# Comprehensive Lake Management Plan

## *Potato Lake*

Washburn County

WBIC No. 2714500
DNR No. LPL-1458-12
SEH No. POTAL 118708

May 23, 2014

# Comprehensive Lake Management Plan

## Potato Lake
## Washburn County

Prepared for:
Potato Lake Association
Spooner, WI

Prepared by:
Dave Blumer, Project Manager
Jacob A. Macholl, Water Resources Scientist

Short Elliott Hendrickson Inc.
1701 West Knapp Street, Suite B
Rice Lake, WI 54868-1350
715.236.4000

Acknowledgements

This management planning effort was a team-based project and could not have been completed without input and assistance from the Potato Lake Association and volunteers.

# Distribution List

| No. of Copies | Sent to |
|---|---|
| 2 | Joe Adler<br>Potato Lake Association<br>3305E 126th Lane NE<br>Blaine, MN 55449 |
| 2 | Pamela Toshner, Regional Lake Coordinator<br>Wisconsin Department of Natural Resources<br>810 W. Maple Street<br>Spooner, WI 54801 |

# Executive Summary

This purpose of this report is to provide a comprehensive lake management plan for Potato Lake to guide improving and maintaining water quality and sustaining a healthy lake ecosystem. The Potato Lake Association was awarded a Wisconsin Department of Natural Resources Lake Grant in 2012 to develop this comprehensive lake management plan. The management goals and activities described in this plan were developed as a collaborative effort between the Potato Lake Association and lake managers from SEH. The goals focus on watershed and near-shore best management practices that will reduce the amount of phosphorus entering the lake and improve the highly valued lake aesthetic.

Plan development included collecting data and information on the lake and its watershed including water quality measurements, surveys of the shoreland area and lake sediments, evaluations of septic systems around the lake, and an investigation of groundwater entering the lake. These data were used to assemble a phosphorus budget for the lake and to support modeling to simulate the effect of various phosphorus loading scenarios to the quality of the lake.

Shallow lakes such as Potato Lake are either plant-dominated or algae-dominated. Potato Lake is in a macrophyte-dominated state. Events called forward switches can flip the lake to the algae-dominated state where the lake will experience frequent massive algal blooms. Forward switches include excessive destruction of aquatic plants (by, for example, motor boats, herbicides, and animals such as carp and grazing birds) and a large population of fish that eat zooplankton (zooplankton eat algae). As nutrient input increases, the lake will become more susceptible to forward switches. Reducing nutrients loading, particularly phosphorus, and preserving the swampy fringes and vegetated shoreland areas will buffer against forward switches.

The annual phosphorus load to the lake for 2012 was computed to be 802.1 pounds, the majority of which is from natural sources including groundwater, forests, and wetlands. About 23% of the 2012 phosphorus load is attributed to agricultural (170.8 pounds) or developed lands (9.3 pounds) in the watershed. Nearly the entire phosphorus load from developed lands is sourced from within 300 feet of the lake. The load from farms and ranches is likely a less during most years as much of the agricultural land drains to closed depressions where runoff is infiltrated into the ground. Sediment release of phosphorus into the lake was found to be insignificant.

A 20% reduction of the 2012 phosphorus load (reduce load by about 160 pounds per year) would bring the lake into the mesotrophic classification with respect to total phosphorus concentrations. Little change to the water quality will be realized with load reductions greater than about 25% of the 2012 load. The lake was found to be more sensitive to increases in phosphorus than decreases— an ounce of prevention is worth a pound of cure. The nutrient modeling also found that a phosphorus load increase or decrease of about 10% or less will have little effect on the water quality. This zone of little change in lake quality to change in phosphorus load represents the natural ability of the lake to assimilate nutrients; however, recent data suggests that Potato Lake is on the verge of becoming an algae-dominated (rather than plant-dominated) system.

The following management goals are recommended:

- Reduce sediment and phosphorus entering the lake to improve water quality.
- Promote sustainable and multi-use recreational opportunities.
- Manage and improve the fishery and wildlife habitat.
- Continue implementing the management activities of the Aquatic Plant Management Plan.
- Implement, update, and maintain this Comprehensive Management Plan.

# Executive Summary (Continued)

Associated with each goal is a number of objective and actions necessary to accomplish the goal. More detail of these activities can be found in Section 2 of this plan. An Implementation and Funding Matrix which outlines a timeline for implementation, identifies possible funding sources, and prioritizes actions for implementation can be found in Section 3 of this plan. Section 11 includes a list of implementation strategies to aid in the successful accomplishment of the plan goals and objectives. The projected timeline for completion of the objectives and actions detailed in this plan and assessment of the goals is five years. The plan is intended to be a living document that will be evaluated on an annual basis and updated as necessary to ensure goals and community expectations are being met.

# Table of Contents

SEH is a registered trademark of Short Elliott Hendrickson Inc.

# Table of Contents (Continued)

## List of Tables

## List of Figures

# Table of Contents (Continued)

## List of Appendices

# Comprehensive Lake Management Plan

## Potato Lake

Prepared for the Potato Lake Association

---

## 1.0 Introduction

Potato Lake is located in east-central Washburn County in the Townships of Crystal and Madge. The lake provides many recreational opportunities to its roughly 70 shoreland property owners and to the public through an often used public access site on the north end of the lake. The Potato Lake Association (Association) has been monitoring the water quality of the lake since the late 1990s. A slight increase in the trophic state of the lake occurred in the mid 2000s; however, the water quality has since returned to conditions similar to those of the early 1990s.

In 2009 the Association began the steps necessary to develop an aquatic plant management plan. A WDNR lake management planning grant was awarded for the development of this Aquatic Plant Management Plan. The APM Plan provides direction for protecting the native plant community, which includes wild rice, and for continued aquatic invasive species monitoring to prevent the introduction of new aquatic invasive species to the lake. The project awarded by the WDNR focused on gaining a better understanding of the aquatic plant community in the lake and other processes affecting the lake. The end goal of this project was to complete an Aquatic Plant Management Plan and to further define the next steps to be taken for completing a formal Comprehensive Lake Management Plan. A lake planning grant was awarded in the fall of 2011 to complete comprehensive lake management planning. This document is the result of that project.

## 2.0 Recommended Management Goals, Objectives, and Actions

The management goals for Potato Lake were developed as a collaborative effort between the Potato Lake Association board and members and lake managers from SEH Inc. In an effort to receive feedback from the general public, the plan was posted on a publicly accessible website. The goals were developed to be inspirational, believable and actionable and are derived from the values of the Potato Lake community.

**Problem Statement**
If not mitigated, cultural eutrophication will cause an increase in algal blooms and nuisance aquatic plant growth in Potato Lake, which can flip the lake from a plant dominated state to an algae-dominated state.

### 2.1 Goal: Reduce sediment and phosphorus entering the lake to improve water quality.

**Objective**: Ensure riparian residents are up-to-date on septic tank inspections and pumping.

**Action Steps**

- Provide notice in newsletter or as separate mailing

**Objective**: Encourage greater use of Best Management Practices (BMPs) by farmers in the watershed

**Action Steps**:

- Provide educational materials on agricultural BMPs
- Host a meeting between lake residents and local farmers and ranchers
- Evaluate and consider incentive programs to local farmers for incorporating BMPs in their operations (secure funds via County resources or WDNR grants)

**Objective:** Install shoreland buffers, rain gardens and other BMPs in the shoreland area to improve water quality and the lake ecosystem.

**Action Steps:**

- PLA to identify shoreland property owners willing to install runoff reduction practices. If sufficient interest, seek grant funding for design and installation
- PLA will sponsor and promote a workshop to provide basic information and training and tips from a qualified specialist.
- Riparians will stabilize the soil in steep areas, locate fire pits at least 50 feet from the lake, keep grass clippings and leaves out of the lake, and clean up pet waste from their yards
- Evaluate the need for and design and installation of a detention basin to contain runoff from the Potato Lake Public Boat Landing

- Recognize property owners who install shoreland buffers, rain gardens and other runoff reduction practices.

**Objective:** Continue to monitor lake water quality through Citizen Lake Monitoring Network to further develop long term data to be utilized to identify problems and improvements. Secchi depth, total phosphorous, chlorophyll *a*, temperature, and dissolved oxygen monitoring should be completed on regular basis during the open water season.

**Action Steps:**

- PLA continues to recruit and support volunteers.
- Evaluate sampling efforts annually based on data needs.
- Install and maintain permanent bench mark and staff gauge to monitor water levels in the lake.

## 2.2 Goal: Promote sustainable and multi-use recreational opportunities

**Objective:** Evaluate the need for a lake-use plan to support a safe and multifaceted recreational environment in the lake. A lake-use plan would delimit areas for specific activities, for example no-wake zones.

**Action Steps:**

- Monitor patterns of recreational use in the lake to identify potential conflicts and guide management activities (for example, education efforts).
- Hold open forums to discuss lake use issues with interested parties.
- Determine the need for a lake-use plan and new lake use ordinances.

**Objective:** Actively engage the public in lake management efforts.
**Action Steps**:

- Encourage membership and participation in Potato Lake Association and its functions including but not limited to: committee membership, meeting attendance and presence at other events, review of lake management actions, and participation in fund raising events.
- Hold an annual lake fair, picnic or other event and invite special presenters.
- Sponsor demonstration projects and public forums.
- Publish a newsletter with distribution to all lake addresses. Newsletter should be published at least annually.
- Secure and support volunteers to perform monitoring efforts (for example, water quality, aquatic invasive species, boat landings, plants, wildlife).

## 2.3 Goal: Maintain and improve the fishery and wildlife habitat.

**Objective:** Improve riparian and littoral zone habitat.

**Action Steps:**

- Develop management goals for coarse woody structure, potentially based on undeveloped lakes or estimates of pre-settlement conditions.
- Maintain riparian buffer strips that include young and mature trees to ensure a natural supply of coarse woody structure for habitat.

**Objective:** Minimize negative impacts to fishery caused by lake management activities

**Action Steps:**

- Work closely with WDNR fisheries staff to identify and mitigate potential effects of management activities that may be detrimental to the fishery (for example, discuss any new shoreline armoring projects such as riprap with WDNR personnel).

**Objective:** Develop a critical habitat protection plan for Potato Lake to identify critical habitat areas up front so future waterfront projects can be designed to protect habitat and ensure the long-term health of the lake.

**Action Steps:**

- Inform WDNR of desire to protect the numerous public rights features of the lake and request a critical habitat area study and report. (Note: critical habitat area studies are not currently a priority activity of the WDNR)

## 2.4 Goal: Continue implementing the management activities of the Aquatic Plant Management Plan.

The current Aquatic Plant Management Plan supports sustainable practices to protect, maintain and improve the native aquatic plant community, the fishery, and the recreational and aesthetic values of the lake. The APM plan is slated for review and update in 2015. The goals of the Aquatic Plant Management Plan are:

- Protect and preserve the native species community within and around Potato Lake;
- Aquatic invasive species education and prevention;
- Monitor water quality conditions in Potato Lake;
- Complete comprehensive lake management planning for Potato Lake.

## 2.5 Goal: Implement, update and maintain this management plan.

**Objective:** Follow and adaptive management approach.

**Action Steps:**

- Draft annual reports that include summaries of management activities (even if none completed), water quality conditions, and future directions and needs.
- Upload digital copies of annual reports and data into the SWIMS digital library.
- Integrate new information and planning elements into the plan as they become known.

It is important to continue monitoring lake water quality through the Citizen Lake Monitoring Network. The water quality of Potato Lake provides a useful barometer of conditions in the watershed. Further developing a long-term dataset can be used to identify both problems and improvements in the lake and to the watershed and to evaluate the effectiveness of management efforts, now and in the future.

The Association should continue to recruit and support volunteers collecting water quality data. Secchi depth, total phosphorous, chlorophyll *a* sampling, and temperature and dissolved oxygen profiles should be completed on regular basis during the open water season at the Deep Hole monitoring site in the northern part of the lake.

**Objective:** Secure funding to support implementation of management activities.

**Action Steps:**

- Finance implementation of management activities through Association funds and by seeking WDNR Lake Protection grant funds.
- Identify other potential funding sources and grant programs for implementation of management activities.

# 3.0 Implementation Matrix

### Potato Lake Comprehensive Management Plan - Implementation and Funding Matrix

| Plan Element | Priority Level | Responsible Parties | Estimated Cost | Sources of Funding | Year 1 2014 | Year 2 2015 | Year 3 2016 | Year 4 2017 | Year 5 2018 |
|---|---|---|---|---|---|---|---|---|---|
| **Goal 1 - Reduce sediment and phosphorus entering the lake** | | | | | | | | | |
| Up-to-date septic tank inspection and repair | | | | | | | | | |
| Remind property owners via newsletter or other media | 2.5 | PLA | minimal | PLA, LP | × | × | × | × | × |
| Encourage greater use of Agricultural Best Management Practices (BMPs) in the watershed | | | | | | | | | |
| Provide educational and information materials to local farmers on BMP | 4.0 | LWCD, PLA, Local Ag, UWEX | minimal | County, NRCS, PLA, LP | × | × | × | × | × |
| Facilitate communication and cooperation between lake residents and local farmers | 4.3 | PLA, Ag, LWCD | minimal | PLA, County, LP | × | × | × | × | × |
| Evaluate and consider a BMP incentives program for local farmers | 4.5 | LWCD, PLA, Ag | minimal | PLA, County, LP | × | | | | |
| Implement BMP incentives program for local farmers | 4.5 | LWCD, Ag, NRCS, PLA | Varies with programs | PLA, County, LP | | ? | ? | ? | ? |
| Encourage implementation of shoreland and in-lake best management practices | | | | | | | | | |
| Identify property owners willing to implement runoff reduction practices; seek grant funding to aid in design and implementation | 2.3 | PLA, Riparians | minimal | PLA, LP | × | × | × | × | × |
| Sponsor and promote a shoreland restoration and rain garden workshop | 3.0 | PLA, LWCD, RP | $2,000 | PLA, County, LP | × | | × | | × |
| Provide education and informational materials for ecologically friendly shoreland protection and uses | 2.0 | PLA, UWEX, LWCD | minimal | PLA, LP | × | × | × | × | × |
| Evaluate the need for and design and installation of a detention basin to contain runoff from the public boat landing | 2.0 | PLA, Township, County, WDNR | minimal | SLP | ? | ? | | | |
| Recognize property owners who install best management practices | 2.5 | PLA, UWEX, LWCD | minimal | PLA, LP | × | × | × | × | × |
| Monitor water quality through the Citizen Lake Monitoring Network | | | | | | | | | |
| Recruit and support volunteer monitors | 1.3 | PLA, WDNR | minimal | PLA, LP, CLMN | × | × | × | × | × |
| Evaluate sampling efforts annually based on data needs and changes to lake | 1.0 | PLA, RP, WDNR | (RP: ~$500/year) | PLA, LP | × | × | × | × | × |
| Install and maintain a permanent bench mark and staff gauge to monitor water levels | 1.3 | PLA, County, Township, RP | Installation and survey: $500 Annual survey: $150 | PLA, LP | × | × | × | × | × |
| **Goal 2 - Promote sustainable and multi-use recreational opportunities** | | | | | | | | | |
| Evaluate need for a lake-use plan | | | | | | | | | |
| Monitor recreational use patterns to guide outreach efforts | 2.5 | PLA | minimal | PLA | × | × | | | |
| Hold open forums to discuss lake use issues with interested parties | 2.3 | PLA, Riparians | $200 | PLA | × | × | × | × | × |
| Develop, implement, and evaluate a Lake-Use Plan that may include new lake use ordinances | 2.8 | PLA, RP, Town, County | $6,000 | SPL Grant | | | × | × | × |
| Actively engage the public in lake management efforts | | | | | | | | | |
| Encourage involvement and participation in lake association functions | 1.3 | PLA | minimal | PLA, LP | × | × | × | × | × |
| Hold an annual lake fair, picnic, or other special event | 1.3 | PLA | $300 | PLA, LP | × | × | × | × | × |
| Sponsor special projects and public forums related to lake management | 2.8 | PLA | | PLA, LP | × | × | × | × | × |
| Publish a newsletter (annual basis at the minimum) | 1.0 | PLA | $250 | PLA, LP | × | × | × | × | × |
| Involve volunteers in lake monitoring programs (CLMN, CBCW, wildlife, AIS monitoring) | 1.8 | PLA, WDNR, UWEX | minimal | PLA, LP | × | × | × | × | × |
| **Goal 3 - Maintain and improve current fishery and wildlife habitat** | | | | | | | | | |
| Improve riparian and littoral zone habitat | | | | | | | | | |
| Develop coarse woody structure management goals | 2.8 | PLA, WDNR | minimal | WDNR | × | × | × | × | × |
| Install and maintain riparian buffer strips that include herbaceous cover, shrubs and young trees, and mature trees | 2.0 | PLA, WDNR | ~$2 per linear foot | PLA, WDNR, LWCD | × | | | | |
| Minimize potential impacts to fishery that may be caused by lake management activities | 3.0 | | | | | | | | |
| Meet annually with WDNR to discuss current fishery management activities and to identify lake management activities that may be in conflict | 1.5 | PLA, WDNR | minimal | WDNR | × | × | × | × | × |
| Develop a critical habitat protection plan for the lake | 0.0 | | | | | | | | |
| Communicate desire for a critical habitat area study and report to WDNR | 3.3 | PLA | minimal | WDNR | × | × | × | × | × |
| **Goal 4 - Implement Aquatic Plant Management Plan** | | | | | | | | | |
| Follow goals, objectives and actions in the 2010 APM Plan | | | | | | | | | |
| Update 2010 APM Plan | 3.3 | PLA, RP | $10,000 | PLA, AIS Grant | | × | | | |
| Implement aquatic plant management actions in the new APM Plan | 2.8 | PLA, RP | | PLA, AIS Grant | | | × | × | × |
| **Goal 5 - Implement CLM Plan activities and maintain plan** | | | | | | | | | |
| Use an adaptive management approach when implementing this plan | | | | | | | | | |
| Complete annual reports (summary of events/activities, suggested strategy revisions, future management plans) | 2.5 | PLA, RP | | PLA, LP | × | × | × | × | × |
| Integrate new information and planning elements as they become available | 3.0 | PLA, RP | | PLA, LP | × | × | × | × | × |
| Secure funding to implementation of this Comprehensive Lake Management Plan | | | | | | | | | |
| Utilize WDNR Lake Protection grants for implementation of management activities | 2.0 | PLA | | LP | × | × | × | × | × |
| Identify other funding sources for implementation of management activities | 3.0 | PLA | | Partners, fund raising | × | × | × | × | × |

**Abbreviations:** PLA, Potato Lake Association; LWCD, Washburn County Land & Water Conservation Dept.; NRCS, U.S. Department of Agriculture-Natural Resources Conservation Service; WDNR, Wisconsin Department of Natural Resources; County, Washburn County; Township, Townships of Crystal and Madge; RP, resource professionals/consultant; UWEX, University of Wisconsin Extension; Riparians, lake property owners; Ag, local farmers and ranchers; LP, WDNR lake protection grant; SLP, small-scale lake planning grant; CBMN, Citizen Based Monitoring Network; CLMN, Citizen Lake Monitoring Network; CBCW, Clean Boats Clean Waters; NA, not applicable.

**Note:** Responsible parties and sources of funding are not exhaustive and could change; Grant eligibility is subject to WDNR approval. It is always the repsonsibility of the Potato Lake Association to intiate these activities by contacting potential partners (Responsible Parties) and Funding Sources.

## 4.0 Needs Assessment

Shallow, polymictic lakes such as Potato Lake are generally either macrophyte (plant)-dominated or phytoplankton (algae)-dominated. Currently Potato Lake is in a macrophyte-dominated state. During macrophyte-dominated conditions, rooted plants prevent sediment from becoming suspended which keeps the water relatively clear. If plant coverage decreases and phosphorus inputs increase, the lake can shift to an algal-dominated state, which is generally less desirable for human and biological use. During the algal-dominated state, the lake can experience frequent massive algal blooms. It is difficult to return a lake to a macrophyte-dominated state from an algal-dominated state due to algae reducing light penetration thus preventing macrophytes from establishing.

The paleocore analysis of historic water quality conditions provides evidence that the nutrient load to Potato Lake has increased. Recently, lake property owners and lake users have raised concerns about decreasing water quality. Excessive aquatic plant growth was considered the number one concern by respondents to the 2010 property owner survey. More than half the respondents indicated that dense plant growth has increased in the lake since they began using it. The paleocore also indicates an increase in the growth of submerged aquatic vegetation over the past 100 years.

The changing density, distribution, and diversity of the native aquatic plant community has a strong influence on the condition of the lake. The aquatic plant community has thus far been able to cope with the additional nutrient inputs to the system from human development; however, the degradation of the system due to excess nutrients in the system appears to be accelerating.

Nutrients are brought into the lake by overland runoff, groundwater, and internal cycling, which until recently, have not been fully evaluated. This Comprehensive Management Plan addresses those and other sources of nutrients to the lake and what can be done to stop or mitigate their negative impact on the lake ecosystem.

## 5.0 Public Input

Throughout the development of this plan, members of the PLA have been asked to comment. The final draft version of this plan was reviewed by the PLA in early 2014. Their comments, and those of the WDNR were incorporated in the final version presented for approval at the May 24, 2014 PLA Annual Meeting.

### 5.1 Property Owner Survey

A property owner survey was completed during the Potato Lake plant management planning project in 2010. Although the primary focus of the survey was on plant management, additional questions from the survey were used to help develop other lake and watershed management goals and recommendations which are included in this document.

### 5.2 Public Meetings

At a meeting of the PLA on July 27, 2013 a power point presentation (Appendix B) was made laying out the results of the data that had been collected as a part of this project and the likely management recommendations to be made. On February 6, 2014 a draft version of the final Comprehensive Lake Management Plan was delivered to the PLA along with an Implementation Matrix. The purpose of the matrix was to give the PLA an opportunity to prioritize the recommendations made to determine which ones they were most able to implement and when.

The Comprehensive Lake Management Plan and Implementation Matrix was also posted in February 2014 on an SEH project link established for Potato Lake Association in 2010. The on-line project link provides access to these and other related Potato Lake management documents for download and review by the public.

## 6.0 Lake Characteristics

Potato Lake (WBIC 2714500) is a spring lake in east-central Washburn County, Wisconsin about 10 miles east of the City of Spooner (Figure 1). Spring lakes have no perennial flowing inlet, but do have an outlet. The primary source of water for spring lakes is groundwater flowing into the bottom of the lake from inside and outside the immediate surface drainage area. Potato Lake covers approximately 230 acres, has a maximum depth of 20 feet, and an average depth of 10.6 feet (Table 1). Potato Lake is located at the northern boundary of the North Central Hardwood Forests ecoregion.

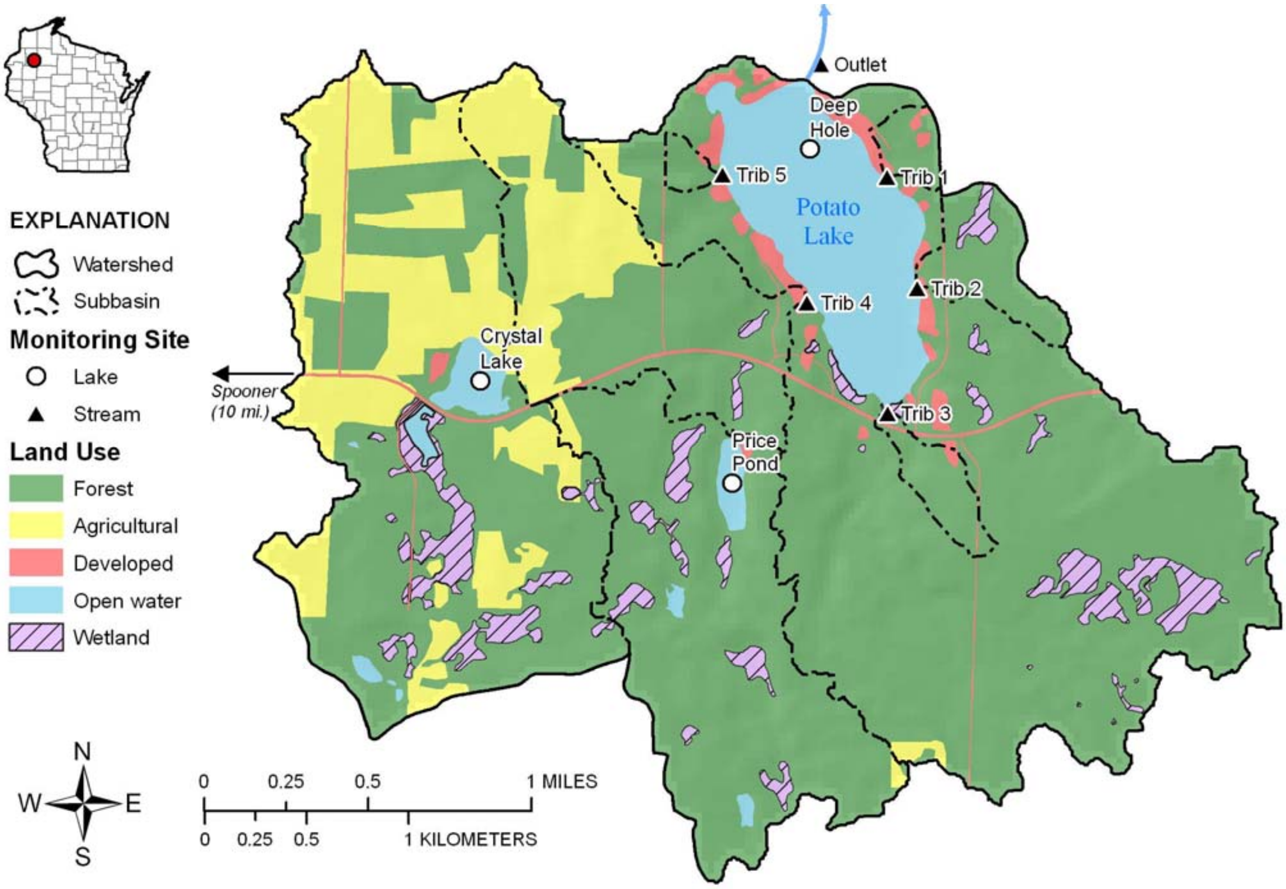


Figure 1 – Location of Potato Lake and Its Watershed.

## Table 1
## Physical Characteristics of Potato Lake.

| | | |
|---|---|---|
| **Lake Area** | 229.6 | acres |
| **Watershed Area** | 3,229 | acres |
| **Watershed to Lake Ratio** | 13:1 | |
| **Maximum Depth** | 20 | feet |
| **Mean Depth** | 10.6 | feet |
| **Volume** | 2437.8 | acre-feet |
| **Maximum Fetch** | 1.14 | miles |
| **Miles of Shoreline** | 2.92 | miles |
| **Elevation** | 1,190 | feet AMSL |
| **Lake Type** | Drainage | |

Potato Lake is a is a discontinuous cold polymictic lake, which means that the lake is ice-covered part of the year, ice-free above 40º Fahrenheit and stratified during the warm season for periods of several days to weeks, but with irregular interruption by mixing. The Osgood Index is used to describe how likely a lake is to mix due to wind forces. Lakes with Osgood Index values less than 4 tend to be polymictic. Potato Lake has an Osgood Index of 3.4. Consistent summer monitoring of temperature and dissolved oxygen in 2010 has indicated that Potato Lake is polymictic. The maximum fetch is the maximum length of open water over which wind can blow. A larger fetch allows larger and more powerful waves to be created from wind and therefore induce mixing to a greater depth in the lake. Areas of the lake with a longer fetch are also more susceptible to shoreline erosion via wind-induced wave action.

The lake is fed by intermittent streams and groundwater. The most obvious groundwater source is a large spring located near the southern terminus of the lake. Potato Lake is the headwaters of the Potato Creek, which flows northwest for about 10 miles where it joins the Namekagon River near Trego, Wisconsin. Two other waterbodies located in the Potato Lake watershed, Crystal Lake (22.3 acres) and Price Pond (13.0 acres), were also monitored during the 2010 field season due to ephemeral flow to Potato Lake.

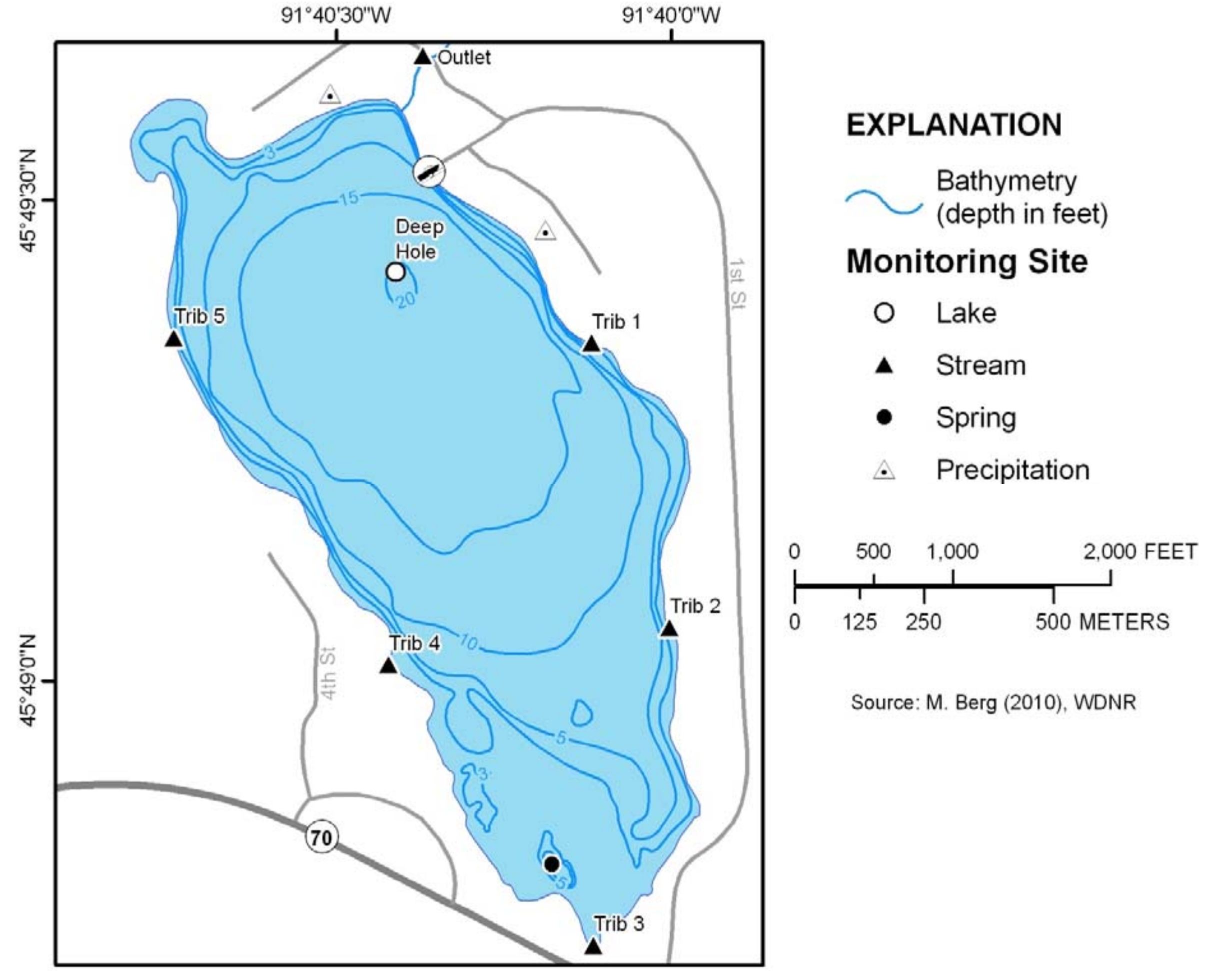
A watershed is an area of land from which water drains to a common surface water feature, such as a stream, lake, or wetland. The watershed of Potato Lake is about 3,229 acres (Figure 1) and primarily forested. This watershed area is 168 acres, less than the previously reported value (Cooper Engineering, 2005) and was determined subsequent a windshield survey of culverts and road grades in the autumn of 2010. The watershed is discussed further in Section 7.0 of this report.

## 6.1 Water Quality

Citizen Lake Monitoring Network volunteers have collected water quality data from the Potato Lake Deep Hole monitoring site (station ID 663055) since 1997 (Figure 2). Volunteers measured quantitative parameters such as temperature, dissolved oxygen, and Secchi depth and collected water samples which were sent to the Wisconsin State Lab of Hygiene for analysis of total phosphorus, chlorophyll *a*, and total Kjeldahl nitrogen. Qualitative observations such as lake level, color, and perception of water quality were also recorded.

These water quality parameters provide information on lake trophic status, the nutrient limiting production in the lake, potential sources of nutrients, and in-lake nutrient release. The information gathered further develops datasets that can be used for analysis trends and establishment of baseline conditions.

Ephemeral tributary channels were sampled during periods of flow and analyzed for total phosphorus and total Kjeldahl nitrogen. Volunteers monitored precipitation in the watershed from May through October to best determine sample times. To describe the flow leaving the lake, Potato Creek at the lake outlet was monitored throughout the year. Staff gauge readings and streamflow measurements, using both float and velocimeter methods, were taken to determine stage-discharge relationships.



Source: M. Berg (2010), WDNR

Figure 2 – Potato Lake Water Quality Monitoring Sites.

### 6.1.1 Temperature and Dissolved Oxygen

Temperature and dissolved oxygen profiles were measured regularly at the Deep Hole site from 2010 through October 2013, including measurements in the winter months. Summer water temperatures remained consistent throughout the water column averaging in the mid to upper 70s Fahrenheit and no obvious thermocline developed. Dissolved oxygen also remained consistent throughout the water column for the majority of the summer. Low dissolved oxygen concentrations representative of anoxic conditions (less than 2 mg/liter) were usually found just above the lake bed, but on a few occasions low dissolved oxygen was present in the bottom 5 feet of the lake.

Thermal stratification is present under the ice. Bottom temperatures are generally near 40º Fahrenheit and temperatures just below the ice were very near freezing. Dissolved oxygen concentrations decreased as winter progressed. Generally, by early February only the upper 3 feet of the water column had dissolved oxygen concentrations above 5 mg/L, below which is stressful to many fish species.

Hypoxic (2 mg/L of dissolved oxygen or less) or near-hypoxic conditions existed in waters deeper than 8 feet. The lack of oxygen in the lake during winter months is attributed to the decay of aquatic plants drawing on oxygen and the influx of groundwater, which naturally has very little dissolved oxygen.

Oxygen depletion can have many adverse impacts to the biology and chemistry of the lake. During the winter oxygen levels are too low to support many forms of aquatic life, including fish. Fish kills have occurred in Potato Lake in the past and will likely occur again. The loss of benthic plants and animals due to anoxic conditions in both the summer and winter can lead to an increase in the release of phosphorus from sediments. If the phosphorus released from sediments reaches the upper part of the lake, it can provide an internal source of phosphorus to fuel algae blooms.

### 6.1.2 Water Clarity

Water clarity was measured by volunteers using a Secchi disk. Data are available from 1997 through 2012. The Secchi disk measurement is the average of the depth that when lowered the disk just disappears from sight and the depth that when raised the disk is just visible. Secchi depths vary throughout the year, with shallower readings in summer when algae become dense and limit light penetration and generally deeper readings in spring and late fall. Because light penetration is usually associated with algae growth, a lake is considered eutrophic, or highly productive, when Secchi depths are less than 6.5 feet.

The Secchi measurements taken in Potato Lake are shown in Figure 3. There has been little change to water clarity over the past 16 years. The 2012 mean summer (June through August) Secchi depth was 8.4 feet, which is slightly greater than the overall mean summer Secchi depth of 8.1 feet. The largest departures from the overall mean water clarity occurred in 2006 and 2007 when the water clarity was about 2 feet less than average (Figure 3). Both the 2006 and 2007 averages are lower primarily due to low Secchi depths (3 to 4 feet) measured in late August.

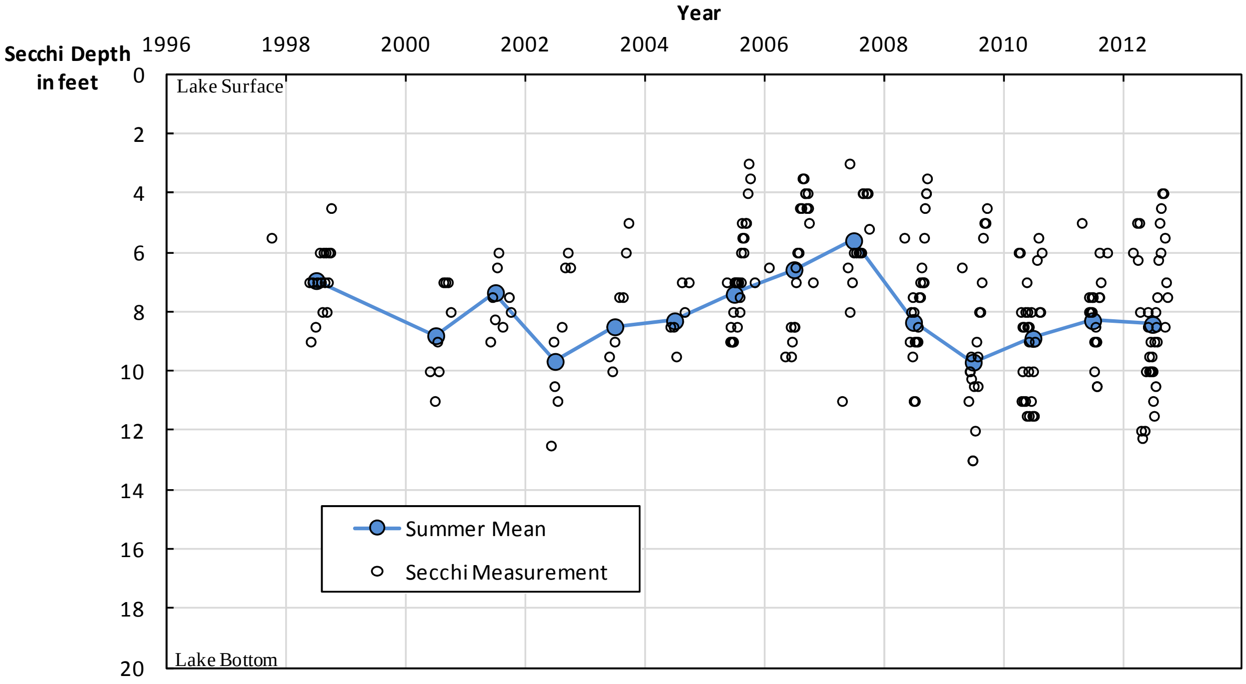


Figure 3 – Water Clarity (Secchi Depth) in Potato Lake, 1997-2012

Seasonal variations of water clarity are also evident in Potato Lake. Figure 4 shows the 46 Secchi measurements taken in 2010. There was a significant decrease ($p < 0.0001$) in the Secchi depth in mid-July. Prior to mid-July, Secchi depths followed a slightly decreasing trend (increasing clarity) and averaged 9.4 feet. After mid-July, depths were following a slightly increasing trend (poorer water clarity) and averaged 5.9 feet. This large mid- to late-summer decrease in water clarity is evident each monitored year since 1998. In 2010, the decrease in water clarity occurs shortly after a 2-inch rain event; however, rainfall does not appear to be a factor in previous or subsequent years.

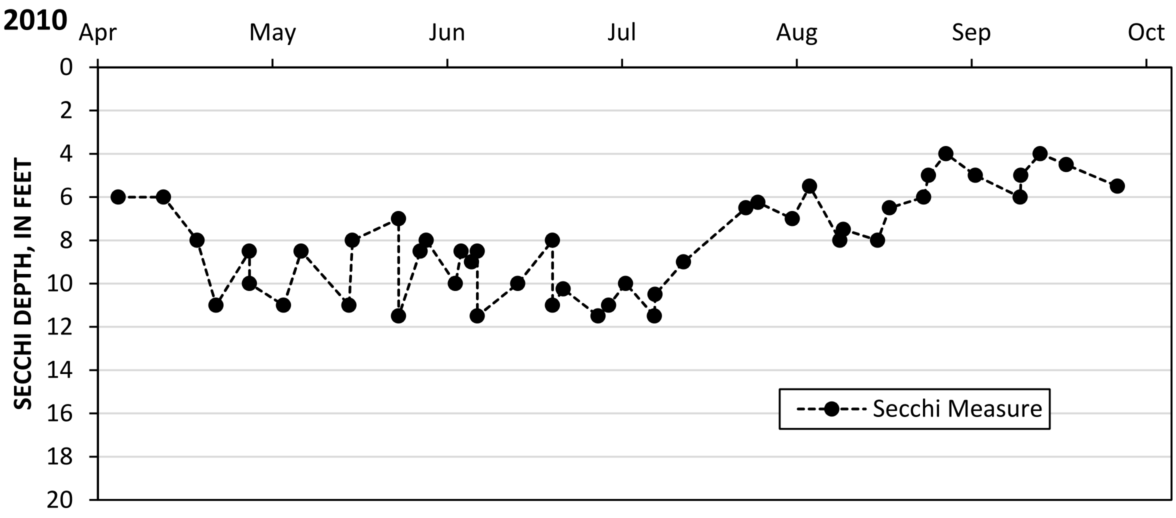


Figure 4 – Secchi Depth at the Potato Lake Deep Hole Site in 2010

### 6.1.3 Chlorophyll *a*

Chlorophyll *a* is a measurement of algae in the water. The concentration varies throughout the year, generally peaking in late summer. Chlorophyll *a* has been measured in Potato Lake since 2004 (Figure 5). The overall mean summer (June through August) chlorophyll *a* concentration from 2004 through 2013 was 9.53 µg/L, lower than the northwest Wisconsin mean of 12.4 µg/L reported by Lillie and Mason (1983). The lowest mean summer concentrations were in 2008 (4.40 µg/L) and 2011 (5.94 µg/L) and highest in 2006 (12.85 µg/L). On an annual basis, chlorophyll *a* peaked in late August or early September.

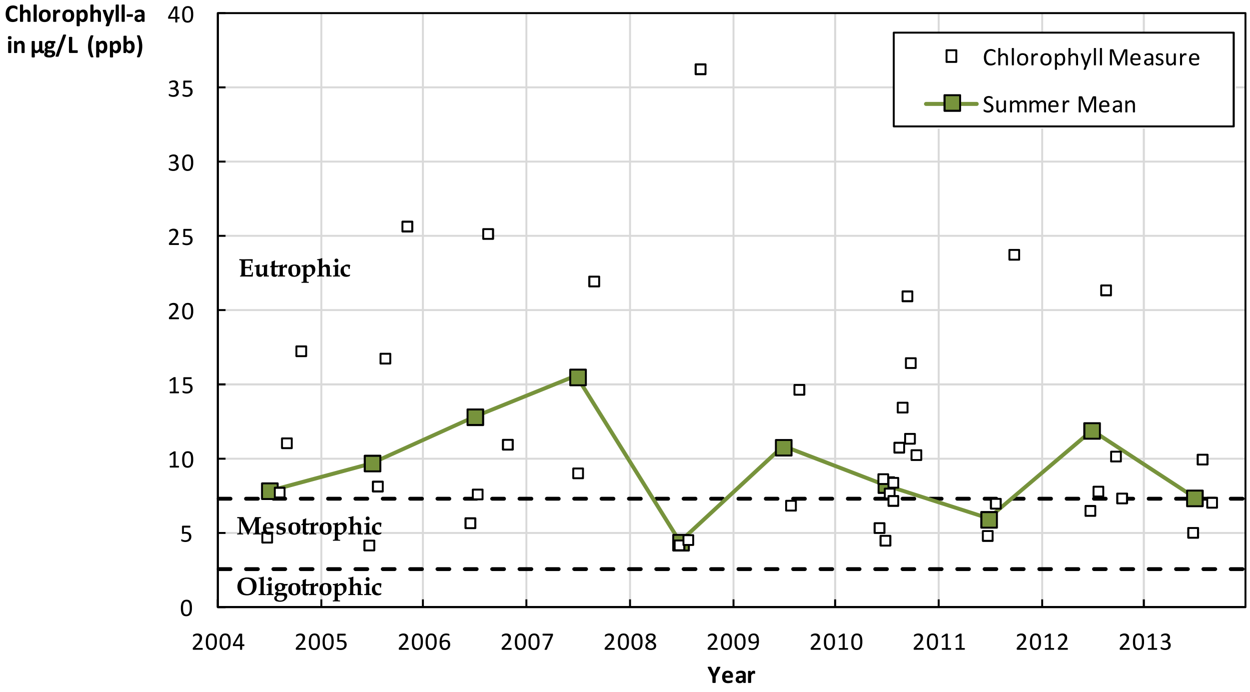


Figure 5 – Chlorophyll *a* in Potato Lake, 2004 – 2013

### 6.1.4 Phosphorus

Phosphorus is an important nutrient for plant growth and is commonly the nutrient limiting plant production in Wisconsin lakes. When phosphorus is limiting production, small additions of the nutrient to a lake can cause dramatic increases in plant and algae growth.

Near-surface total phosphorus concentrations measured throughout the open water season have ranged from 19 to 52 µg/L (Figure 6). The mean summer (June through August) concentration in 2013 was 17.6 µg/L, lower than the overall summer mean of 25.0 and lower than the mean reported for northwest Wisconsin lakes (28.0 µg/L) by Lillie and Mason (1983). Higher concentrations are generally measured during the spring months and are due to lake turnover, which distributes high-phosphorus water from the hypolimnion throughout the water column.

Near-bottom total phosphorus was measured during 2010 and 2004. Total phosphorus was found to increase during anoxic conditions in July 2010. In late June, the near-bottom concentration was 24 µg/L which rose to 251 µg/L by mid July and 260 µg/L by late July. Surface concentrations varied little during this time period, ranging from 20 to 24 µg/L. Near-bottom samples collected in 2004 did not show elevated conditions, indicating summer anoxic conditions and the associated release of phosphorus from bottom sediments is an infrequent occurrence.

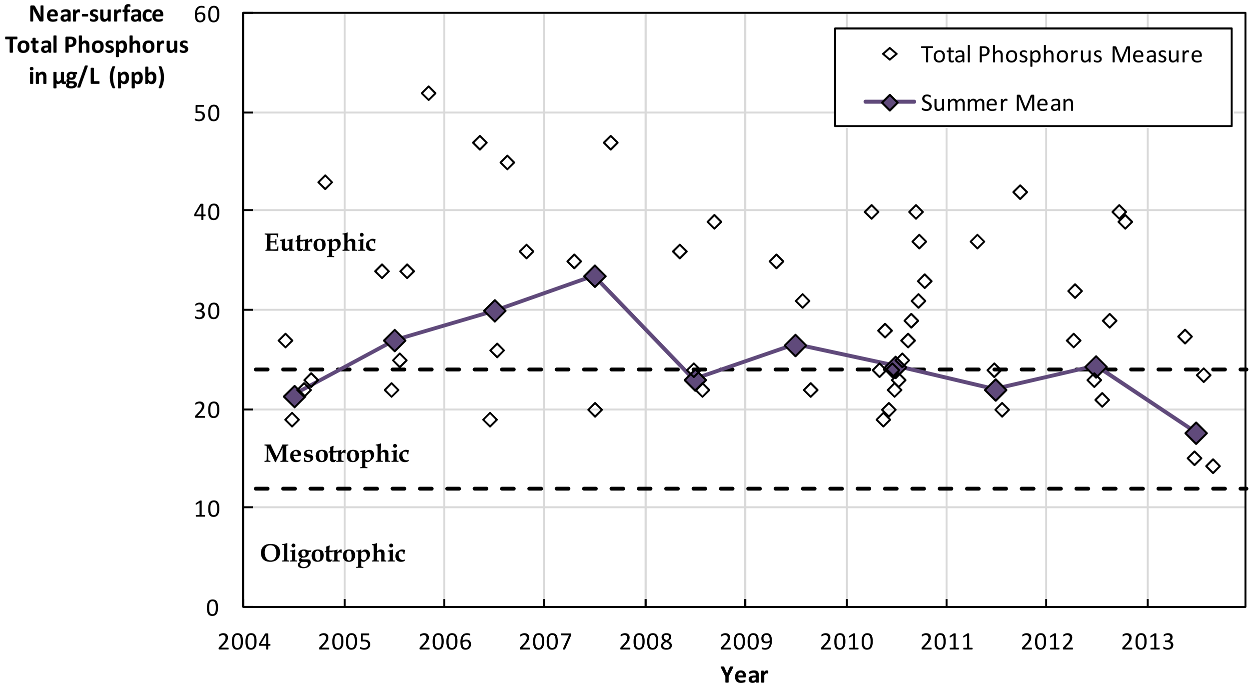


**Figure 6 – Near-surface Total Phosphorus in Potato Lake, 2004-2013**

### 6.1.5 Nitrogen

The amount of nitrogen in a lake usually corresponds to local land use. Sources of nitrogen include fertilizer and animal waste on agricultural land and human waste from septic systems. In 2010, the concentration of total Kjeldahl nitrogen (TKN) was measured throughout the growing season in the lake and ephemeral tributaries. Total Kjeldahl nitrogen is the sum of ammonia ($NH_3$) and organic nitrogen (i.e., a nitrogen compound that had its origin in living material, such as the nitrogen in protein and urea). These data were used to determine the nutrient limiting plant growth in Potato Lake.

### 6.1.6 Nitrogen to Phosphorus Ratio

Nitrogen and phosphorus are the basic building blocks for life. Although plants require about twenty elements for growth, aquatic life is often limited by the availability of one of these two essential nutrients. The ratio of the total nitrogen to total phosphorus (N:P) is used to determine which nutrient likely limits aquatic plant growth in a lake. When N:P is greater than 16:1, phosphorus is interpreted as the limiting nutrient and when the ratio is less the 10:1, nitrogen is likely the limiting nutrient. Other factors that limit plant growth at various points of the year include light, temperature, and grazing by zooplankton.

Although total nitrogen was not measured during 2010, the total Kjeldahl nitrogen (TKN) to phosphorus ratio averaged 23. Because TKN is only the organic and ammonia portion of total nitrogen and the ratio was above 16:1, phosphorus is likely limiting plant growth in the lake. This is also evident in a significant positive correlation between phosphorus and chlorophyll *a* concentrations in the lake ($R^2 = 0.670$; p, <0.0001); additional phosphorus equals more algae. With phosphorus as the likely limiting nutrient in the lake, one pound of phosphorus can grow up to 500 pounds of algae (Wetzel, 2001). Management activities should focus on reducing phosphorus loading into the lake in order to control plant and algae growth.

Data collected from the ephemeral inflow sites have higher TKN:P ratios (average 11:1) than the outflow (24:1) and of the lake, suggesting phosphorus is being utilized by plants before the water leaves the lake. The high TKN:P of the inflow sites indicates that excess phosphorus is not being assimilated before entering the lake. The mean inflow TP concentration (134 µg/L) was higher than the outflow concentration (23 µg/L) which also indicates phosphorus is being utilized in the lake. It is, however, unclear whether sedimentation or uptake by plants is the primary mechanism of phosphorus removal because there is no data on the how much of the total phosphorus is dissolved phosphorus, which is the form of phosphorus that is easiest to assimilate by organisms. It is important to note that the inflow sites were sampled in spring when plant growth was less compared to when the outflow was sampled in early summer.

### 6.1.7 Water Quality Discussion

There were no consistent long term trends in the total phosphorus, chlorophyll *a* and Secchi depth of Potato Lake. The longer Secchi depth record shows little change in water quality over the past 16 years. The poorest water quality was from 2005 through 2007 which was also a period of moderate to severe drought in northwestern Wisconsin (Wisconsin State Climatology Office, 2011), suggesting an increase in lake retention time (less frequent flushing) is detrimental to the lake water quality.

As is common in many lakes, total phosphorus concentrations are significantly ($p < 0.05$) correlated to chlorophyll *a* in Potato Lake. As total phosphorus values increase, chlorophyll *a* increases indicating that increases in phosphorus are detrimental to the perceived water quality of the lake. This also provides evidence that improving water quality conditions in the lake can be achieved by reducing phosphorus loading.

## 6.2 Aquatic Plants

Aquatic plants play an important role in lakes. They anchor sediments, buffer wave action, oxygenate water, and provide valuable habitat for aquatic animals. The amount and type of plants in a lake can greatly affect nutrient cycling, water clarity, and food web interactions. Furthermore, plants are very important for fish reproduction, survival, and growth, and can greatly impact the type and size of fish in a lake.

Healthy aquatic plant communities can be degraded by poor water clarity, excessive plant control activities, and the invasion on non-native nuisance plants. These disruptive forces alter the diversity and abundance of aquatic plants in lakes and can lead to undesirable changes in many other aspects of a lake’s ecology (Figure 7). Consequently, it is very important that lake managers find a balance between controlling nuisance plant growth and maintaining a healthy, diverse plant community.

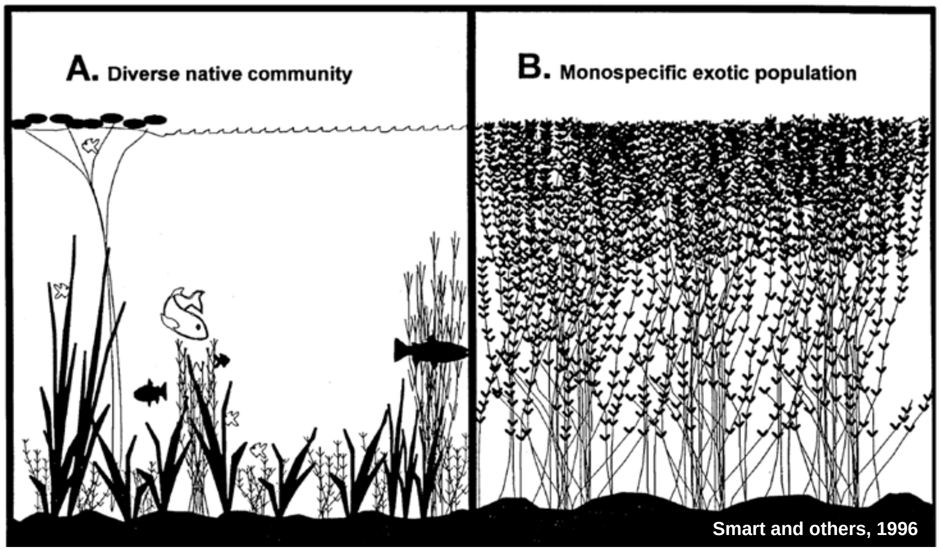


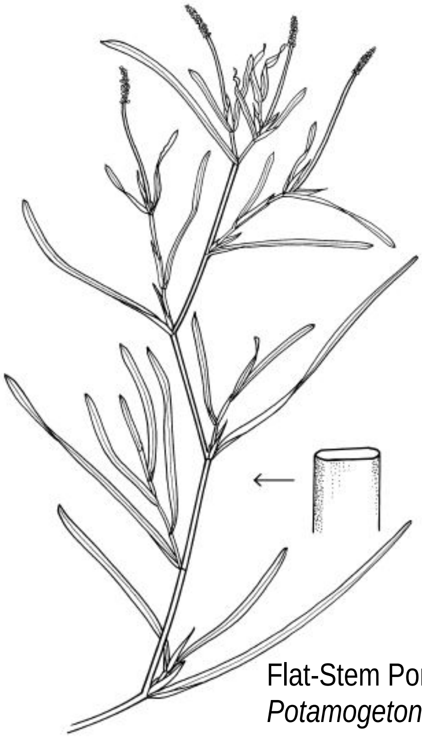
**Figure 7 – Submersed Aquatic Plant Communities**

Two aquatic plant surveys have been completed in Potato Lake. In 2005, a transect survey was completed to provide a baseline measure of the aquatic plant community. A more comprehensive point-intercept survey, which also included a survey for invasive plant species, was conducted in 2010. The littoral zone, or the maximum depth of plant growth, was to 15 feet and covered about two-thirds of the lake bed.

The 2010 survey identified 39 aquatic plant species in the lake. This species richness is much higher than the state median of 13 native species and the Floristic Quality Index of 31.4 is also much higher than the state median of 22.2. Neither curly-leaf pondweed nor Eurasian watermilfoil were found during the plant surveys or during subsequent volunteer monitoring by the Association.

The most common aquatic plant species found during the 2010 survey were flat-stem pondweed, fern-leaf pondweed, coontail, and Fries' pondweed. These four species account for more than 55% of the total relative frequency of plants.

### 6.2.1 Common Plants in Potato Lake

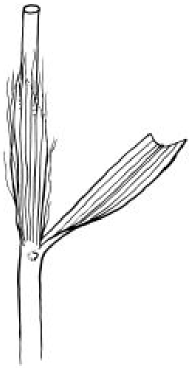


Flat-Stem Pondweed
*Potamogeton zosteriformis*

Coontail
*Ceratophyllum demersum*

Images from Nichols, S.A., 1999. *Distribution and habitat descriptions of Wisconsin Lake Plants*. WGNHS Bulletin 96.

Fern-leaf Pondweed
*Potamogeton robbinsii*



Fries' Pondweed
*Potamogeton friesii*

The historic plant community of Potato Lake was explored to a limited degree in the top/bottom paleocore taken in 2010. The diatoms identified in the core indicate that the level of phosphorous has increased in the lake since before development, however, that increase has not necessarily led to an increase in aquatic plant or algae growth, except in the most recent timeframe (last few years). A potential explanation for this is given in the paleocore report (Appendix B in the Aquatic Plant Management Plan), which suggests that the abundance of submerged aquatic vegetation has always been high in the lake, but there may have been a shift from small low growing species to larger taller species as a result of increased phosphorus.

### 6.2.2 Wild Rice (Zizania palustris)

Potato Lake is considered an Area of Special Natural Resource Interest (ANSRI) because of presence of wild rice beds in the small northern bay and in much of the southern bay (Figure 8). Wild rice is a highly prized and protected emergent plant species in Wisconsin. Any activity included in a comprehensive lake or aquatic plant management plan that could potentially impact wild rice habitat requires consultation with the Voigt Intertribal Task Force. This task force, established in 1983, represents tribes with inland ceded territory treaty rights and is charged with overseeing the management and harvest of treaty resources in the inland ceded territories of Wisconsin, Minnesota, and Michigan (http://www.glifwc.org). This consultation with the Task Force is carried out by the WDNR.

**Figure 8 – Aerial Photo of 2008 Wild Rice Beds in Potato Lake**

Wild rice has been abundant in Potato Lake for many years. A wild rice inventory completed by the Great Lakes Indian Fish and Wildlife Commission (GLIFWC) in 1986 lists 30 acres of dense wild rice growth in Potato Lake (Andryk, 1986). A survey done in 2010 as part of the development of the Aquatic Plant Management Plan also mapped about 30 acres of wild rice in the lake.

### 6.2.3 Aquatic Plant Management Plan

The Potato Lake Association has been active with Clean Boats-Clean Waters inspection and outreach at the public boat launch and water quality monitoring through the Citizen Lake Monitoring Network. Issues with dense native aquatic plant growth and changing lake conditions, most apparent by the appearance of large algae colonies in 2010, prompted the Association to develop an aquatic plant management plan. The goals of the Potato Lake Aquatic Plant Management Plan are to:

- Protect and preserve the native species community within and around Potato Lake.
- Aquatic invasive species education and prevention.
- Monitor water quality conditions in Potato Lake.
- Complete comprehensive lake management planning for Potato Lake.

## 6.3 Fishery and Wildlife

The 2010 sociological survey of lake property owners identified angling as the second most popular use of the lake by both permanent and seasonal residents. The Wisconsin Lakes Bulletin (WDNR, 2005) indicates that northern pike (*Esox lucius*) are abundant, largemouth bass (*Micropterus salmoides*) are common, and panfish (*Lepomis* spp., *Pomoxis* spp.) are present in the lake. Fish stocking records show that largemouth bass fry were planted in the lake in 1979, 1981, and 1984 and fingerlings in 1996 through 1998. During the latter period, 11,100 fingerlings were stocked each year. Fish stocking has not been done since 1998.

Due to the importance of the fishery to lake users, it is recommended that the Potato Lake Association work with the WDNR to develop fishery goals for the lake. Creel surveys or comprehensive fishery surveys have not been completed for Potato Lake. A survey should be done to gain a better understanding of the fish community and population dynamics within the lake. Spawning areas should be located and afforded the appropriate protections (e.g., sensitive area listing) in order to maintain a sustainable sport fishery.

The Natural Heritage Inventory database contains recent and historic observations of rare species and plant communities. Each species has a state status including Special Concern (SC), Threatened (THR) or Endangered (END). Documented observations as of October 6, 2009 in or near the Potato Lake watershed include:

- three plant species: Deam’s rockcress, *Arabis missouriensis var. deamii*, SC; arrow-headed rattle-box, *Crotalaria sagittalis*, SC; adder’s-tongue, *Ophioglossum pusillum*, SC,
- two fish species: banded killfish, *Fundulus diaphanous*, SC; Ozark minnow, *Notropis nubilus*, THR,
- one frog species: American bullfrog, *Lithobates catesbeianus*, SC,
- one mammal species: gray wolf, *Canis lupis*, SC,
- two bird species: bald eagle, *Haliaeetus leucocephalus*, SC; osprey, *Pandion haliaetus*, THR, and
- seven plant communities: northern mesic forest; northern sedge meadow; northern wet forest; open bog; soft bog lake; deep, soft seepage lake; springs and spring runs.

## 6.4 Critical Habitat

Every body of water has areas of aquatic vegetation or other features that offer critical or unique aquatic plant, fish and wildlife habitat. Such areas can be mapped by the WDNR and designated as Critical Habitat Areas. Areas are designated as Critical Habitat when they include important fish and wildlife habitat, natural shorelines, physical features important for water quality (such as springs) and navigation thoroughfares. These areas, which can be located within or adjacent to the waterbody, are particularly valuable to the ecosystem and would be significantly impacted by most disturbances or development. In sensitive areas, the use of pesticides for plant control is generally not allowed, disturbances to the areas during mechanical harvesting should be avoided, and the removal of plants to improve navigation should be limited to the minimum amount practical.

Currently there are no officially designated Critical Habitat Areas on Potato Lake. Some examples of potential Critical Habit Areas include the large springs at the southern end of the lake, rice beds, wetlands adjacent to the south end of the lake, and steep shorelines along the northwest shore. These areas provide spawning habitat, contain sensitive aquatic plant and wildlife habitat, have features important to water quality, and, in the case of steep shorelines, are prone to erosion.

### 6.4.1 Coarse Woody Structure

Coarse woody structure (CWS) is a type of structural habitat found in the littoral zone, or near-shore region, of lakes and is contributed as trees fall from shore into lakes. Natural addition of CWS to lakes can be a very slow process. For example, the mean germination date of eastern white pine (*Pinus strobus*) sampled from the littoral zone of a lake in Ontario was 600 years ago (Guyette and Cole, 1999). Therefore, most of the CWS in the littoral zone took 600 years to grow and eventually fall into the lake. Many studies suggest that CWS is an important component of habitat in littoral zones. Wood provides a surface for insect larvae and provides shelter for small fish from predation.

Complex interactions among fish are at play with abundant structural habitat as discussed above. Predator and prey dynamics among varying macrophyte densities may be comparable to those occurring among CWS (Sass and others, 2006), especially if most of the branches and twigs are intact. Compared to macrophytes, however, CWS as structural habitat in littoral zones is scarce. For example, a survey of 13,657 square meter quadrats (small, square plots) in 12 lakes revealed that only 6% of quadrats had CWS within one meter (Schmidt, 2010).

One reason for scarce CWS in the littoral zone is shoreline development. As shoreline development increases, CWS abundance decreases (Jennings et al. 2003, Christensen et al. 1996) mainly due to riparian tree removal. Despite its rarity, CWS has very little protection in Wisconsin statutes related to lakes and lake habitat. Furthermore, an official method for measuring CWS in lakes has not yet been adopted by the state.

During a cursory survey completed by volunteers in 2012, CWS was found throughout the near-shore area of the lake except in the southern shallow part. (Figure 9). CWS was defined as wood greater than 2 meters in length, greater than 15 centimeters in diameter (about wrist sized or larger), mostly submerged in the lake, less than 25 meters from the shore, and in water less than 2 meters deep. Volunteers also rated the shoreline with respect for the potential of CWS generation. The majority of the shoreline was found to have riparian trees with a healthy understory (Figure 9), which bodes well for future natural CWS input for the lake as long as the resource is protected.

Although abundant structural habitat in the form of macrophytes exists in Potato Lake, it would still be beneficial develop management goals for CWS protection. Management goals could be based on a percentage of pre-settlement conditions. For example, Christensen et al. (1996) found an average of 555 logs/km of shoreline in lakes with no development versus a range of 57-379 logs/km in lakes with development.

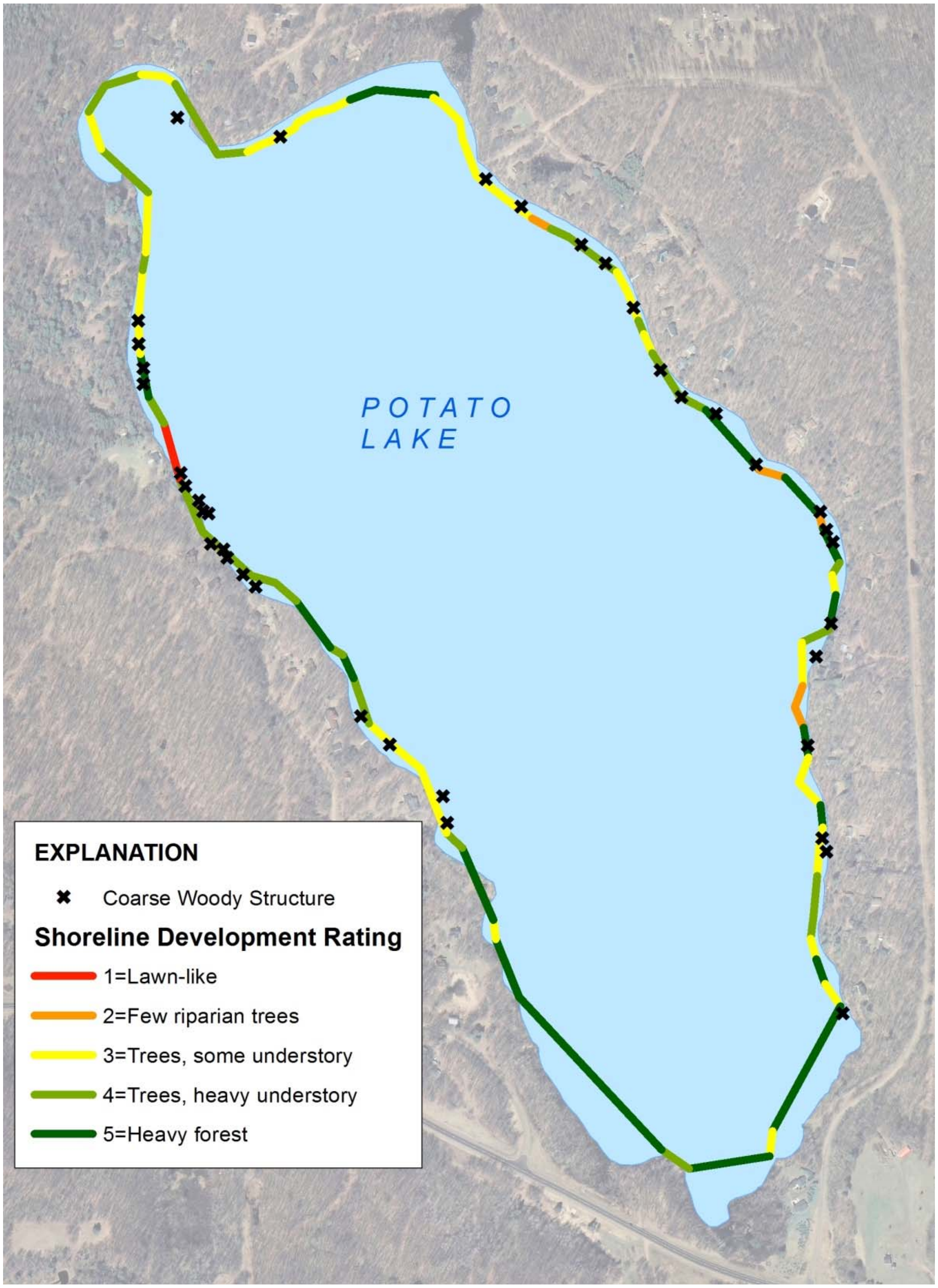


**Figure 9 – Coarse Woody Structure and Shoreline Condition of Potato Lake in 2012.**

# 7.0 Watershed Setting

## 7.1 Land Use

The land use and land cover in the watershed was determined via analysis of the 2010 National Agriculture Imagery Program (NAIP) orthophotos. The area is primarily forest (68%) and agriculture (15.2%), followed by open water (8.7%, including Potato Lake) and wetland (5.3%) (Table 2 and Figure 10). Residential areas represent only 2.9% of the watershed, but are concentrated around the lake and therefore have a stronger influence on water quality. Runoff from agricultural areas primarily drains to Crystal Lake before reaching Potato Lake. During much of the year, there is no outflow from Crystal Lake

**Table 2**
**Land Use in the Potato Lake Watershed.**

| Land Use | Acres | Percent of Total |
|---|---|---|
| Forest | 2195.83 | 68.0 |
| Agricultural | 489.34 | 15.2 |
| Residential | 93.39 | 2.9 |
| Wetland | 170.89 | 5.3 |
| Open Water | 279.88 | 8.7 |
| **TOTAL** | **3229.33** | **100.0** |

Land cover and land use management practices within a watershed have a strong influence on water quality. The increases in impervious surfaces, such as roads, rooftops and compacted soils, associated with residential and agricultural land uses can reduce or prevent the infiltration of runoff. This can lead to an increase in the amount of rainfall runoff that flows directly into Potato Lake and its tributary streams. The removal of riparian, or near-shore, vegetation causes an increase in the amount of nutrient-rich soil particles transported directly to the lake during rain events.

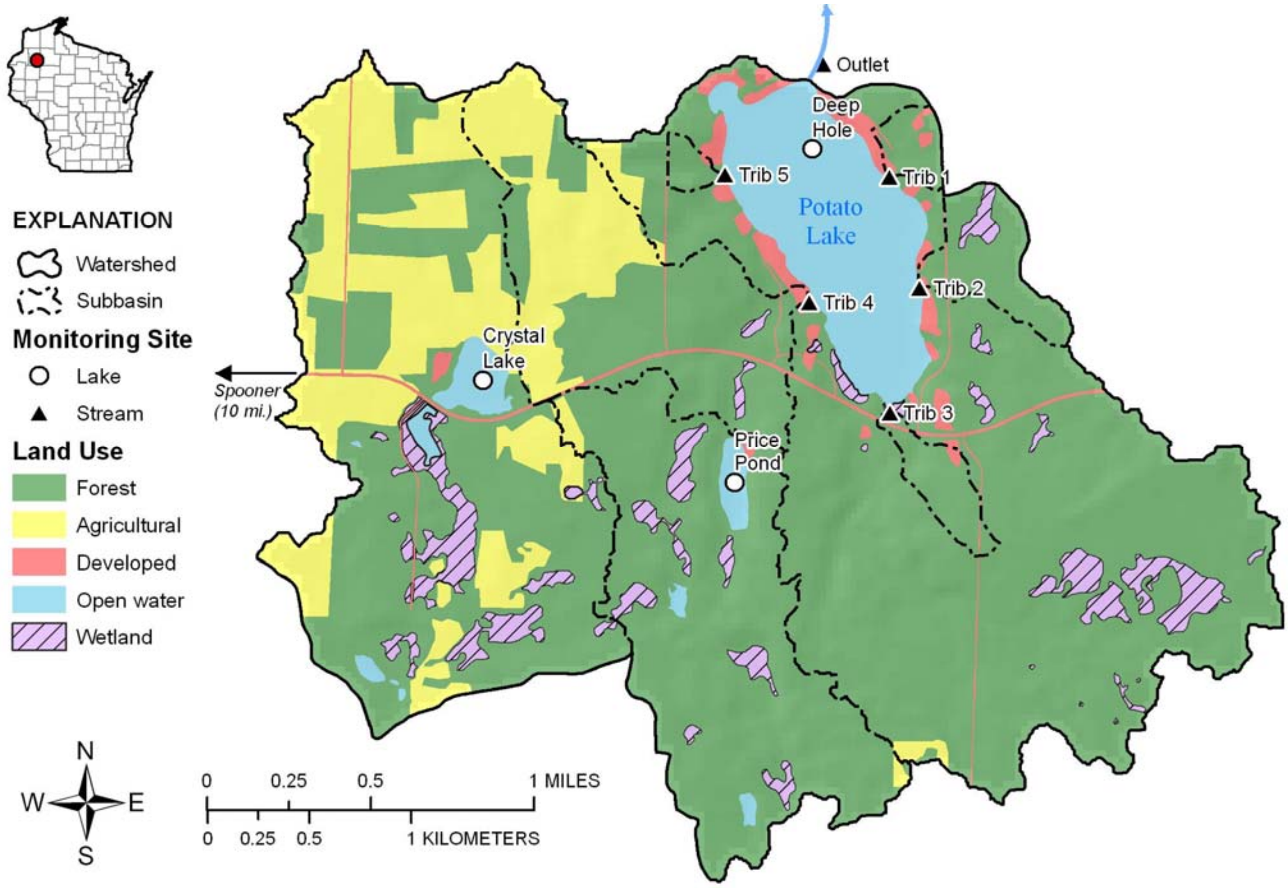


**Figure 10 – Land Use and Cover of the Potato Lake Watershed (2010)**

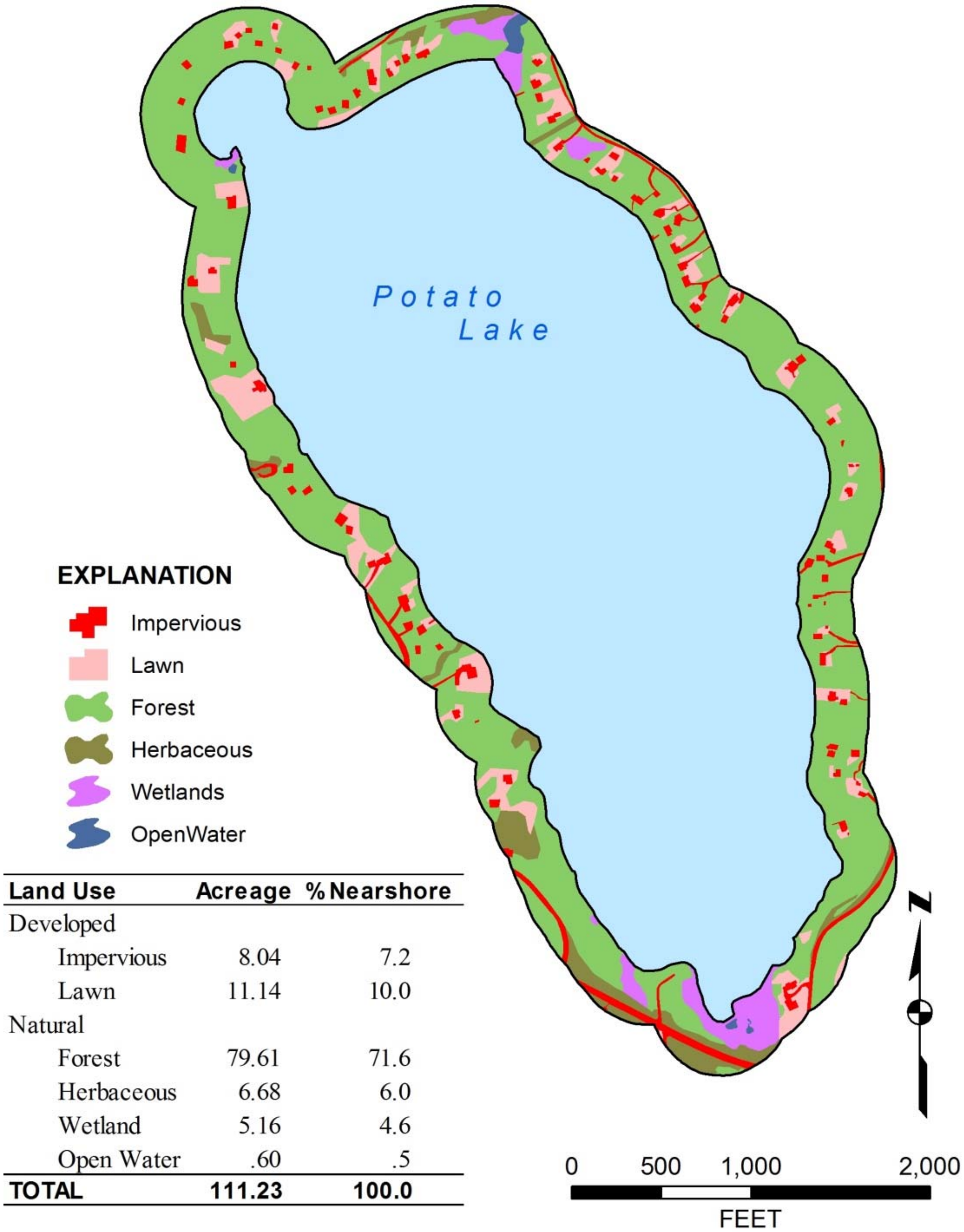
## 7.2 Near-shore and Shoreland Surveys

Although residential areas only make up a small percentage of the total land use in the watershed, the residential areas are concentrated around the lake as seen in Figure 10 above. Development replaces the natural landscape with buildings, roads, driveways and lawns which prevent rainwater and snowmelt from slowly infiltrating into the ground. The increased runoff carries with it sediment, pollutants, and nutrients which can lead to poor water quality and can fuel algae growth. Nutrients and pollutants are also supplied by the fertilizers, pesticides and septic systems associated with development.

The condition of the shoreline and the near-shore land uses (within 300 feet of the lake) were assessed to evaluate the impact the near-shore area has on water quality. The immediate shoreline was visually inspected via boat during the summer of 2012 by volunteers. A GPS was used to mark the location of different types of shoreline cover (e.g. lawn, forest, herbaceous), the presence of riprap, shoreland buffers, and emergent aquatic vegetation.

The land use in the near-shore area was assessed using recent high resolution (6-inch) orthophotos and GIS. Land use was classified as developed (lawn, impervious surface) or natural (forest, herbaceous, wetland, open water) (Figure 11). The land use data was input into the Wisconsin Lake Modeling Suite (WiLMS) (Panuska and Kreider, 2002) to estimate the nutrient loading to the lake from the near-shore area. Loading from septic systems in the near-shore area was estimated from the septic system usage data, which was collected for both permanent and seasonal dwellings as part of the sociological survey, and from the number of near-shore dwellings, which were identified during the analysis.

There has been a substantial increase in development around the lake since the mid-1970s when there were approximately 25 cabins around the lake. There are now more than 70 dwellings on the lake, most of which are seasonal, and developed land covers just over 17% of the near-shore area. The shoreline is in relatively good condition; the 2012 survey found that at least some level of shoreline buffer around the entire lake and the vast majority included all three tiers of vegetation: sedges/grasses, shrubs/immature trees, and mature trees.



| Land Use | Acreage | % Nearshore |
|---|---|---|
| Developed | | |
| Impervious | 8.04 | 7.2 |
| Lawn | 11.14 | 10.0 |
| Natural | | |
| Forest | 79.61 | 71.6 |
| Herbaceous | 6.68 | 6.0 |
| Wetland | 5.16 | 4.6 |
| Open Water | .60 | .5 |
| **TOTAL** | **111.23** | **100.0** |

**Figure 11 – 2010 Land Use/Cover within 300 Feet of Potato Lake.**

# 8.0 Lake and Watershed Assessment

## 8.1 Phosphorus Sources

Phosphorus enters the lake water from many different sources, both from within the lake and from the surrounding environment. External sources include the watershed, atmospheric deposition, and the movement of groundwater into the lake. Internal sources include phosphorus present in the lake sediments and the cycling of phosphorus in the lake by plants, animals, and chemical processes.

Sources of phosphorus evaluated during the development of this plan include atmospheric deposition, groundwater flow, tributary loading, the near shore and direct drainage (nonpoint source) areas, septic systems, and internal loading (recycling of nutrients already in the lake from sediment release). The methods used to calculate each component of the phosphorus budget are outlined in the following sections.

### 8.1.1 Internal Phosphorus Sources

8.1.1.1 Sediment Release

Sediment cores were collected from near the deepest spot in Potato Lake in early July, 2012, for determination of rates of phosphorus release from sediment under controlled laboratory conditions. Rates were determined for anoxic (no oxygen) and oxic (oxygen present) conditions. Phosphorus release rates from the sediment were used to estimate the internal load to the lake.

The phosphorus release from sediments collected in Potato Lake was found to be near zero (<0.1 milligram released per square meter of lake bed per day) under both anoxic and oxic conditions. An anoxic release rate near zero is very low relative to other lakes in the region. This is attributed to the floccy nature (very high moisture content) of the lake sediments sampled. The results suggest a very low potential for sediment internal phosphorus loading in the lake. A detailed description of sampling methods and results can be found in Appendix A.

### 8.1.2 External Phosphorus Sources

8.1.2.1 Atmospheric Contribution

Atmospheric deposition of phosphorous comes from the phosphorous found in the dust and other particulate matter that is blown over and settles into the lake or is cleansed from the air when it rains. This particulate matter could be carried to the lake from a great distance away by a weather system or be blown off the land immediately adjacent to the lake. Control consists of best management practices aimed at fixing the dust to the ground. Grass cover on crop land and dampening of exposed sediment, sand, and gravel areas to prevent wind erosion are examples of best management practices that could be implemented. The default atmospheric deposition value for Washburn County in the Wisconsin Lake Modeling Suite (WiLMS) was used to estimate the atmospheric contribution of phosphorus.

8.1.2.2 Groundwater Contribution

Groundwater flow into the lake also contributes phosphorous. The type of substrate groundwater flows through, the areas of inflow and outflow, and the volume of groundwater that is moving influences the amount of phosphorous it carries into the lake. The amount and direction of groundwater flow for Potato Lake was estimated by installing mini-piezometers around the perimeter of the lake. Areas of inflow and outflow are determined by the difference in head height (the hydraulic gradient) within each piezometer from the lake level. If the head is greater than the lake level then groundwater is flowing into the lake and if it is less than the lake level it is flowing out of the lake. Water samples were collected and analyzed for nutrients from 7 inflowing piezometers to quantify the phosphorus load.

Water quality samples were collected each month from the spring hole on the southern end of the lake during the growing season (from April through October) of 2012. This large spring is a major source of water to the lake throughout the year. Total phosphorus concentrations were consistent and ranged from 53 to 83 µg/L with an average concentration of 70 µg/L, more than double the average total phosphorus measured at the Deep Hole site. Nitrate and nitrite were below detection limits in all samples collected suggesting there has been little cultural impact (such as agricultural activities or development) to groundwater in the area and the higher phosphorus is a natural phenomenon.

#### 8.1.2.3 Septic Systems

Septic system dye surveys were completed in August and September of 2012 at residences around the lake. The intent of the survey was not to identify and penalize problems with specific septic systems but to provide a starting place to encourage landowners to make septic system improvements if needed. Property owner participation was entirely voluntary and over half of the 70 residents with septic systems were willing to participate in the dye survey. Due to time restrictions and scheduling conflicts, 28 of the 70 septic systems were evaluated.

A sewer tracing dye (Total Solutions™) was flushed through the main water drain of the home or cabin by a trained tester. The dye creates an intense fluorescent yellow-green color when diluted. After 1 hour, the tester walked the shoreline looking for the presence or absence of the dye in the lake or appearing somewhere on the property (to identify leachate ponding). During the 1 hour wait time, the tester walked the property with the land owner to identify and sketch the layout of the septic system if known. Return visits were scheduled for 24 hours (1 day) and 72 hours (3 days) later during which the lake and property were rechecked for the presence of dye. Following the third visit, the property owner checked the lake and landscape for two to three days for any signs of dye.

No dye was found reaching the lake or ponding on the land surface during this survey. This indicates that the septic systems tested were not having an immediate or direct negative impact to the lake; however, even properly functioning systems do not remove all nutrients and chemicals from the water. It is important to note that water soluble pollutants such as pharmaceuticals, solvents, drain cleaners, and many household chemicals are not removed or treated in septic systems.

In order to determine the potential phosphorous load contributed by septic systems around the lake, several pieces of information are needed: an estimate of the total number of failing or passing systems, the number of per-capita years (people present for one year) the system is in use, an export coefficient based on an average household phosphorous discharge of wastewater to septic systems, and a soil retention coefficient based on the type of soil around the lake and slope of the lake shore. Public input survey results were used to determine the per-capita years (57.5) and default WiLMS coefficients for soil retention were used to estimate septic loading. We assumed no failing or short-circuited septic systems were present around the lake.

#### 8.1.2.4 Tributary Loading

The ephemeral tributaries to the lake (shown in Figure 2) were sampled at various times from 2010 through 2013. There are no perennial tributaries (streams that flow year round) to the lake. From one to four water quality samples were collected from each tributary. The majority of rain events did not produce runoff in the stream channels. Runoff that was generated was disproportional around that lake, that is, flow in one tributary did not mean flow would be found in the other tributaries. Streamflow was flashy and ranged from a small trickle to about 1 cubic foot per second.

Average total phosphorus in the tributaries ranged from 86 to 178 µg/L. Site 4, which enters the lake from the west, was found flowing most often (four samples collected) and had the highest average total phosphorus concentration (178 µg/L). Flow from the other tributary sites was only noted during spring snowmelt and following summer rain events greater than about 1 inch. Due to the absence of streamflow measurements, land use-based export values found in the WiLMS were used to determine watershed phosphorus loading to the lake.

## 8.2 Phosphorus Budget

The annual total phosphorus load into the lake is approximately 800 pounds. The phosphorus sources are summarized in Table 3 below. Phosphorus starts being used in the lake as soon as it enters the waterbody. Plants and algae take up available phosphorous (primarily the dissolved form) and some settles out to the bottom of the lake and is trapped in the sediment (primarily the particulate form). The total amount of phosphorous that is used up by plants and that settles out of the water column is difficult to determine. Phosphorus is further removed from the system via lake outflow. The outflow from Potato Lake averages about 3.8 cubic feet per second and the amount of phosphorus removed by outflow from the lake is approximately 186.4 pounds per year.

**Table 3. Phosphorus sources and annual phosphorus load to Potato Lake.**

| Source | Annual P Load (pounds) | | % Total Load | |
|---|---|---|---|---|
| Groundwater | 345.3 | | 43.0 | |
| Watershed | 382.4 | | 47.7 | |
| *Nearshore (within 300 ft of lake)* | | *16.1* | | *Development: 8.6 lb* |
| Watershed | | 366.3 | | |
| Septic Load (lb) | 12.7 | | 1.6 | |
| Atmospheric Deposition (lake surface) | 61.7 | | 7.7 | |
| **TOTAL** | **802.1** | | **100.0** | |

Some of these sources of phosphorous can be readily controlled, while others cannot. For example, many best management practices exist that can reduce the external sources of phosphorus, such as that from near-shore development, but controlling the amount of precipitation and dust that falls on the lake or treating groundwater entering the lake would be exceedingly expensive and difficult.

The majority of the 802.1 pounds of phosphorus entering the lake is natural. 180.1 pounds of the phosphorus load (22.5%) is from agricultural or developed lands in the watershed. Of the 180 pounds contributed by humans, 8.6 pounds are estimated to be sourced from development in the near-shore area (that is, within 300 feet of the lake). The 170.8 pounds estimated to be contributed by agricultural lands is considered conservative (high); during most years with normal or low precipitation, the majority of the agricultural lands in the watershed do not drain to the lake, rather to closed depressions where runoff is infiltrated into the ground.

The following section (*Section 9.0 Nutrient Reduction Modeling*) outlines a number of phosphorus reduction scenarios and the subsequent expected changes to lake water quality.

## 9.0 Nutrient Reduction Modeling

A number of nutrient loading and reduction scenarios were simulated with the Wisconsin Lake Modeling Suite (WiLMS) program to predict the expected changes in near-surface water quality in Potato Lake. WiLMS is a lake water quality-planning tool that consists of a suite of 13 different predictive water quality models that have been shown in the past to accurately reflect lake conditions. These models simulate the total phosphorus concentration for the either the spring overturn, the growing season (May through September), or an annual average concentration.  The inputs for the model suite include the annual phosphorus load, lake characteristics, and water quality parameters.

Of the thirteen predictive models in WiLMS, Potato Lake fit the parameter requirements for 10 models of which 9 were appropriate for the lake conditions. The model with the best fit to Potato Lake is Vollenweider/OECD (1982) model. The Vollenweider/OECD model predicts the annual average total phosphorus concentration of a lake. The total phosphorus concentration simulated for Potato Lake using the nutrient budget presented above was 28 µg/L, the same as the 2012 growing season mean and slightly less than the average of all 2012 measurements (April through October) of 30 µg/L.

The simulated total phosphorus values are used to predict chlorophyll *a* and Secchi depth measurements using models developed specifically for Wisconsin lakes. Using a total phosphorus concentration of 28 µg/L, the north region model predicts an average chlorophyll *a* concentration of 10.7 µg/L and a Secchi depth of 3.9 feet compared to the 2012 average measured values of 10.7 µg/L and 8.2 feet, respectively. The models in WiLMS are empirically derived and as such the results of the models more accurately predict the percentage of change rather than absolute values; therefore, the percent change is applied to measured average values as a means of site-specific calibration. For example, although the modeled Secchi depth is much lower than the measured Secchi depth under current conditions, a 10% reduction in phosphorus indicates there will likely be an 8% increase in Secchi depth.  This equates to a change in Secchi depth from 8.2 feet to 8.9 feet in Potato Lake.

The limited impact of internal loading from sediment release on the water quality of the lake is substantiated by modeling; the modeled near surface total phosphorus concentrations are within a few per cent of measured values when the phosphorus from sediment release is not included. This is because the internal load is accounted for in the models. If the sediment release phosphorus had accounted for a substantial portion of the load, modeled total phosphorus estimates would have been far lower than measured values.

Scenarios that were evaluated using the Vollenweider/OECD model were 10-, 25-, and 50-percent decreases and increases in the growing season total phosphorus load. The model results are appropriate for the current ecological state of the lake (plant dominated) and do not represent conditions should the lake flip to a turbid water (algae dominated) state. Results of the predicted lake response to these scenarios are presented in Table 4 and Figure 12. Figure 12 includes the average total phosphorus concentration simulated by all 9 of the models that fit the parameters of Potato Lake for comparison.

**Table 4. Predicted water quality in Potato Lake in response to different phosphorus loads.**

| Change in Phosphorus Load (scenario load, in pounds) | Total Phosphorus (µg/L) | Chlorophyll *a* (µg/L) | Secchi Depth (feet) |
|---|---|---|---|
| -50%<br>(401.1 lb) | 21 | 10.2 | 9.6 |
| -25%<br>(601.6 lb) | 22 | 10.3 | 9.6 |
| -10%<br>(721.9 lb) | 26 | 10.6 | 8.9 |
| 0% — 2012 Conditions<br>(802.1 lb) | 28 | 10.7 | 8.2 |
| +10%<br>(882.3 lb) | 30 | 10.8 | 8.2 |
| +25%<br>(1,002.6 lb) | 34 | 11.0 | 7.5 |
| +50%<br>(1,203.2 lb) | 39 | 11.2 | 7.5 |

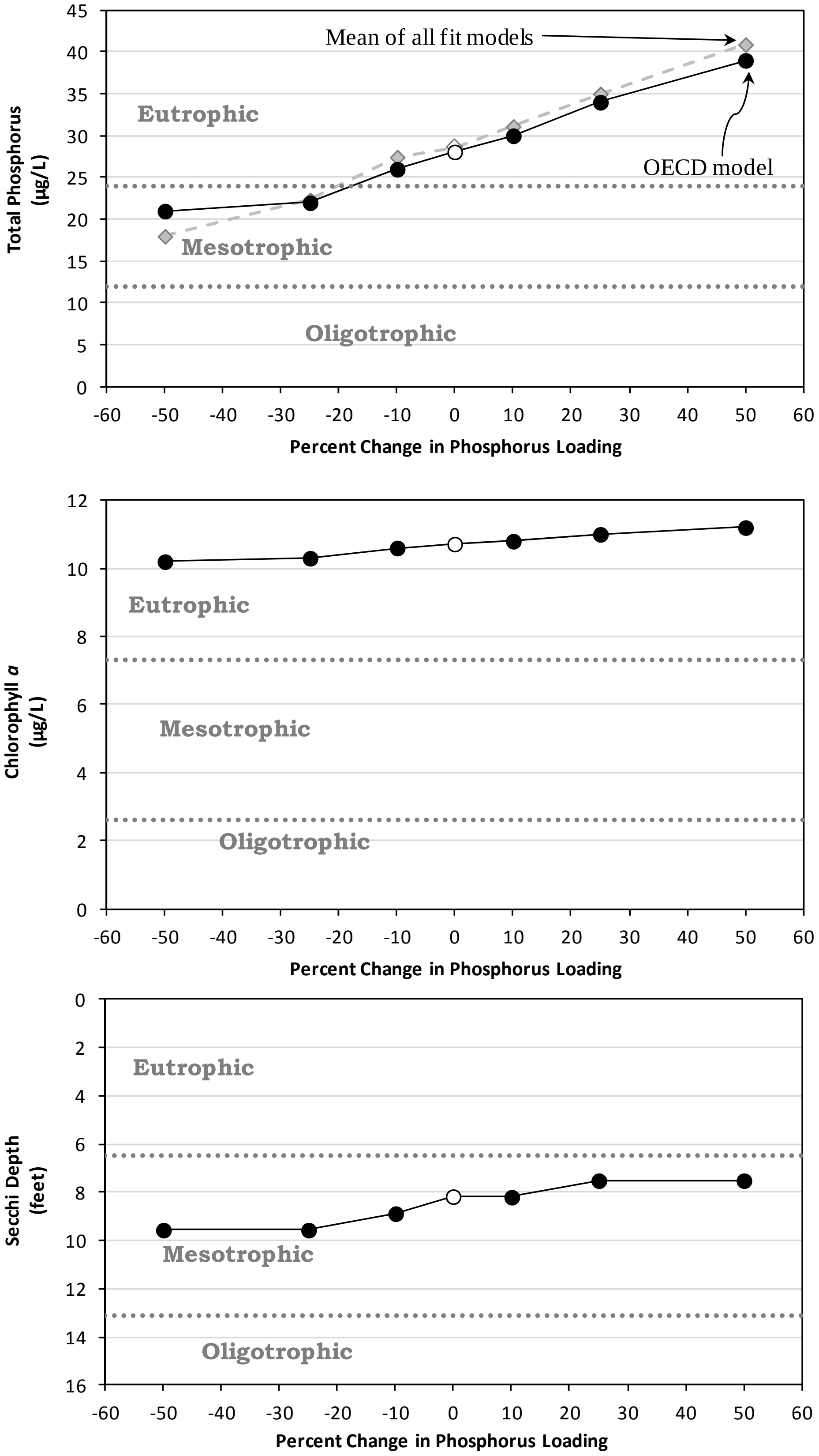


**Figure 12 – Predicted water quality conditions and Carlson trophic state index of Potato Lake in response to different phosphorus loading scenarios.**

## 10.0 Nutrient Reduction Strategies

The phosphorus budget for Potato Lake shows that the natural phosphorus load to the lake is relative. Because the natural background phosphorus is high, it is therefore important to mitigate anthropogenic (caused by human beings) nutrient loading to the lake to the greatest extent practical. Modeling suggests that a 10% increase or decrease in the total phosphorus concentration has little effect to the lake. The model also suggests that increases in total phosphorus have a larger negative impact on the lake than the positive impact caused by decreases in phosphorus loading of the same magnitude. Relatively small additions of phosphorus may therefore have a large negative impact to water quality. Such sources of phosphorus include increased development in the near-shore area and more intensive farming practices such as row cropping.

A 20% reduction of the 2012 phosphorus load (reduce load by about 160 pounds per year) would bring the lake into the mesotrophic classification with respect to total phosphorus concentrations. Little change to the water quality will be realized with load reductions greater than about 25% of the 2012 load. This can be seen in Figure 12 where the slope of the line decreases. The costs of load reductions greater than about 25% (201 pounds) are likely greater than the benefit to the lake ecosystem and lake users.

The most cost-effective manner of reducing the phosphorus load to the lake is through best management practices that infiltrate or filter runoff in both the near-shore area and throughout the watershed. Studies have found that infiltration practices, such as rain gardens, reduce total phosphorus concentrations by 80% and dissolved phosphorus (the form readily available for uptake by plants) concentrations by 83%. Runoff filtering practices, such as vegetated buffers and grassed swales, reduce total phosphorus by 59%. Applying these figures to Potato Lake suggests about 7 pounds of phosphorus can be removed using infiltration and filtering practices installed along the shoreline and near-shore area.

Installation of such practices along the shoreline and in agricultural drainage ways could have a substantial impact on the phosphorus load to the lake. The University of Nebraska demonstrated that on a watershed scale, grassed buffers, riparian forest buffers, and other conservation practices applied on the same watershed can reduce total phosphorus loads to a seasonally flowing stream by 95%. This suggests up to 160 pounds of phosphorus can be removed from the annual load to the lake by implementing agricultural best management practices throughout the watershed. As discussed above, a 160 pound reduction in the phosphorus load approaches the predicted maximum reduction where costs begin to outweigh the benefits.

Minimizing or disconnecting impervious cover in the shoreland area can reduce phosphorus levels. This and the application of better site design practices (also known as low impact development) that minimize impervious cover, conserve natural areas, and improve stormwater treatment on individual parcels will reduce phosphorus loading. Using these practices at sites of new construction or retrofitting existing properties in the shoreland area can achieve nutrient load reductions of about 33%.

Nutrient reduction can also be achieved through the completion of nutrient management plans for farmers in the watershed. Although primarily a County Land and Water Conservation Department led effort, the Association could help identify problem areas in the watershed, further develop relationships with farmers in the watershed, and seek funding sources to assist with plan completion.

Although difficult to quantify, motor boat activity does have a negative impact on water quality in shallow waters (less than 10 feet deep) and in areas with shorelines sensitive to erosion. Developing a lake use plan that includes scientifically and lake user defined no-wake zones can reduce sediment re-suspension and phosphorus release, shoreline erosion, and conflict between lake users. Ordinances can be created at the Town and County level if deemed appropriate and necessary.

## 11.0 Implementation and Evaluation

The management goals for Potato Lake were developed as a collaborative effort between the Potato Lake Association, its members, and lake managers from SEH. The goals were developed to be inspirational, believable and actionable and are derived from the values of the Potato Lake community. This plan is not intended to be a static document, but rather a living document that will be evaluated on an annual basis and updated as necessary to ensure goals and community expectations are being met.

The prioritization and implementation of activities presented in Section 3.0 of this report can be completed in a number of ways. Below is a list of implementation strategies assembled by Patrick Goggin of the UW- Extension Lakes program (note: all internet links active on December 12, 2013).

### Phased Approach — Incremental vs. System Functionality

- Do we want/need all activities/function/services available “Day One”?
- Can we absorb that level of change at one time?
- Can we take on that level of implementation work at one time?
- If not, based on the priorities of project goals and depending on the time and resources that can be allocated:
    - What functions do we want/need immediately?
    - In what sequence should we add the other functions?
    - Over what time period?

### Money or Time Notion

- Some lake organization put pledges in from the memberships, asking them to either volunteer for lake management projects for 4 hours per season, or commit to making a financial contribution to pay for 4 hours of worker time as match to ongoing grant work.

### *Lake List* Tool and Learning from Other Lake Citizens, Consultants, and Businesses

- The Wisconsin Lake List is the UW-Extension’s directory of lake organizations.
- Use the Lake List to find a lake organization or an officer, to find out how folks deal with lake management issues by checking out their management profile, and to find contact information for many businesses that service the needs of lake organizations. If you’re not sure of the spelling, enter a partial name to search.
- http://www4.uwsp.edu/cnr/uwexlakes/lakelist/

### Structure Committees to Implement Assorted Lake Management Planning Themes

## Match People with Their Skill-sets and Interests — Community Assets Idea

- Community-asset based stakeholder participation: http://www.abcdinstitute.org/

## Behavioral Change/Community-based Social Marketing

- Social marketing consists of several basic components including: exchange, positioning, focusing on behaviors, understanding the target audience, creating and delivering messages that will prompt people to change certain behaviors, and forming strategic partnerships with community resources.
- Challenge of the 10-year average flip of lakefront properties
- Background information on community-based social marketing (CBSM): http://www4.uwsp.edu/cnr/uwexlakes/ecology/shorelands/community_based_social_marketing.asp

## Communication

- Lake Coordinator, contractors or service providers, organization members, town and county boards, county zoning and land and water conservation department, etc.
- Newsletters, blogs, websites, workshops, special sessions, forums, fact sheets, etc.
- *Lake Tides* and *Lakes Connection* stories can be utilized.

## Words Matter: Framing Your Message and the Language of Conservation

- Water Words That Work LLC is a for-profit company with a mission to protect nature and control pollution; they do this by helping non-profit organizations: www.waterwordsthatwork.com/
- Language of conservation analysis: http://dnr.state.md.us/irc/conservationcoursedocs/lesson8/languageofconservation.pdf
- Readability statistics with Microsoft Word spell check — look for Flesch-Kincaid Grade Level: http://office.microsoft.com/en-us/word-help/display-readability-statistics-HP005189601.aspx

## Try to Make It Fun

- Lake maps, t-shirts and sweatshirts and other lake gear, tables, boat parades, potlucks and social gatherings.

## Some Common Contributing Factors to Implementation Failure

- Lack of planning: unclear vision, goals, and approach; not aligned with vendor/service provider incentives; schedules; other program priorities and other resource responsibilities.
- Incomplete, unclear, and (or) changing requirements.
- Lack of executive/community support and commitment.
- Lack of resources dedicated to the project (staff, time, money, participant involvement, project management, and IT support).

## Other Factors Contributing to Implementation Failure

- Unrealistic expectations for what can be accomplished and how quickly it can occur.
- Believing the vendor/service provider will assume responsibility for all tasks.
- Hoping the vendor/service provider will fix your operations and personnel problems.
- Fear of change.
- Fear of technology.

## Implementation Team Members Should Include

- People skilled and knowledgeable about plan contents.
- Lake community leadership/change agents.
- Local lake community representation – people who make up your lake community – lake leaders, county LWCD, WDNR, UWEX, etc.
- Networkers, connectors and communication specialists – web sites, newsletter, blog, email lists, etc.
- Trainers, educators, and mentors.

## 12.0 Bibliography

Andryk, Timothy, 1986. Wild Rice Wetland Inventory of Northwest Wisconsin. Great Lakes Indian Fish and Wildlife Comission, Odanah, WI. 51 p.

Apslund, Timothy R., 2000. The Effects of Motorized Watercraft on Aquatic Ecosystems. Madison, Wis: Wisconsin Department of Natural Resources PUBL-SS-948-00.

Berg, Matt 2010. Curly-leaf Pondweed P/I, Bed Mapping, and Warm Water Point/Intercept Macrophyte Surveys Potato Lake (WBIC: 27134500) Washburn County, Wisconsin. Endangered Resource Services, LLC. St. Croix Falls, WI, 94 p.

Christensen, D. L., B. R. Herwig, D. E. Schindler, and S. R. Carpenter, 1996. Impacts of lakeshore development on coarse woody debris in north temperate lakes. Ecological Applications 6:1143-1149.

Guyette, R. P., and Cole, W. G., 1999. Age characteristics of coarse woody debris (Pinus strobus) in a lake littoral zone. Canadian Journal of Fisheries and Aquatic Sciences, 56(3), 496-505.

James, William F., 2012. Internal Phosphorus Loading and Sediment Phosphorus Fractionation Analysis for Potato and Sand Lakes, Wisconsin. Menomonie, Wis. University of Wisconsin - Stout Sustainability Sciences Institute.

Jennings, M. J., E. E. Emmons, G. R. Hatzenbeler, C. Edwards, and M. A. Bozek, 2003. Is littoral habitat affected by residential development and land use in watersheds of Wisconsin lakes? Lake and Reservoir Management 19:272-279.

Lillie, R. A., and Mason, J. W., 1983. Limnological Characteristics of Wisconsin Lakes. Wisconsin Department of Natural Resources, Madison, WI., 116 p.

Lillie, R. A., S. Graham, and P. Rasmussen, 1993. Trophic state index equations and regional predictive equations for Wisconsin Lakes. Wisconsin Department of Natural Resources Research Management Findings No. 35, 4 pp.

Masek, Sharon, and K. Rehling 2005. Potato Lake Baseline Analysis – Phase One Report. Cooper Engineering Co. Inc. Rice Lake, WI.

Nichols, Stanley A. 1999. Floristic Quality Assessment of Wisconsin Lake Plant communities with Example Applications. Journal of Lake and Reservoir Management 15 (2): 133-141.

Panuska, J.C., and Kreider, J.C., 2002, Wisconsin lake modeling suite program documentation and user's manual, Version 3.3 for Windows. Wisconsin Department of Natural Resources PUBL-WR-363-94, 32 p.

Sass, G. G., Kitchell, J. F., Carpenter, S. R., Hrabik, T. R., Marburg, A. E., and Turner, M. G., 2006. Fish community and food web responses to a whole-lake removal of coarse woody habitat. Fisheries, 31(7), 321-330.

Scheffer, Marten. 2004. Ecology of Shallow Lakes. Kluwer Academic Publishers, Norwell, MA. Pp 357.

Schmidt, S. M., 2010. Development of Multi-Dimensional Littoral Zone Habitat Fingerprints and Quantifying Structural Habitat in Lake (Masters Thesis, University of Wisconsin-Stevens Point).

Smart, R., Doyle, R., Madsen, J., and Dick, G., 1996. Establishing Native Submersed Aquatic Plant Communities in Southern Reservoirs. Technical Report A-96-2. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Wetzel, R.G., 2001. Limnology: Lake and River Ecosystems, Third Edition. Academic Press, San Diego, CA.

Wisconsin Department of Natural Resources Natural Heritage Inventory (NHI) Portal. http://dnr.wi.gov/topic/nhi/

Wisconsin Lakes, 2005. WDNR Publication PUB-FH-800

Wisconsin State Climatology Office http://www.aos.wisc.edu/~sco/

# Appendix A

## Phosphorus Release from Sediments in Potato Lake, Washburn County, Wis.

# Internal Phosphorus Loading and Sediment Phosphorus Fractionation Analysis for Potato and Sand Lakes, Wisconsin

1 September, 2012

William F. James
University of Wisconsin - Stout
Sustainability Sciences Institute
Menomonie, Wisconsin 54751

## OBJECTIVES

The objectives of this investigation were to determine rates of phosphorus (P) release from sediments under laboratory-controlled oxic (i.e., aerobic) and anoxic (i.e., anaerobic) conditions and to quantify biologically-labile (i.e., subject to recycling and P flux to the water column) P fractions for sediments collected in Potato and Sand Lakes, Wisconsin.

## APPROACH

*Laboratory-derived rates of P release from sediment under oxic and anoxic conditions:* Duplicate sediment cores were collected from the north, central, and south basins of Sand Lake and the central basin of Potato Lake in early July, 2012, for determination of rates of P release from sediment under controlled laboratory conditions (Table 1). Phosphorus release rates were determine under anoxic (i.e., anaerobic) conditions for sediment cores collected at all sites. Additionally, oxic (i.e., aerobic) P release rates were determined for sediment cores collected in Potato Lake. In the laboratory, all cores were drained of overlying water and the upper 10 cm of sediment was transferred intact to a smaller acrylic core liner (6.5-cm dia and 20-cm ht) using a core remover tool. Surface water collected from each lake was filtered through a glass fiber filter (Gelman A-E), with 300 mL then siphoned onto the sediment contained in the small acrylic core liner without causing sediment resuspension. Sediment incubation systems consisted of the upper 10-cm of sediment and filtered overlying water contained in acrylic core liners that were sealed with rubber stoppers. They were placed in a darkened environmental chamber and incubated at a constant temperature of ~20 $^{o}$C to reflect summer conditions. The oxidation-reduction environment in the overlying water was controlled by gently bubbling air (oxic) or nitrogen (anoxic) through an air stone placed just above the sediment surface in each system. Bubbling action insured complete mixing of the water column but did not disrupt the sediment. Anoxic conditions were verified using a dissolved oxygen electrode.

Water samples for soluble reactive P were collected from the center of each system using an acid-washed syringe and filtered through a 0.45 µm membrane syringe filter (Nalge). The water volume removed from each system during sampling was replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition. These volumes were accurately measured for determination of dilution effects. Soluble reactive P was measured colorimetrically using the ascorbic acid method (APHA 2005). Rates of P release from the sediment (mg $m^{-2}$ $d^{-1}$) were calculated as the linear change in mass in the overlying water divided by time (days) and the area ($m^2$) of the incubation core liner. Regression analysis was used to estimate rates over the linear portion of the data.

*Sediment chemistry:* The upper 10 cm of an additional core collected from each lake station was sectioned for analysis of moisture content (%), sediment density (g/mL), loss on ignition (i.e., organic matter content, %), loosely-bound P, iron-bound P, and labile organic P ( all expressed at mg/g). A known volume of sediment was dried at 105 $^{o}$C for determination of moisture content and sediment density and burned at 500 $^{o}$C for determination of loss-on-ignition organic matter content (Håkanson and Jansson 2002).

Phosphorus fractionation was conducted according to Hieltjes and Lijklema (1980), Psenner and Puckso (1988), and Nürnberg (1988) for the determination of ammonium-chloride-extractable P (loosely-bound P), bicarbonate-dithionite-extractable P (i.e., iron-bound P), and sodium hydroxide-extractable P (i.e., aluminum-bound P). A subsample of the sodium hydroxide extract was digested with potassium persulfate to determine nonreactive sodium hydroxide-extractable P (Psenner and Puckso 1988). Labile organic P was calculated as the difference between reactive and nonreactive sodium hydroxide-extractable P.

The loosely-bound and iron-bound P fractions are readily mobilized at the sediment-water interface as a result of anaerobic conditions that result in desorption of P from sediment and diffusion into the overlying water column (Mortimer 1971, Boström 1984, Nürnberg 1988). The sum of the loosely-bound and iron-bound P fractions are referred to as redox-sensitive P (i.e., the P fraction that is active in P release under anaerobic and reducing conditions). In addition, labile organic P can be converted to soluble P via bacterial mineralization (Jensen and Andersen 1992) or hydrolysis of bacterial polyphosphates to soluble phosphate under anaerobic conditions (Gächter et al. 1988; Gächter and Meyer 1993; Hupfer et al. 1995). The sum of redox-sensitive P and labile organic P are collectively referred to a biologically-labile P. This fraction is generally active in recycling pathways that result in exchanges of phosphate from the sediment to the overlying water column and potential assimilation by algae. In contrast, aluminum-bound P is more chemically inert and subject to burial rather than recycling.

## RESULTS AND INTERPRETATION

### *Rates of Phosphorus Release from Sediment*

Phosphorus mass and concentration increased in the overlying water column of Sand Lake sediment systems maintained under anoxic conditions (Figure 1). Rates of P mass and concentration increase were generally linear over the first 5 days of incubation; concentrations tended to a lesser extent thereafter. This pattern was probably due to diminishment of P concentration gradients at the sediment-water interface over time, which drive P diffusion out of sediment and into the overlying water column. The mean P concentration in the overlying water column of sediment systems at the end of the incubation period was relatively high for sediment cores collected in the north and south basins of Sand Lake at 1.746 mg/L (±0.154 standard error; SE) and 1.733 mg/L (±0.304 SE), respectively, suggesting the potential for the buildup of high concentrations of P in the hypolimnion during the summer stratified period. The mean P concentration was lower for the central basin sediments of Sand Lake (0.698 mg/L ± 0.00 SE), compared to the other basins. Nevertheless, the mean concentration was high and typical of concentrations observed in the hypolimnion of eutrophic lakes. In marked contrast, P mass and concentrations did not increase in the overlying water column of sediment systems incubated under anoxic conditions for Potato Lake sediments (Figure 2). This pattern was very unusual given the concentration of biologically-labile P in the sediment (see below).

Overall, mean rates of P release under controlled laboratory conditions at ~ 20 $^{o}$C were high for Sand Lake sediments, ranging between 6.2 and 14.9 mg m$^{-2}$ d$^{-1}$ (Table 2). Mean anoxic P release rates were greatest for north and south basin sediments, versus the central basin of the lake. This pattern may be related to bathymetric patterns and possible variations in the deposition of P-rich sediments in the deep basins of the lake. The north and south Sand Lake stations were located deep depressions versus the central station, which was located in a shallower region that spanned the north and south basins. The north and south basins would tend to function as zones of sediment accumulation as a result of focusing of P-rich fine-grained sediments with higher concentrations of redox-sensitive P (see below and Table 3). Indeed, patterns of higher anoxic P release rates correlated well with higher concentrations of loosely-bound and iron-bound P fractions in the north and south basin versus lower anoxic P release rates and lower concentrations of redox-sensitive P at the central station.

Anoxic P release rates in the north and south basins of Sand Lake exceeded the upper 25% quartile for regional lakes in west-central Wisconsin (Figure 3). Rates determined for the central station in Sand Lake fell within the lower 25% quartile while those measured for Potato Lake were very low relative to other lakes in the region.

In addition to negligible P release under anoxic conditions, the mean rate of P release from sediment was also negligible under oxic conditions for Potato Lake sediments. These results were very surprising and reasons for this pattern are not entirely known. Rates are typically low or negligible under aerobic conditions if iron oxyhydroxides play a role in binding phosphate at the sediment oxygenated microzone (i.e., the thin layer of surface sediment exposed to oxygenated conditions). However, P release rates usually increase under anoxic conditions when iron becomes reduced during anaerobic bacterial metabolism and looses its binding efficiency for phosphate. The surface sediments in Potato Lake were very flocculent and exhibited a high moisture content of 97%, indicating that the sediment was composed primarily of interstitial water (i.e., porewater) with very little sediment iron-bound P mass per unit volume of sediment (i.e., expressed on a $m^3$ or $m^2$-cm, basis). The concentration of iron-bound P per fresh mass of sediment (i.e., including porewater as well as sediment mass) was minor at 6 µg P/g sediment fresh mass and 0.06 g P/$m^2$-cm (see Table 3), which might explain the negligible rates of P release under anoxic conditions. Using the regression relationship between iron-bound P and the anoxic P release rate developed by Nürnberg (1988), the predicted anoxic P release rate for an iron-bound P concentration of 6 µg P/g fresh mass sediment was 0.3 mg $m^{-2}$ $d^{-1}$ (i.e., predicted anoxic P release rate = (6 µg/g * 0.285) – 1.38), which is low and compares with the actual undetectable rate measured for Potato Lake sediments.

### *Sediment Textural and Chemical Characteristics*

Sediments from Potato and Sand Lake stations generally exhibited very high moisture content and low bulk density, indicating very fined-grained flocculent sediment (Table 2). Organic matter content was nominal for Sand Lake sediments compared to other lakes in the region (Table 2 and Figure 4). In contrast, Potato Lake sediments exhibited very high organic matter content at ~56%, relative to some other lakes in Wisconsin (Figure 4).

Iron-bound P (expressed on a sediment dry mass basis; mg P/g DW sediment) accounted for greater than 50% of the biologically-labile P for the north and south basin stations of Sand Lake (Figure 5 and 6). Loosely-bound and iron-bound P concentrations were also very high at these stations versus the central station of Sand Lake (Figure 6) and they fell above the 25% quartile compared to other regional Wisconsin lakes (Figure 7). Expressed on a fresh sediment mass basis (µg P/g fresh mass sediment), concentrations of iron-bound P were relatively high for the north and south basin sediments of Sand Lake, reflecting higher rates of P release under anoxic conditions at these same stations.

In contrast, labile organic P (expressed on a sediment dry mass basis; mg P/g DW sediment) represented most of the biologically-labile P at the central station sediments of Sand Lake (Figure 5). However, concentrations of this fraction fell near the median concentration for regional Wisconsin lakes (Figure 7). The central station sediments of Sand Lake also exhibited a relatively low loosely-bound P and iron-bound P concentration versus other Sand Lake stations (Figure 6), reflecting a lower rates of P release under anoxic conditions. Overall, sediments from the north basin exhibited the greatest concentration of biologically-labile P followed by the south basin (Figure 6). The central station exhibited the lowest concentration of biologically-labile P.

The biologically-labile P fraction (expressed on a sediment dry mass basis; mg P/g DW sediment) for sediment collected in the central basin of Potato Lake was dominated by the labile organic P fraction at 66% (Figure 5). Loosely-bound P represented 21% and iron-bound P accounted for 13% of the biologically-labile P (Figure 5). The loosely-bound P and labile organic P concentrations for Potato Lake sediments were higher and fell above the upper 25% quartile compared to other lakes on the regional area (Figure 7). Iron-bound P fell near the median for lakes in west-central Wisconsin. However, as mentioned above, the very high moisture content of sediments in Potato Lake translated into very low concentrations when expressed on a sediment volumetric or wet mass basis.

### *Summary*

Rates of P release from sediment under laboratory-controlled conditions at 20 $^{o}$C were relatively high in Sand Lake and suggested the potential for internal P loading, particularly for the north and south basin sediments,. High sediment dry mass concentrations of loosely-bound and iron-bound P (collectively referred to as redox-sensitive P), which have been positively correlated with anoxic P release rates (Nürnberg 1988), tended to correlate with anoxic P release rates in Sand Lake, suggesting that iron-bound P in sediment is an important source for diffusive P flux under anoxic conditions. These rates represented a potential maximum internal P loading rate for Sand Lake and are likely higher compared to P mass balance because factors like variation in temperature and hypolimnetic anoxia were not factored into the laboratory rate calculation.

In contrast, rates of P release from sediments collected in Potato Lake were negligible under both oxic and anoxic conditions. On a sediment dry mass basis, iron-bound P concentrations were near the median compared to other lakes in west-central Wisconsin. However, very high sediment moisture content implied that sediment was very fluid in Potato Lake and composed almost entirely of porewater. Thus, the iron-bound P concentration was much lower per unit volume of sediment, which likely explains the very low potential for sediment internal P loading in the lake.

## REFERENCES

APHA (American Public Health Association). 2005. Standard Methods for the Examination of Water and Wastewater. 21th ed. American Public Health Association, American Water Works Association, Water Environment Federation.

Boström B. 1984. Potential mobility of phosphorus in different types of lake sediments. Int. Revue. Ges. Hydrobiol. 69:457-474.

Gächter R., Meyer JS, Mares A. 1988. Contribution of bacteria to release and fixation of phosphorus in lake sediments. Limnol. Oceanogr. 33:1542-1558.

Gächter R, Meyer JS. 1993. The role of microorganisms in mobilization and fixation of phosphorus in sediments. Hydrobiologia 253:103-121.

Håkanson L, Jansson M. 2002. Principles of lake sedimentology. The Blackburn Press, Caldwell, NJ USA.

Hjieltjes AH, Lijklema L. 1980. Fractionation of inorganic phosphorus in calcareous sediments. J. Environ. Qual. 8: 130-132.

Hupfer M, Gächter R., Giovanoli R. 1995. Transformation of phosphorus species in settling seston and during early sediment diagenesis. Aquat. Sci. 57:305-324.

Jensen HS, Kristensen P, Jeppesen E, Skytthe A. 1992. Iron:phosphorus ratio in surface sediment as an indicator of phosphate release from aerobic sediments in shallow lakes. Hydrobiol. 235/236:731-743.

Mortimer CH. 1971. Chemical exchanges between sediments and water in the Great Lakes – Speculations on probable regulatory mechanisms. Limnol. Oceanogr. 16:387-404.

Nürnberg GK. 1988. Prediction of phosphorus release rates from total and reductant-soluble phosphorus in anoxic lake sediments. Can. J. Fish. Aquat. Sci. 45:453-462.

Plumb RH. 1981. Procedures for handling and chemical analysis of sediment and water samples. Technical Report EPA/CE-81-1. US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Psenner R, Puckso R. 1988. Phosphorus fractionation: Advantages and limits of the method for the study of sediment P origins and interactions. Arch. Hydrobiol. Biel. Erg. Limnol. 30:43-59.

**Table 1. Redox (i.e., oxic and/or anoxic) conditions used for determination of rates of phosphorus release from sediment for various stations.**

| | | Redox Condition | |
|---|---|---|---|
| Lake | Station | Oxic | Anoxic |
| Sand | North Basin | | X |
| Sand | Central Basin | | X |
| Sand | South Basin | | X |
| Potato | Central Basin | X | X |

**Table 2. Textural characteristics for sediments collected in Sand and Potato Lakes.**

| Lake | Station | Moisture Content (%) | Bulk Density (g/cm$^3$) | Sediment Density (g/cm$^3$) | Loss-on-ignition (%) |
|---|---|---|---|---|---|
| Sand | North Basin | 93.1 | 1.033 | 0.072 | 23.4 |
| | Central Basin | 94.2 | 1.028 | 0.062 | 23.6 |
| | South Basin | 95.1 | 1.024 | 0.054 | 22.1 |
| Potato | Central Basin | 97.3 | 1.007 | 0.031 | 56.5 |

**Table 3. Mean (1 standard error in parentheses; n=2) rates of phosphorus (P) release and concentrations of biologically-labile (i.e., subject to recycling and flux to the hypolimnion) P for sediments collected in Sand and Potato Lakes. DW = dry mass, FW = fresh mass).**

| Lake | Station | Diffusive P flux | | Biologically labile P | | | | | | Refractory P |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Oxic | Anoxic | Loosely-bound P | Iron-bound P | | | Redox-sensitive P | Labile organic P | Aluminum-bound P |
| | | (mg $m^{-2}$ $d^{-1}$) | (mg $m^{-2}$ $d^{-1}$) | (mg/g DW) | (mg/g DW) | (ug/g FW) | ($g/m^2$-cm) | (mg/g DW) | (mg/g DW) | (mg/g DW) |
| Sand | North Basin | | 13.1 (0.9) | 0.319 | 2.911 | 199 | 2.075 | 3.230 | 0.303 | 1.430 |
| | Central Basin | | 6.2 (0.1) | 0.020 | 0.216 | 12 | 0.129 | 0.236 | 0.354 | 0.125 |
| | South Basin | | 14.9 (3.0) | 0.325 | 1.195 | 72 | 0.600 | 1.520 | 0.879 | 1.195 |
| Potato | Central Basin | <0.1 | <0.1 | 0.369 | 0.216 | 6 | 0.059 | 0.585 | 1.136 | 0.320 |

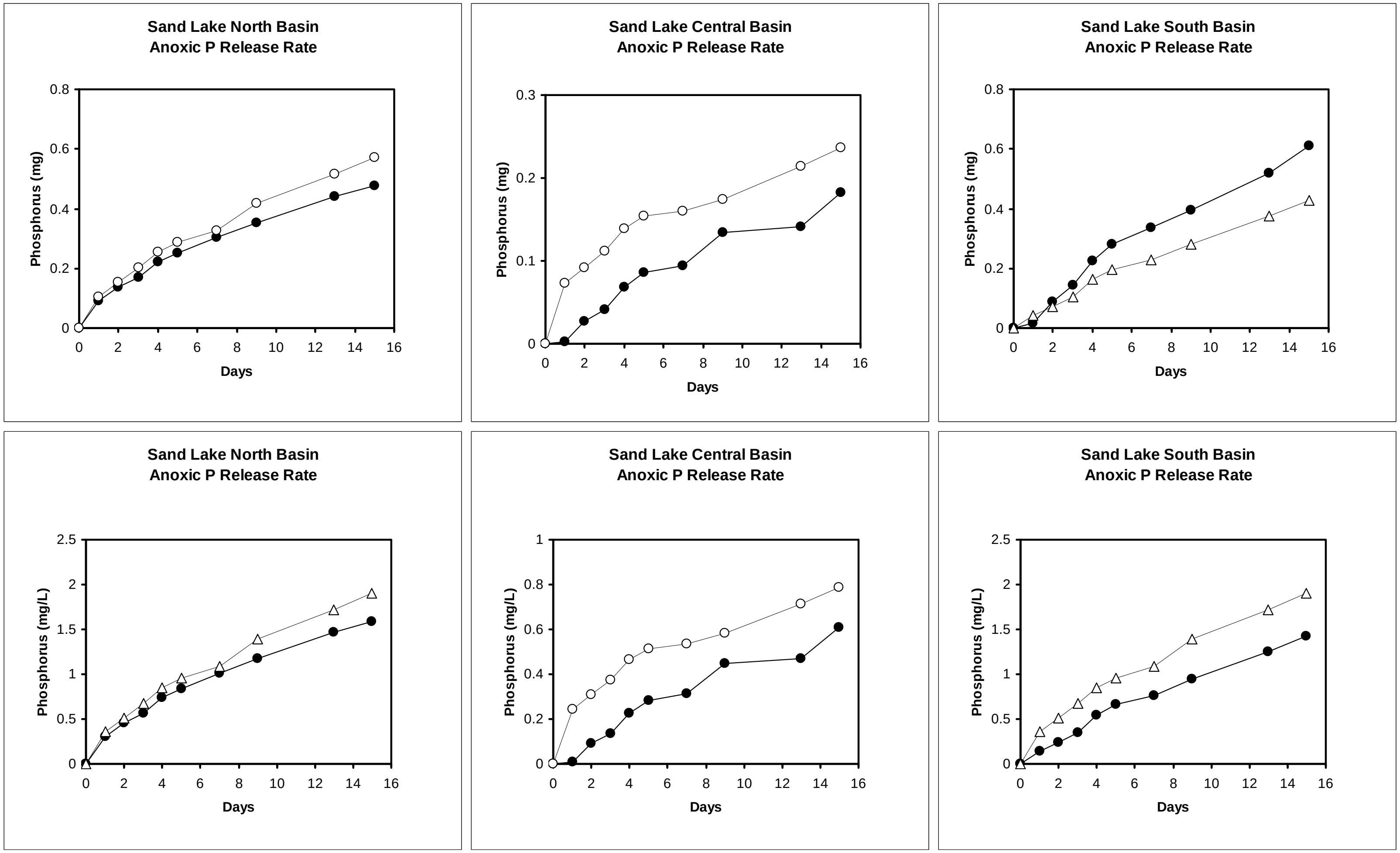


*Figure 1. Changes in soluble reactive phosphorus mass (upper panel) and concentration (lower panel) in the overlying water column of sediment systems incubated under anoxic conditions versus time for sediment cores collected in Sand Lake.*

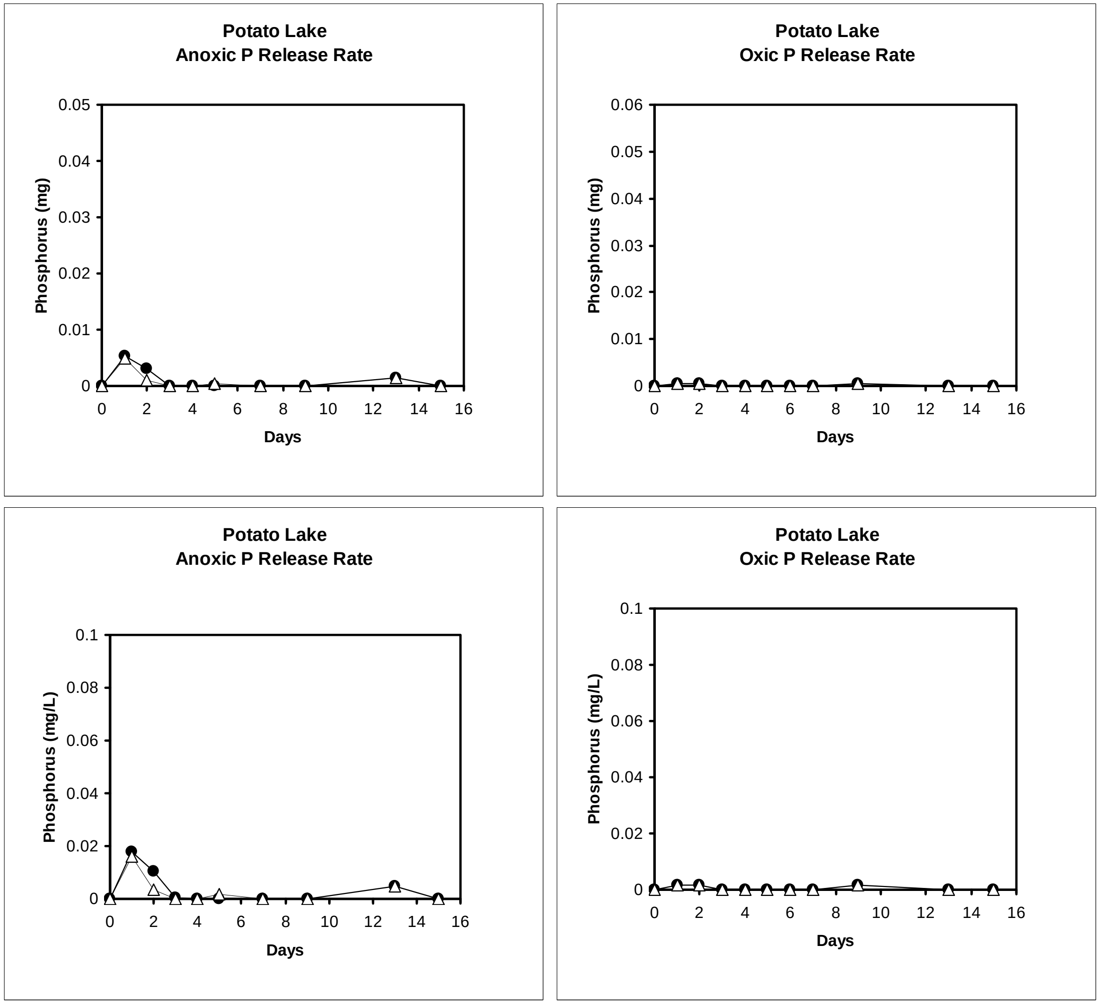


*Figure 2. Changes in soluble reactive phosphorus mass (upper panel) and concentration (lower panel) in the overlying water column of sediment systems incubated under anoxic(left panels) and oxic (right panels) conditions versus time for sediment cores collected in Potato Lake.*

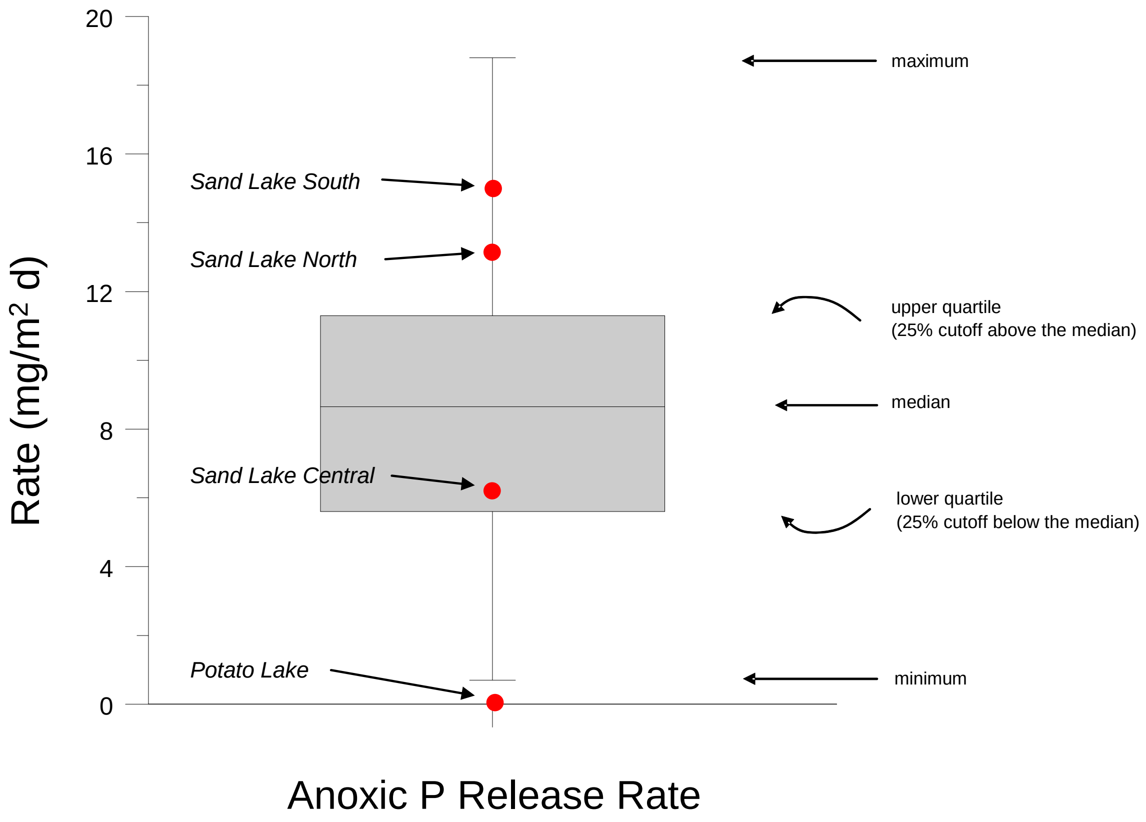


*Figure 3. Box and whisker plot comparing the anoxic phosphorus (P) release rate measured Sand and Potato Lakes (red circles) with statistical ranges (7 lakes; ~ 50 stations) for lakes in west-central Wisconsin.*

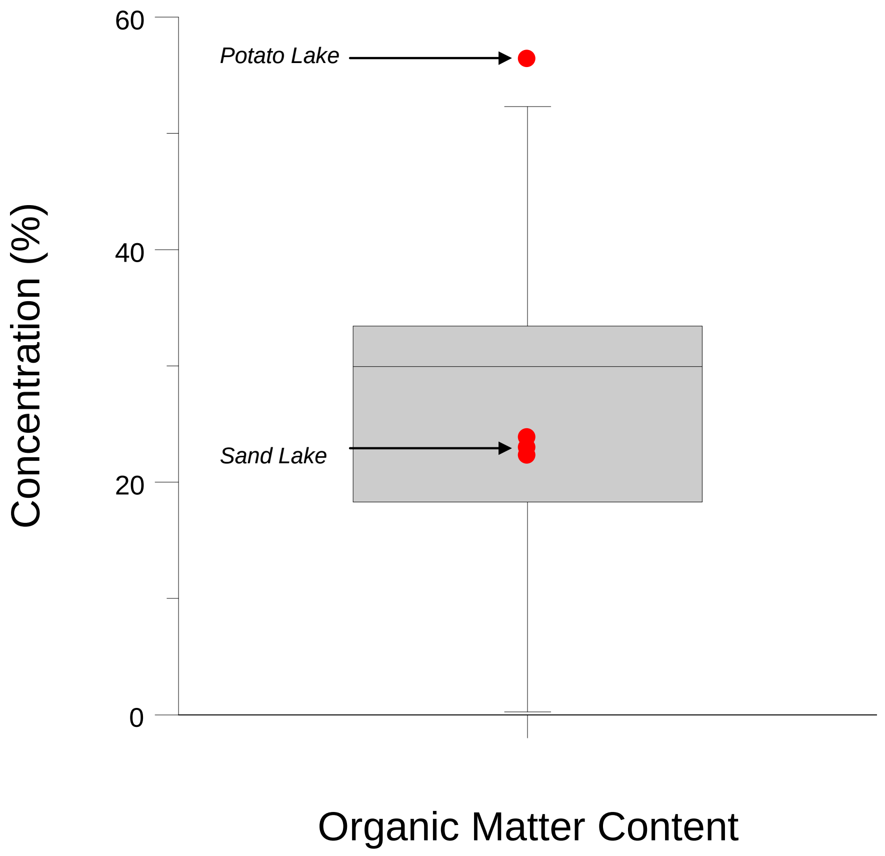


*Figure 4. Box and whisker plot comparing the sediment organic matter content measured in Sand and Potato Lakes (red circles) with statistical ranges (7 lakes; ~ 50 stations) for lakes in west-central Wisconsin.*

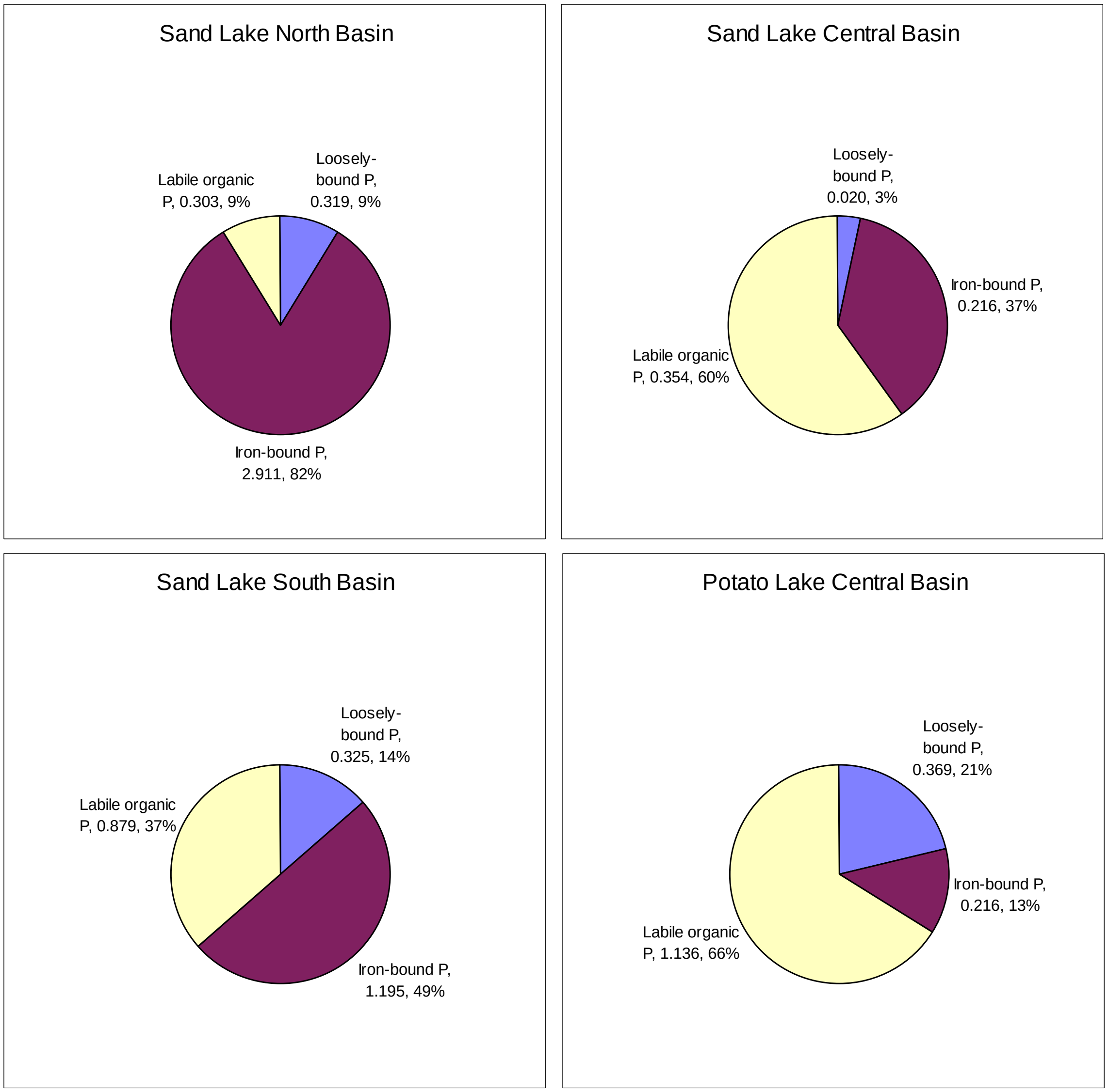


*Figure 5. Biologically-labile phosphorus (P) composition for sediment collected at various stations in Sand and Potato Lakes. Loosely-bound, iron-bound, and labile organic P fractions are biologically reactive, subject to recycling, and correlated with rates of internal P loading. Values next to each label represent concentration (mg·g$^{-1}$dry mass of sediment) and percent biologically-labile P, respectively.*

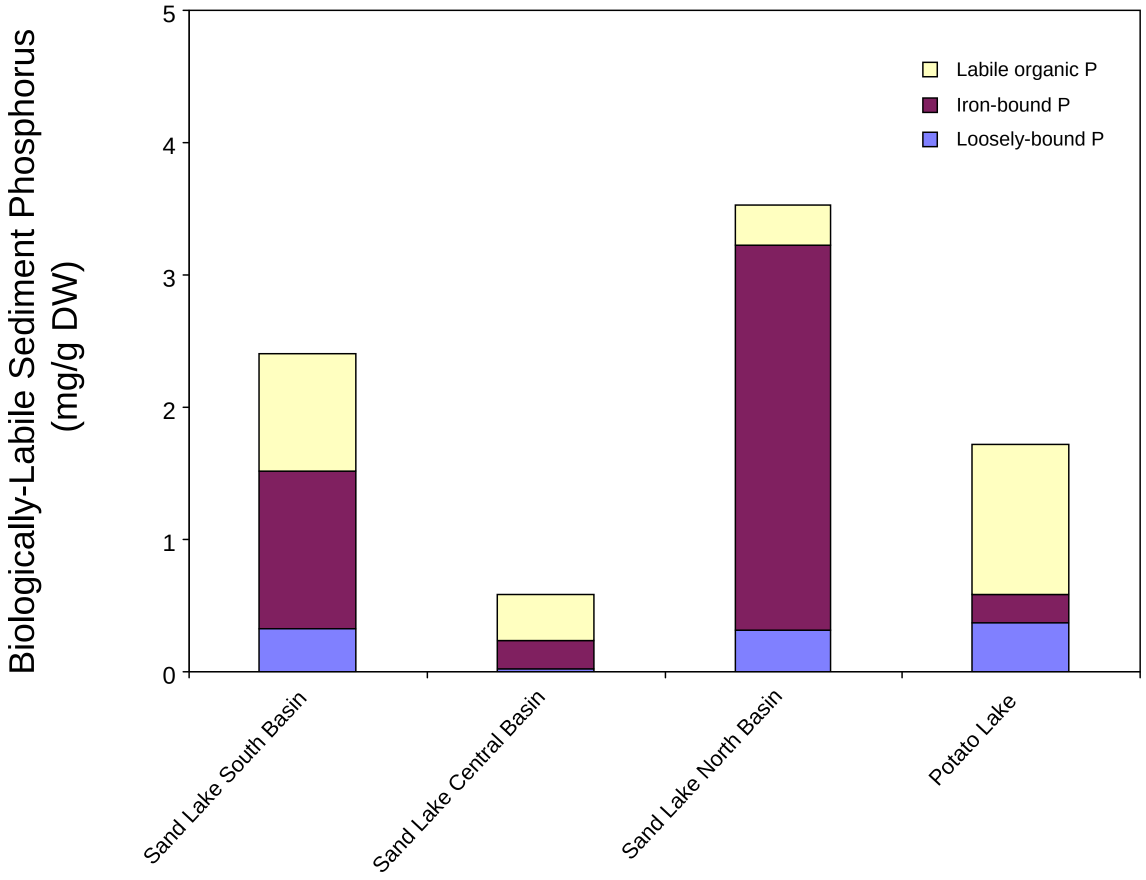


*Figure 6. Comparison of biologically-labile phosphorus (loosely-bound, iron-bound, and labile organic P) concentrations in sediment for various stations in Sand and Potato Lakes.*

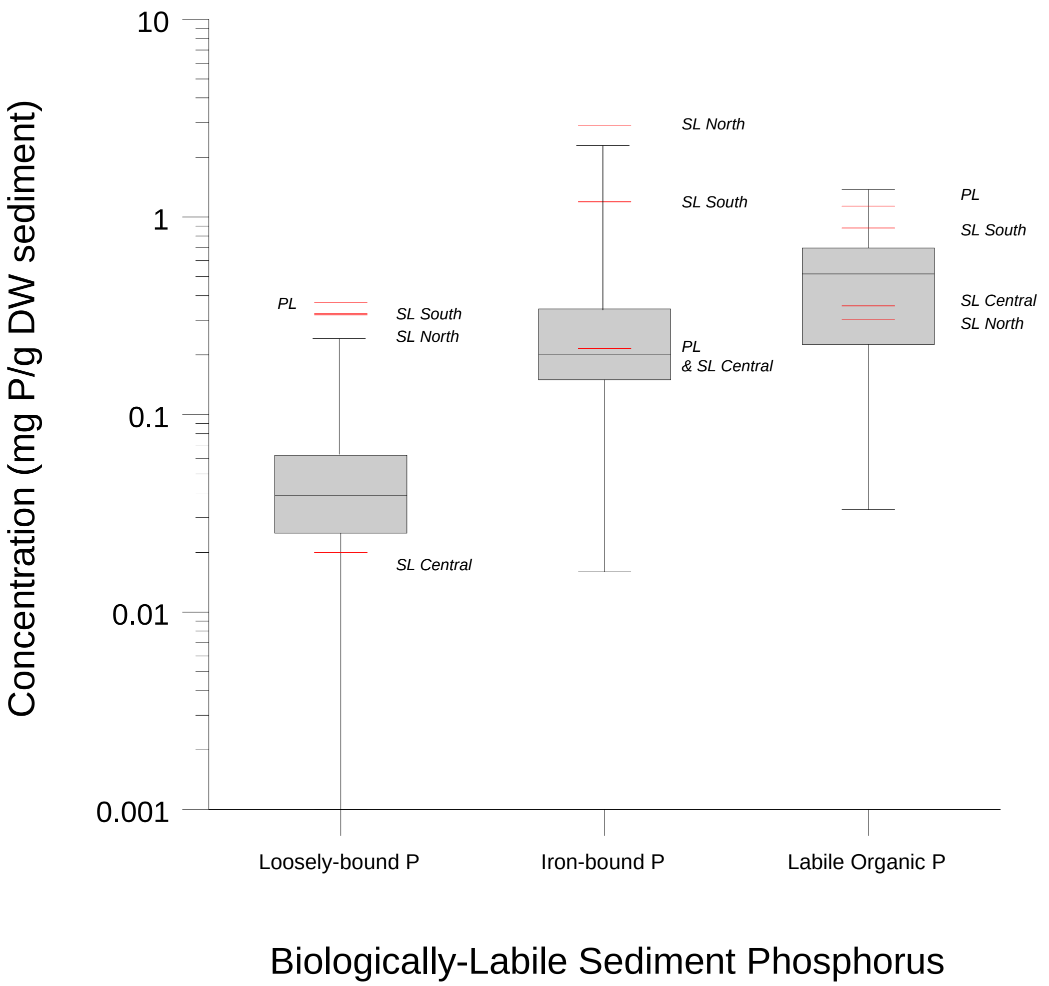


*Figure 7. Box and whisker plots comparing biologically-labile sediment phosphorus (P) fractions measured for Sand (SL) and Potato Lakes (PL; red lines) with statistical ranges (7 lakes; ~ 50 stations) for lakes in west-central Wisconsin. Loosely-bound, iron-bound, and labile organic P fractions are biologically reactive, subject to recycling, and correlated with rates of internal P loading. Please note the logarithmic scale.*

# Appendix B

July 2013 Presentation of Lake Data and Preliminary Management Recommendations

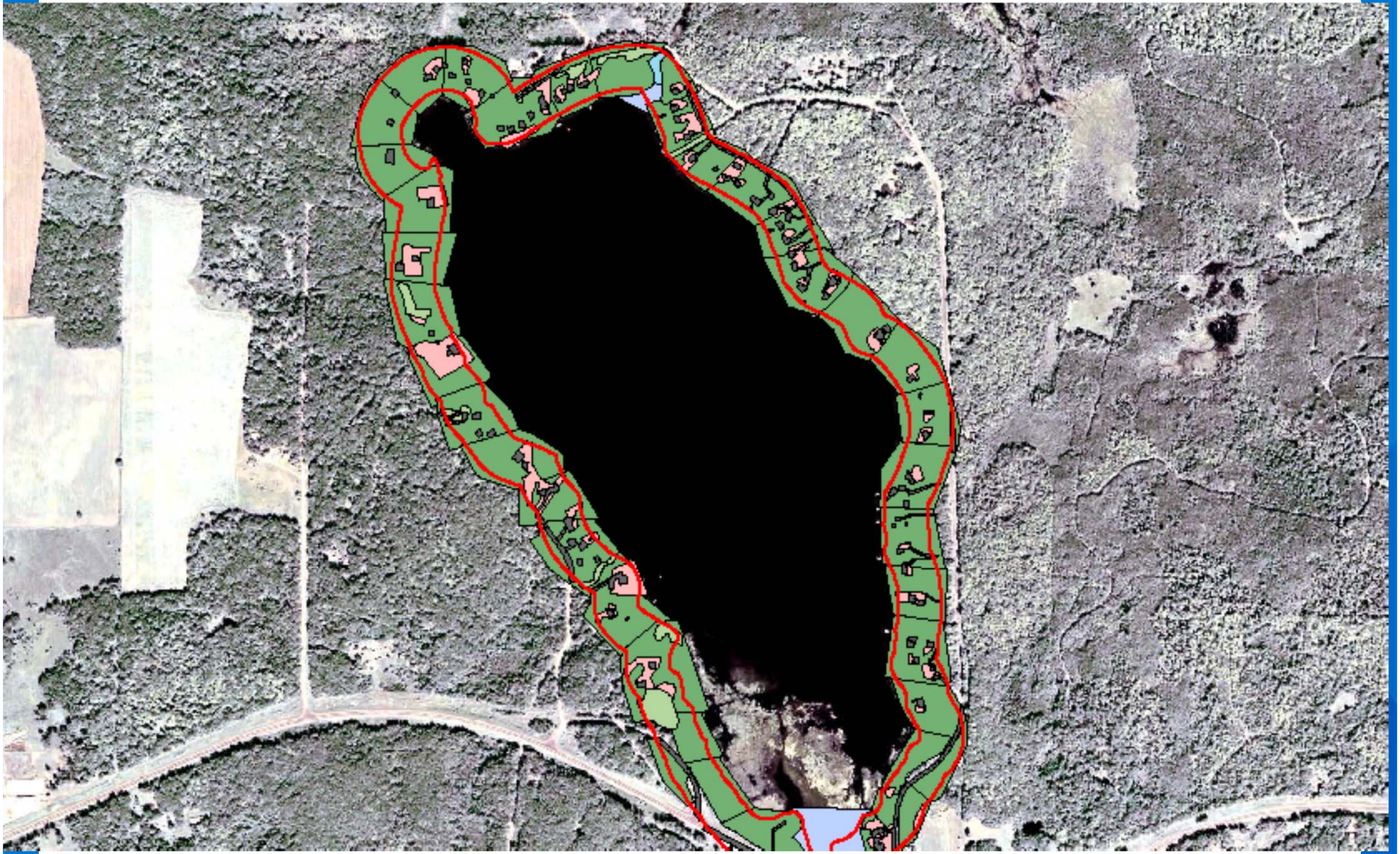
# Potato Lake Comprehensive Lake Management Summary

Potato Lake Annual Meeting

July 27, 2013

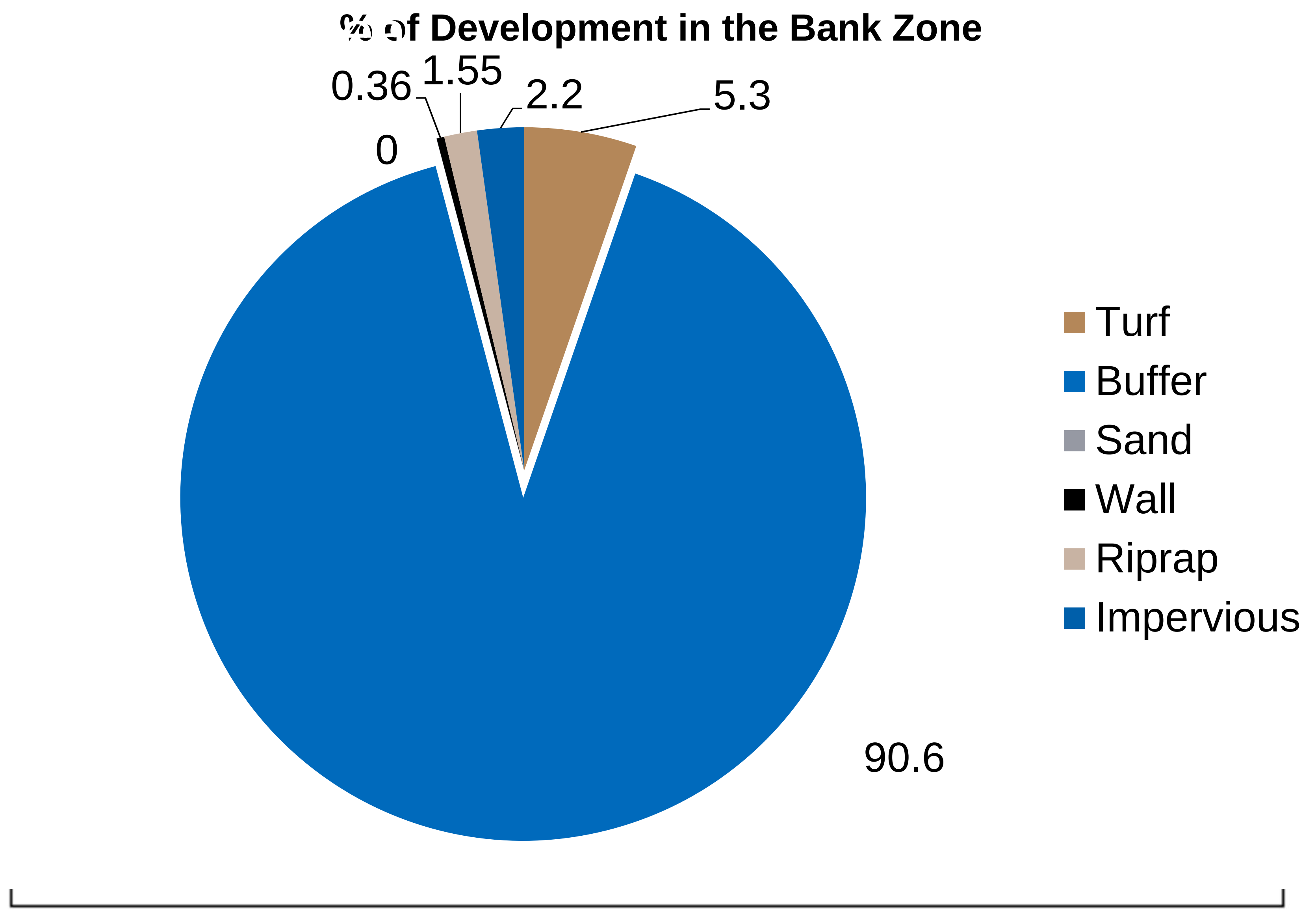
SEH

# % of Land Use in the Nearshore Area (300-ft band)



# Land/Water Interface

- E



# Water Quality Measurements

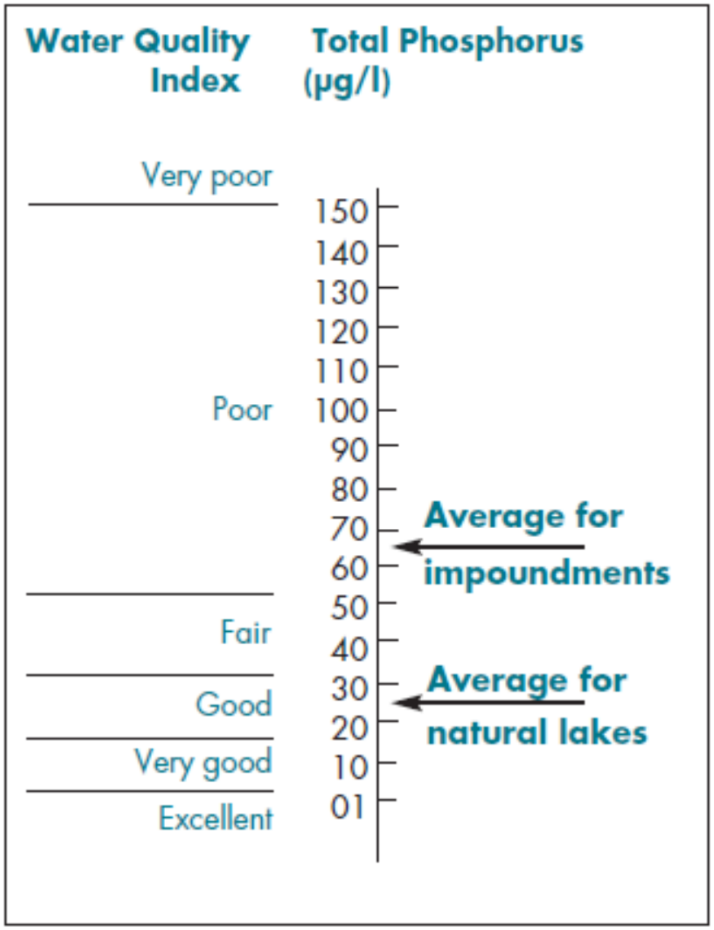
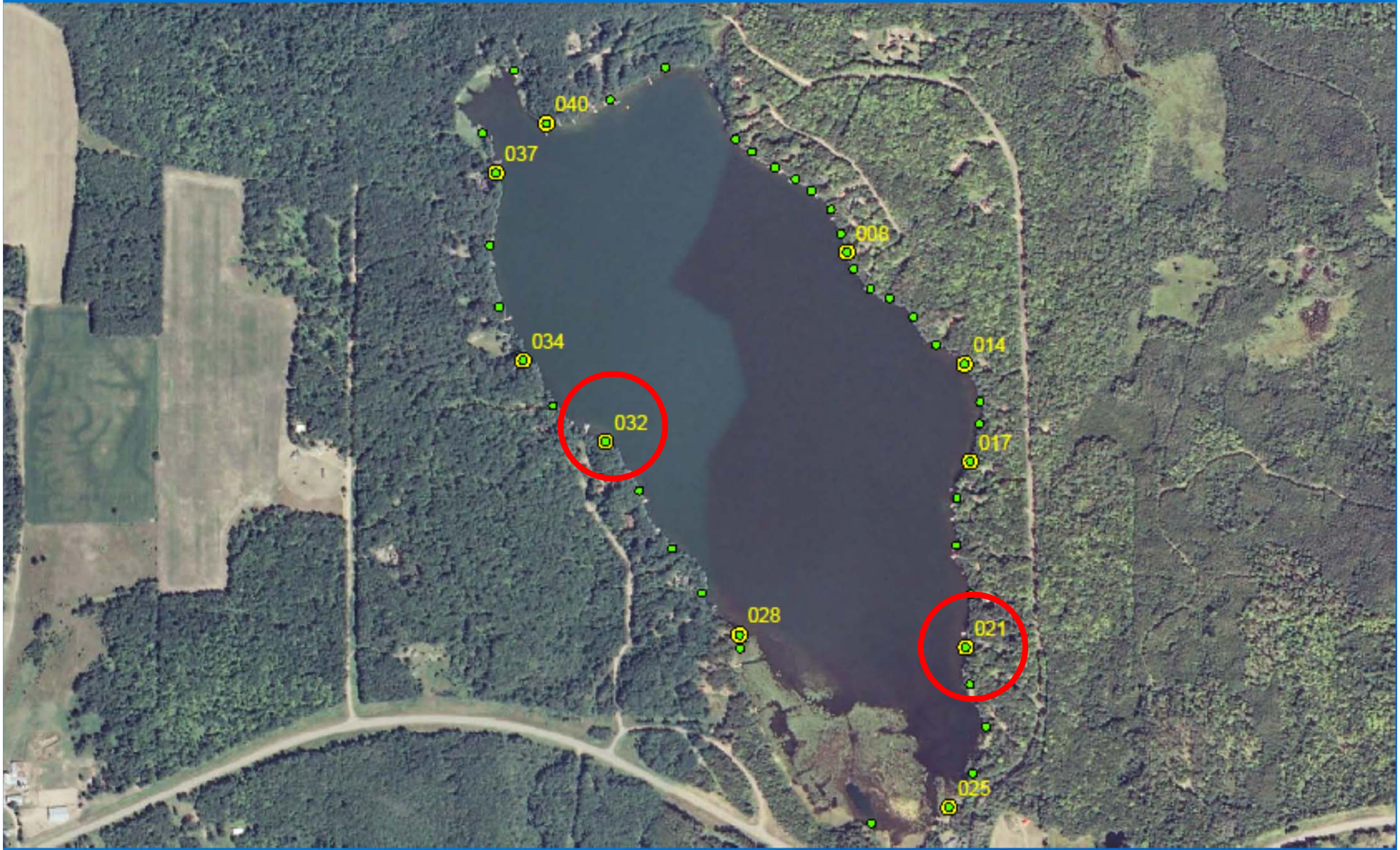


**FIGURE 4.** Total phosphorus concentrations for Wisconsin's natural lakes and impoundments. *(Adapted from Lillie and Mason, 1983.)*

- **Total Phosphorous**
  - **Values < 20 ug/L are desirable**
- **Total Dissolved Phosphorous**
  - **Values < 10 ug/L are desirable**
- **Inorganic Nitrogen (NO3, NO4, NH4)**
  - **Values < 0.3 mg/L is desirable**

# Groundwater Mini-Piezometer Study



# Ground Water Sampling - Aug 2012

| **Sample** | **Site** | **TDP** | **TKN** | **Ammonia** | **Nitrate/nitrite** | **Location** |
|---|---|---|---|---|---|---|
| | | **ug/L** | **mg/L** | **mg/L** | **mg/L** | |
| 1 | 21 | 40 | ND | ND | **0.85** | **SE corner** |
| 2 | 17 | 61 | ND | ND | 0.194 | **east shore** |
| 3 | 14 | 46 | ND | ND | 0.163 | **east shore** |
| 4 | 25 | 91 | ND | ND | 0.155 | **south end closest to the road** |
| 5 | 28 | 30 | 0.22 | ND | 0.249 | **SW nearest the spring hole** |
| 6 | 32 | **334** | ND | ND | ND | **west shore** |
| 7 | 34 | 57 | 0.97 | 0.429 | ND | **west shore** |
| 8 | 8 | 19 | 0.81 | 0.133 | ND | **east shore closest to the landing** |
| 9 | 40 | 25 | 1.21 | 0.324 | ND | **north shore east of bay** |
| 10 | 37 | 40 | 1.23 | 0.528 | ND | **north shore west of bay** |
| Average | | 74.3 | 0.89 | 0.3535 | 0.3222 | |
| | | 45.444 | | | 0.19025 | |

**Comments:**

dissolved reactive phosphorous being brought in by ground water is generally pretty high

Site 6 on the west shore has a massive spike in TDP in front of it.

Nitrites and Nitrates brought in with groundwater are pretty high, particularly from the southeast corner of the lake