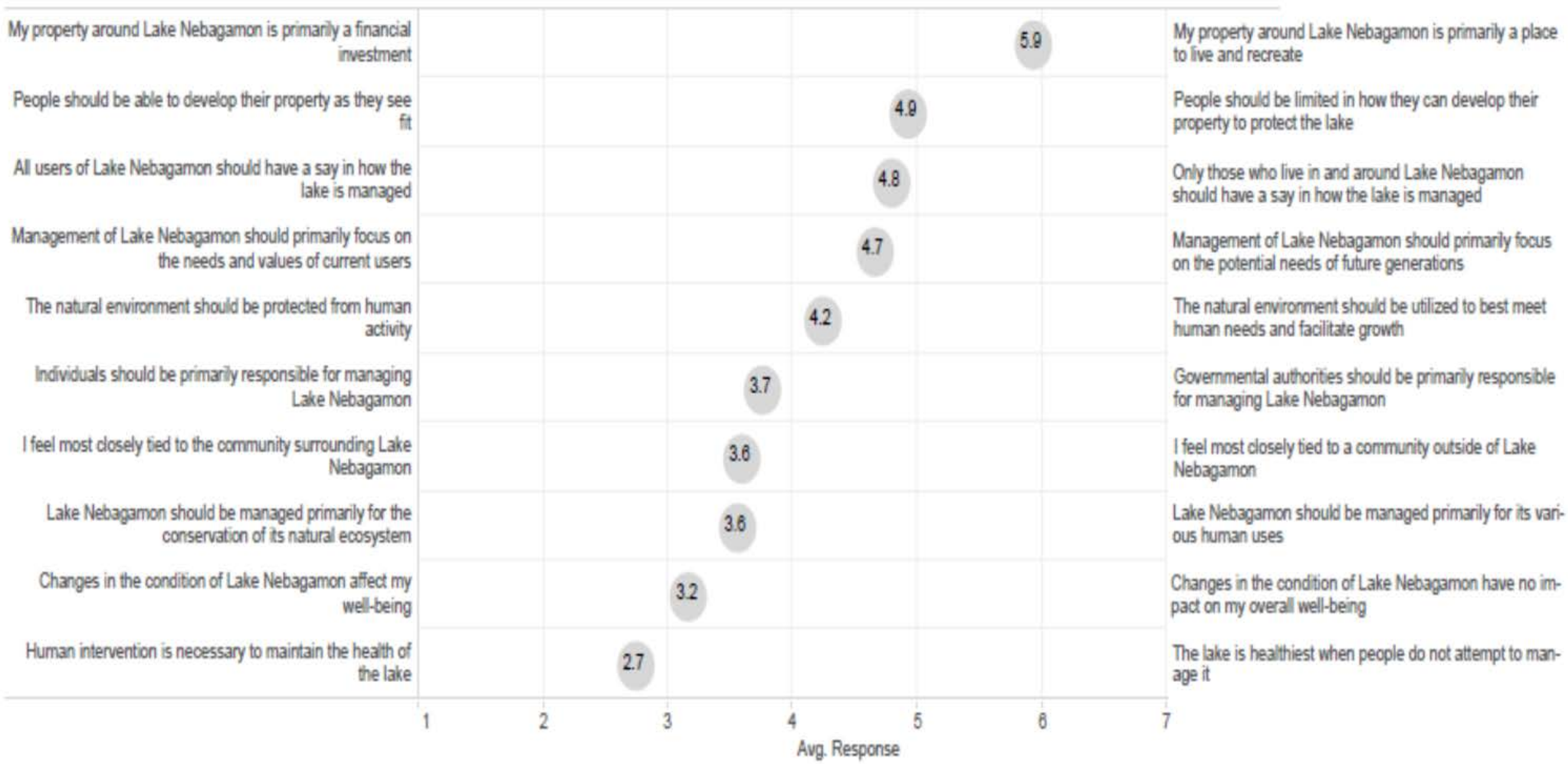


Figure 10.7 Participant Values

11. Appendix B – Summary of Physical-chemical Conditions

Introduction

This report summarizes the status of water quality conditions and physical processes in Lake Nebagamon. Given the importance of physical processes and water quality conditions (see Sections 5.1 and 5.4) in lake management, a detailed assessment of these systems was conducted in Lake Nebagamon. Results from this assessment were summarized and used to inform the watershed assessment (Appendix D) and ecosystem modeling efforts (Appendix G).

Methods

To assess physical and chemical conditions and processes in Lake Nebagamon, water chemistry and lake discharge were sampled throughout the two year study. Chemistry and discharge data were used to assess tropic conditions, describe stratification processes and develop water and nutrient budgets for the lake.

All water quality samples were collected and analyzed following methods outlined by USEPA (2007). Samples were collected from epi, meta and hypolimnion layers of the lake (during stratification) every two week from ice off (generally May) to fall turnover (generally October) throughout the study period. Surface water samples were collected using a two-meter composite method. Samples were collected from the deepest point in the northern and southern sections of the lake (Figure 2.1) to represent the historical range of water quality conditions observed throughout the system. Surface water samples were analyzed for TP, SRP, Chlorophyll-a and Total Nitrogen. Meta and hypolimnion samples were collected using a Van Dorn sampler and analyzed for TP and SRP. Dissolved oxygen, temperature, pH and conductivity data were collected throughout a vertical profile using a YSI multi-probe water quality meter. All water quality samples were analyzed at the Wisconsin State Lab of Hygiene and the Applied Research and Environmental Laboratory (ARELab) at Northland College following Standard Methods for Analysis of Water and Wastewater 21st Ed. (2005). All data were uploaded to the SWIMS system under the Station ID codes 163394 (NEBBDH, north basin) and 163127 (NESB, south basin).

A water budget for Lake Nebagamon was developed following a modified version of protocols described by Robertson et al. 2003. Estimation of the water budget for Lake Nebagamon was based on continuous measurement of discharge at the two primary tributary inputs (Steele and Minnesuing Creeks) and the main outlet (Nebagamon Creek). Throughout the study period discharge from Lake Nebagamon was measured following protocols described by Rantz et al. 1982.

Water inputs and output to and from Lake Nebagamon were described with respect to precipitation, evaporation, groundwater inflow and watershed runoff. Within the discharge record, periods of base flow were identified and used as a direct estimate of groundwater discharge to the lake (given the proximity of the gauge site to the outlet, all base flow discharge was assumed to originate from groundwater inflow to the lake). Direct precipitation to the lake was calculated by summing the total inches of rainfall from a corresponding regional weather station (located 23 miles away in Drummond, WI) across the total area of the lake on a monthly basis. Watershed runoff was estimated separately for gauged and ungagged sections of the watershed. Discharge from ungaged areas was estimated by summing the monthly precipitation accumulation across the associated watershed area and using estimates of soil infiltration capacities and hydrologic connectivity to establish a monthly percentage of precipitation that likely directly runs off to the lake. Given the high infiltration capacity of the soils in the surrounding watershed, ~87% percent of annual precipitation was assumed to infiltrate into the soils. Discharge from gaged areas was calculated from the continuous discharge record.

Water losses from Lake Nebagamon were accounted for evaporation, tributary discharge and changes in storage. Evaporation was estimated using monthly unit area evaporation rates (evaporation during ice cover was assumed to be zero) based on observation from regional evaporation studies (see Robertson et al. 2003). Changes in storage were estimated as the difference between the total inputs to the lake minus the losses from the lake from tributary discharge and evaporation. Changes in storage were then converted to a potential corresponding change in water level to ground-truth the water budget.

An external nutrient budget (i.e., all sources of phosphorus originating outside of the aquatic system) was developed by either assigning annual mass loads of phosphorus to a particular input source or by multiplying likely input concentrations to an associated inflow volume. Phosphorus inputs from precipitation were estimated by assigning an average concentration to annual monthly precipitation measurements. A regional precipitation concentration of 7 ug P /L was assigned to rainfall data. Watershed runoff of phosphorus was estimated by multiplying existing land cover areas by a likely area-based annual phosphorus export coefficients (see Appendix D). Septic system inputs were estimated by combining parcel residency data (see Appendix A) with annual per capita export coefficients (see Appendix D). Groundwater inputs were estimated by multiplying estimated groundwater influx values by a corresponding regional average groundwater phosphorus concentration of 20 ug/L. Phosphorus loss via outlet discharge was estimated by multiplying monthly average discharge values by the corresponding surface water concentration. Winter concentrations were estimated by linearly interpolating between fall and spring phosphorus measurements. All phosphorus not discharged via outflow was assumed to be retained within the system (internal phosphorus dynamics are described further in Appendix G)

Results and Discussion

Water Budget

Water levels in Lake Nebagamon are predominantly influenced by surface water runoff from Steele and Minnesuing Creeks (Table 11.1). Throughout the year, approximately 75% of the total input of water to Lake Nebagamon occurs through surface water. The majority of water lost from Lake Nebagamon each year occurs though the outlet tributary (Nebagamon Creek) that ultimately flows into the Brule River and Lake Superior (Figure 11.1). As a result, water levels in Lake Nebagamon generally rise each spring in response to snow melt and early season precipitation and then gradually fall over the course of the year reaching minimum flow conditions in early to late fall.

Physical Processes

Physical processes in Lake Nebagamon are consistent with most lake throughout the region. As described in Section 5.1, most lakes throughout northern WI, mix twice per year and stratify throughout the summer (i.e., are dimictic). In both 2013 and 2014, Lake Nebagamon stratified in the early summer and turned-over in early fall. As the summer progressed, the depth of stratification increased, but was occasionally broken up by wind mixing events. Following wind-driven de-stratification events, return to stratified conditions returned within 1-2 weeks.

Water Clarity
Water clarity in Lake Nebagamon is consistent with other dimictic, mesotrophic lakes throughout the region. Average Secchi depths range from 1 to 3 meters and this clarity is generally mirrored by the Chl-a concentrations, which range from 3 to 10 ug/L (Figures 11.6 and 11.7). These results suggest that water clarity in Lake Nebagamon is primarily driven by algal growth and productivity. Based on the dissolved oxygen concentrations observed in Lake Nebagamon, it is likely that maximum algal densities occur in the upper two meters of water, which is consistent with other lakes throughout the region.

Nutrient Concentrations
Nutrient concentrations in Lake Nebagamon are consistent with regional mesotrophic lakes (Figure 11.8). Surface water total phosphorus concentrations averaged 18 ug/L during growing season conditions, while hypolimnetic phosphorus concentrations averaged 34 ug/L during the same time period. Surface water TP concentrations are consistent with mesotrophic conditions within the lake.

These results suggest that sediment release of soluble phosphorus as a result of anoxic conditions in the hypolimnion is somewhat common in Lake Nebagamon. However, because of the concentrations of phosphorus in the hypolimnion are only slightly higher (~2x) than in surface waters it is unlikely these processes are negatively affecting water quality conditions. Rates of sediment release of nutrients was also greater in the southern basin, suggesting that water quality conditions may vary throughout the lake system and that some regions are more susceptible algal blooms than others.

External Nutrient Budget
Within the Lake Nebagamon ecosystem, the majority of the annual phosphorus load originates from watershed runoff (Table 11.2). Most of this watershed loading of phosphorus occurs as part of spring snowmelt and rainfall. Approximately 56% of the phosphorus delivered to the lake from external sources is discharged through the outlet to Nebagamon Creek. Additional "internal" sources and loss processes are discussed in Appendix G.

Trophic State and Water Quality Attainment
The combination of nutrient, Secchi depth and chlorophyll-a data suggest that the current conditions in Lake Nebagamon are consistent with its designation as a mesotrophic lake. Current phosphorus TSI values average 47. Additionally, average annual surface water phosphorus concentrations are below the 30 ug/L level identified as a threshold for water quality impairment in mesotrophic lake types, like Lake Nebagamon. The water quality conditions observed throughout this study are consistent with the fishery, aquatic plant and plankton community data that have been collected for the lake (see Section 5.4 and Appendices E and F).

Management and Monitoring Considerations
Because Lake Nebagamon is currently meeting water quality standards, primary management activities should focus on protection efforts to minimize nutrient runoff to the lake and alteration of the lake's hydrologic cycle. The primary regulatory and technological options related to water quality protection in Lake Nebagamon are related to land use and planning, and thus are described in Section 7.

In addition to these management considerations, a series of ongoing monitoring and assessment studies should be considered. Relatively little is known about the groundwater system surrounding

Lake Nebagamon. Because of the potential for increased residential development around the lake, future assessment work should quantify the existing groundwater nutrient concentrations to more accurately characterize any future potential impacts of septic system discharge of phosphorus to the lake. This assessment characterized the water quality trends and process at two sites that reflect general conditions throughout the lake. However, given the presence of discrete, hydrologically isolated embayments throughout the lake, future monitoring work should characterize the diversity and connectivity of water quality conditions throughout the lake to identify areas that may be particularly susceptible to changes in water quality conditions. Using a monthly water quality sampling regime, it will take approximately 10 years of continuous monitoring to detect a change in average phosphorus concentrations of 15% — and 20% for Secchi transparency (summarized in NPS, 2008).

Uncertainty and Data Interpretation

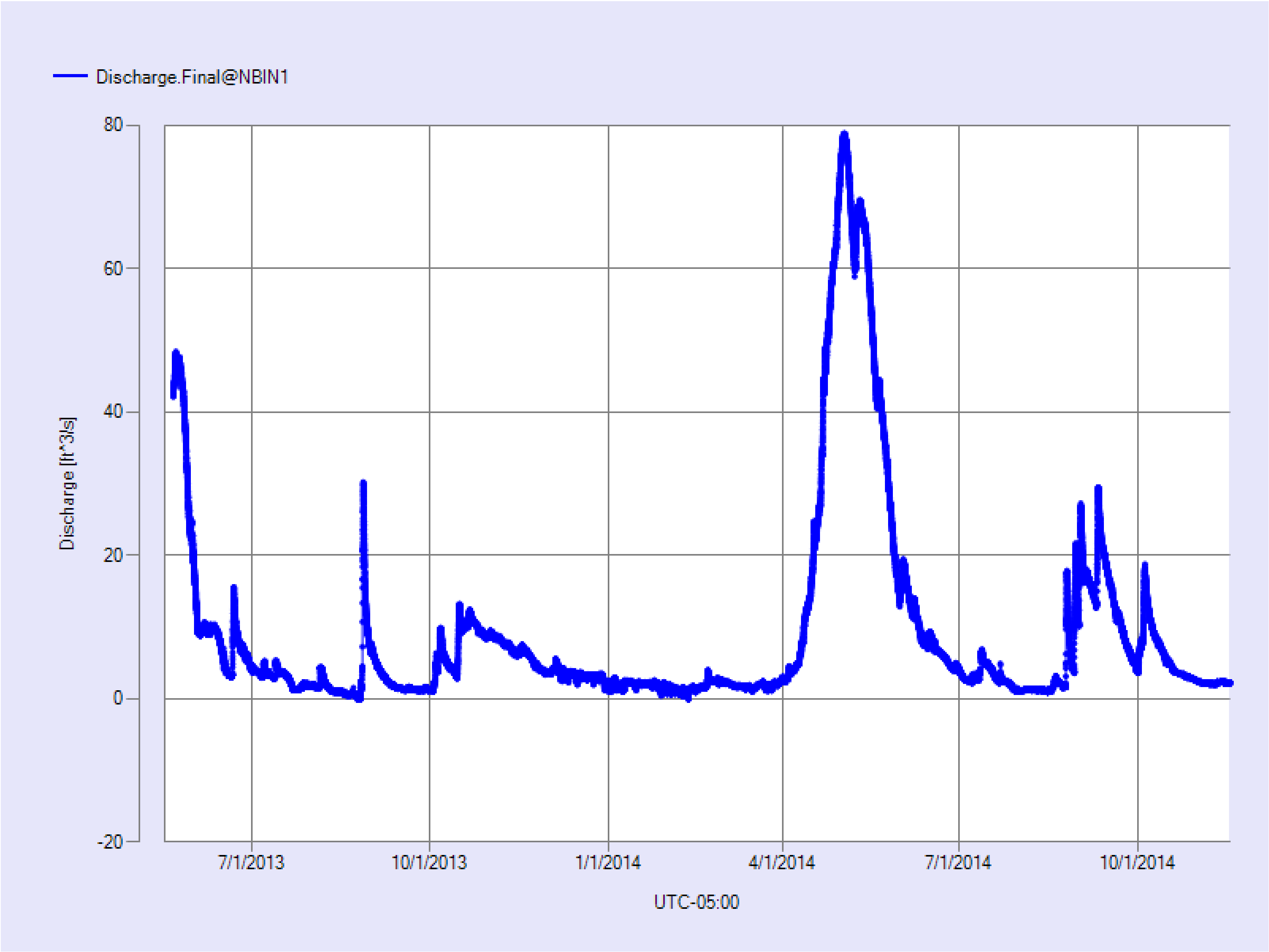
Given that many elements of the water and nutrient budget were derived from literature values, instead of field measurements, a significant level of uncertainty exists within the analyses. Results from these analyses likely represent the general trends in Lake Nebagamon quite well, but there is likely to be a significant amount of site specific variability in and around the lake. For example, some areas of the lake are likely to be more important sites for groundwater inflow, while others are likely to be sites for groundwater recharge. Similarly, some areas of the lake likely have higher nutrient concentrations in inflowing ground and surface water and some embayments may be more susceptible to nutrient runoff than others (because of their isolation). Given these uncertainties, these results should be used as general guidance to management planning, but field observations should be collected to support any site-specific management decisions.

Table 11.1. Water budget for Lake Nebagamon based on 2013 and 2014 monitoring.

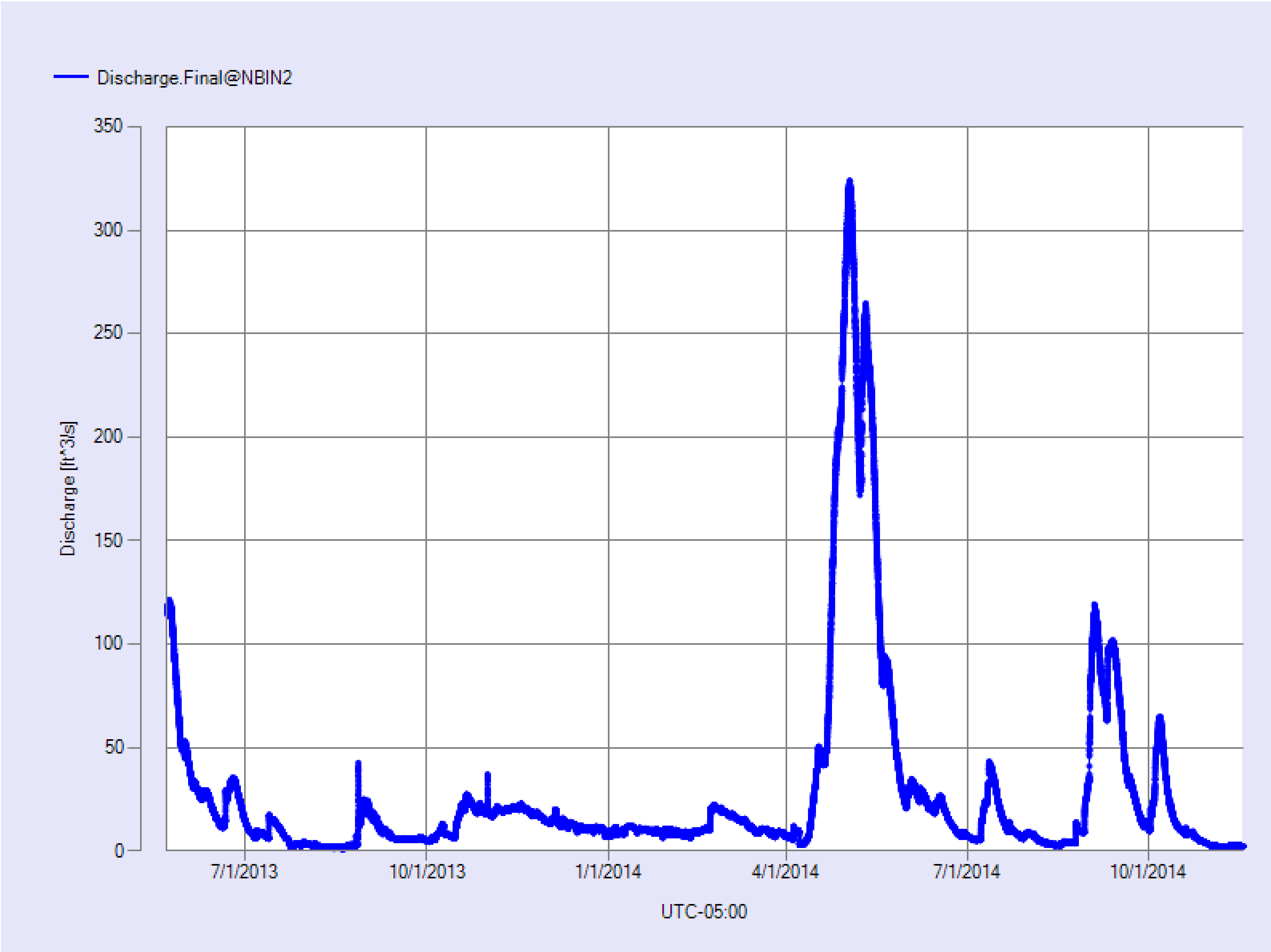
Month	Inputs				Outputs			Maximum Change in Lake Level (ft)
	Precipitation	Ungaged Runoff	Tributary Inflow	Direct Groundwater	Evaporation	Nebagamon Creek	Change in Storage	
Jan	78	0	943	331	0	757	306	0.31
Feb	113	0	994	331	0	957	146	0.15
Mar	121	215	1084	331	0	1034	139	0.14
April	447	921	7422	331	67	5378	662	0.67
May	483	3062	13040	331	304	9378	835	0.85
June	487	54	2509	331	336	3576	-1564	-1.59
July	234	26	1148	331	346	1793	-846	-0.86
Aug	432	48	767	331	297	893	-203	-0.21
Sept	319	35	3331	331	230	2555	179	0.18
Oct	279	31	1861	331	168	2167	-525	-0.53
Nov	182	60	1148	331	39	1323	-132	-0.13
Dec	174	0	1220	331	0	842	436	0.44
Total	3347	4452	35466	3968	1788	30654	-568	-0.58
Percent	7%	9%	75%	8%	5%	93%	2%	

Table 11.2. External Phosphorus Budget for Lake Nebagamon based on 2013 and 2014 monitoring.

Month	Phosphorus Mass Load (g)					
	Inputs				Outputs	
	Direct Precipitation	Watershed Runoff	Groundwater	Septic	Nebagamon Creek	In-lake Retention
Jan	678	28026	8157	2945	18668	21137
Feb	972	29549	8157	2945	23603	18020
Mar	1043	38622	8157	2945	25505	25261
April	3856	247896	8157	2945	165827	97027
May	4168	478448	8157	2945	231364	262354
June	4204	76146	8157	2945	66161	25290
July	2022	34868	8157	2945	33171	14820
Aug	3732	24218	8157	2945	22039	17012
Sept	2753	100017	8157	2945	69347	44524
Oct	2405	56209	8157	2945	53462	16254
Nov	1571	35907	8157	2945	32640	15940
Dec	1501	36258	8157	2945	10391	38469
Total	28903	1186164	97886	35334	752180	596108
Percent	2%	88%	7%	3%	56%	44%



Discharge.Final@NBIN1
80
60
40
20
0
-20
Discharge [ft^3/s]
7/1/2013
10/1/2013
1/1/2014
4/1/2014
7/1/2014
10/1/2014
UTC-05:00


Discharge.Final@NBIN2
350
300
250
200
150
100
50
0
Discharge [ft^3/s]
7/1/2013
10/1/2013
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10/1/2014
UTC-05:00

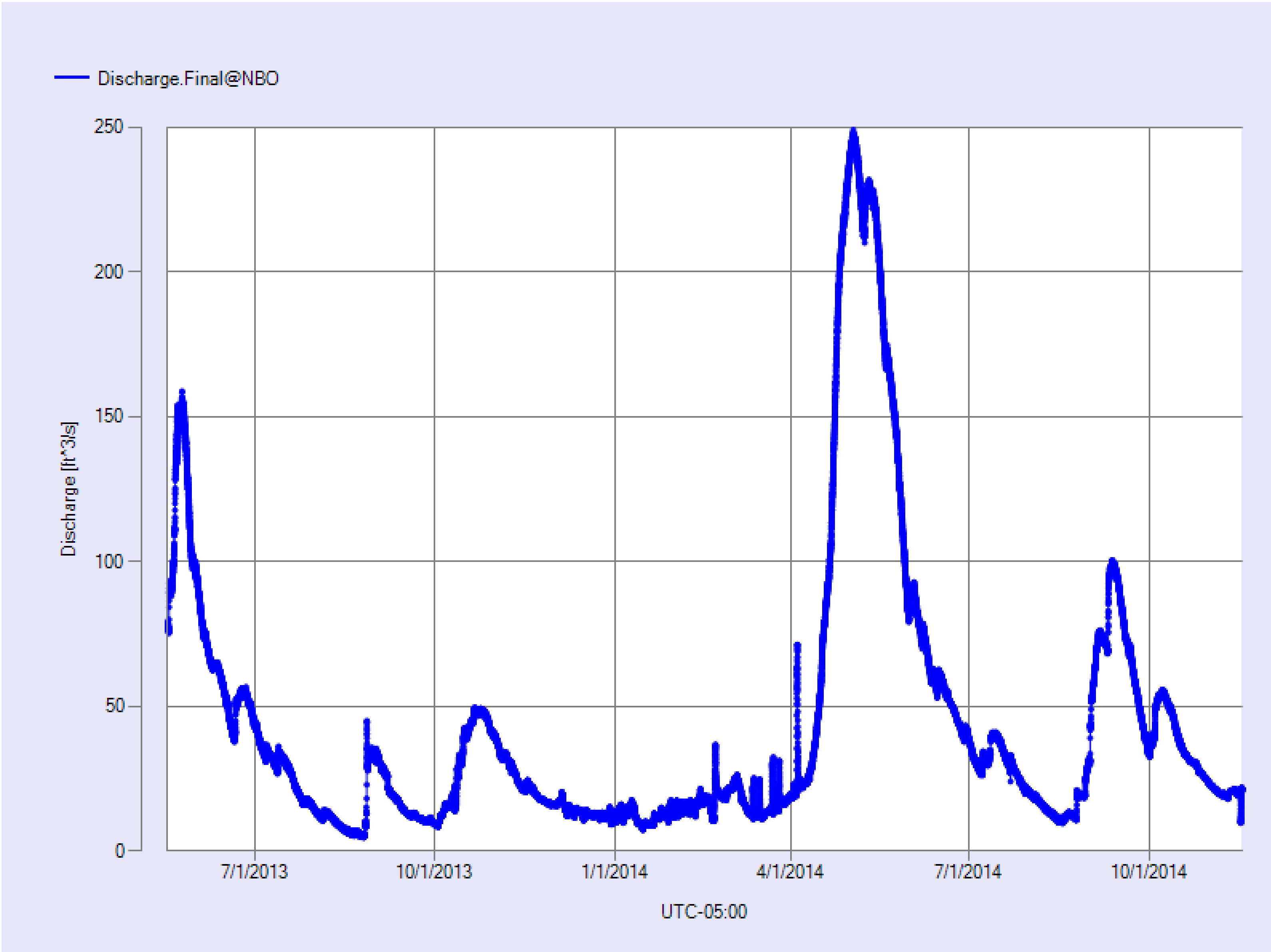


Figure 11.1 Discharge record from the Lake Nebagamon, 2013 to 2014 (NBO, Nebagamon Creek Outlet; NBIN1, Steele Creek; NBIN2, Minnesuing).

North Basin South Basin

2013

2014

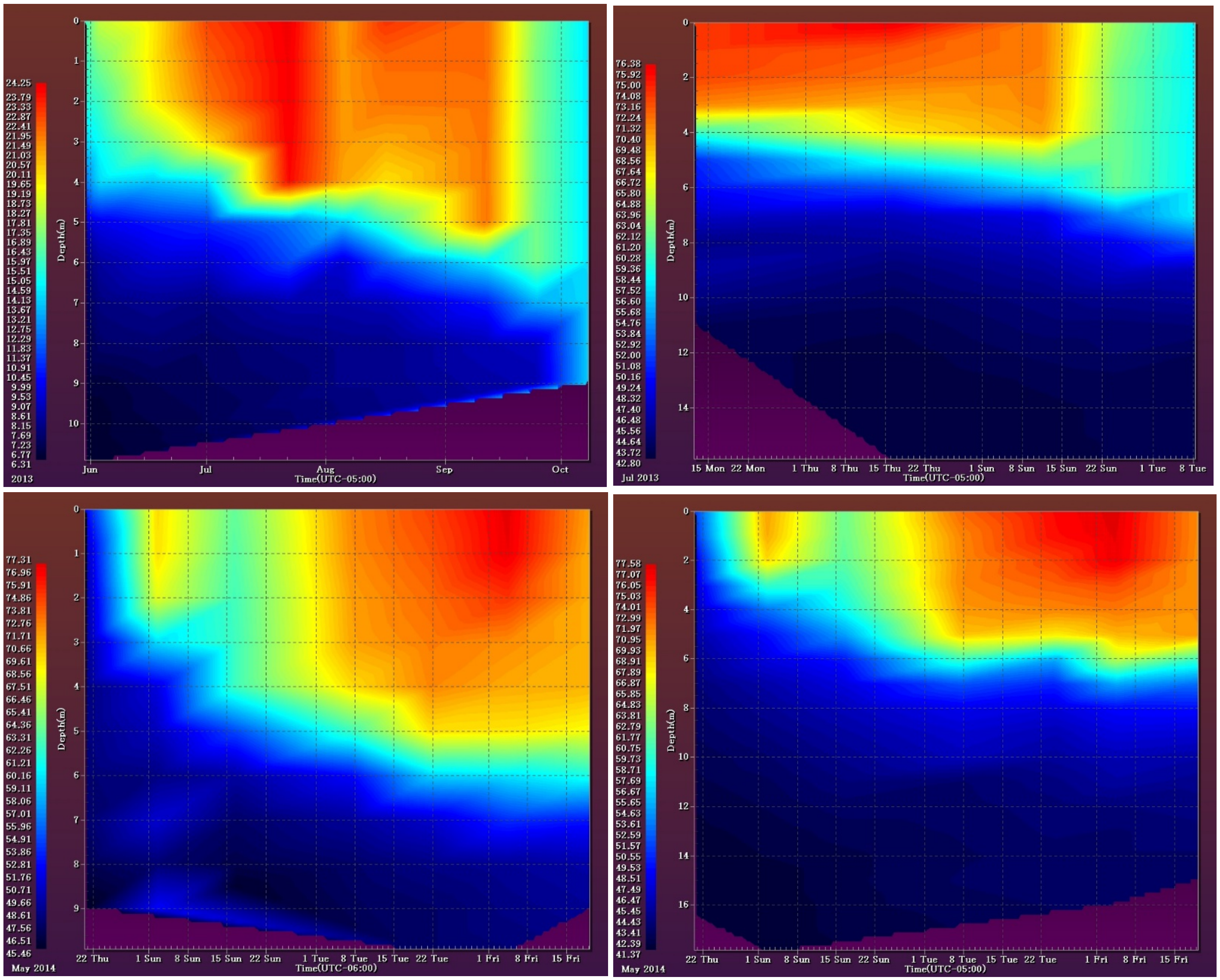


Figure 11.2 Thermal stratification in the north and south basins of Lake Nebagamon in 2013 and 2014.

North Basin South Basin

2013

2014

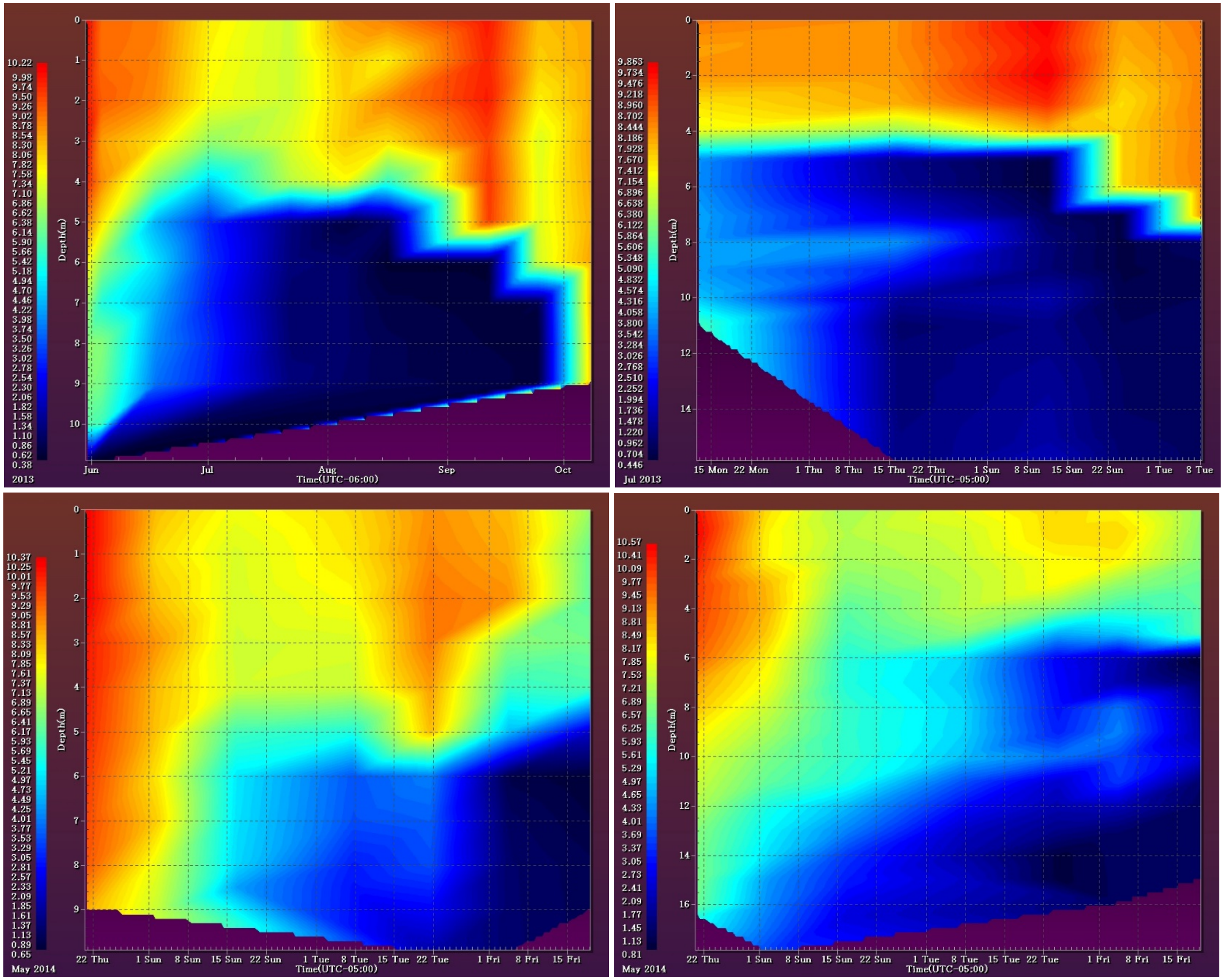


Figure 11.3 Dissolved oxygen stratification in the north and south basins of Lake Nebagamon in 2013 and 2014.

North Basin South Basin

2013

2014

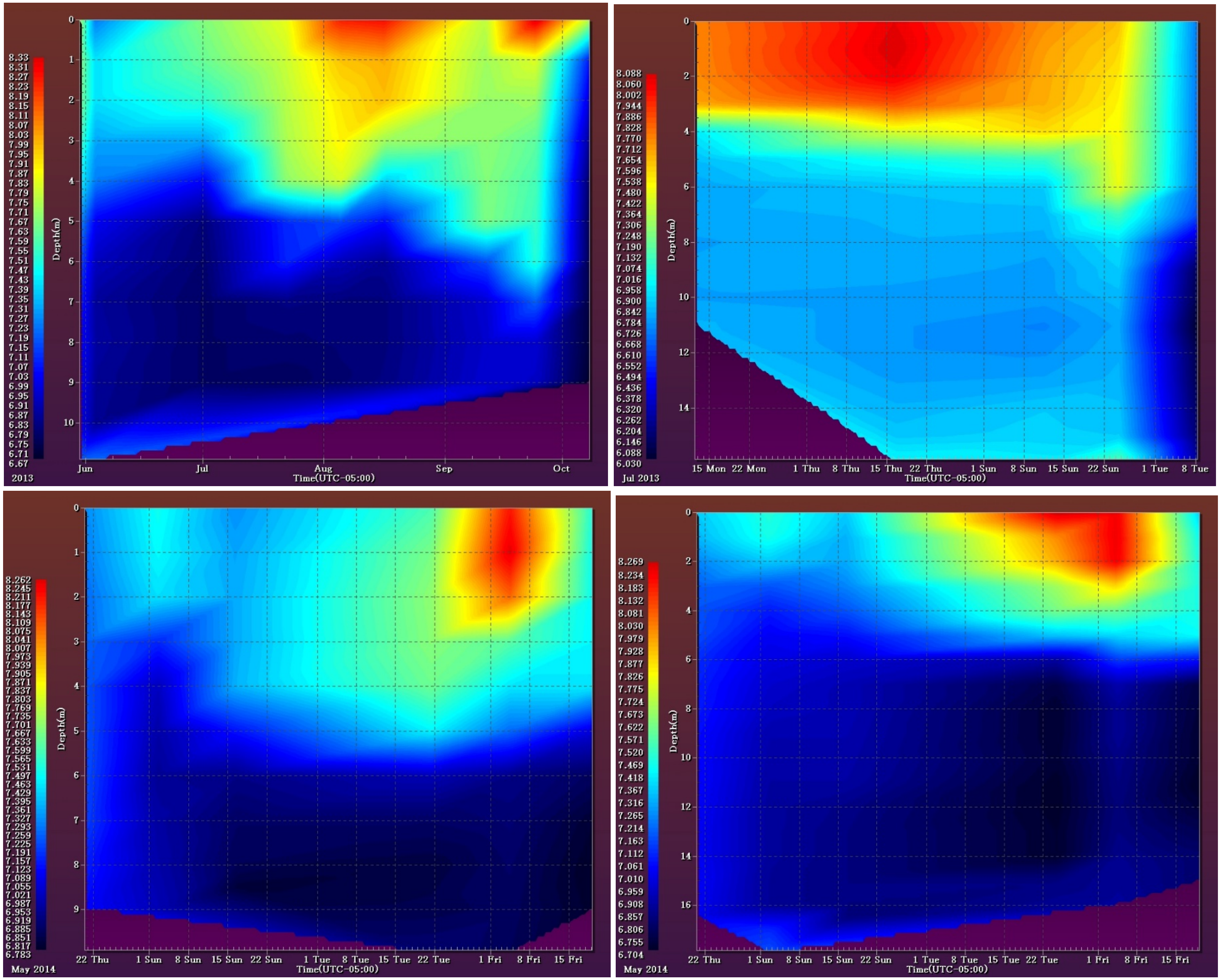


Figure 11.4 pH stratification in the north and south basins of Nebagamon in 2013 and 2014

North Basin South Basin

2013

2014

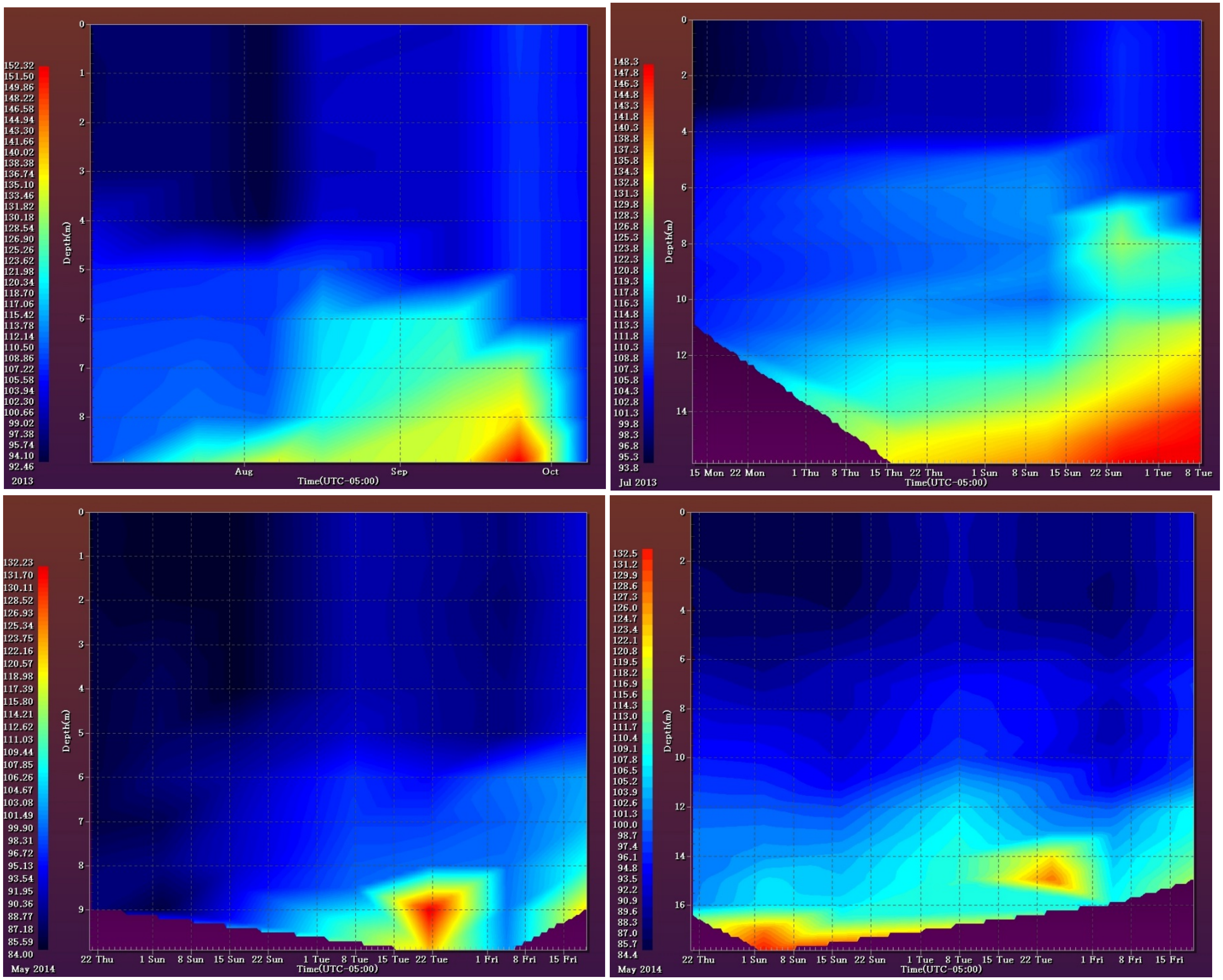


Figure 11.5 Conductivity stratification in the north and south basins of Lake Nebagamon in 2013 and 2014

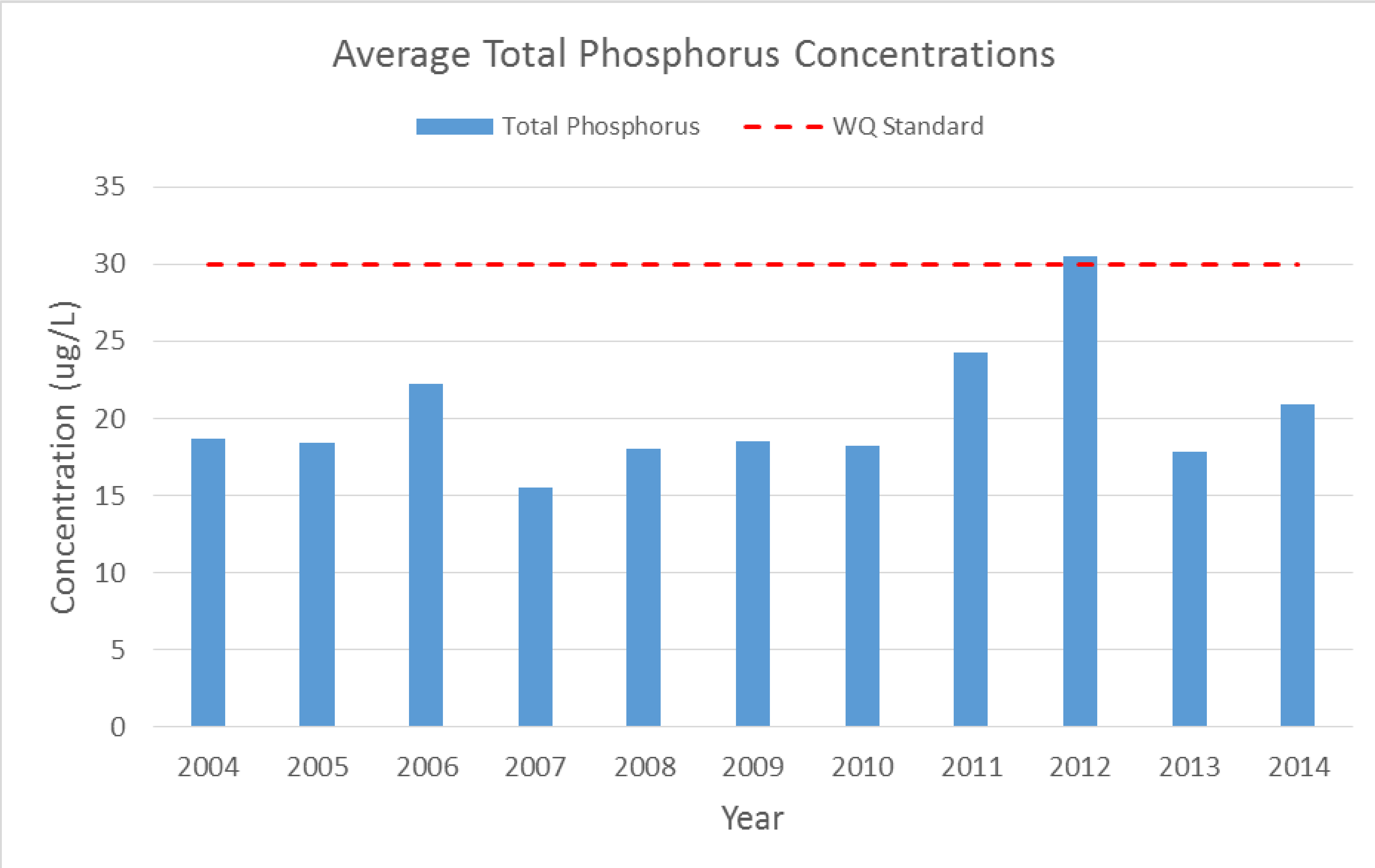


Figure 11.6 Average annual water quality trends in Lake Nebagamon (2004-2014).

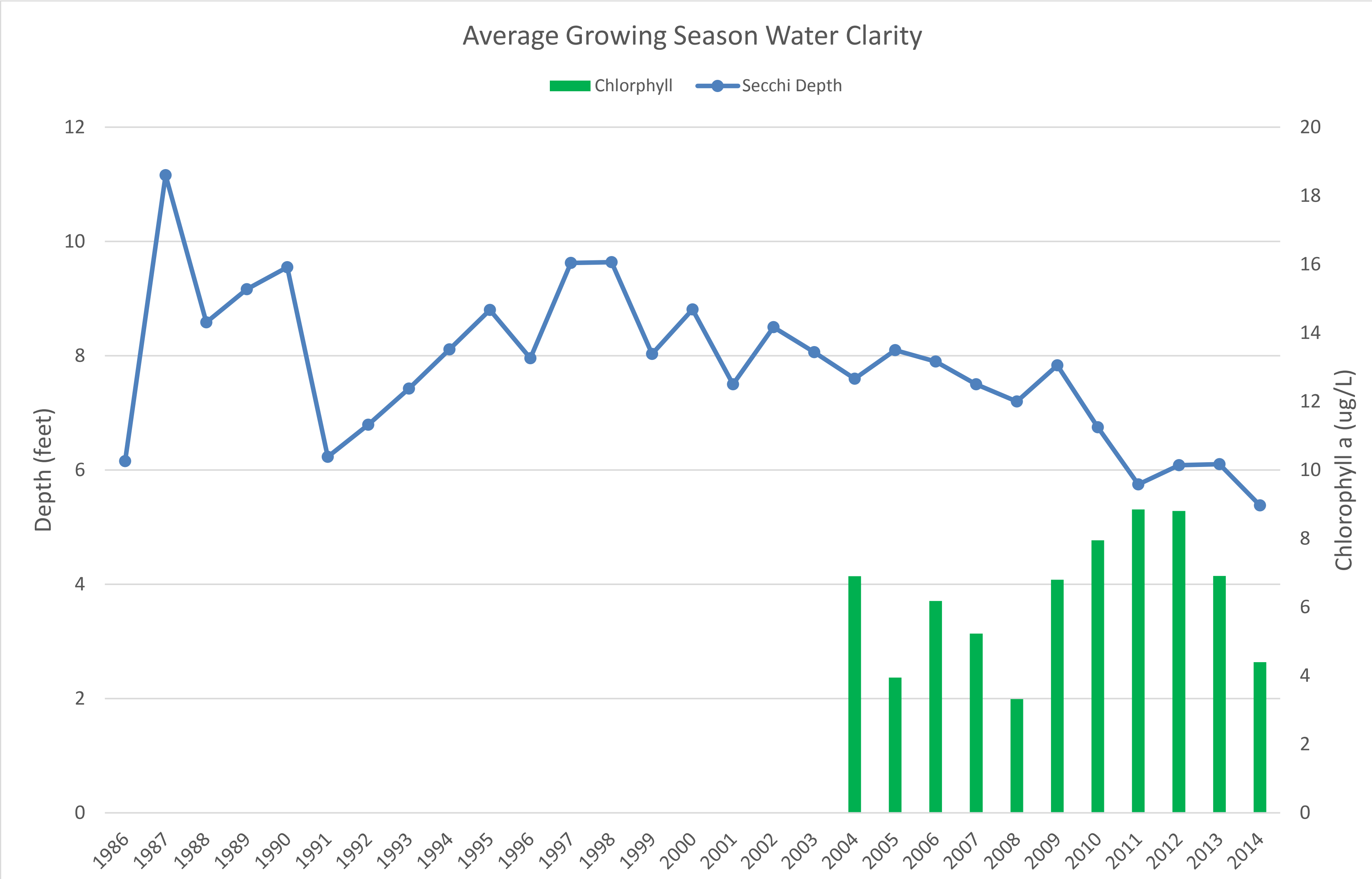


Figure 11.7 Historical trends in water clarity across all sites in Lake Nebagamon.

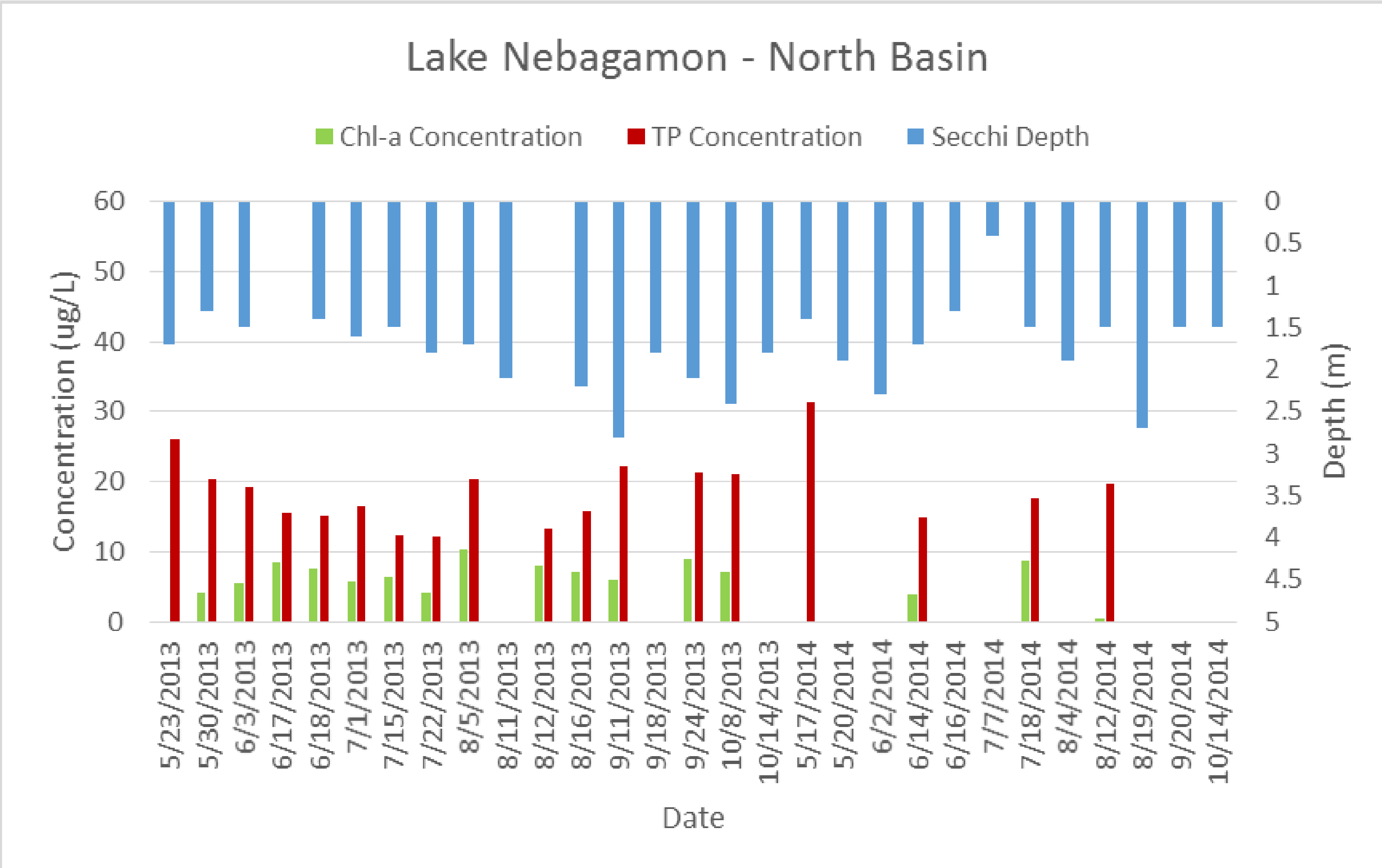
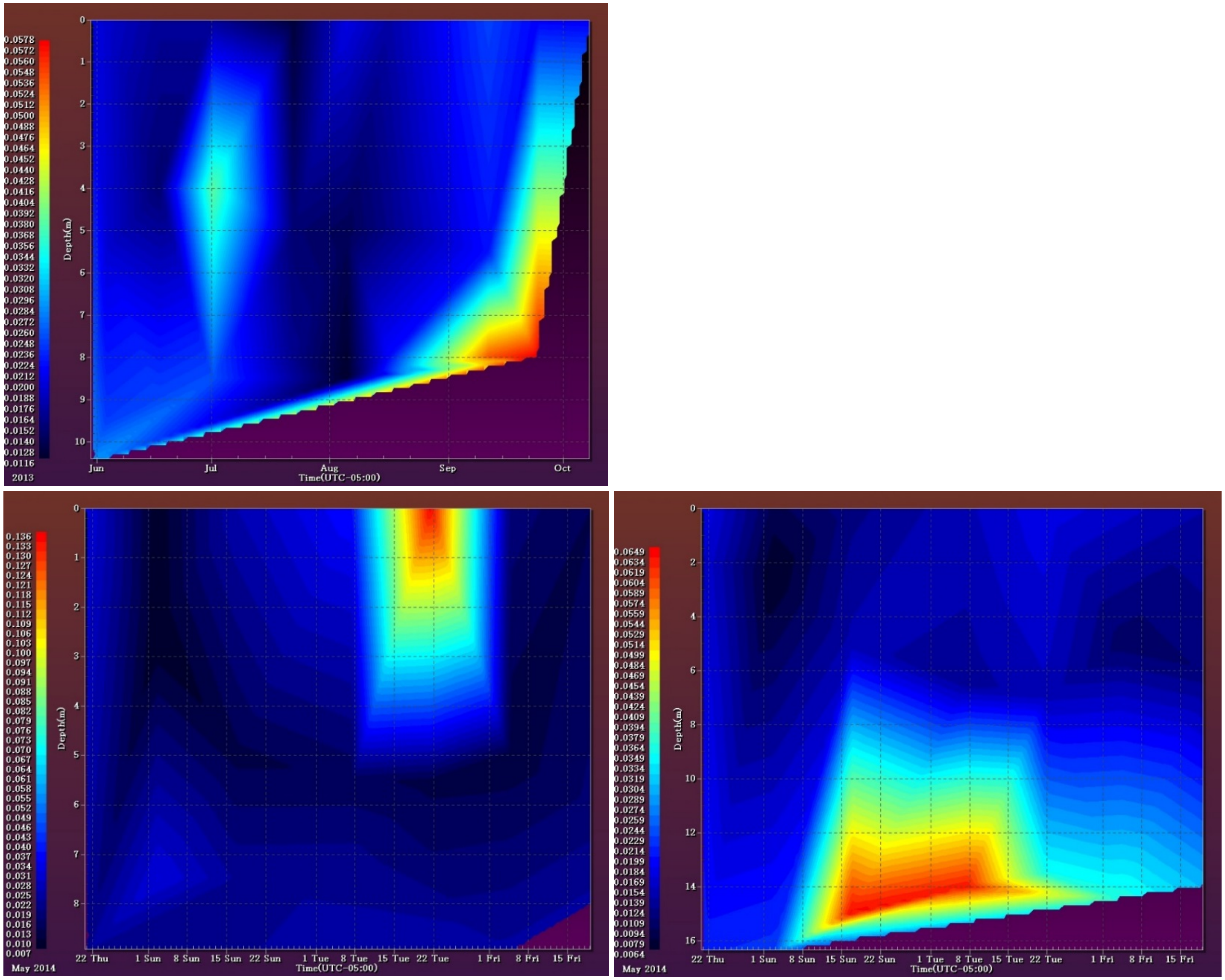


Figure 11.8 Seasonal water quality trends in Lake Nebagamon (north basin).

North Basin South Basin



2013

2014

Figure 11.9 Total phosphorus stratification in the north and south basins of Lake Nebagamon in 2013.

12. Appendix C – Shoreline Habitat Assessment and Management Plan

Introduction

This report summarizes the status of shoreline/nearshore habitat in Lake Nebagamon and describes a long-term restoration/management plan for the system. Given the importance of shoreland habitat (see Section 5.1), a detailed assessment of the current conditions in three shoreland habitat zones was conducted in Lake Nebagamon. Results from this assessment were combined with data from the point-intercept survey (see Appendix F) to develop recommendations to protect and restore shoreland and critical nearshore habitat.

Methods

Habitat conditions were described for all parcels surrounding Lake Nebagamon. Parcel data were separated into public and private ownership and summarized with respect parcel size and shoreline size. Average parcel shoreline length was calculated by extracting the shoreline borders for all privately owned parcels into an aggregate polyline layer. Average length of shoreline parcels was then calculated as the total shoreline length for privately owned parcels divided by the total number of parcels. The potential number of parcels under different land use scenarios was calculated by dividing the total length of privately owned shoreline by the minimum parcel length allowed in current shoreland zoning guidelines. All parcel data were obtained from Douglas County zoning.

To describe shoreland habitat conditions in Lake Nebagamon, shoreline and nearshore habitat were quantified using methods described by the Environmental Protection Agency (USEPA, 2007). Following this method, sample transect points were identified at 20 locations around the lakeshore. At each transect, data were collected to describe the habitat condition and level of disturbance in upland, transition (i.e., riparian) and in-lake (i.e., littoral) zones of the lake using a series of semi-quantitative ranking criteria. Additionally, shoreland habitat conditions and restoration potential were quantified along each parcel using a modified version of the USEPA, 2007 protocol. Data from both the lake-wide and parcel-specific assessments were geospatially processed and represented in a series of maps that describe the relative condition of the upland, transition and in-lake habitat. Shoreland habitat data were used to develop a shoreline habitat restoration/protection plan and combined with sediment and aquatic plant data to highlight areas of critical habitat in and around Lake Nebagamon.

Results

The shoreline around Lake Nebagamon is approximately 11.6 miles in lengths. Throughout this distance, land is divided into 400 discrete parcels (Figure 12.1). Of these parcels, 5 are publicly owned and 395 are privately owned. Average size of privately owned parcels is 6.7 acres. Average linear shoreline distance of privately owned parcels is approximately 154 feet.

Based on future land use zoning (see Appendix C), the number of parcels around Lake Nebagamon has the potential to increase. Current zoning requires a minimum of 150 shoreline feet per lot bordering Lake Nebagamon. Since the current average shoreline length per parcel is 154, full developed of the current zoning regulations would result in a relatively modest increase in the number of parcels. If this increase in parcel density occurs, it would likely be concentrated in areas of sanitary sewer service and in larger parcels located around the lake shore.

Critical Habitat and Sediment Types

Results from the point intercept survey and shoreline habitat assessment suggest that there are a range of habitat types and conditions throughout the Lake Nebagamon ecosystem (Figure 12.2). Not surprisingly, areas of the highest quality aquatic habitat are often adjacent to the areas of highest quality shoreline habitat. Sediment types varied across the lake, with areas of muck being most common in protected embayments and areas of rock and sand being most common along less protected shorelines and adjacent to steep bathymetric drops (Figures 12.3 and 12.4).

Shoreland Habitat

Results from the habitat assessment suggest that shoreland habitat is relatively impacted by human disturbance throughout Lake Nebagamon. Of the 372 parcels surveyed, the majority were in "marginal" or "poor" habitat conditions and that habitat conditions were relatively consistent across the upland, aquatic and shoreline zones—although some within parcel variability does exist (Table 12.1). Areas of the highest quality shoreland habitat are concentrated in the northern and southern bays.

Discussion and Management Recommendations

Given that most shoreline habitat surrounding Lake Nebagamon has been significantly modified over time, the majority of shoreline management activities should focus on restoration efforts. As described in Section 7.1, shoreland habitat protection for Lake Nebagamon is primarily driven by the Village of Lake Nebagamon' s Shoreland Zoning Ordinance. Relatively little additional shoreland development is expected, but future monitoring efforts should focus on recurring assessment of user perceptions of the lake as well as general shoreland/critical habitat. Recurring surveys should be conducted every three to five years, depending on the rates of shoreline development.

Significant areas for shoreline restoration exist throughout the Lake Nebagamon system. Areas of greatest opportunity for shoreland habitat restoration are most common on the southern and eastern shorelines of the lake, however areas adjacent to critical habitat locations should be considered the highest priority for restoration work. The primary restoration tools that should be considered are dependent on the shoreland zone for which restoration is to be targeted. In general, restoration practices that minimize direct runoff to the lake should be considered in areas with medium to high upland and shoreline restoration potential (Figures 12.5 and 12.6) and practices that maximize habitat complexity should be focused in the in-lake zone (Figure 12.7) in areas with medium to high aquatic restoration potential. Details of appropriate restoration practices are described in the WDNR Healthy Lake Initiative Implementation Plan (http://www.uwsp.edu/cnr-ap/UWEXLakes/Documents/resources/healthylakes/HealthyLakesPlan.pdf).

Table 12.1. Described the relative condition of the different habitat zones in parcels surrounding Lake Nebagamon.

Nebagamon Parcel Data			
Parcel Condition	Upland / Terrestrial (OHWM inland 15m)	Shoreline / Riparian Buffer (1m)	Aquatic / Littoral (10m from shore)
Ideal	33	31	30
Very Good	37	56	66
Marginal	72	85	210
Poor	230	204	69
Total	**372**		

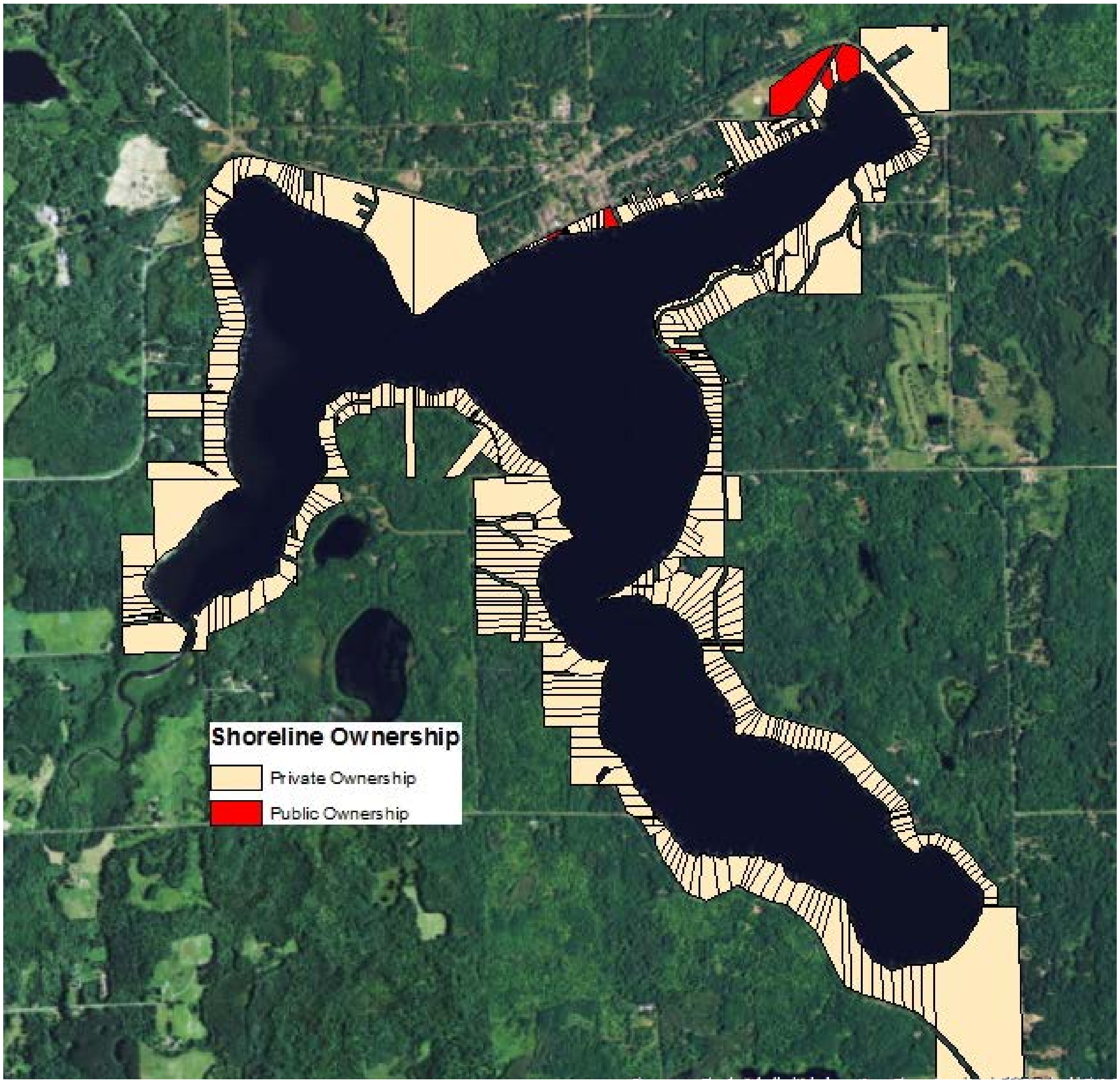


Figure 12.1 Shoreline parcel ownership surrounding Lake Nebagamon.

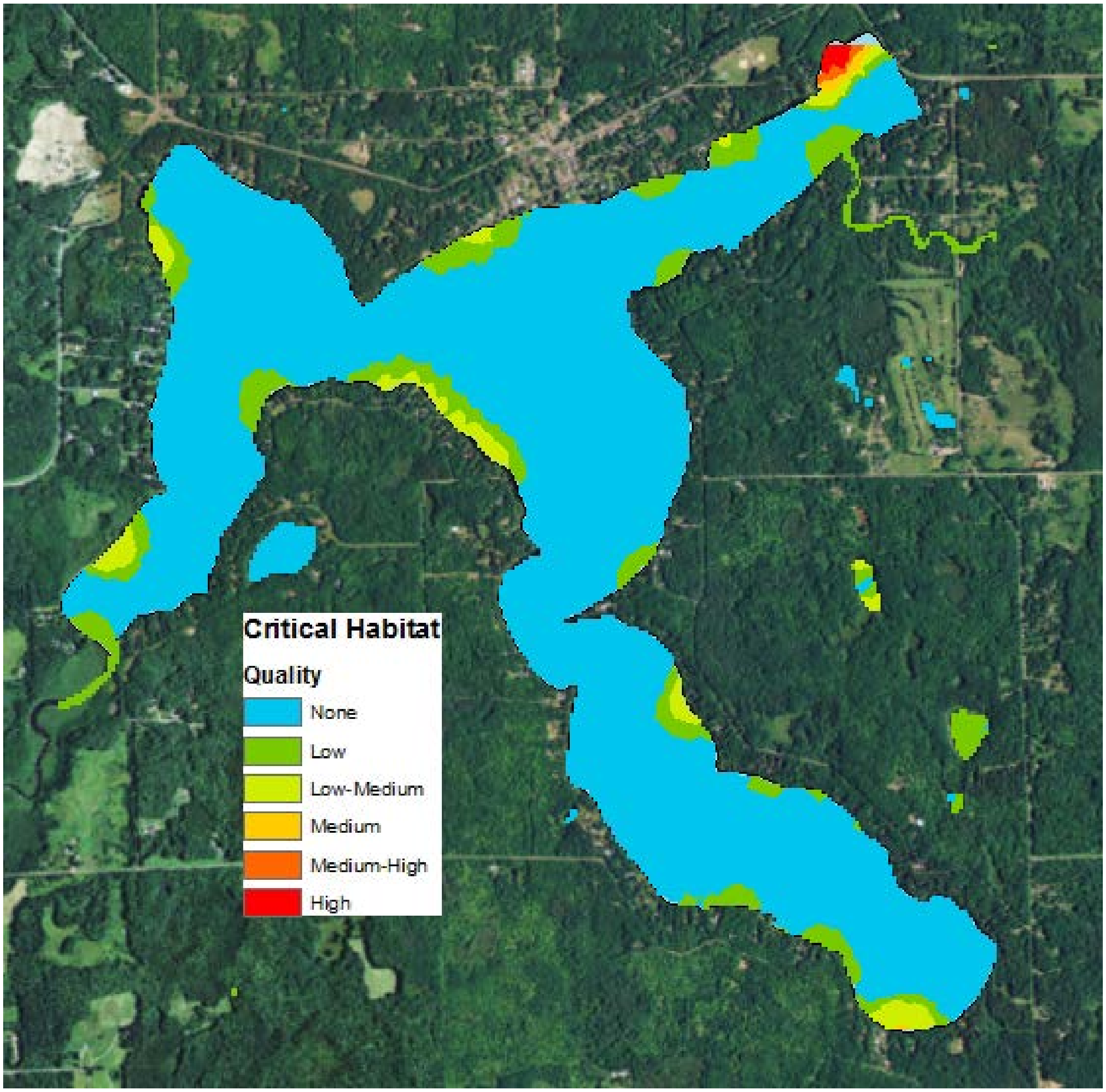


Figure 12.2 Locations of highest quality aquatic and shoreline habitat.

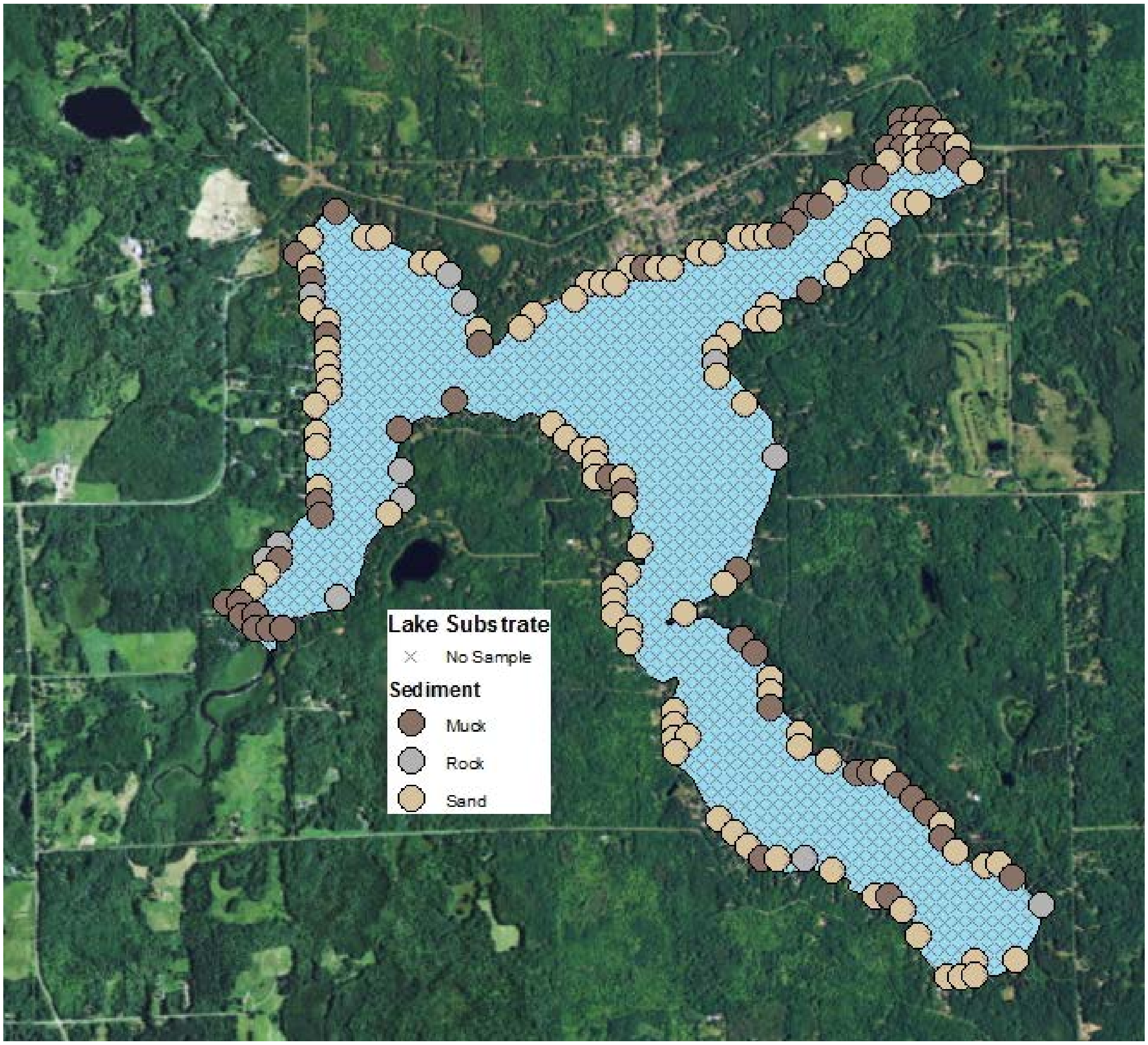


Figure 12.3 Locations of different sediment types in Lake Nebagamon.

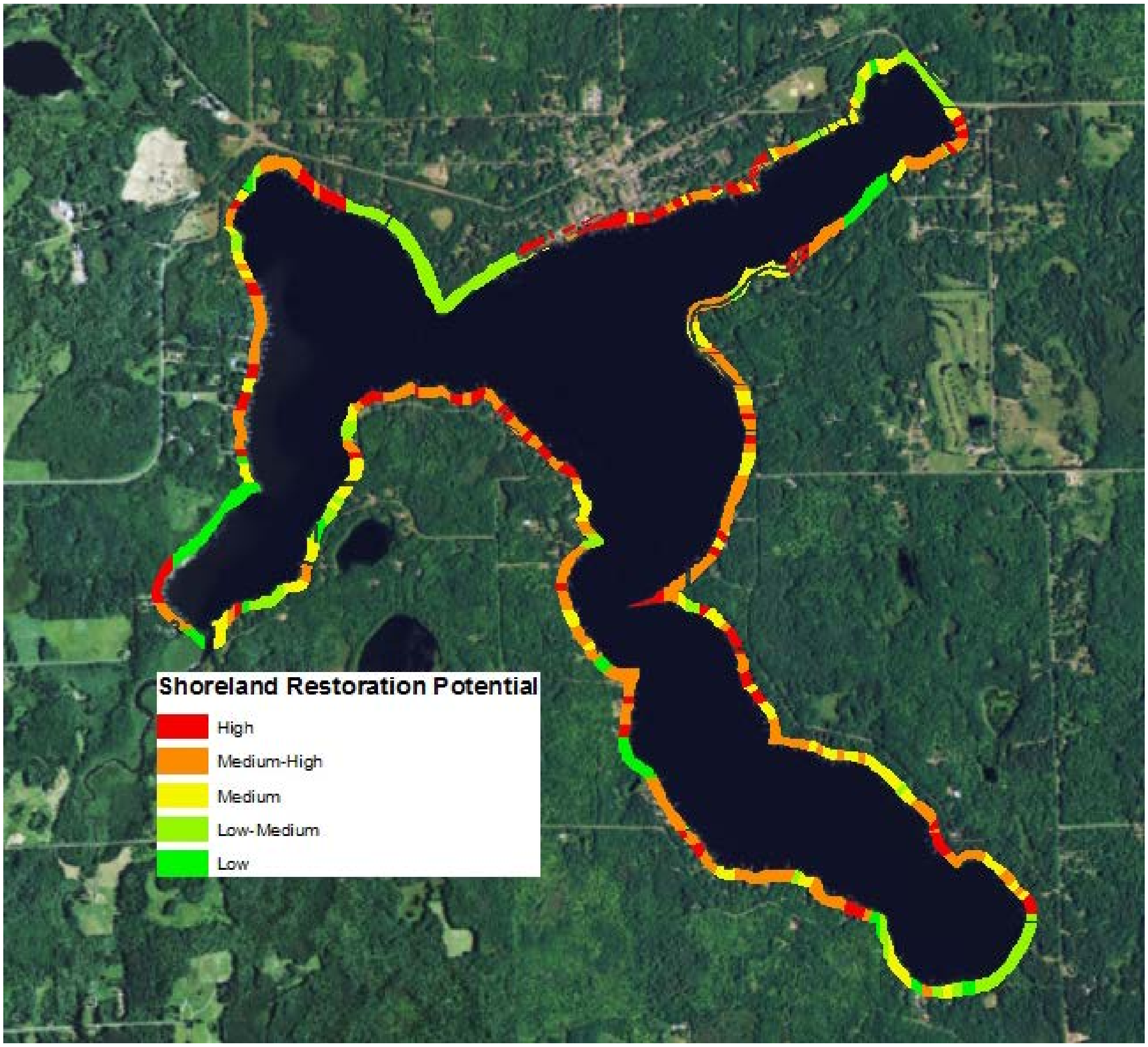


Figure 12.4 Average restoration potential of shoreland areas surrounding Lake Nebagamon.

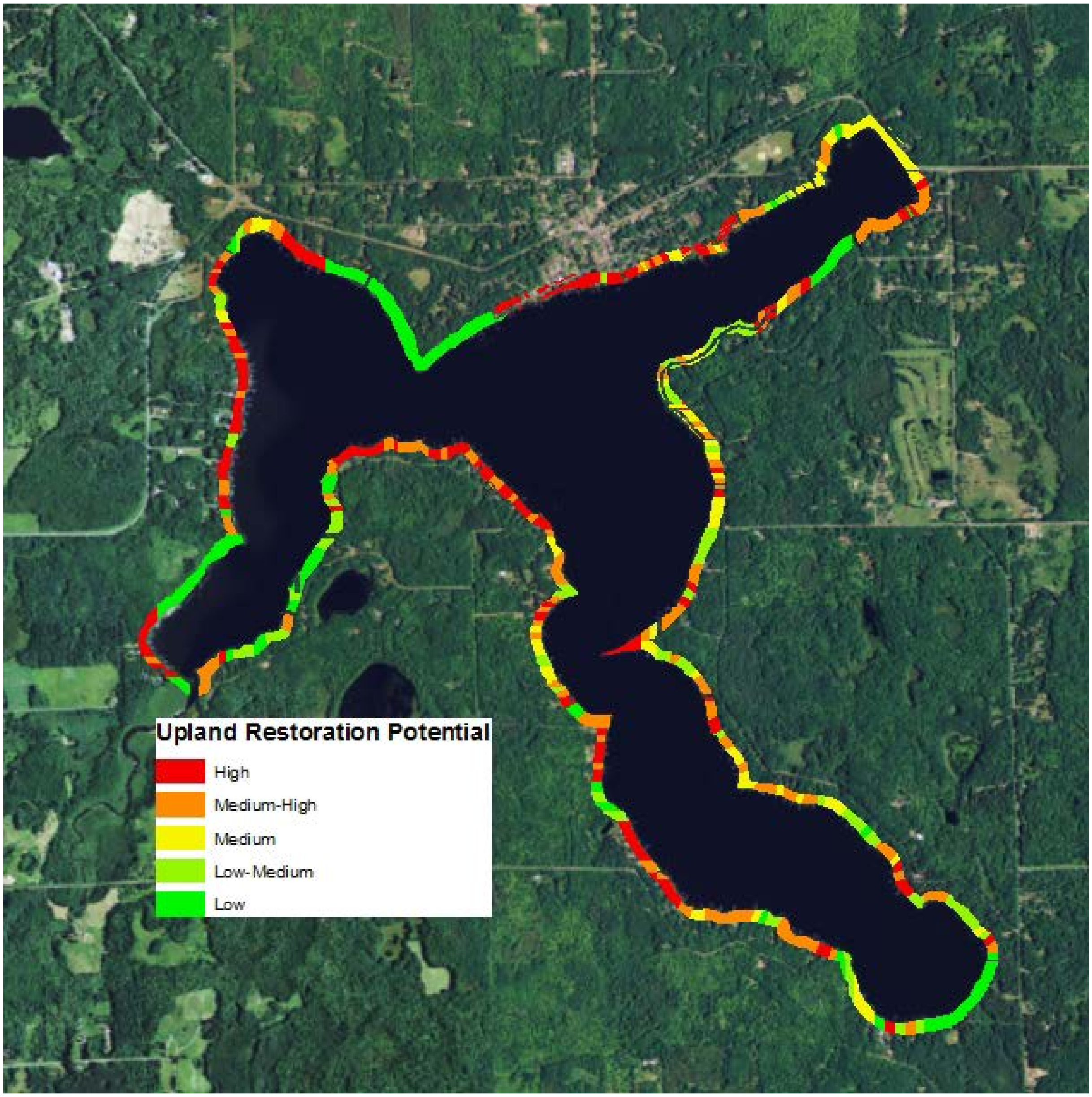


Figure 12.5 Average restoration potential of upland areas surrounding Lake Nebagamon.

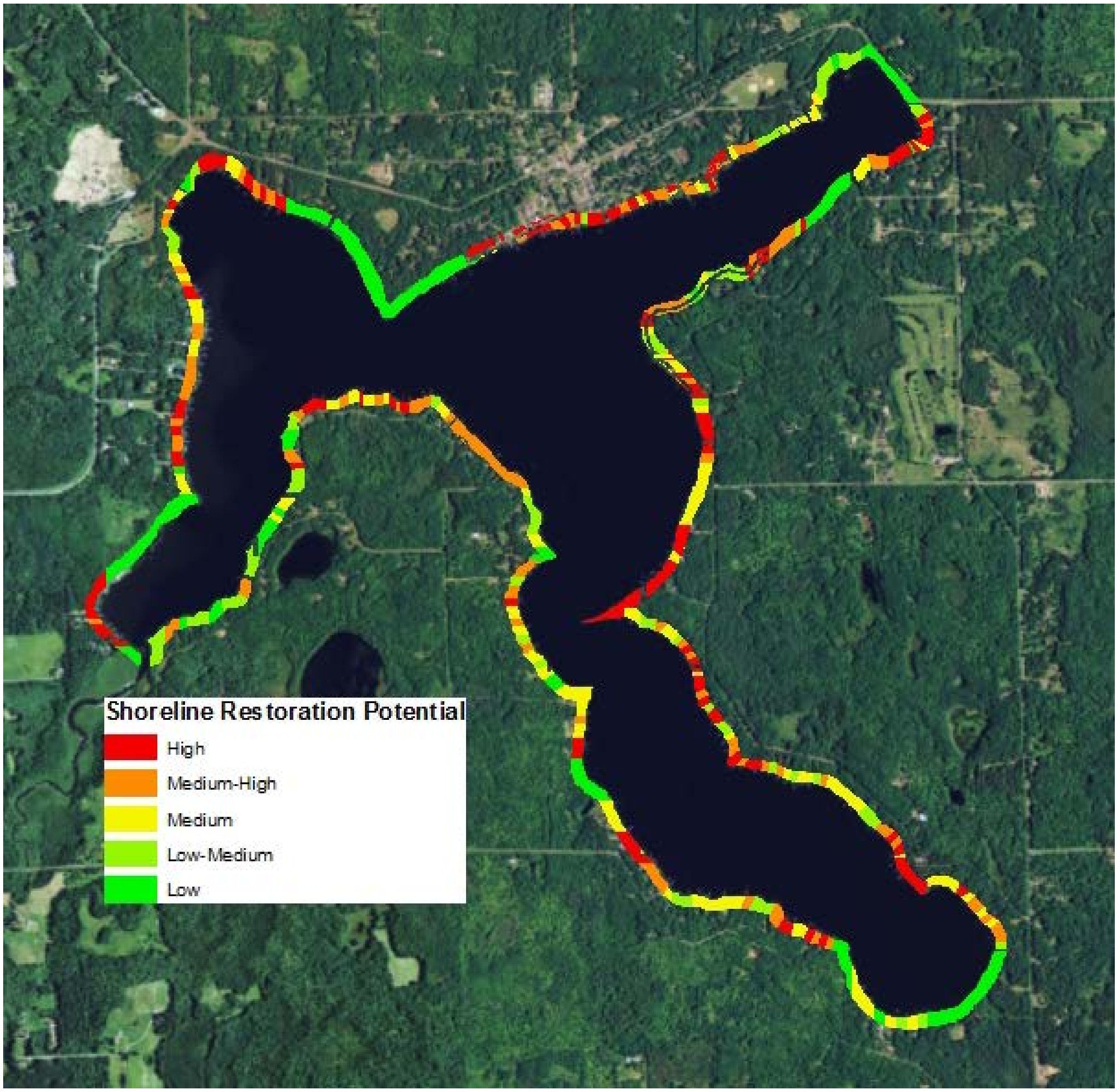


Figure 12.6 Average restoration potential of shoreline areas surrounding Lake Nebagamon.

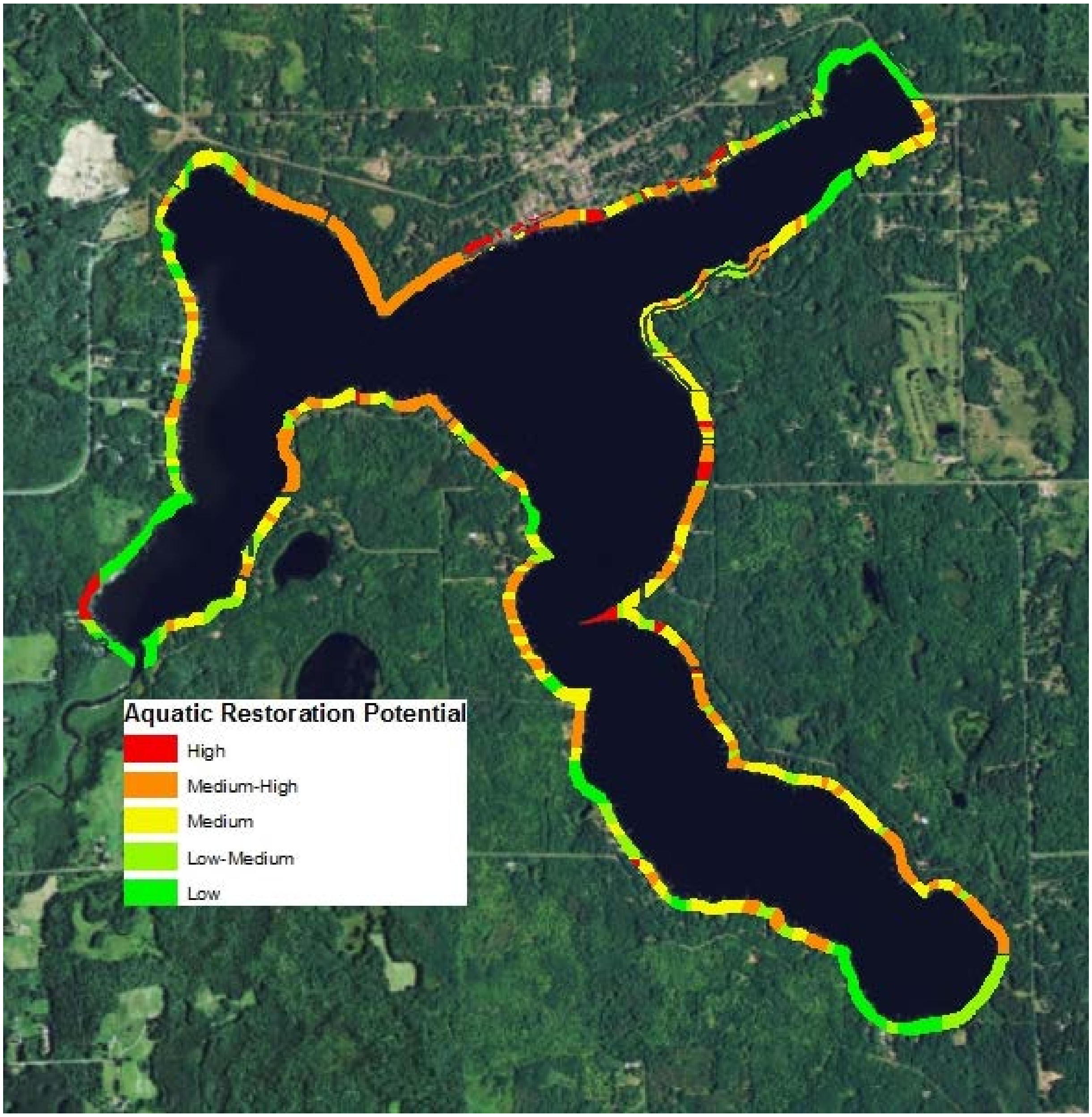


Figure 12.7 Average restoration potential of aquatic/littoral areas surrounding Lake Nebagamon.

13. Appendix D – Watershed Assessment and Management Plan

Introduction

This report summarizes the condition of, and potential management options for, the Lake Nebagamon watershed. Given the importance of watershed nutrient runoff (see Section 5.2), a detailed assessment of the of the land use types and potential phosphorus sources to Lake Nebagamon was conducted. Results from this assessment were compared against the different federal, state and local regulatory/land use policies to develop a watershed nutrient management plan for Lake Nebagamon.

Methods

Watershed nutrient loads to Lake Nebagamon were developed using land-use specific, annual phosphorus export coefficients. Initially, the Lake Nebagamon watershed was delineated and spatially characterized use the ArcHydro feature in ArcGIS. The watershed boundary was then used to extract and summarize the relative area of different land cover types using a time series of GIS data layers. Historical land cover was based on the WDNR Original Vegetation data layer. Land cover from 1992 to 2011 was based on the USGS National Land Cover Datasets and data from the shoreline assessment. Future potential land cover was based on the future land use/zoning plans for the Village of Lake Nebagamon (all areas outside of the comprehensive zoning plan were assumed to remain constant).

Annual watershed nutrient loads to Lake Nebagamon were calculated by multiplying the total area of different land cover types by a corresponding average annual loading estimate (lbs. P/acre/year; based on PRESTO export coefficients). Annual watershed phosphorus loads were calculated for historical (circa 1856), current (2013) and future land use (~2030) scenarios. Annual loads were summarized as total and average, per acre values. Watershed nutrient loads were used to develop an external nutrient budget and integrated into an AQUATOX model to describe the relationship between land use and lake condition (see Appendix G).

Septic system phosphorus loads were estimated following methods described by Reckhow et al. (1980). Following this approach, septic system phosphorus load (M) is estimated using a system phosphorus export coefficient (scaled to the number users and time period of use) and soil retention. Phosphorus export coefficients were based on a range of 1.1 to 1.8 lbs/capita/year, with a most likely value of 1.5 lbs/capita/year. Soil retention was assumed to be 0.7, based on soil type (with a corresponding export ratio of 0.3). Numbers of septic system were based on current land use and occupancy was based on the results from the user survey (see Appendix A for more detail). Input parameters were used to estimate a range of septic system phosphorus loads under current and future land use scenarios.

Results and Discussion

The Lake Nebagamon watershed is approximately 24,959 acres (including waterbodies). Land cover throughout the Lake Nebagamon watershed is dominated by deciduous and mixed forest types, while developed and agricultural lands make up a relatively small percentage of the land area (Figure 13.3 and Table 13.2).

Land cover throughout the watershed has significantly shifted since the mid-1800s and is anticipated to continue to change in the coming years (Figures 13.1, 13.2, 13.3 and 13.4). Historically, white pine and spruce dominated much of the watershed with patches of oak and aspen found in isolated areas. Over time, the relative abundance of coniferous species has declined and this land cover type has been replaced by mixed forests and small amounts of urban and agricultural lands. As the permanent and seasonal population in the area continues to grow, land cover throughout the watershed is expected to become more dominated by low and medium density urban development.

Phosphorus loads to Lake Nebagamon from septic systems comprise approximately 6 percent of the total watershed load. Based on future land use plans, phosphorus loads from future land uses have the potential to increase to approximately 11 percent.

In correspondence to the land use changes described above, phosphorus runoff has increased, and has the potential to increase into the future under current land use plans. Historical phosphorus loads to the lake were approximately 734 lbs/yr. Annual phosphorus loads to the lake increased to approximately 2779 in 2013 and have the potential to increase to 3342 by 2030. Historical increases in phosphorus loads to the lake have likely had a modest impact on water quality (see Section 5.4) and the increased phosphorus loads expected into the future have the potential to have similar impacts on the Lake Nebagamon ecosystem (see Appendix G for further discussion on the relative impacts of nutrient loads to Lake Nebagamon).

Management and Monitoring Recommendations

Changes in land use throughout the Lake Nebagamon watershed have likely increased phosphorus runoff to the lake and phosphorus runoff to the lake has the potential to increase by a significant level into the future, depending on land use planning. To prevent any future changes in water quality conditions resulting from watershed nutrient runoff, future management actions should focus on the on-site treatment of stormwater to minimize runoff to the lake. Current per acre export of phosphorus to Lake Nebagamon from the surrounding land use is relatively low, predominantly because of the large areas of undeveloped land throughout the watershed. However, based on current zoning regulations it is likely that a larger percentage of the watershed will be occupied by low and medium density urban/residential lands. Over time, these urban lands have the potential to become the dominant source of phosphorus to the system. As such, future management activities should focus on reducing runoff from existing parcels and minimizing runoff from a new land development.

The capacity of current zoning and stormwater regulations to manage runoff under future land use scenarios is mixed. However, the potential impact of shoreline development on water quality may be dependent on the on-site wastewater treatment required. Future septic design/requirements should incorporate an assessment potential cumulative septic impacts to the lake system, preferentially focusing on the use of holding tank systems over traditional or mounded systems. Guidance for on-site wastewater treatment can be seen at http://water.epa.gov/scitech/wastetech/upload/septic_guidelines.pdf.

Runoff from lands outside of the shoreland zone also has the potential to impact water quality in Lake Nebagamon. However, potential impacts from upland areas is more likely to occur as a result of stormwater runoff than on-site wastewater management. Because the population density in the Village of Lake Nebagamon is below 5000, state stormwater management standards are not required as part of new development. Although the potential impacts of stormwater runoff are potentially mitigated by large lot size requirements in different rural residential areas, cumulative potential impacts as well as directed runoff from higher density residential/commercial areas throughout the watershed should be considered.

To effectively mitigate the potential impacts of watershed runoff to Lake Nebagamon, all future development activities should incorporate stormwater management requirements in a similar form to those required in larger urban centers. A range of different practices and technologies are available to mitigate stormwater runoff from different land development types (see http://www.epa.gov/greeningepa/stormwater/best_practices.htm for a complete discussion of potential best management practice options). Additionally, given the likely changes in precipitation patterns that are expected in the future, stormwater design should incorporate up-to-date (e.g., Atlas 14) and potentially future precipitation estimates into engineering model design standards.

Uncertainty and Data Interpretation

Although the existing simulations suggest there is potential for phosphorus levels to increase in Lake Nebagamon in the future in response to shoreland and upland development, a range of uncertainty is present that should be considered. Because of the diffuse nature of overland runoff to Lake Nebagamon, direct measurements of phosphorus runoff are difficult. As such, phosphorus loads to the lake are estimated based on literature values from studies in which more precise measurements could be made. Similarly, estimates of phosphorus from septic systems are also based on literature values of phosphorus discharge. The estimates presented within represent the most likely phosphorus runoff, but do not likely provide accurate representation of runoff from all parcels of land throughout the watershed.

Estimates of future land scenarios are also uncertain. Because land is zoned for a particular development type, it does not guarantee that it will undergo the potential land cover transition—as many factors impact this transition (most of which cannot be accurately forecast). Additionally, although zoning laws provide a minimum standard, it is quite possible that voluntary efforts to reduce runoff will be made by landowners, in the absence of regulation. As such, individual variability in land management and on-site waste treatment have the potential to significantly influence future water quality conditions. Additionally, because future land use prescriptions in local comprehensive plans do not encompass the entire watershed, it is difficult to full forecast any potential land changes.

Given these sources of uncertainty, future monitoring efforts and scientific investigations should focus on: tracking land use change over time, tracking the different on-site waste system that are implemented and developing more site specific characterizations of nutrient runoff from the Lake Nebagamon watershed.

Table 13.1. Percent land cover change over time, based on past present and anticipated future land uses.

	Year						
	Historic Vegetation	National Land Cover Database (NLCD)				Local Zoning	
Land Cover Classification	*1850s	**1992	2001	2006	2011	‡Potential Current Land Cover	‡‡Potential Future Land Cover
Open Water	7%	14%	15%	15%	15%	15%	8%
Rural Roads and Open Lands	0.00%	5%	6%	6%	6%	2%	6%
Low Density Residential	0.00%	0.00%	0.00%	0.00%	0%	6%	10%
Rural Preservations	0.00%	0.13%	0.22%	0.22%	0.22%	10%	64%
Medium Density Residential	0.00%	0.02%	0.01%	0.01%	0.01%	0.01%	0.09%
High Density Urban	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.7%
Deciduous Forest	15%	0.03%	0.03%	0.03%	0.03%	2%	0%
Evergreen Forest	78%	44%	39%	39%	38%	27%	0%
Mixed Forest	0%	12%	9%	9%	9%	9%	0%
Shrub/Scrub	0%	15%	23%	23%	23%	18%	0%
Grassland	0.00%	2.1%	3.4%	3.3%	4%	4%	0%
Pasture/Hay	0.00%	0.12%	0.44%	0.44%	0.55%	1%	0%
Cultivated Crops	0.00%	3%	2%	2%	2.2%	4%	0%
Woody Wetland	0.0%	0.29%	0.22%	0.22%	0%	0.22%	12%
Emergent Wetland	0.00%	3.6%	2.0%	2.0%	2%	2%	0.12%

Table 13.2. Watershed areas covered by different land use types throughout the Lake Nebagamon watershed from historical (~1856), current (2013) and future potential (2030) land use conditions. *Note: forest and grassland areas were redistributed as Rural Preservation lands to reflect comprehensive planning guidance.*

	Relative Watershed Land Cover					
	Historic Land Cover ~1856		Current Land Cover 2013		Potential Future Land Cover (2030)	
Land Cover Classification	Percent	Total	Percent	Total	Percent	Total
Open Water	7%	1747	8%	1937	8%	1937
Rural Roads and Open Lands	0.00%	0	6%	1413	1%	250
Low Density Residential	0.00%	0	0%	0	10%	2496
Rural Preservations	0.00%	0	0%	55	68%	17067
Medium Density Residential	0.00%	0	0.07%	18	0.09%	22
High Density Urban	0.00%	0	0.01%	2	0.7%	175
Deciduous Forest	15%	3744	47%	11680	0%	0
Evergreen Forest	78%	19468	5%	1314	0%	0
Mixed Forest	0%	0	14%	3412	0%	0
Shrub/Scrub	0%	0	5%	1249	0%	0
Grassland	0.00%	0	1.50%	373	0%	0
Pasture/Hay	0.00%	0	1.9%	471	0%	0
Cultivated Crops	0.00%	0	0.09%	21	0%	0
Woody Wetland	0.0%	0	12%	2982	12%	2982
Emergent Wetland	0.00%	0	0.12%	31	0.12%	31

Table 13.3. Estimated annual phosphorus loads from septic systems

Time Period	Residency	Number of Septic Systems	Number of Users per System	Seasonal Ratio	Soil Retention	Export (lbs/capita years)			Load (lbs/year)		
						Low	High	Average	Low	High	Average
Current Conditions	Full-time	90	2.5	1	0.3	1.1	1.8	1.5	74	121	**101**
	Seasonal	187	2.5	0.3	0.3	1.1	1.8	1.5	46	76	**63**
	Total	**359**	**2.5**	**0.65**	**0.3**	**1.1**	**1.8**	**1.5**	**120**	**197**	**164**
Addition of 150	Full-time	152	2.5	1	0.3	1.1	1.8	1.5	126	206	**171**
	Seasonal	317	2.5	0.3	0.3	1.1	1.8	1.5	79	128	**107**
	Total	**610**	**2.5**	**0.65**	**0.3**	**1.1**	**1.8**	**1.5**	**204**	**334**	**278**
Removal of 100	Full-time	65	2.5	1	0.3	1.1	1.8	1.5	53	87	**73**
	Seasonal	135	2.5	0.3	0.3	1.1	1.8	1.5	33	55	**45**
	Total	**259**	**2.5**	**0.65**	**0.3**	**1.1**	**1.8**	**1.5**	**87**	**142**	**118**
Removal of 150	Full-time	52	2.5	1	0.3	1.1	1.8	1.5	43	70	**59**
	Seasonal	109	2.5	0.3	0.3	1.1	1.8	1.5	27	44	**37**
	Total	**209**	**2.5**	**0.65**	**0.3**	**1.1**	**1.8**	**1.5**	**70**	**114**	**95**

Table 13.4. Estimated annual total phosphorus loads to Lake Nebagamon from all sources.

Potential Phosphorus Source	Annual TP Loads			Estimated Annual Phosphorus Loads to Lake Nebagamon					
				Historical (1856)		Current (2013)		Potential Future (2030)	
	Minimum	Maximum	Most Likely	Units	TP Load	Units	TP Load	Units	TP Load
Agriculture Lands	(lbs./acre/yr)			Acres	lbs.	Acres	lbs.	Acres	lbs.
Cultivated Crops	0.5	3	1	0	0	21	21	0	0
Pasture/Hay	0.1	3	1	0	0	472	472	0	0
Urban Lands	(lbs./acre/yr)			Acres	lbs.	Acres	lbs.	Acres	lbs.
Rural Roads and Open Lands	0.1	0.5	0.3	0	0	1412	424	3896	1169
Developed, Rural Residential	0.05	0.25	0.1	0	0	53	5	15911	1591
Developed, Medium Density	0.3	0.8	0.5	0	0	17	9	22	11
Developed, High Density	1	2	1.5	0	0	2	2	175	263
Forest and Grasslands	(lbs./acre/yr)			Acres	lbs.	Acres	lbs.	Acres	lbs.
Deciduous Forest	0.05	0.2	0.09	5360	732	11679	1589	0	0
Evergreen Forest				2010		1314		0	
Mixed Forest				766		3412		0	
Shrub/Scrub				0		1250		0	
Grassland	0.01	0.25	0.17	0	0	373	63	0	0
Wetland	0.01	0.01	0.01	191	2	3012	30	3012	30
Permitted Sources	(lbs./source/yr)			Sources	lbs.	Sources	lbs.	Sources	lbs.
None	-	-	-	-	-	-	-	-	-
Non-permitted Sources (lbs./system)	(lbs./systems/yr)			Systems	lbs.	Systems	lbs.	Systems	lbs.
*Septic Systems	1.1	1.8	1.5	0	0	359	164	610	278
Relative Changes in Phosphorus Load					**Total**	**%**	**Total**	**%**	**Total**
Total Watershed Load					**734**	**0.72**	**2615**	**0.15**	**3064**
Permitted/Non-permitted Source Load					**0**	**1.00**	**164**	**0.41**	**278**
Total Phosphorus Loads					**734**	**0.74**	**2779**	**0.17**	**3342**
Per Acre Phosphorus Load					**0.03**	**0.72**	**0.10**	**0.15**	**0.12**

*Phosphorus loads from septic systems are scaled to account for seasonal residency. See Table 13.3 for further details.

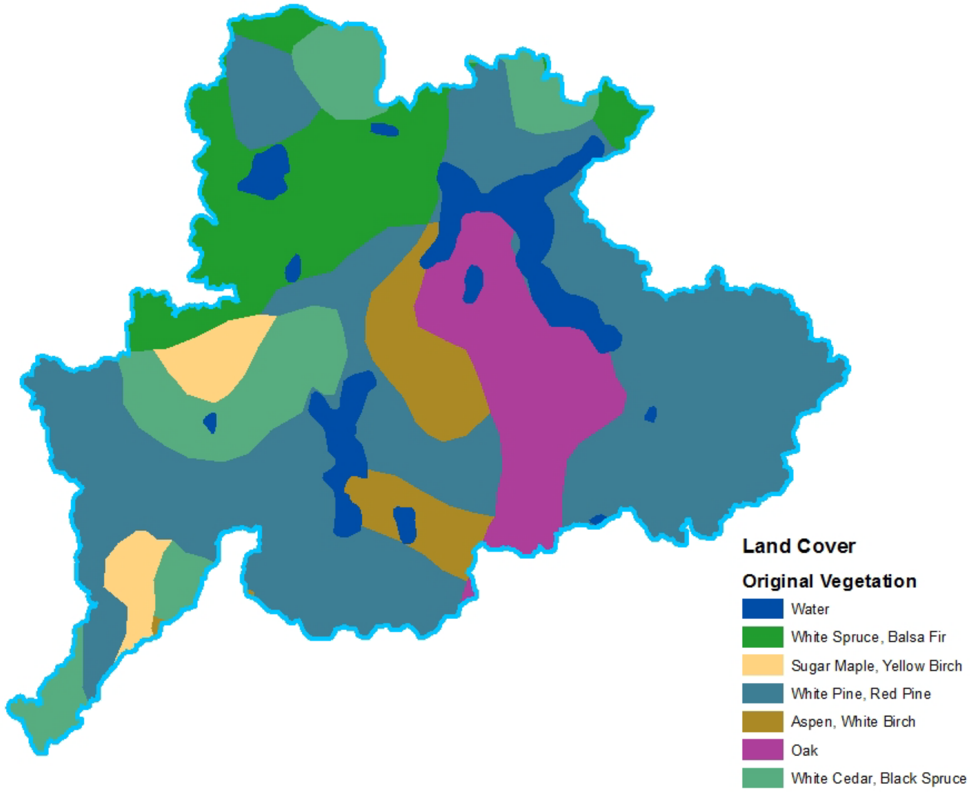


Figure 13.1 Historical vegetative cover in the Lake Nebagamon watershed. Based on ~1856 vegetative cover assessments.

Figure 13.2 Land cover in the Lake Nebagamon watershed in 2011.

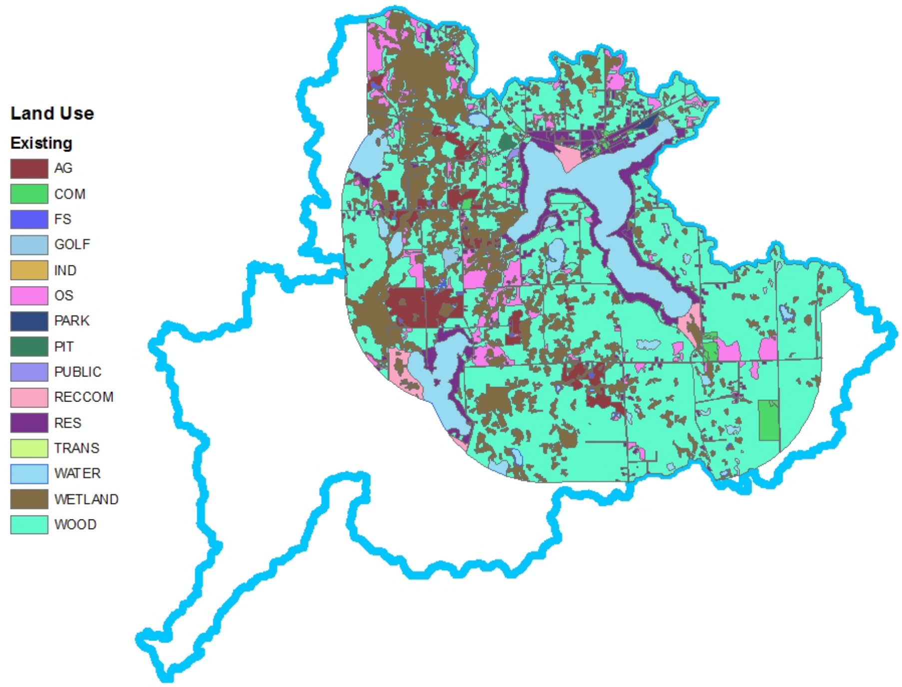


Figure 13.3 Existing land use in the Lake Nebagamon watershed as described in the local comprehensive plan.

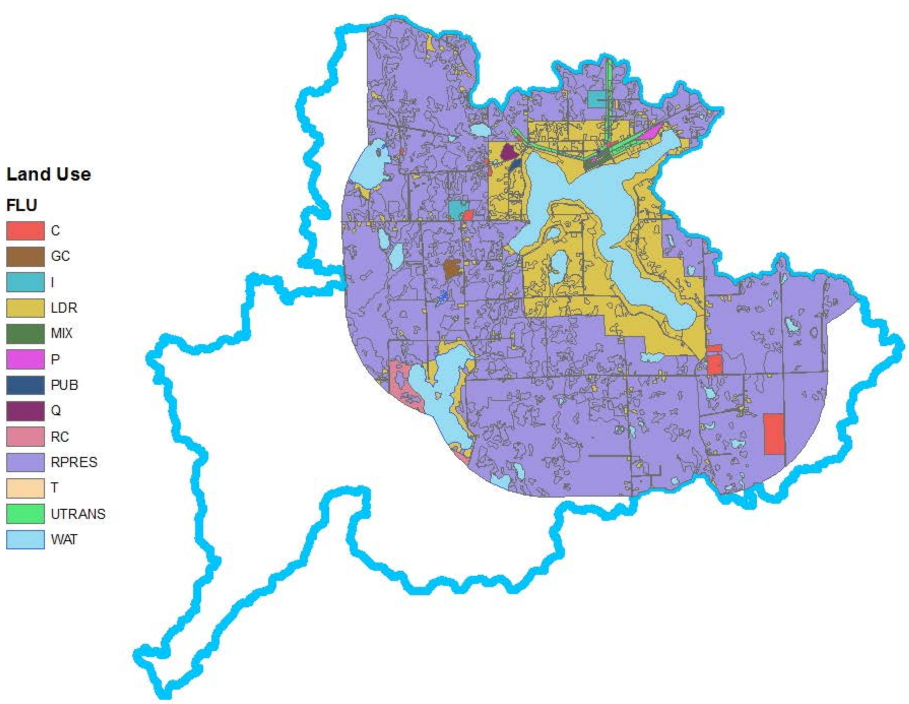


Figure 13.4 Future potential land use in the Lake Nebagamon watershed as described in the local comprehensive plan (2030).

14. Appendix E – Plankton Community Assessment

Introduction

This report summarizes the status of the plankton communities in Lake Nebagamon. Given the importance of plankton in the food web of lake ecosystems (see Section 5.5), a detailed assessment of the current plankton was conducted for Lake Nebagamon. Results from these assessments were used to characterize variations in the biological communities throughout the lake system and calibrate/validate and AQUATOX model (see Appendix G).

Methodology

All plankton samples were collected and analyzed following methods outlined by USEPA (2007). At each site, samples were collected monthly throughout the growing season in year two of the study. Each sample was collected as a spatially integrated composite from 3-5 sites around the sampling boat. Given the depth of Lake Nebagamon, all samples were collected from ~ 8 meters, which sampled below the thermocline during each sampling visit. Individual tows from each site were combined on-site and preserved for transportation to the laboratory. In the laboratory, samples were condensed and preserved for long-term archival. Triplicate, one milliliter aliquots were analyzed from each sample, and taxa were identified down to the major taxonomic groups. Aliquot abundance was converted into whole-lake abundance and biomass by multiplying the aliquot taxa density by the corresponding water volume sampled throughout the vertical plankton tow. Biomass estimates were based on literature values of length-weight ratios.

Results and Discussion

Plankton communities are temporally variable throughout the Lake Nebagamon ecosystem (Figures 14.1 and 14.2). The overall densities of phytoplankton varied throughout the summer, as did the relative abundance of different taxonomic groups varied. Early season samples were dominated by blue green algae and diatoms and golden brown algae became increasingly abundant throughout the growing season. Conversely, overall densities of zooplankton did not vary throughout the summer, while the relative abundance of different taxa remained consistent in June and July with copepods becoming more abundant in August. These results suggest that zooplankton predation may be an important driver of water quality conditions in Lake Nebagamon.

Management and Monitoring Recommendations

These results highlight the relative importance of zooplankton and phytoplankton in the structure and function of the Lake Nebagamon ecosystems. Given that plankton provide a critical food source for juvenile fish it is important to continually monitor this portion of the food web and track its concurrence with planktivorous fish abundance.

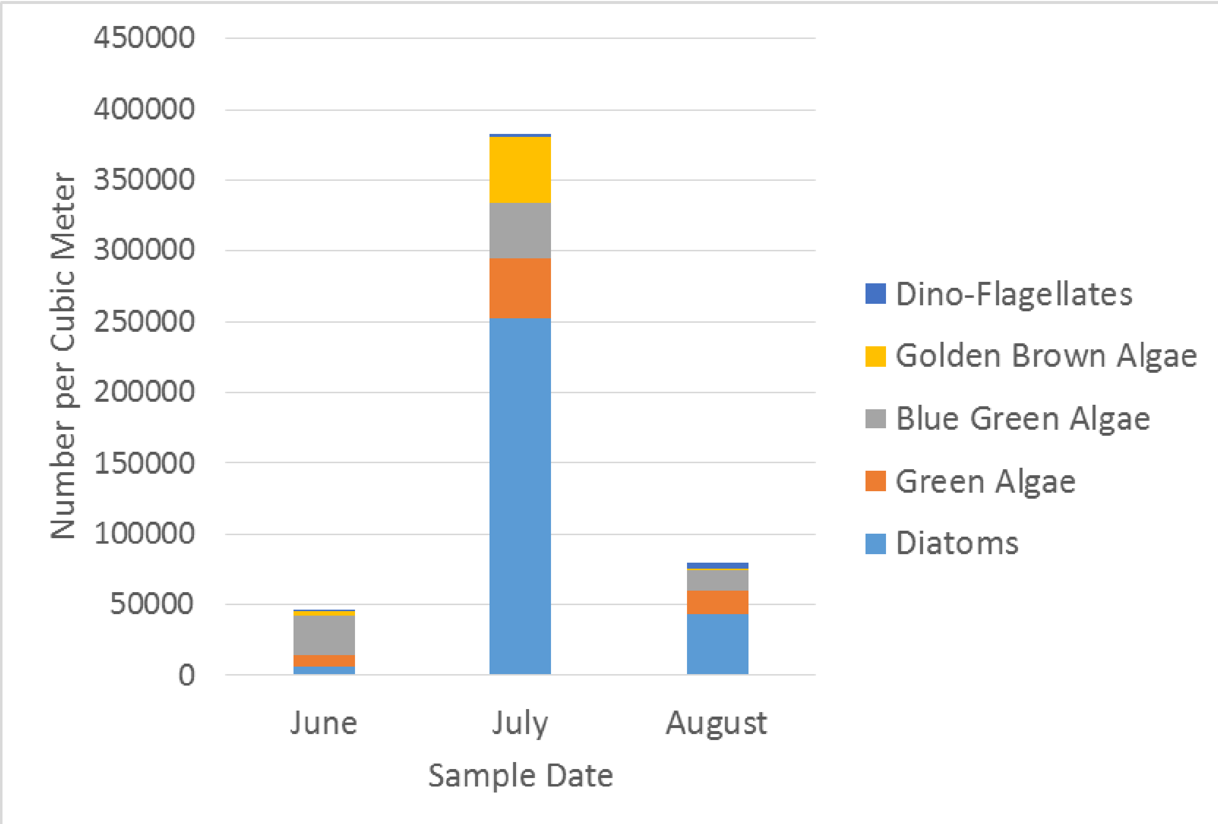


Figure 14.1. Seasonal variation in relative phytoplankton abundance in Lake Nebagamon in 2014.

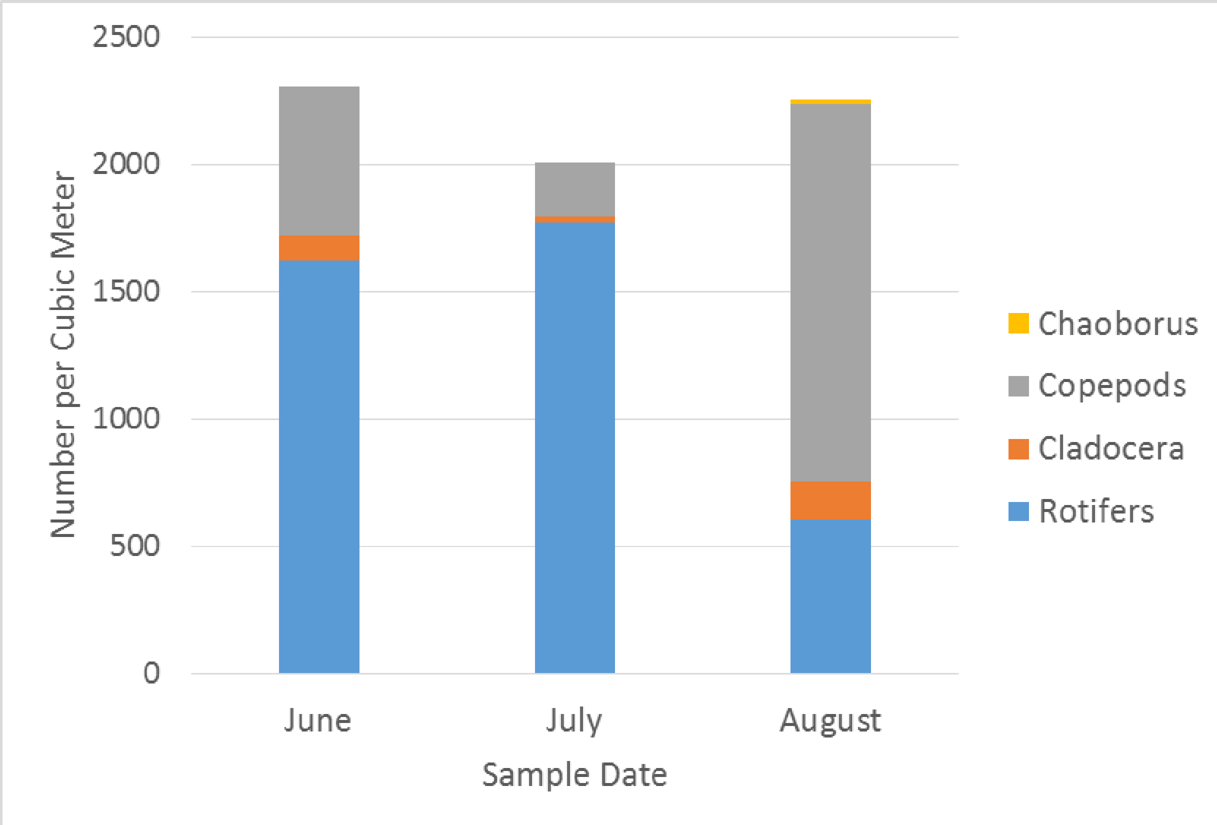


Figure 14.2. Seasonal variation in relative zooplankton abundance in Lake Nebagamon in 2014.

15. Appendix F – Aquatic Plant Assessment and Management Plan

Introduction

This report summarizes the status of the aquatic plant communities in Lake Nebagamon and describes a plan to manage aquatic plants and invasive species throughout the system. Given the importance of healthy native aquatic plant communities and potential negative impacts of invasive species (see Section 5.5), a detailed assessment of the current plant communities and risk of invasive species introduction was conducted for Lake Nebagamon. Results from these assessments were combined to develop recommendations to maintain diverse native plant communities and prevent invasive species introductions.

Methodology

Aquatic plant communities were sampled from 202 points in the littoral zone of Lake Nebagamon. Surveys were conducted from July to August, 2013. All work was implemented by the SOEI at Northland College on behalf of the Lake Nebagamon Sanitary Sewer Commission. All field staff were trained in the annual WDNR aquatic plant management workshop and overseen by the Lake Program Coordinator at SOEI.

Sampling Procedure

Plant communities were sampled following the WDNR Point Intercept Survey Methodology (Hauxwell, et al. 2010). Following this protocol, plant communities were sampled across a grid of points in shallow waters of the lake—the littoral zone. All sampling grids were generated by WDNR staff (e.g., Figure 15.1).

At each sample point, plant communities were sampled using a double-sided rake sampling device (Figure 15.1). Following the WDNR procedure, the rake is dropped to the bottom, turned three times and pulled to the surface. Once in the boat, the different species are identified and the relative density of the individual species and total plant density are recorded as rake fullness (Figure 15.1). Species composition and relative density data are recorded on the WDNR survey form and voucher specimens are kept for each species. In addition to species data, water depth, sediment type and sample site location are measured and recorded at each point using a handheld sonar and GPS units.

Following completion of the field survey, all data were entered into the WDNR spreadsheet template and analyzed. Raw data were processed to describe the total number and relative abundance of the different plant species encountered throughout the lake. Data were also used to calculate Floristic Quality Index (FQI).

The FQI describes how well the historical aquatic plant community (i.e., the plant community that likely occupied these lakes before human settlement) has been conserved over time. To calculate FQI, biologists have assigned Coefficients of Conservatism to different species based on their ability to survive across a range of environments. Species that are assigned a value of 0 are species that can survive in most lakes. Species that are assigned a value of 10 are those that represent historical plant communities and are often very sensitive to environmental change. The FQI is calculated by combining the species presence data with the appropriate Coefficient of Conservatism to estimate the historical characteristics of the plant community (methods described in detail in Nichols 1999).

Raw species data for each point were combined with GPS data and used to develop a series of maps to describe the aquatic plant communities. Maps depicting the total number of species detected at each point were developed for all lakes. Point data were then analyzed using a Spline Interpolation technique to estimate the likely species distribution between the individual sample points. The resulting data were used to develop a color-coded intensity map in which areas of high species richness are colored red and areas of low species richness are colored green. Areas of dense floating and emergent vegetation were identified by interpolating between points where these species were identified.

Voucher Specimens

Voucher specimens were retained for all species in all lakes and identified to species using: "Michigan Flora" Part I, by Edward G. Voss (1972); as well as the "Manual of Aquatic Plants" by Norman C. Fassett (1940). Voucher specimens were then pressed, dried and archived at the SOEI and sent to the Freckman Herbarium at the University of Wisconsin – Stevens Point for confirmation and long-term archival (Figure 15.1).

Pathway/Vector Analysis

Five primary pathways (or vectors) exist for invasive species entry into lakes (Table 15.1). Potential pathways were identified and characterized for Lake Nebagamon. Risk of introduction for each pathway was assessed and ranked using a five point, qualitative scale. Qualitative rankings are described below:

1. Low – Unlikely to result in species introduction in the short-term
2. Low-Moderate – Somewhat unlikely to result in species introduction in the short-term
3. Moderate – Moderate potential to result in species introduction in the short-term
4. Moderate-High – Somewhat likely to result in species introduction in the short-term
5. High – Likely to result in species introduction in the short-term

Results

Point Intercept Survey

Lake Nebagamon contains a robust aquatic plant community. Throughout this study, 35 species were identified (Table 15.3). The majority of plants were observed growing between 1 and 11 feet, up to a maximum depth of 26 feet (Figure 15.2 and Table 15.2). Average Simpson's diversity score was 0.92. The diversity and richness of species also varied among sites within the lake, with some individual rake pulls not collecting any plants and other collecting up to eleven individual species. In general, the areas of highest species richness were in protected bays at the northern and southern end of the lake (Figures 15.3, 15.4 and 15.5).

Throughout Lake Nebagamon, the most common species detected were Wild celery (*Vallisneria Americana*), Clasping-leaf pond weed (*Potamogeton richarsonii*) and Variable pondweed (*Potamogeton richardsonii*). The species that were detected that represent the high level of floristic quality were blunt-leaf pondweed (*Potamogeton obtusifolius*) and narrow-leaved bur-reed (*Sparganium angustifolium*), In general, the FQI scores for Lake Nebagamon (average of 31) were higher than the regional average of 26. **No invasive aquatic plant species were detected throughout the lake.**

Pathway/Vector Analysis
Six potential pathways for invasive species introduction were identified and evaluated (Table 15.4). Of the six introduction pathways, four were classified as Low or Low-Moderate risk and two were identified as Moderate risk. The two moderate risk pathways identified were watercraft access through the Village Land at Lake Nebagamon and the connected upstream waterbodies (particularly Minnesuing Lake).

Discussion and Management Recommendations

Aquatic plant management efforts in Lake Nebagamon should build on the ongoing work of the NLA and its collaborators to continue to address two primary goals:

1) Monitoring and maintaining the diversity of native aquatic plants;
2) Prevention of the introduction of new invasive species.

Existing Management Efforts
Existing management efforts are primarily implemented through volunteer the efforts of the NLA. The primary work of the NLA is to increase awareness of invasive species and their prevention. To this end, the NLA hosts an annual meeting and distributes recurring newsletters that highlight ongoing work and needs related to invasive species prevention and management. The NLA contracts with local partners to implement watercraft inspections at the Village launch from Memorial Day to Labor Day from 8 am to 4 pm seven days per week.

Monitoring and Maintaining the Diversity of Native Aquatic Communities
Diverse native aquatic communities are a key component of healthy lake ecosystems. Native plant communities: 1) support healthy fisheries by providing spawning and rearing habitat for juvenile fish; 2) promote water quality by providing habitat for zooplankton (which control algal blooms) and preventing sediments (and the associated nutrients) from being re-suspended throughout the lake; and 3) prevent the establishment and spread of invasive species by occupying habitat that invasive species could potentially utilize.

The first step in maintaining diverse native plant communities is to establish/maintain a recurring monitoring program to document any changes in community composition or structure over time. A recurring aquatic plant monitoring program like this would be implemented by conducting a point-intercept survey (the same protocol described above) to characterize the extent and composition of aquatic plant communities in all shallow waters (depth of < 25 feet) of the lake every three to five years. This work would build on the aquatic plant surveys that were conducted as part of the development of this management plan.

Prevent the Spread and further Introduction of Invasive Species
Given that no invasive aquatic plant species have been detected in Lake Nebagamon, continuing efforts that build on the NLA's ongoing work to minimize the potential for the introduction of invasive species are critical. To this end, three approaches are recommended: 1) expand educational efforts to include a broader range of potential sources; and 2) develop and implement an early detection, rapid response plan.

Expanded Educational Efforts
Given the potential for invasive species to be introduced to lakes beyond public/private boat launches, targeted educational efforts may help reduce risk of introduction beyond efforts at boat launches. In particular, outreach and educational efforts targeted at 1) local bait dealers to minimize the potential inadvertent distribution of invasive species; 2) lakeshore landowners to minimize inadvertent introduction of invasive ornamental species; 3) individual launch owners to minimize potential impacts of long-range boat transport; 4) upstream lake residents to minimize introduction to the connected system; and 5) beach managers to minimize wildlife attraction to waterfront areas (currently not a high risk activity in Lake Nebagamon).

Early Detection, Rapid Response Planning
An early detection, rapid response plan combines targeted invasive species monitoring activities with a document that articulates the action steps and decision criteria that will be used to prevent the establishment of new invasive species in a particular lake. Annual monitoring activities are generally comprised of high intensity monitoring efforts in the areas of highest probability for invasive species spread or introduction (e.g., adjacent to boat launches and areas of high traffic—connecting channels). The rapid response planning document is developed collaboratively with the Wisconsin Department of Natural Resources and articulates how (i.e., by what means?), when (i.e., in response to what change?) and by what process (i.e., who needs to be involved when, and in what order) new or expanding invasive species will be managed. Rapid response plans are then implemented in tandem with outreach efforts to increase awareness among lake users of the potential risks of invasive species and the options to prevent future spread or introduction.

Table 15.1. Description and potential risk for different invasive species introduction pathways

Pathway	Description	Risk of Introduction
Boat Launches	Watercraft movement between lakes is a primary vector for the introduction of invasive species. Invasive species can be transported in bait and ballast water, in and around the motor and on a transportation trailer.	Risk of introduction varies depending on the rates of usage and the levels of invasive species infestation in commonly visited waterbodies
Connected/adjacent Waterbodies	Invasive species are commonly spread between connected and/or adjacent waterbodies by human activities and wildlife movement	Risk of introduction varies depending on the size, level of connectivity and invasive species infestation in connected/adjacent waterbodies
Stormwater Runoff	Invasive species can washed into a lake through storm drain system when introduced to surrounding urban area	Risk of introduction varies depending on the area and usage of lands that directly drain to the lake.
Wildlife	Wildlife (particularly waterfowl) can introduce invasive species from one waterbody to another	Risk of introduction varies depending on the frequency of use and may be increased through human attraction of wildlife to lake systems (e.g., geese at beaches)
Riparian Introduction	Species commonly used in gardens along lakeshore properties can be introduced to lake systems and may become invasive	Risk of introduction varies depending on the density and species composition of gardens around lake systems

Table 15.2. Summary of Results from Aquatic Plant Survey on Lake Nebagamon

SUMMARY STATS	Results
Total number of sites visited	202
Total number of sites with vegetation	117
Total number of sites shallower than maximum depth of plants	182
Frequency of occurrence at sites shallower than maximum depth of plants	64.29
Simpson Diversity Index	0.92
Maximum depth of plants (ft)**	15.80
Number of sites sampled using rake on Rope (R)	3
Number of sites sampled using rake on Pole (P)	160
Average number of all species per site (shallower than max depth)	1.53
Average number of all species per site (veg. sites only)	2.40
Average number of native species per site (shallower than max depth)	1.53
Average number of native species per site (veg. sites only)	2.40
Species Richness	35
Species Richness (including visuals)	35

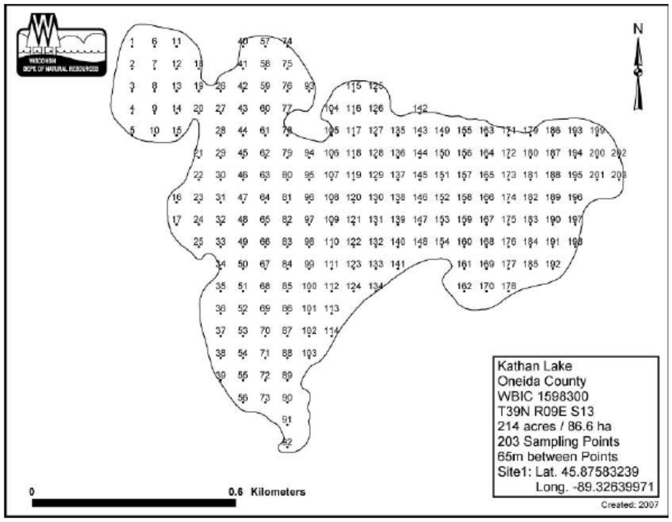
Table 15.3. Relative occurrence of different aquatic plant species throughout Lake Nebagamon.

Species	Statistics					
	Frequency of occurrence within vegetated areas (%)	Frequency of occurrence at sites shallower than maximum depth of plants	Relative Frequency (%)	Relative Frequency (squared)	Number of sites where species found	Average Rake Fullness
Vallisneria americana, Wild celery	41.03	26.37	17.08	0.03	48.00	1.00
Potamogeton richardsonii, Clasping-leaf pondweed	34.19	21.98	14.23	0.02	40.00	1.08
Potamogeton gramineus, Variable pondweed	24.79	15.93	10.32	0.01	29.00	1.03
Chara sp., Muskgrasses	20.51	13.19	8.54	0.01	24.00	1.04
Potamogeton robbinsii, Fern pondweed	18.80	12.09	7.83	0.01	22.00	1.59
Potamogeton zosteriformis, Flat-stem pondweed	13.68	8.79	5.69	0.00	16.00	1.13
Ceratophyllum demersum, Coontail	7.69	4.95	3.20	0.00	9.00	1.44
Potamogeton foliosus, Leafy pondweed	6.84	4.40	2.85	0.00	8.00	1.00
Bidens beckii (formerly Megalodonta), Water marigold	5.98	3.85	2.49	0.00	7.00	1.00
Eleocharis acicularis, Needle spikerush	5.13	3.30	2.14	0.00	6.00	1.00
Myriophyllum sibiricum, Northern water-milfoil	5.13	3.30	2.14	0.00	6.00	1.00
Nitella sp., Nitella	5.13	3.30	2.14	0.00	6.00	1.00
Brasenia schreberi, Watershield	4.27	2.75	1.78	0.00	5.00	1.00
Elodea canadensis, Common waterweed	4.27	2.75	1.78	0.00	5.00	1.00
Potamogeton pusillus, Small pondweed	4.27	2.75	1.78	0.00	5.00	1.00
Sagittaria sp., Arrowhead	4.27	2.75	1.78	0.00	5.00	1.00
Nuphar variegata, Spatterdock	3.42	2.20	1.42	0.00	4.00	1.25
Potamogeton amplifolius, Large-leaf pondweed	3.42	2.20	1.42	0.00	4.00	1.00
Potamageton sp.	3.42	2.20	1.42	0.00	4.00	1.00
Najas flexilis, Slender naiad	2.56	1.65	1.07	0.00	3.00	1.00
Nymphaea odorata, White water lily	2.56	1.65	1.07	0.00	3.00	1.33
Potamogeton friesii, Fries' pondweed	2.56	1.65	1.07	0.00	3.00	1.00
Potamogeton illinoensis, Illinois pondweed	2.56	1.65	1.07	0.00	3.00	1.00
Najas sp.	2.56	1.65	1.07	0.00	3.00	1.00
Lemna trisulca, Forked duckweed	1.71	1.10	0.71	0.00	2.00	1.00
Stuckenia filiformis, Fine-leaved pondweed	1.71	1.10	0.71	0.00	2.00	1.00
Freshwater sponge	1.71	1.10			2.00	1.00
Elodea nuttallii, Slender waterweed	0.85	0.55	0.36	0.00	1.00	2.00
Myriophyllum verticillatum, Whorled water-milfoil	0.85	0.55	0.36	0.00	1.00	1.00
Najas gracillima, Northern naiad	0.85	0.55	0.36	0.00	1.00	1.00
Potamogeton natans, Floating-leaf pondweed	0.85	0.55	0.36	0.00	1.00	1.00
Potamogeton nodosus, Long-leaf pondweed	0.85	0.55	0.36	0.00	1.00	1.00
Potamogeton obtusifolius, Blunt-leaf pondweed	0.85	0.55	0.36	0.00	1.00	1.00
Potamogeton spirillus, Spiral-fruited pondweed	0.85	0.55	0.36	0.00	1.00	1.00
Sparganium angustifolium, Narrow-leaved bur-reed	0.85	0.55	0.36	0.00	1.00	1.00
Sparganium sp., Bur-reed	0.85	0.55	0.36	0.00	1.00	1.00
Total				**0.08**		**1.37**

Table 15.4. Risk of introduction from different invasive species pathways

Pathway	Description	Risk of Introduction
Village Landing, Lake Nebagamon	Moderate use access, primarily from regional and extended users	Moderate; Moderate usage by boaters who generally frequent regional lakes, many of which have existing invasive species
Launch from Public Lands	Moderate use access, primarily from local users	Moderate; Moderate usage by boaters who generally frequent regional lakes, many of which have existing invasive species
Connected/adjacent Waterbodies	Lake not directly to two upstream waterbodies	Moderate; Moderate usage by boaters who on connected lakes. Connected lakes currently do not have existing invasive species
Individual Boat Launches	Access primarily from adjacent landowner	Low; Relatively few individial launches surrounding the lake
Stormwater Runoff	Primarily from urban areas along the northern shoreline	Low; Runoff from a relatively limited urban area
Wildlife	Migratory and local wildlife	Low; Limited use concentration beyond background levels
Riparian Introduction	Potentially from ornamental gardens in shoreline properties	Low; Relatively few ornamental gardens surrounding the lake

a)



b)

Fullness Rating	Coverage	Description
1		Only few plants. There are not enough plants to entirely cover the length of the rake head in a single layer.
2		There are enough plants to cover the length of the rake head in a single layer, but not enough to fully cover the tines.
3		The rake is completely covered and tines are not visible.

c)

Figure 15.1 General description of the a) point intercept sampling grid development; 2) semi quantitative criteria used to describe relative plant abundance; and the archival procedures.

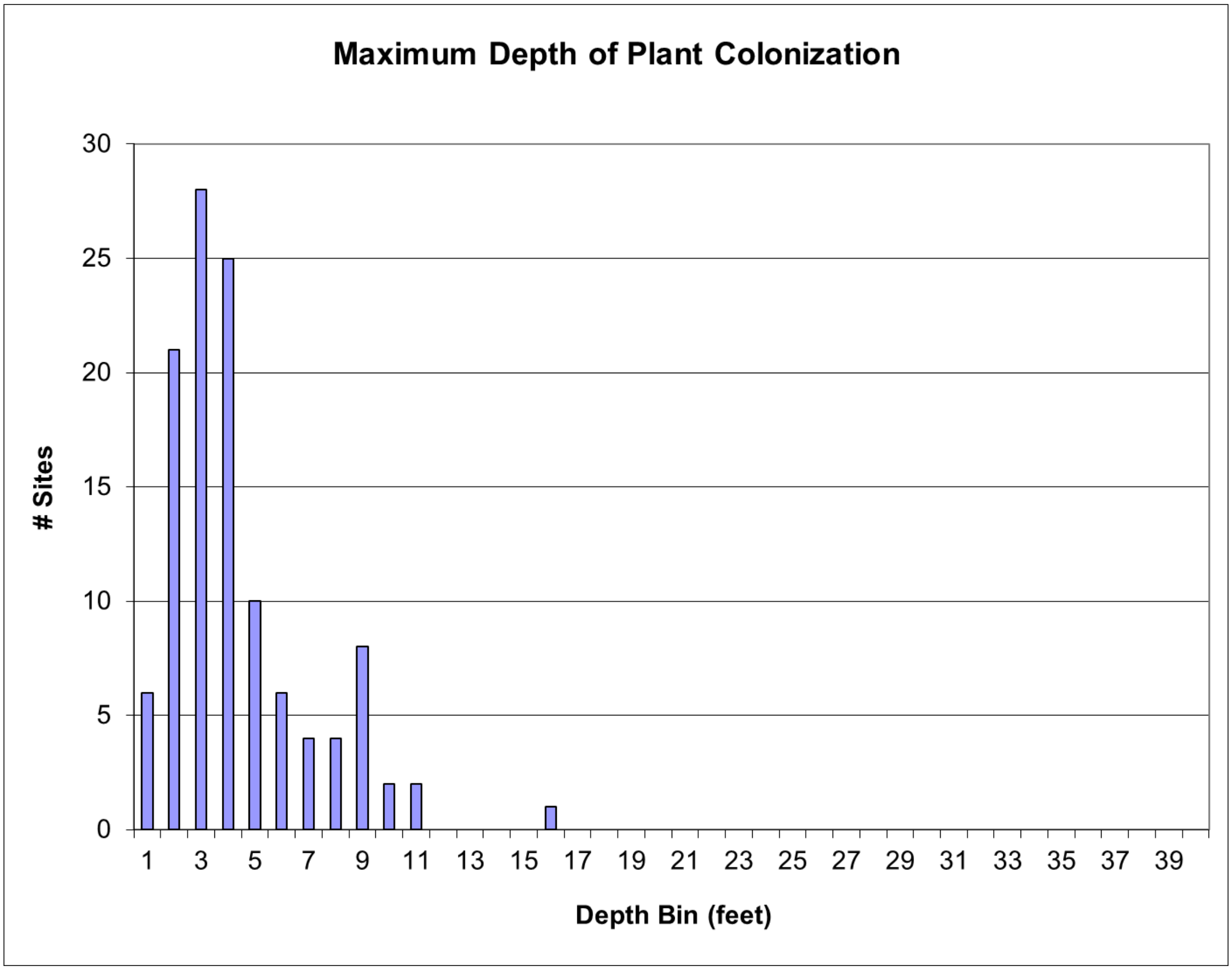


Figure 15.2 Frequency of plant growth at different depths throughout Lake Nebagamon.

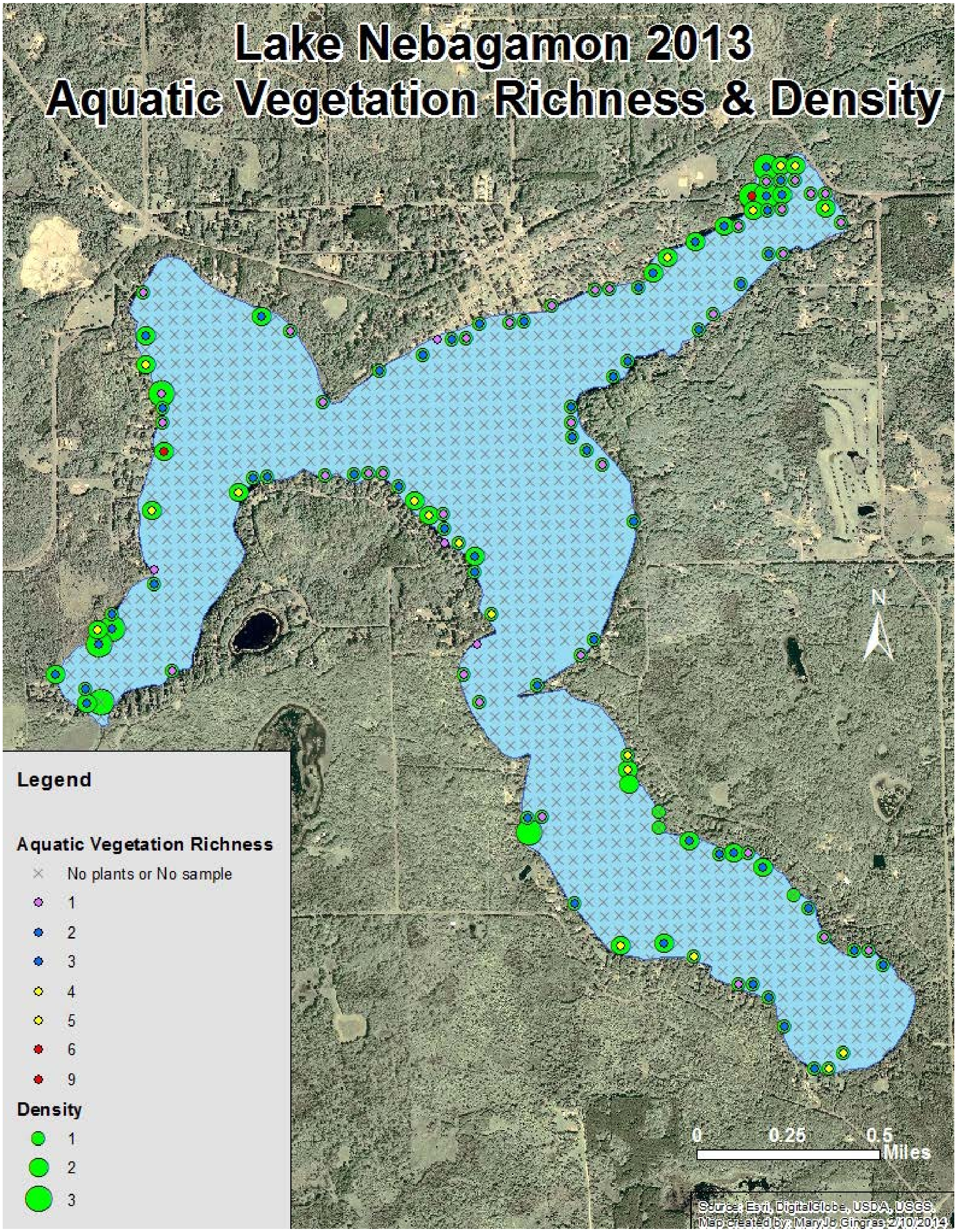


Figure 15.3 Species richness and density of aquatic plants throughout Lake Nebagamon.

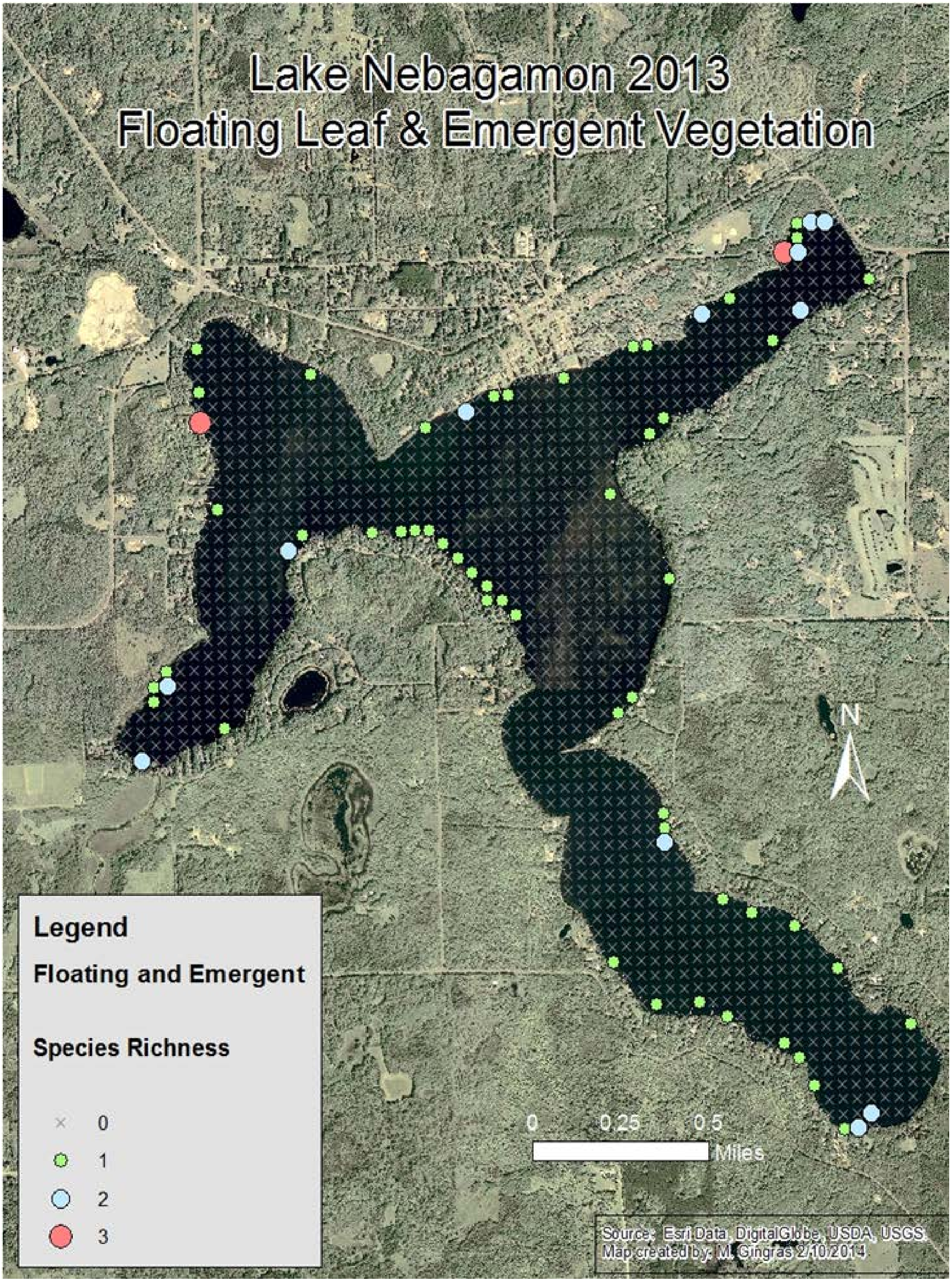


Figure 15.4 Location of floating and emergent leaf aquatic plant communities in Lake Nebagamon.

16. Appendix G – Ecosystem Modeling and Scenario Forecasting

Introduction
To understand the relative role of the different components of the Lake Nebagamon ecosystem, it is necessary to develop a framework that relates physical, chemical and biological processes. To this end, we developed an in-lake aquatic response model using the AQUATOX simulation program.

> AQUATOX is a PC-based ecosystem model that predicts the fate of nutrients, sediments, and organic chemicals in water bodies, as well as their direct and indirect effects on the resident organisms. AQUATOX simulates the transfer of biomass and chemicals from one compartment of the ecosystem to another. It does this by simultaneously computing important chemical and biological processes over time. AQUATOX simulates multiple environmental stressors (including nutrients, organic loadings, sediments, toxic chemicals, and temperature) and their effects on the algal, macrophyte, invertebrate, and fish communities. AQUATOX can help identify and understand the cause and effect relationships between chemical water quality, the physical environment, and aquatic life. It can represent a variety of aquatic ecosystems, including vertically stratified lakes, reservoirs and ponds, rivers and streams, and estuaries (EPA 2009, http://www.epa.gov/waterscience/models/aquatox/).

Methods
Lake Nebagamon was represented as a single lake site with linked epilimnion and hypolimnion layers. The Lake Nebagamon model was based on the model template for Lake George, NY. The model was constructed and initialized using the physical, chemical and biological data described in Appendices B, D and E and the fishery data described by Sand (2008). In the initial model structure, all model components were consistent with the Lake George template, except for the modification of the food web (which was based on Sand 2008 and the concurrent plankton assessment). Nutrient inputs to the lake were based on the nutrient budget describe in Appendix B. The lake was allowed to dynamically stratify based on wind speed and direction from the Drummond, WI weather station and discharged based on bathymetry and inflow volumes. Given the complexity and unique internal nutrient dynamics in the lake, a simplified representation of the lake ecosystem was ultimately adopted.

Model calibration followed an interactive approach using 2014 data and validated against measurements from the 2013 field season. Based on these initial conditions, model runs were conducted for one year periods from January 1st to December 31st. Initial model validation was conducted for physical-chemical parameters in the absence of nutrient and biological constituents (Figure 16.1). Results from this validation suggest that physical-chemical process are well represented for temperature and dissolved oxygen and that epilimnion oxygen concentrations are primarily governed by atmospheric diffusion and water temperature. External nutrient loads were added to the model to validate TP, Chl-a and Secchi depth responses. Predicted TP and Secchi depth responses represented average conditions as well as general interannual patterns in observed data sets. Despite the strong agreement between modeled and observed values, some isolated divergences were observed, suggesting that food web processes and/or seasonal events are important drivers of water quality conditions in Lake Nebagamon (Figure 16.2). Hypolimnion phosphorus concentrations were disproportionately high, suggesting that there is a significant source of phosphorus sequestration in Lake Nebagamon, not currently represented in the model.

To simulate trophic dynamics, a simple food web of primary producers (algae), primary consumers (herbivorous zooplankton), secondary consumers (predatory zooplankton), tertiary consumers (juvenile fish) and quaternary consumers (predatory fish) was constructed. Water quality conditions in this more complex system were simulated using the same physical-chemical drivers as in the initial validation run. Temperature and dissolved oxygen dynamics in this model remained well aligned with observed values (Figure 16.3). Model fit to trends in epilimnion TP, Chl-a and Secchi depth increased in the complex model and the characterization of seasonal trends was enhanced. (Figure 16.4).

To evaluate the potential impact of different nutrient loads on water quality conditions, three simulations were run based on historical, current and potential future land uses. All future simulations were run using the complex food web model. All watershed and septic phosphorus loads are described in Appendix C.

Results and Discussion

In general model results strongly aligned with observed values across both annual averages and seasonal trends. Model outputs best described surface water trends and exhibited some disagreement with observed values, particularly under late season conditions. Changes in water quality conditions that are likely to result from future land use change and septic system density, will likely be relatively small. A transition from historical to current land covers has likely resulted in an approximate 40 percent increase in TP concentration and a 46 percent reduction in water clarity. Based on this relationship, it is likely that future land use conditions (and septic loads) will result in an additional increase in TP of 12 percent and decrease in Secchi depth of 23 percent.

Management and Monitoring Recommendations

These results suggest that future increases in runoff and nutrient loads to Lake Nebagamon may have a moderate impact on water quality conditions. However, given the uncertainty surrounding future land use scenarios and the potential impacts of climate change on runoff processes, it is important to ensure that best management practices are consistently implemented as part of future land use development and that they are appropriately scaled to existing hydrologic regimes. Additionally, because these simulations represent annual growing season averages, minimum and maximum values may be divergent (i.e., periods of reduced/increased water clarity could occur in any given year).

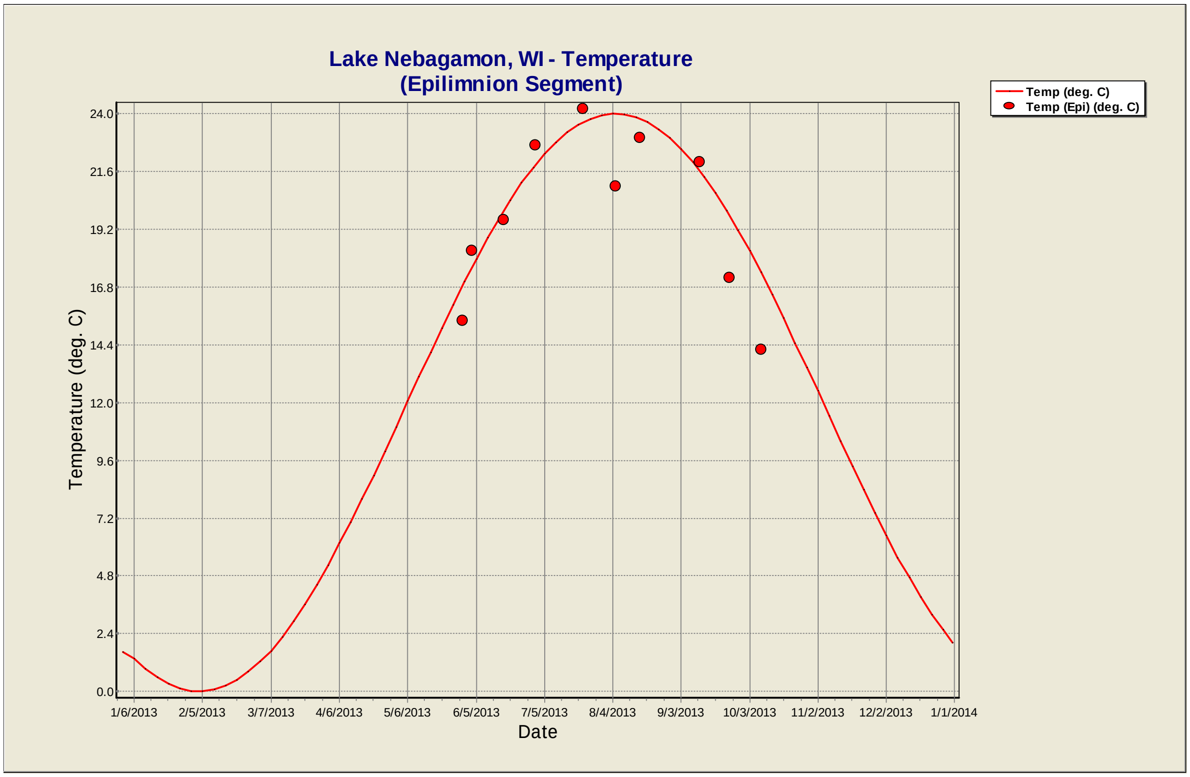
These model simulation also suggest that the elevated hypolimnion TP concentrations have the potential to have significant impacts on surface water quality conditions, depending on the structure of the food web. As such, it is important to understand this food web-water quality relationship and how it may respond to future climate and use regimes.

Uncertainty and Data Interpretation

These model simulations represent the best-possible mechanistic description of water quality conditions in Lake Nebagamon given the available data. However, the mechanistic understanding of the Lake Nebagamon ecosystem is incomplete, and thus should be used for general planning purposes only. Given the uncertainty surrounding future land use and climate scenarios and incomplete understanding of the Lake Nebagamon ecosystem, future management should include additional data collection to reduce uncertainty.

Table 16.1. Water quality changes potentially resulting from future land use/nutrient loading scenarios

Land Use Condition	Total Phosphorus Load (Pounds/year)	Water Quality Conditions			
		TP (ug/L)	Chl-a (ug/L)	Secchi (m)	TSI
Historical (~1850)	734	12.0	5.7	3.2	39.5
Monitored Data (2013)	2779	18.7	6.9	1.8	46.8
Current Model Predictions (2013)		19.7	6.7	1.7	45.5
Future (2030)	3342	22.3	8.6	1.3	51.0



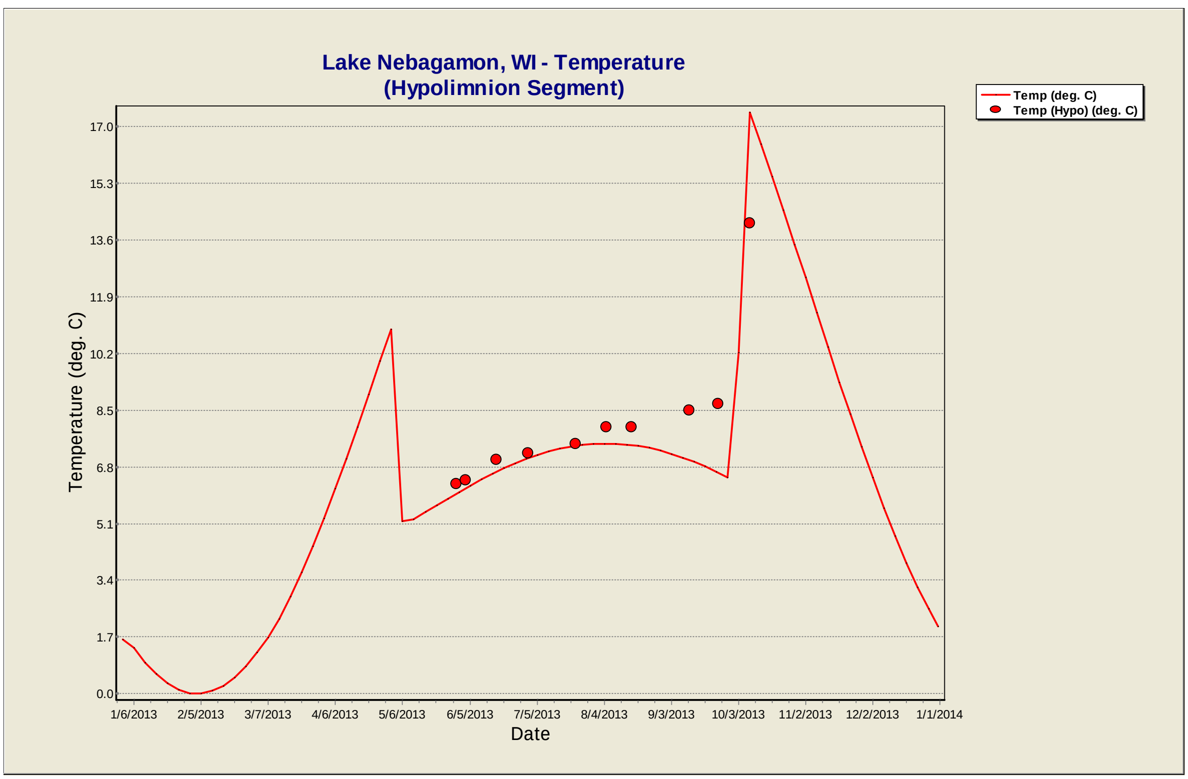
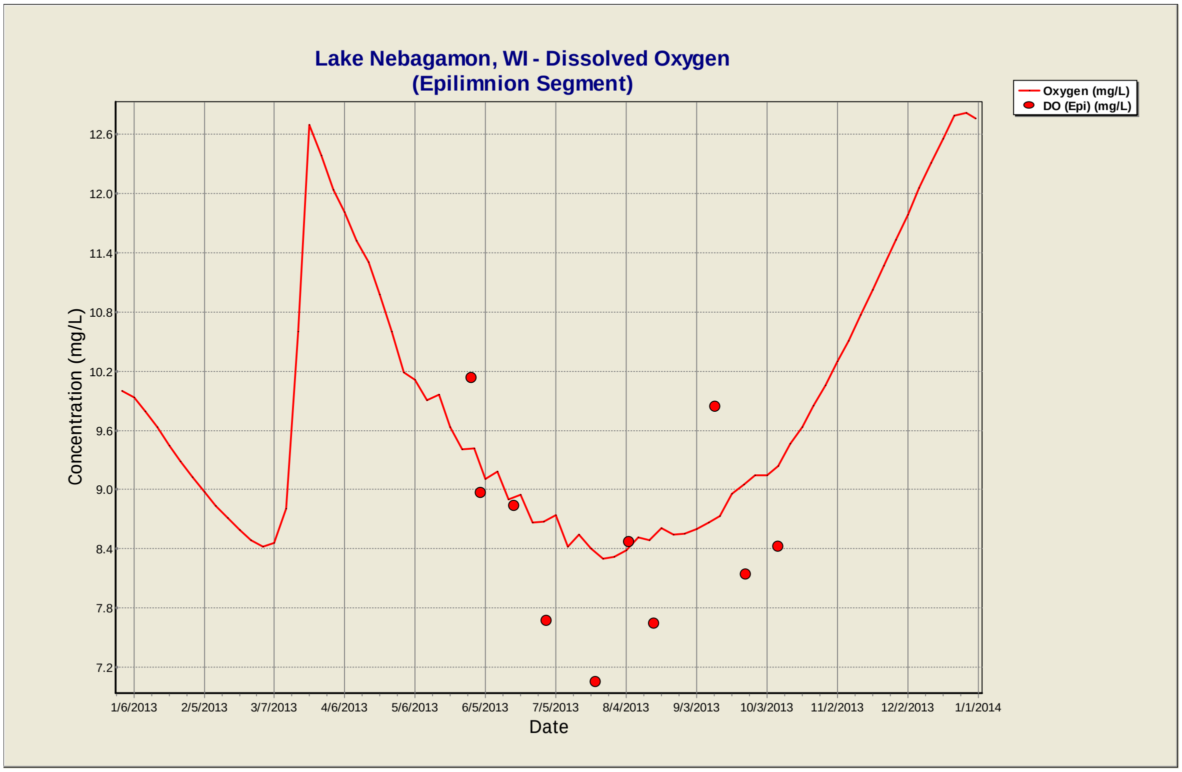


Figure 16.1 Validation of temperature representation in the AQUATOX model.



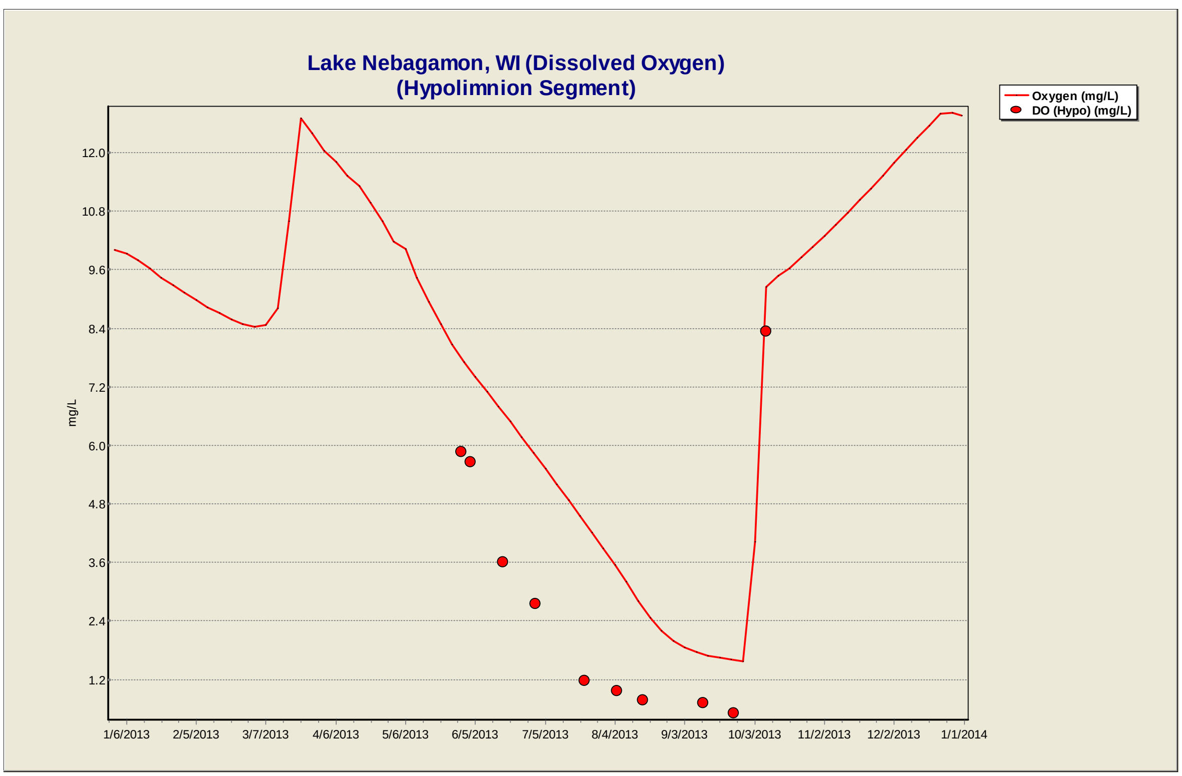
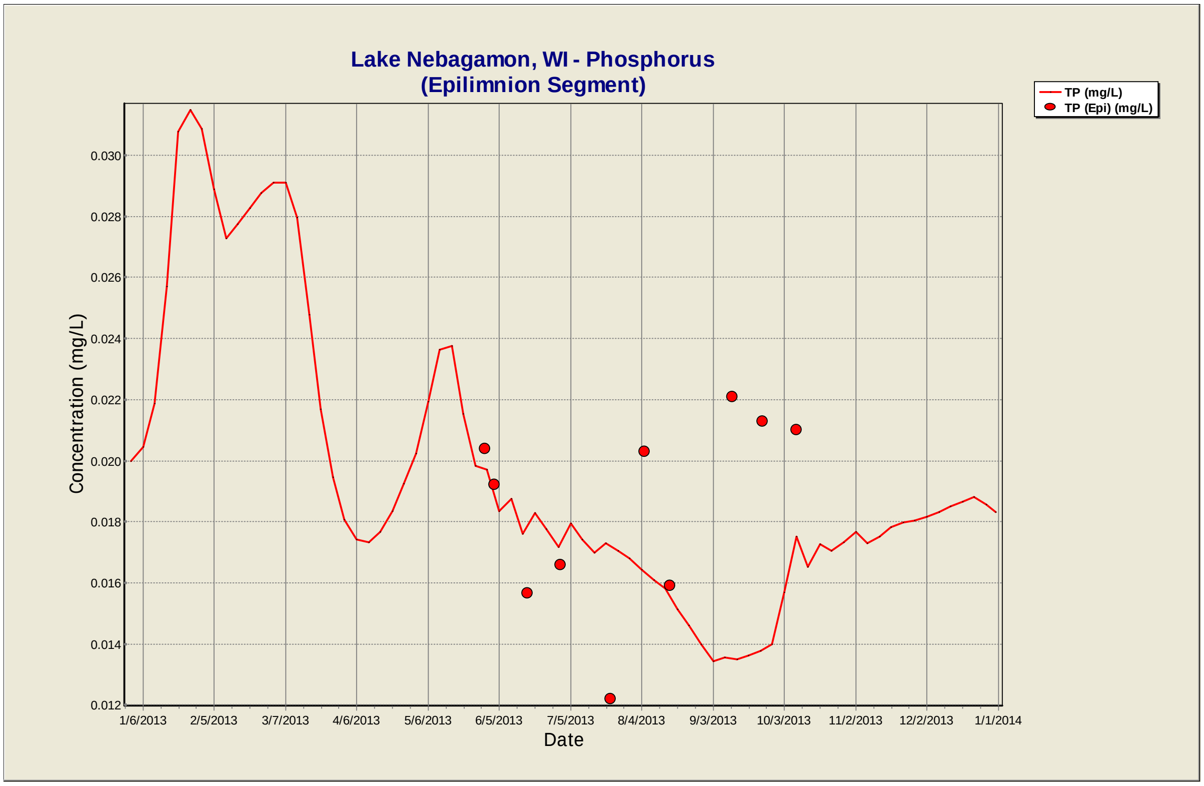


Figure 16.2 Validation of dissolved oxygen representation in the AQUATOX model.



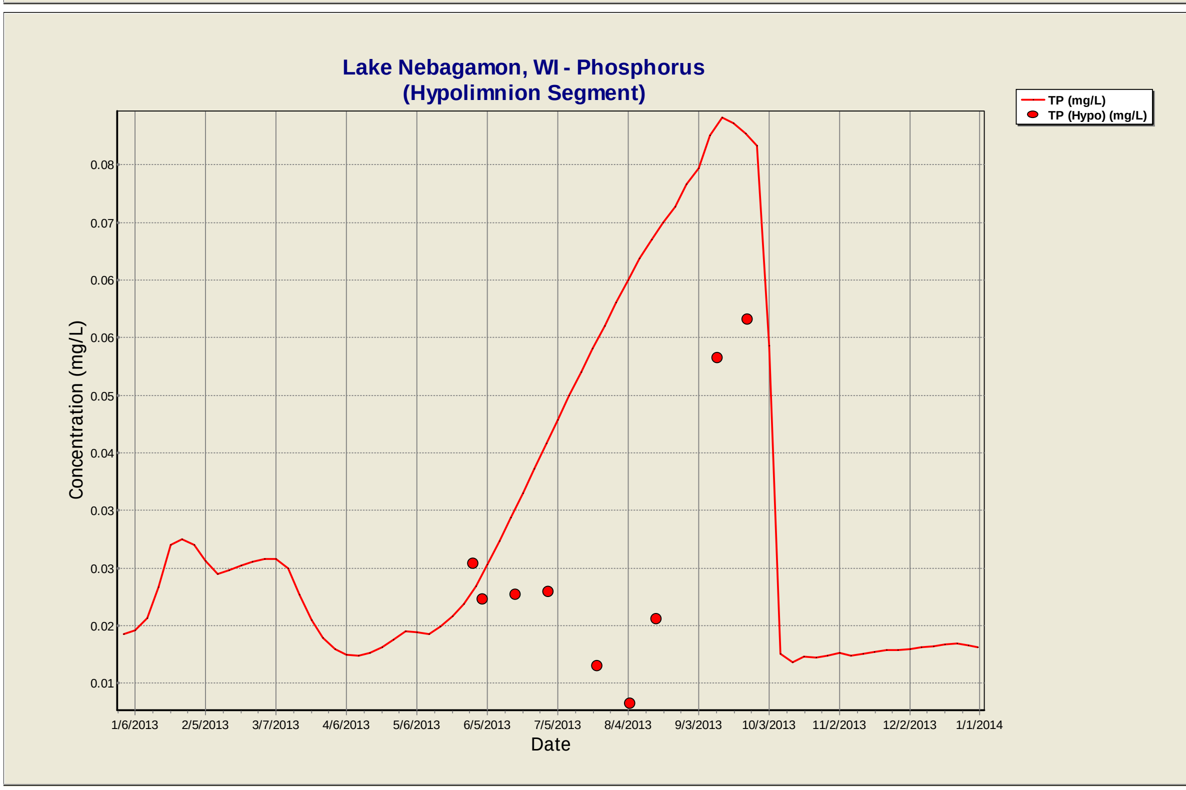


Figure 16.3 Validation of nutrient parameters in the AQUATOX model.

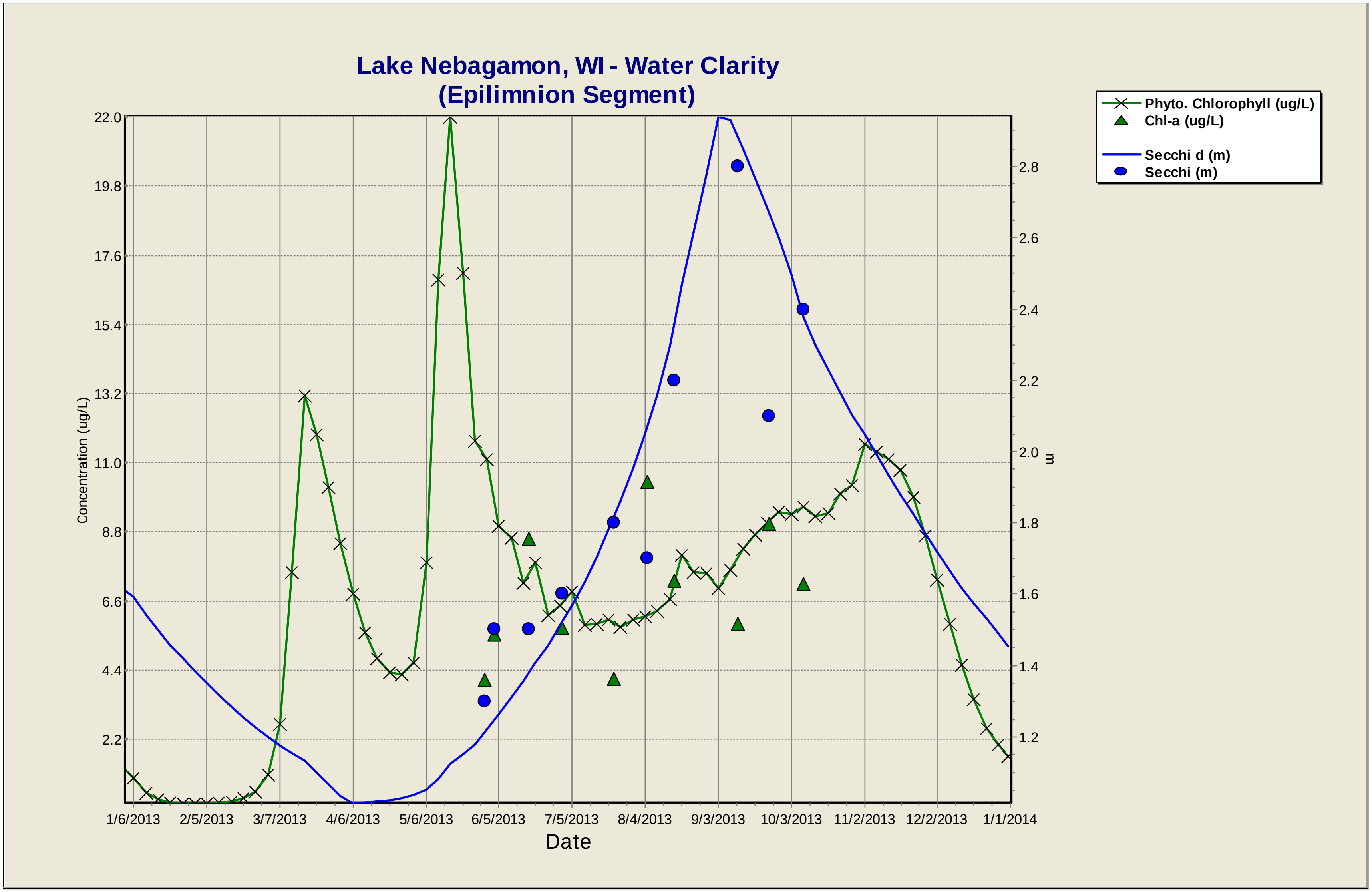


Figure 16.4 Validation for water clarify measures.