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HORSESHOE LAKE, BARRON AND POLK COUNTIES

2016 AQUATIC PLANT MANAGEMENT AND LAKE MANAGEMENT PLANNING GRANT SUMMARY REPORT

WDNR WBIC: 2630100

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July 10, 2017

HORSESHOE LAKE PUBLIC
INLAND PROTECTION AND
REHABILITATION DISTRICT
TURTLE LAKE, WI 54889

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2016 AQUATIC PLANT MANAGEMENT SUMMARY REPORT-HORSESHOE LAKE

PREPARED FOR THE HORSESHOE LAKE PUBLIC INLAND PROTECTION AND REHABILITATION DISTRICT

INTRODUCTION

This report discusses aquatic plant management activities completed by the Horseshoe Lake Public Inland Protection and Rehabilitation District (formerly the Horseshoe Lake Improvement Association) and Lake Education and Planning Services (LEAPS) during the 2016 season and provides a preliminary hybrid Eurasian watermilfoil (HWM) treatment plan for 2017. The 2017 treatment proposal provides the Association with the information needed to contract with a certified aquatic herbicide applicator to complete the necessary WDNR permitting and herbicide treatment. 2015 was the first year of implementation for the new Aquatic Plant Management Plan that was approved in early 2015.

In addition, the Lake District also implemented a lake management planning grant in 2016 as well. The following list of education and management actions were completed in 2016.

- 2016 HWM Treatment Planning and Implementation
- 2016 Fall HWM Bed-mapping Survey
- Clean Boats Clean Waters
- AIS and Purple Loosestrife Monitoring and Removal
- HWM Identification and Removal Workshop
- Annual Meeting and Lake Fair/Picnic
- Habitat Assessment Survey
- Nearshore Land Use Digitization
- Citizen Lake Monitoring Network Water Quality Testing
- Lake Management Planning Grant Water Quality Testing
- Tributary Monitoring
- Bottom Phosphorus Sediment Release Study (UW-STOUT)
- Preliminary HWM 2017 management planning

Each of these actions will be summarized in the following sections of this report.

2016 HWM TREATMENTPLANNING AND IMPLEMENTATION

PRIOR TO TREATMENT

A fall HWM bed-mapping survey completed on September 20, 2015 (Berg, 2015) only identified two areas of high density HWM that totaled 0.26 acres and an additional 22 HWM plants outside of these areas (Figure 1). Based on this survey and an informal early season survey conducted by LEAPS, one area totaling 1.03 acres was proposed for chemical treatment in the spring of 2016 with granular 2, 4-D (Navigate) at a rate of 3.0 to 4.0 ppm (Figure 2). Due to the small size of the treatment, a formal pre-treatment survey was not conducted and the fall bed mapping replaced the post-treatment survey.

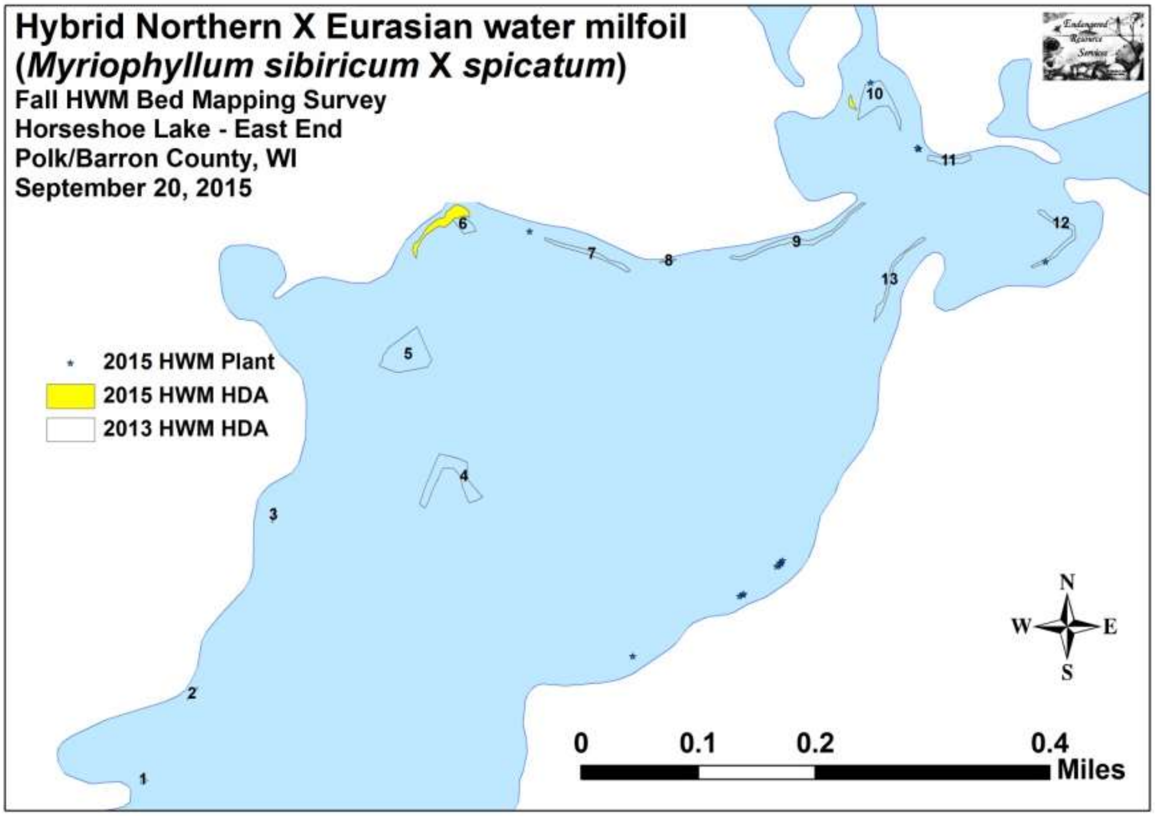


Figure 1: 2015 Fall HWM Bed-mapping Results

Figure 2 - 2016 Spring Treatment Areas Totaling 1.03 Acres

SPRING TREATMENT

Application of Navigate® herbicide was completed by Northern Aquatic Services (NAS) on May 24th. Surface water temperature was 66°F with 3 mph winds from the South. A description of the site and the amount of herbicide applied is in Table 1. At the time of application, common waterweed, HWM, coontail, and white water lily were the only species identified. No species of pondweed were present in the treatment area prior to application of herbicide.

Table 1 - 2016 HWM Herbicide Management Details

2016 Horseshoe Lake Hybrid EWM Final Treatment Proposal Details 5-23-2016 (LEAPS)						
Name	**Acres**	**Mean Depth (feet)**	**Acre-Feet**	**Target 2,4-D (ppm a.e.)**	**Navigate Application (pounds)**	**Navigate Dose (pounds/acre)**
Bed1-16-HDA6	1.03	5.00	5.15	3.5	256.0	249
TOTAL	***1.03***		***5.15***		***256.0***	

A fall HWM bed-mapping survey was completed on October 9th, 2016 by ERS (Berg, 2016). A "bed" is determined to be any area where HWM is visually estimated to make up >50% of the area's plants and is generally continuous with clearly defined borders. At the time of the fall survey, water clarity was approximately 6-7-ft making it difficult to find young plants that might have been present in deep water. On a more positive note, this poor clarity appeared to be limiting plant growth in general and HWM growth in particular. As in the past, very few areas of HWM were found that meet the definition of a true bed. ERS instead mapped out the areas that were considered "High Density Areas" (HDA). Using these criteria, 13 areas totaling 1.93 acres were found. This was a 742% increase from the 0.26 acres found in 2015. There were 22 additional HWM plants found outside of the 13 areas which were removed by the survey specialist (Figure 3).

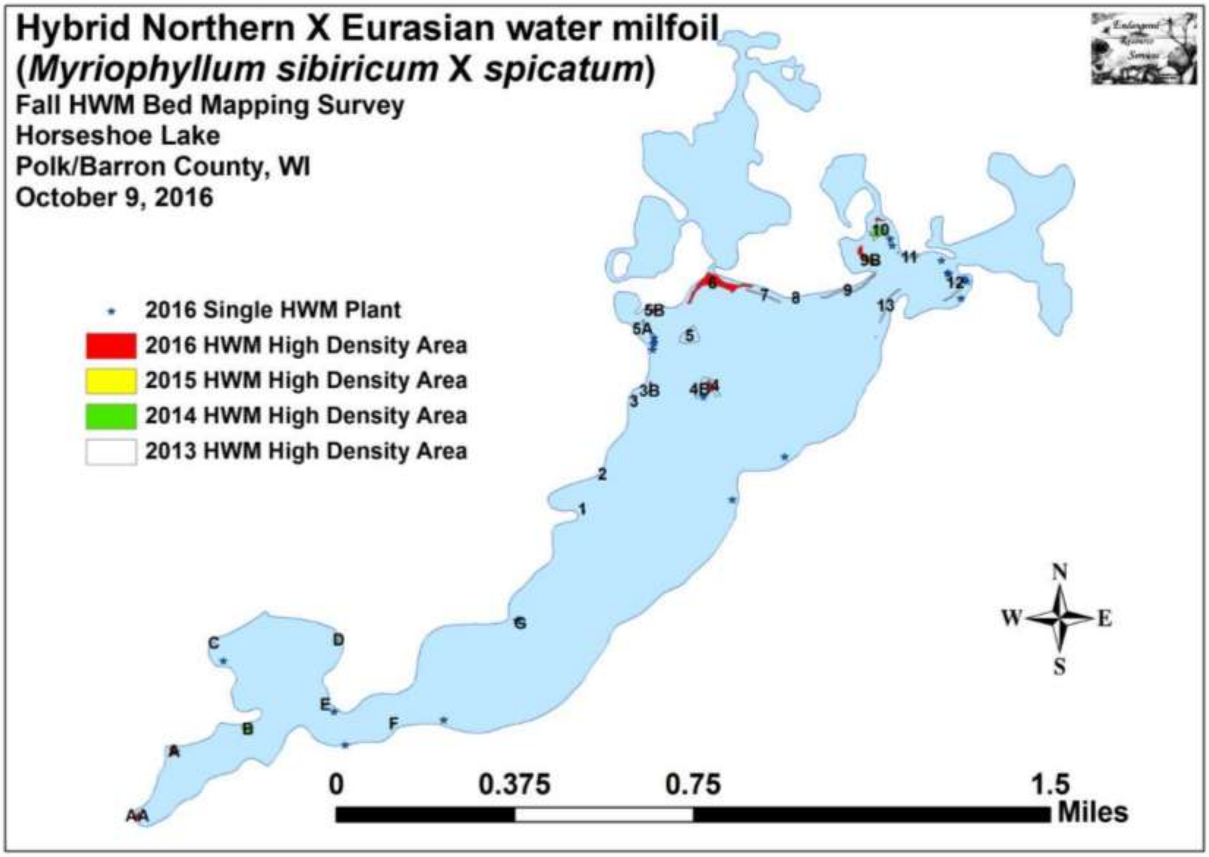


Figure 3 – October 2016 fall HWM survey results

In 2015, there were no HDAs in the west end of the lake despite several having been found in 2014. However two HDAs reappeared in 2016 in this portion of the lake with six additional plants, outside of these areas, that were removed (Figure 4).

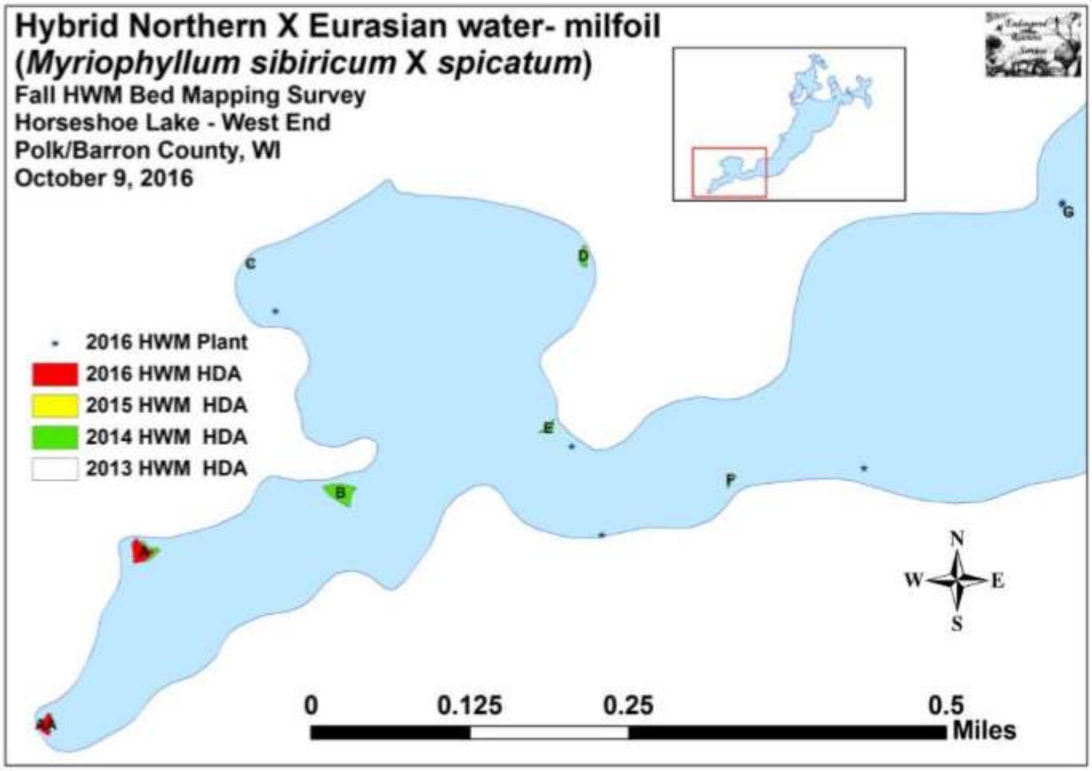


Figure 4 - 2016 HWM in the West End of the lake

HDA AA was a new area that was added with the 2016 survey. This is the first time HWM has been observed in this area. This area appeared to be actively spreading which makes it likely to be much larger if the water remains relatively clear in 2017.

HDA A was a significantly bed near the public access point. The plant survey specialist speculates that this bed is comprised of classic Eurasian watermilfoil. While a DNA test would be needed to confirm this, it is very likely to be true which could make the milfoil in Horseshoe Lake slightly easier to manage.

HDAs B and D had no evidence of HWM in these areas despite their proximity to the boat launch.

HDAs C, E, F, and G had individual plants that were removed with the rake.

Between the herbicide application in the spring and poor water clarity throughout the summer and fall, visible HWM was reduced to almost nothing in 2015. As was expected, the improved water clarity led to more HWM being identified in the usual areas.

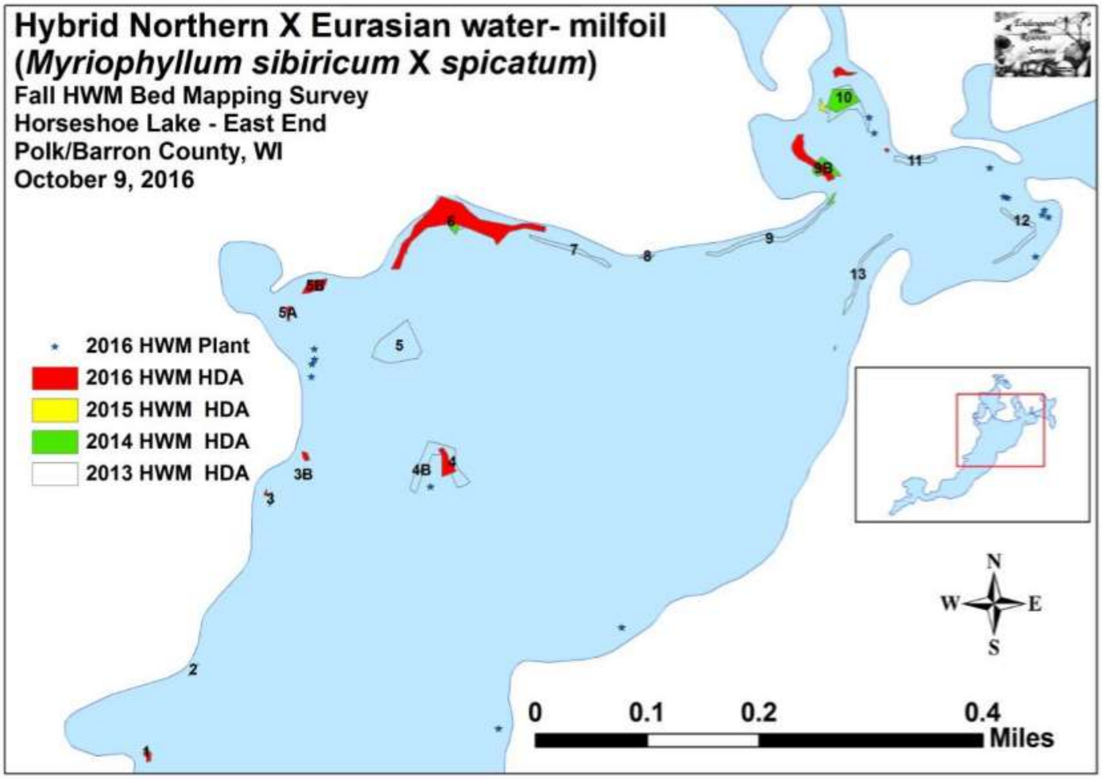


Figure 5- 2016 HWM in the East end of the lake

The east end of the lake had significantly more HWM in 2016 than the previous year. There were 11 HDAs mapped in this area with an additional 16 individual plants removed.

HDAs 2, 7, and 8 have shown no evidence of HWM since 2013.

HDAs 9 and 13 have not had HWM since 2014.

HDA 6 was considerably worse in 2016 than it was in 2015 despite the spring treatment in this area. This area was five times larger than it was in 2015. This is usually the worst HDA due to fragments being pushed into this area by the prevailing winds.

HDA 12 had seven plants which were removed.

CLEAN BOATS, CLEAN WATERS

In 2016 there were 219 hours of paid and volunteer watercraft inspection time. During this time 352 people were contacted and 158 boats were inspected at the Horseshoe Lake public boat landing. This data was recorded in the WDNR SWIMS database.

AIS AND PURPLE LOOSESTRIFE MONITORING AND REMOVAL

Several Lake District volunteers completed 38 hours of AIS monitoring on Horseshoe Lake in 2016. The first monitoring date was June 6, 2016 and the last was August 27, 2017. An Aquatic Invasives Surveillance Monitoring End of Season Report was sent to the SWIMS data base (Appendix A). Purple loosestrife monitoring and physical removal was completed by HLIA volunteers in 2016.

HWM IDENTIFICATION AND REMOVAL WORKSHOP

On July 8th, 2016 a EWM Identification and Removal Training Session was conducted at the Horseshoe Lake Public Boat Landing from 10:00am to 1:00pm. The workshop was publicized through the webpage and a flyer distributed to lake residents (Appendix B). The workshop included an on-shore component where different aquatic plant species were discussed and comparisons made between them and non-native invasive species. Following the on-shore portion, two pontoons were used to take participants out onto the lake to actually look for and rake-remove EWM. The on the lake portion was somewhat limited by high water, in that EWM was not as easily found as was expected, even with a trip out to the lake the day before to find it. Still, some EWM was identified and training to remove it using a two-sided rake was completed.

Approximately 25-30 people showed up for the on-shore training, with about half going out on the lake to do identification and physical removal.

ANNUAL MEETING AND LAKE FAIR/PICNIC

The Lake District held the 2016 Annual Meeting on May 28, 2016. LEAPS were present at that meeting and gave a short presentation on Horseshoe Lake management actions for 2016 (Appendix C). The presentation focused on the differences between a Lake District and a Lake Association and how that affects lake management planning and implementation. The presentation also introduced the new lake management planning grant project to collect additional water quality data from the lake and the surrounding watershed through several tributaries that feed the lake. The new project also focuses on the immediate nearshore area and what could be done by property owners to reduce runoff into the lake.

The HLIA held its annual Lake Fair and Picnic on September 3, 2016 from 9:00am to 2:00pm at the Turtle Lake Park Pavilion. This was an informal gathering where Lake District residents were able to meet with LEAPS to discuss the rankings and recommendations from the shoreline survey. As always the Annual Meeting is well attended. The Lake District had several displays set up for public viewing including AIS identification, Snuba gear, and water quality monitoring equipment.

HABITAT ASSESSEMENT SURVEY

This survey, developed by the Wisconsin Department of Natural Resources (WDNR), is a means to identify best management practices that could be implemented along the shoreline to reduce runoff in the nearshore area (from the waterline back 35-ft inland) and improve habitat. Native plantings, rain gardens, runoff diversions, rock infiltration trenches, tree and shrub planting, no-mow areas, etc. are all examples of said best management practices. The survey is completed from the water with each parcel evaluated based on a list of criteria including the amount of impervious surface, slope of the parcel, tree cover, shrub and native grasses, and so on. The result is a document that can be used by the sponsoring organization to prioritize efforts now or in the future that focus on shoreland improvement projects that can be covered by the new Healthy Lakes Grant Program. What the sponsoring organization chooses to do with the document is up to them.

PROTOCOL

This survey is intended to provide management recommendations to individual property owners based on an assessment of their property. The protocol involves photographing each parcel from the lake which is then matched to land use information about the riparian zone. For this survey, the riparian zone is defined as the strip of land, along the shore, from the high water level back 35 feet. The information collected includes ground cover which includes lawn, impervious surfaces, and native plants. Additional land use information includes the number of human structures in the riparian zone and various other runoff concerns. This protocol also assesses the amount of woody debris present in the lake however this is done for the entire lake instead of for each individual parcel. Woody debris provides habitat for fish, birds, and numerous other types of wildlife as well as providing some protection from bank erosion. This protocol defines woody debris as wood in no deeper than 2 feet of water that is at least 4 inches in diameter, at the widest point, and at least 5 feet long. The purpose of this book is to provide shoreline recommendations to individual property owners, for this reason the woody debris data will not be addressed in this book, but a map of the woody debris locations can be found in Appendix D.

PRIORITY RANKING PARAMETERS

The priority rankings that accompany each parcel evaluation were developed by LEAPS in order to determine the needs of the each lake that the survey is conducted on with concern to the projects that could realistically be completely on each parcel. The parameters used to determine the priority were considered to be those that would contribute most significantly to the rainwater runoff. This includes percentage of canopy cover, as well as the percentage of undisturbed vegetation and a summed percentage of ground covered by manicured lawn and impervious surfaces. Additional consideration was given to the number of buildings present in the riparian zone, the presence or absence of trails to the lake, lawns that sloped directly to the lake, bare soil deposits that can run into the lake, and any other runoff concerns such as the large patches of artificial beach. For each factor being considered, there are value ranges assigned to determine the color, the value ranges can be seen below in Table 2. Values that fall within the red range are worth 2 points, values in the yellow range are worth 1 point, and values in the white range are not given any points. The points are then summed and the properties prioritized based on the point range for the entire lake.

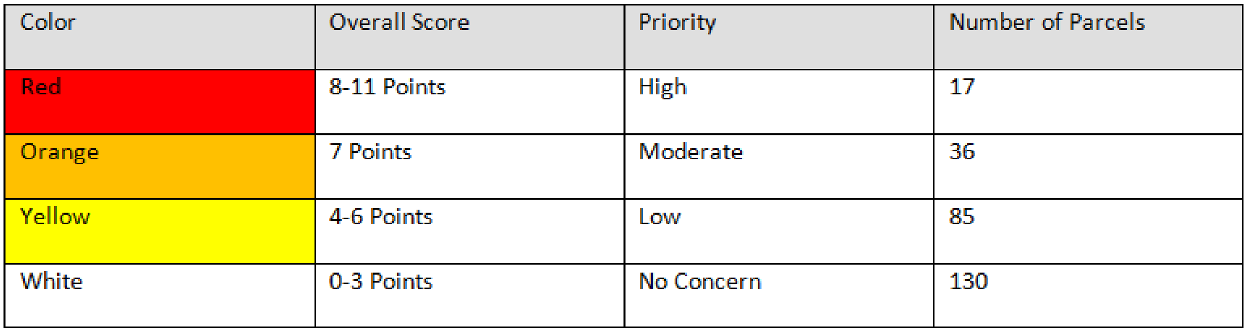
Table 2 - Value ranges for color assignments of each parameter of concern

Parameter	Red range (2 points)	Yellow Range (1 Point)	White (No points)
Percent canopy cover	0-15%	16-30%	>30%
Percent shrub and herbaceous (undisturbed)	0-15%	16-30%	>30%
Percent lawn and impervious surface	>65%	31-65%	0-30%
Number of buildings	>1	1	0
Trail to lake	>1	1	0
Presence/ Absence of lawn sloping to lake	N/A	1 (Present)	0 (Absent)
Presence/ absence of bare soil deposits	1 (Present)	N/A	0 (Absent)
Presence/ absence of other runoff concerns	1 (Present)	N/A	0 (Absent)

LAKE-WIDE SUMMARY

To establish priority rankings for this lake, it was important to consider the entire lake. The maximum possible score was 16 points, but the highest scoring parcel only scored 11 points. From here, four levels of concern were established: red, orange, yellow, and white. These colors correspond to the priority of concern red properties are of high concern, orange are moderate, yellow is low, and white parcels are of almost no concern. Table 3 summarizes the survey results for the entire lake.

Table 3 - Score ranges and priority rankings for the 268 parcels surrounding Horseshoe Lake



Color	Overall Score	Priority	Number of Parcels
Red	8-11 Points	High	17
Orange	7 Points	Moderate	36
Yellow	4-6 Points	Low	85
White	0-3 Points	No Concern	130

A separate document from this report summarizes the evaluations of each parcel. The evaluations in the separate document include the numbers used to determine the overall score as well as a photograph, and management recommendations for each parcel. Photos were intended to provide reference for individual property owners. The photos were matched to the correct properties to our best knowledge though there are likely several that do not fully match. However assessments are correctly matched to the appropriate parcel. It is important to note that while ranking each parcel ONLY the 35-ft along the shoreline was considered. The photos were not used to assess properties and can be misleading for certain parameters, particularly canopy cover. For example, some parcels appear mostly shaded, but only have 15% canopy cover. This is likely because the assessment only considered 35-ft back and the canopy cover started beyond that mark. In addition, there are other considerations such as camera angle, time of day, etc. All evaluations were done in the field to prevent any misdirection that would have been caused by using photos to assess the properties.

The management recommendations are explained, in more detail, in the section of the separate document following the rankings. Generally speaking, there are very few recommendations for properties scoring under 4 points, so these have been marked with no priority ranking. Many of the low priority parcels would benefit from native plantings along the shore to act as a buffer zone. The high and moderate priorities would do well with rain gardens, rock infiltrations, as well as several other remedies. These are all general patterns, but it is important to note that there is a good amount of variation between each parcel. To account for this, there are specific management recommendations for each parcel. The recommendations for each parcel are meant to give property owners an idea of some of inexpensive small scale projects that would best suit the needs of their property. The projects suggested come primarily from the WDNR's Healthy Lakes Initiative which means most of them are eligible for grant funding through the WDNR.

LAKE MANAGEMENT BEST PRACTICES (HEALTHY LAKES INITIATIVE)

The Healthy Lakes Initiative is a program that has been set up by the WDNR to provide support through information and grant funding to small scale projects that will help improve both shoreline habitat and lake health. The grants available for these projects are intended for fairly small, inexpensive projects, so there is $1000 limit in grant funding per project with a 25% match required from either the Lake District or property owner. This program is focused on helping individual property owners improve their shoreline. There are five projects that are eligible for Healthy Lakes Grants. The projects that qualify for these grants are installing fish sticks, rain gardens, native plantings, diversions, and rock infiltrations.

Fish sticks is taking trees from inland, and installing them in the lake to mimic shore trees that will eventually fall into the lake. The trees used must be taken from a minimum of 35 feet inland and are then secured to the shore with cables for approximately 3 years. This provides habitat for fish, birds, and many other animals. In addition to providing habitat, fish sticks help protect the shoreline from some bank erosion. Fish sticks project costs range anywhere from $100 to $1000, averaging about $500. These are very low maintenance because it is only necessary to occasionally check the cables to ensure they are secure. This practice would help improve almost any of the developed parcels.

Rain gardens are shallow depressions that contain loose soil and native plants. These are intended to capture the runoff, allowing the water to be filtered, naturally through the ground instead of flowing directly into the lake. Rain gardens are designed to allow the rainwater to soak into the ground with 1-2 days, to prevent any of the issues created by standing water. The project cost for rain garden range anywhere from $500 to $9,500, but this is very dependent on the size of the rain garden. The maintenance is fairly low, only requiring watering for about two weeks, until the plants have established. Weeding is occasionally needed during the first year. This project is best suited to parcels on a smaller incline to catch rainwater runoff that would otherwise run into the lake.

Native plantings are intended to establish a buffer zone between the developed portion of a parcel and the lake. The buffer helps filter and slow rainwater runoff so much of it filters into the ground. This buffer zone is created by changing a strip of turf grass, at least ten feet wide, along the shoreline to a natural area composed of native shoreline plants. Similar to rain gardens, these are fairly low maintenance requiring water only until the plants have become established. The only ongoing maintenance is the removal of any invasive species that find their way into the planting. On average, native plantings cost around $1000. This project will work for almost any developed parcel that does not have a sand beach as the primary frontage.

Diversions are placed across a sloping path or driveway to divert runoff water to an area where it can be absorbed into the ground instead of flowing directly into the lake. In addition to helping improve lake health, these can also reduce the effects of erosion on the paths that the diversions are installed on. Diversions are created by entrenching a log or creating a small earthen berm approximately 30 degrees from the angle of the slope. The cost of these range anywhere from $25 to $3,750, but the average diversion costs $200. These are very low maintenance, and only require some debris removal that could get stuck in the diversion and occasionally ensuring everything is still secure and in place. This practice does not work well for the purposes of this particular survey, but it is mentioned here as a nod to projects that could be completed further inland than this survey was meant to assess.

Rock infiltrations are meant for relatively low traffic areas as a way to catch rainwater runoff and divert it into the ground. These consist of a pit which is no more than five feet deep. This pit is lined with filter fabric and filled with small rock. More filter fabric is placed on top and larger rock is then placed over that to hold everything in place. These range in price from $500 to $9,500, on average costing $3800. This requires some maintenance to function properly. It is necessary to remove any debris such as leaves or pine needles that may collect. It is also necessary to occasionally clean out the rock as it collects sediment. This works well around building that can be seen in the riparian zone. The rock infiltrations allow for rainwater coming off of the roof to be collected and filtered without damaging the building it surrounds.

NEARSHORE SURVEY

While the habitat assessment survey is a good tool to help identify projects that shoreland owners could implement to reduce stormwater runoff from their property and to improve habitat, it does not provide much to work with in terms of the amount of runoff and nutrient loading that could be reduced by implementing those projects. A Nearshore Survey was also completed in Horseshoe Lake in 2016.

Land use in the nearshore areas within 300-ft of the lake's edge was evaluated by digitizing aerial photos of the lake. In this survey, an estimate of the acreage within the 300-ft zone around the lake covered by roads and driveways, mowed lawn, rooftops, wetland, agriculture, and forest/shrubs was calculated. The total acreage within the 300-ft zone was 376 acres (Table 4, Figure 5). Using the WiLMS model and default values for phosphorus loading, human development (structures, roadways, driveways, and mowed lawn) accounted for 20% of the land use but contributed more than 50% of the nutrient loading from the nearshore area.

Table 4 – Nearshore Digitizing Survey of Horseshoe Lake, Barron/Polk County

2016 Horseshoe Lake Nearshore Area (300-ft inland from waters edge)			
Land Use	Acres	Percentage	TP Load (WiLMS)
Mowed Lawn	39.5	11	54.3
Roads and driveways	21.3	6	
Rooftops (approx. 294 structures)	11.8	3	
Wetlands	26.6	7	4
Agriculture	4.3	1	5.1
Woods/Shrub	272.5	72	36.6
TOTAL	**376**	**100**	**100**

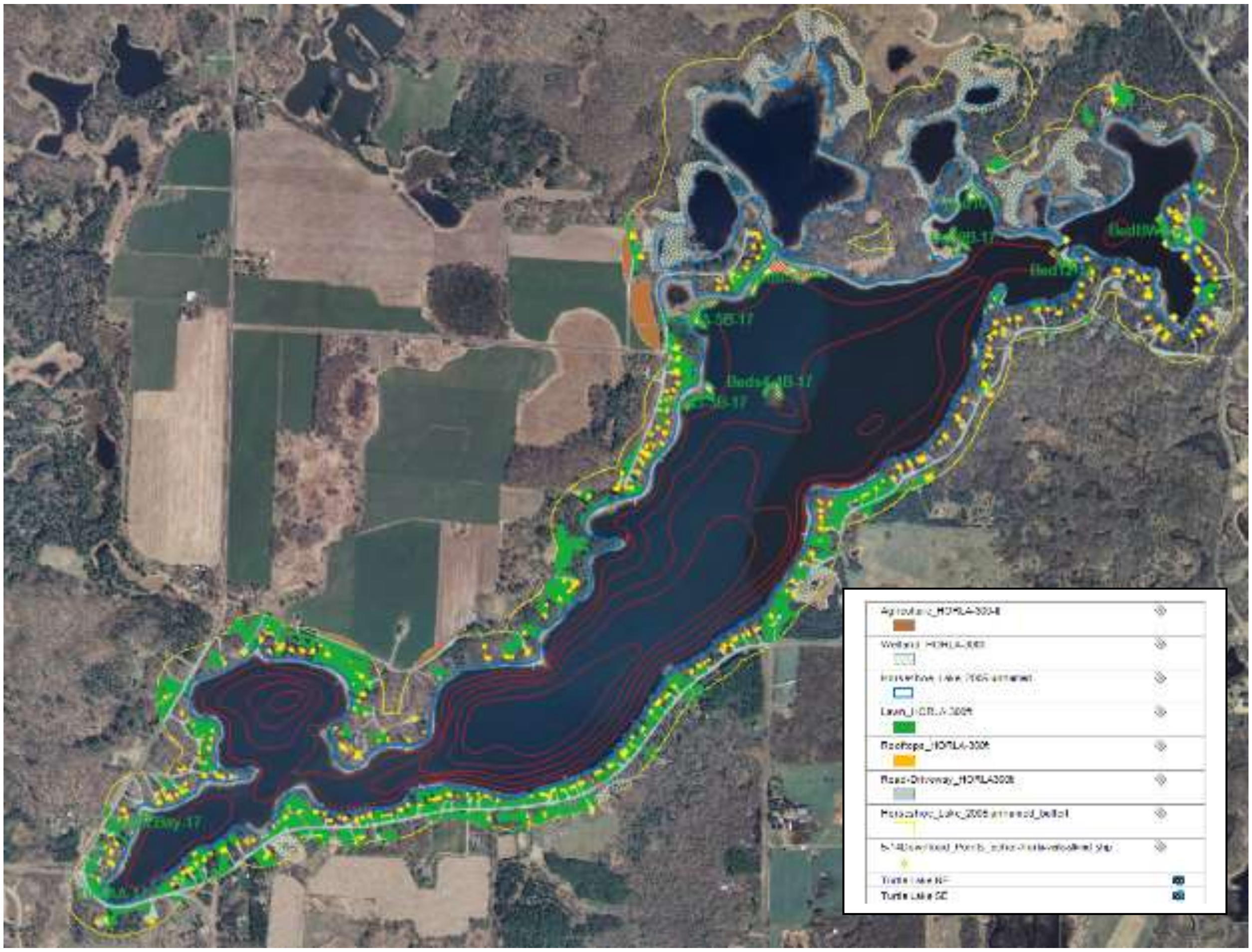
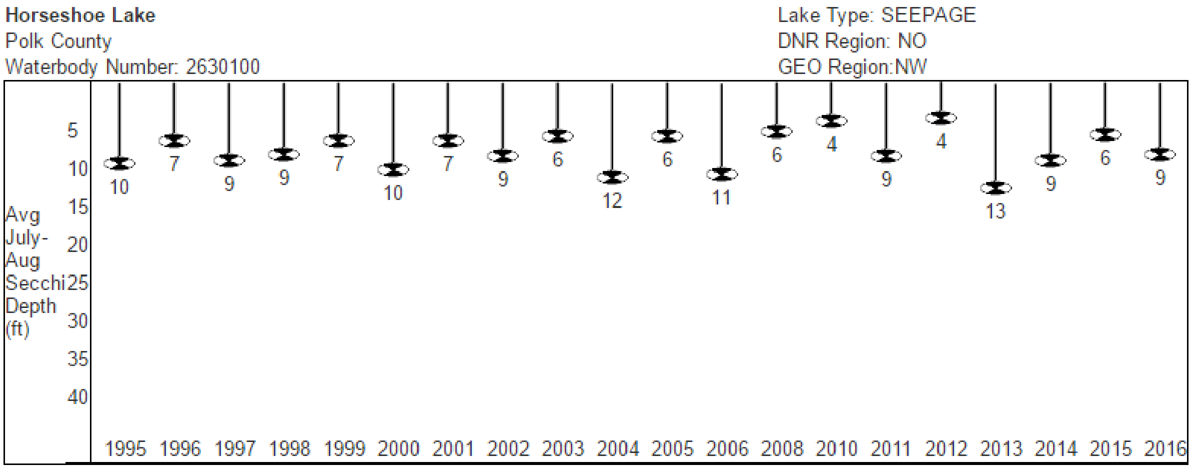


Figure 6 – Nearshore (300-ft) Land Use on Horseshoe Lake, Polk/Barron County

Combined with tributary loading and the bottom sediment phosphorus release study parts of a phosphorus budget can be established. Additional sampling at the outlet of the lake to Echo Lake would be beneficial, particularly if water levels stay high and continues to flow to Echo.

Figure 7 shows the average summer (July-August) Secchi disk readings since CLMN began. In 2016, the average summer (July-Aug) Secchi disk reading for Horseshoe Lake at the Deep Hole was 8.63 feet. This was a full 2.63 feet greater than it was in 2015 despite the ice going out about a week earlier this year than in 2015. The summer average for the Northwest Georegion was 8.4 feet. Typically the summer (July-Aug) water was reported as CLEAR and BLUE. This suggests that the Secchi depth may have been impacted by either algae or the above average rainfall in 2016. The high amount of rainfall experienced in 2016 would have likely stirred up the lake which would have decreased the visibility. Algal blooms are generally considered to decrease the aesthetic appeal of a lake because people prefer clearer water to swim in and look at. Algae are always present in a balanced lake ecosystem. They are the photosynthetic basis of the food web. Algae are eaten by zooplankton, which are in turn eaten by fish.



Past secchi averages in feet (July and August only).

Figure 7 - Average summer (July and August) Secchi disk readings at the Deep Hole

CLMN chemistry data collected in 2016 at the Deep Hole in Horseshoe Lake showed an average summer Chlorophyll level of 5.4ug/l, substantially lower than the 15.0 μg/l recorded in the summer of 2015 and even lower than the summer average for the Northwest Georegion (17.5ug/l). The summer Total Phosphorus average for 2016 was 17.3ug/l, again lower than the summer 2015 average of 17.7μg/l. Lakes that have more than 20μg/l of total phosphorus may experience noticeable algae blooms.

Figure 8 shows the average summer Trophic State Index (TSI) value for total phosphorus, chlorophyll, and Secchi disk readings. The overall Trophic State Index in 2016 (based on chlorophyll) for the Deep Hole in Horseshoe Lake was 48, seven points lower than the 2015 average of 55. The TSI suggests that Horseshoe Lake at the Deep Hole shifted from the eutrophic state seen in 2015 to a mesotrophic state in 2016.

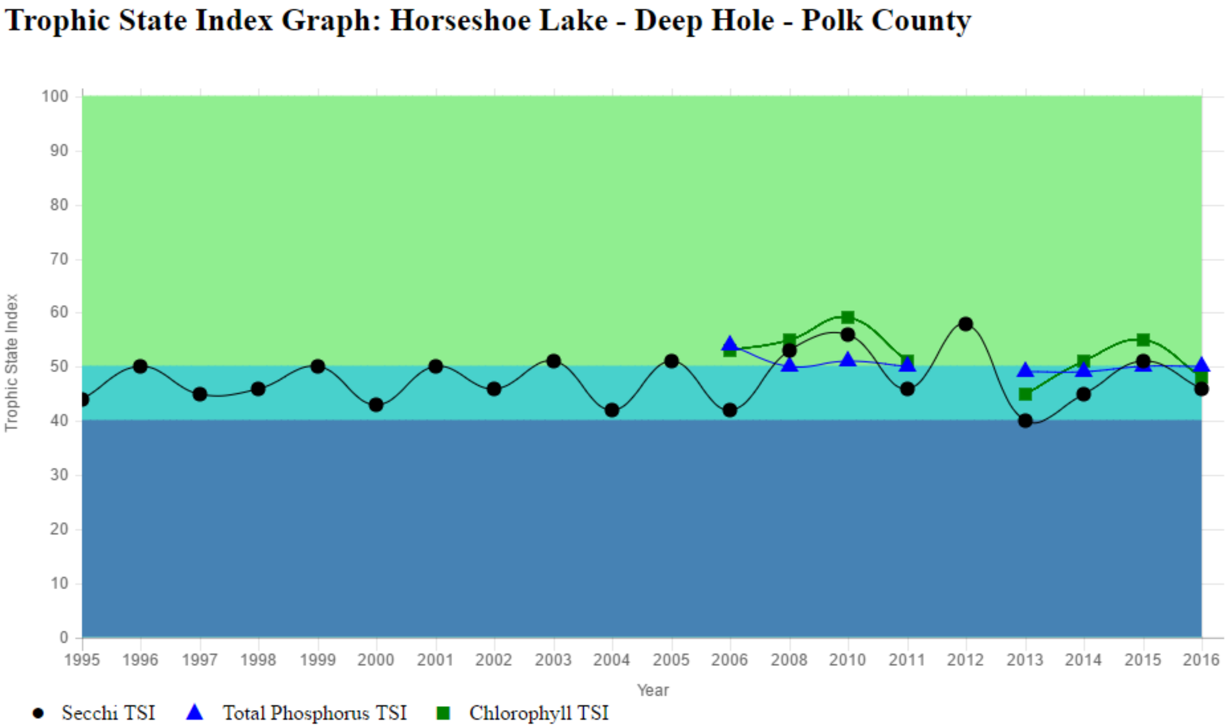


Figure 8 - Summer (July and August) TSI values for total phosphorus and chlorophyll-a at the Deep Hole on Horseshoe Lake

In addition to the regular CLMN water quality monitoring program, the lake management planning grant added sampling twice a month April-October for surface water total phosphorus, orthophosphates, and chlorophyll A. It also included bottom water sampling once a month from April – October for iron, total phosphorus, and orthophosphates. The results of the data are shown in Figures 9-13. Bottom water results for iron, total phosphorus, and orthophosphates will be used by Bill James from UW-STOUT to estimate internal loading in the lake.

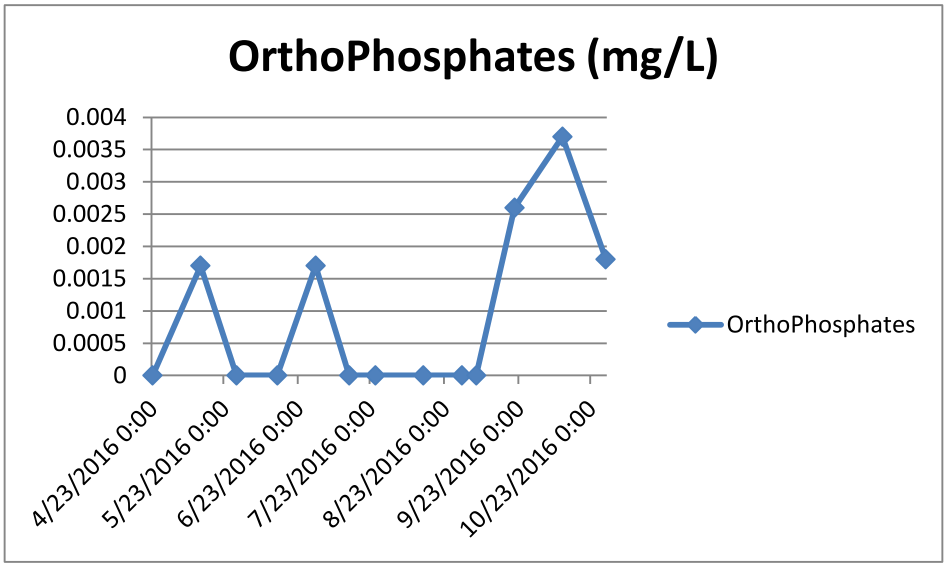


Figure 9 – 2016 Horseshoe Lake Deep Hole Orthophosphate Results (a "zero" value represents "no detect")

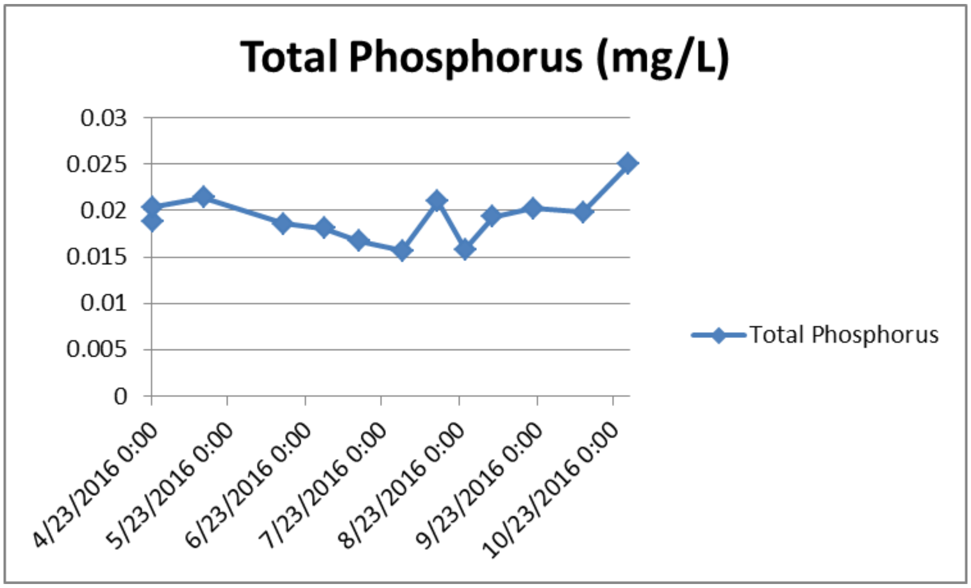


Figure 10 - 2016 Horseshoe Lake Deep Hole Total Phosphorus Results

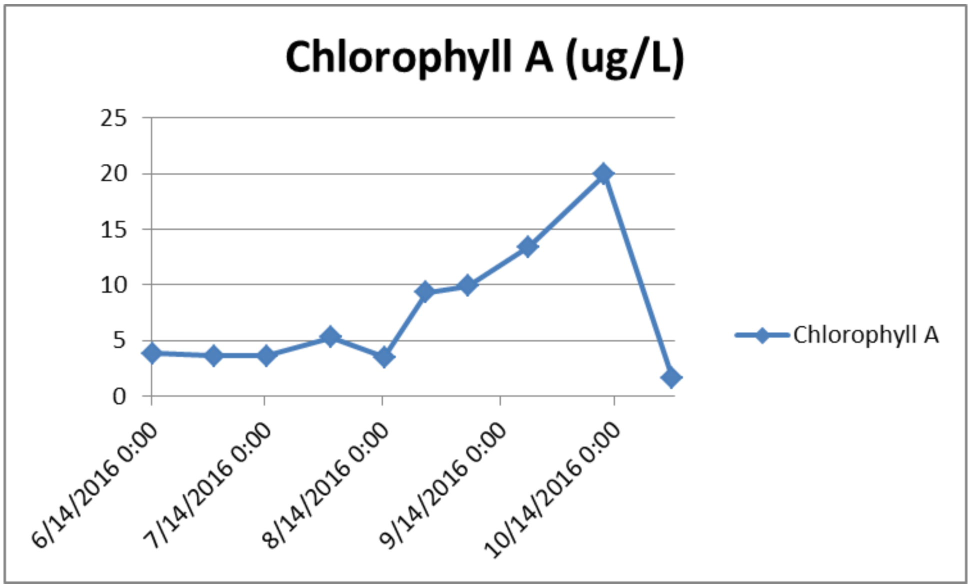


Figure 11 - 2016 Horseshoe Lake Deep Hole Chlorophyll A Results

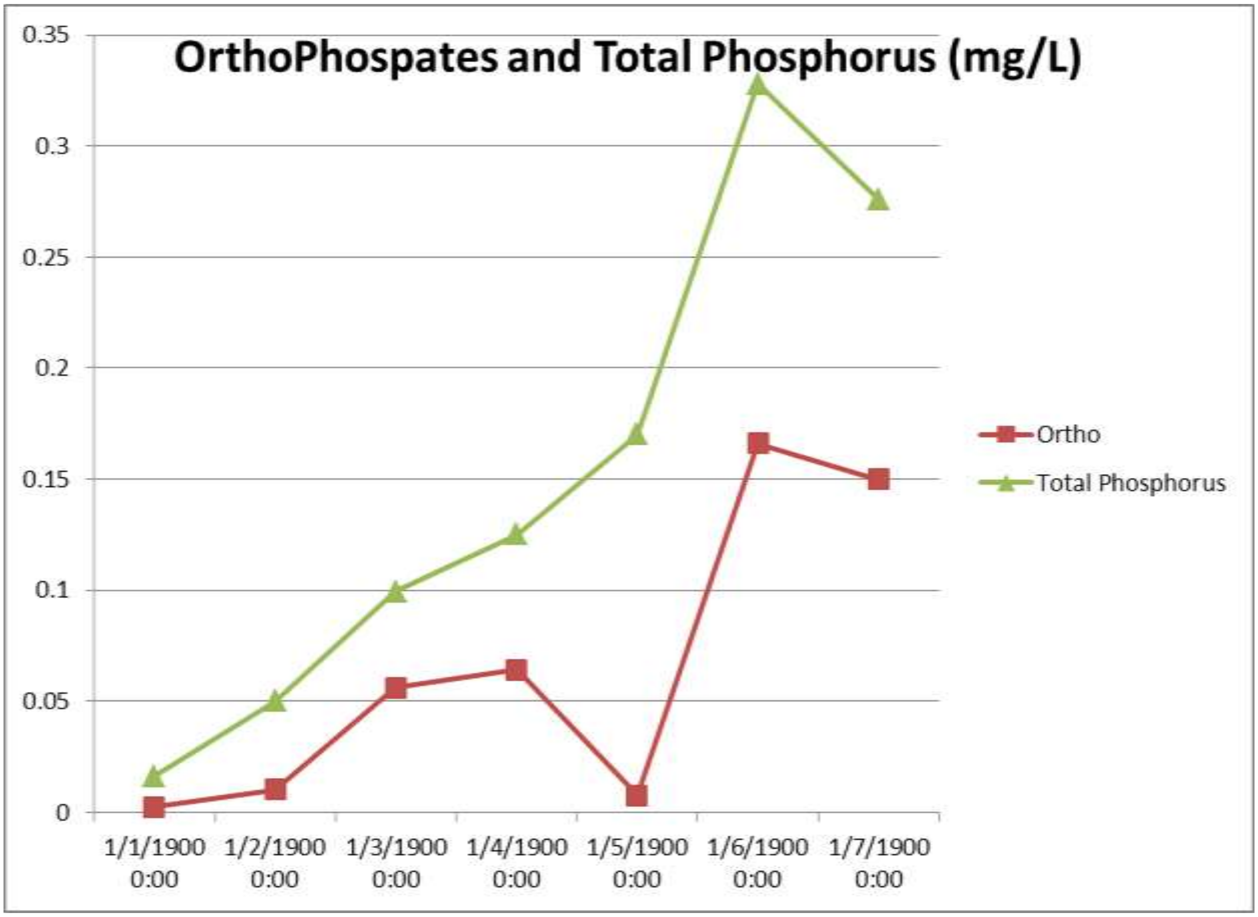


Figure 12 – 2016 Horseshoe Lake Deep Hole Bottom Water Sampling Results

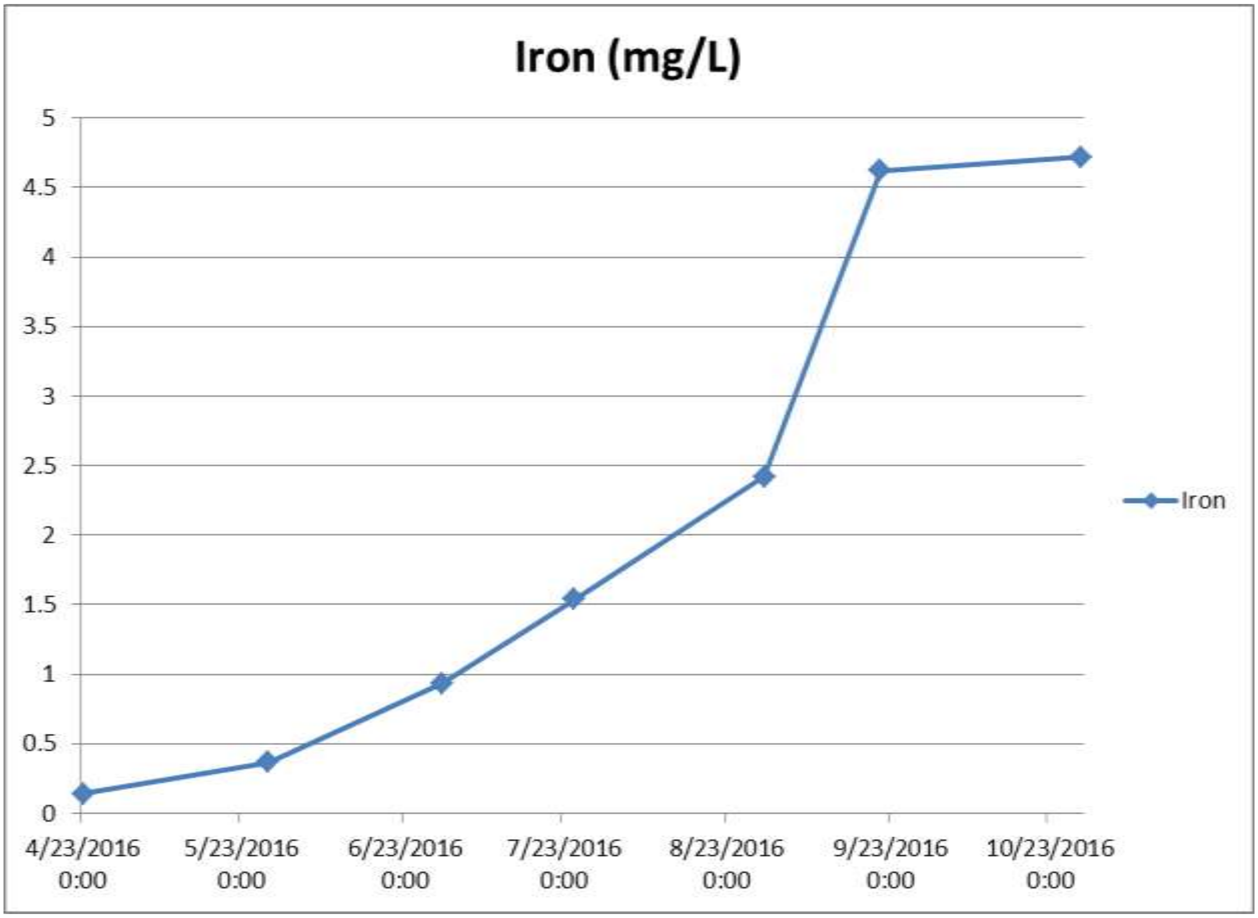


Figure 13 – 2016 Horseshoe Lake Deep Hole Bottom Water Sampling Results - Iron

TRIBUTARY MONITORING

As a part of the 2016-17 lake management planning grant, an attempt was made to monitor flow, volume, and nutrient loading from three tributaries to Horseshoe Lake. The three original sites were: the northern shore of the southwest basin; a tributary off Greatwood Lane on the north central shoreline of the lake; and the inlet from Mud Lake (Figure 14). Unfortunately extremely high water in the spring and early summer basically prevented any meaningful data collection at the Mud Lake inlet as water from the main body of Horseshoe Lake flooded into it. After the first sample completed in April, it was decided to switch from the Mud Lake Inlet site to a site on the South Shore that was draining a wetland complex (Figure 14). Unfortunately this site only had water in it in during the second of four sampling rounds. It was dry the other two dates. The plan was to collect water samples and analyze them for total phosphorus and orthophosphates at four different times during the 2016 open water season. In addition, flow and volume information was to be collected at least two times during the year at all of the sites. Only two of the three sites actually had moving water in them most of the open water season: the site on the SW Basin of the lake and the site at Greatwood Lane. Flow and volume were only recorded on one occasion in late April, and at no other time.

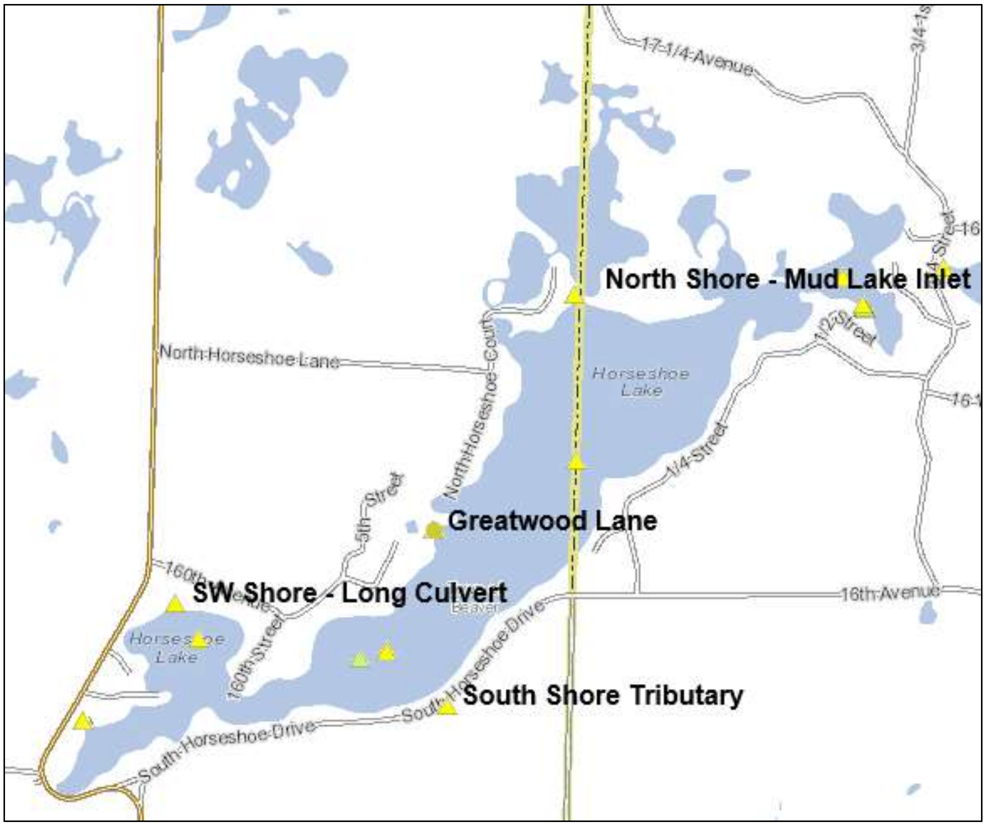


Figure 14 – 2016 Horseshoe Lake tributary sampling sites

Four separate nutrient sampling events were completed at the Greatwood and SW Shore sites. Only one nutrient sampling event was completed at each of the Mud Lake Inlet site and the South Shore tributary site.

Using the flow from the one measuring event and the average total phosphorus concentration over the four sampling events, it was calculated that the Greatwood Lane site carried in approximately 3,373 lbs. of phosphorus over about a 9 month period of open water. The SW Shore site carried approximately 1,221 lbs. of phosphorus into the lake over the same time period. These values are likely exaggerated by a lack of adequate flow and volume data, but do suggest that more phosphorus is being carried into the lake from the agricultural fields just north of the lake, then what is coming in from any of the other tributaries intermittent or otherwise.

2016 was the first year in many that water flowed out of Horseshoe Lake through the manmade outlet to Echo Lake all year. No phosphorus testing was completed in the outlet, nor was any flow/volume calculated. Hence determining nutrient and water budgets for the lake is not possible with this data.

BOTTOM PHOSPHORUS SEDIMENT RELEASE STUDY (UW-STOUT)

Sediment cores were collected from 3 stations in Horseshoe Lake in July, 2016, to examine phosphorus (P) release from sediment under anaerobic conditions and pools of mobile P fractions in the sediment. Overall, rates of P release under anaerobic conditions were moderate, ranging between 2.4 and 3.3 mg/m^2 d. Labile organic P (i.e., sediment P that can be broken down to phosphate by bacteria) dominated the mobile P fraction in the upper 5-cm sediment layer at all stations followed by the iron-bound P fraction. Station 10 and 20 exhibited the highest labile organic and iron-bound P (i.e., subject to release and recycling) concentrations in the upper 5-cm layer. Iron-bound P at these stations fell near the median compared to other lakes. Labile organic P was high at all stations compared to the median. Station 10 and 20 sediment cores exhibited a slight surface concentration maximum in mobile P, suggesting the potential for modest internal P loading. Station 30 mobile P concentrations were relatively constant with increasing sediment depth. This information will need to be combined with information on hypolimnetic anoxia and the Fe:P in order to assess the importance of internal P loading to the P budget and algal blooms in Horseshoe Lake.

As of July 2017, UW-STOUT was still working on the sediment release report modifications necessary with the hypolimnetic anoxia and the Fe:P information. The existing report from UW-STOUT is included as Appendix E.

A HWM treatment proposal was made for 2017 that includes 10 beds totaling 4.14 acres using Navigate granular herbicide at 3.5 and 4.0 ppm. The concentration of herbicide used depends on bed size and average depth of the treatment area (Table 5, Figure 15). The HWM treatment for 2017 was proposed according to the new guidelines suggested in the new APM Plan. A EWM Readiness Survey was completed by LEAPS prior to application of herbicide. No post treatment survey will be completed however a fall EWM bed mapping will be completed in late summer or early fall.

Table 5 - 2017 HWM Herbicide Management Proposal

2017 Horseshoe Lake Hybrid EWM FINAL Treatment Proposal Details - Revised 5-23-2017 for high water (LEAPS)							
Name	**Acres**	**Mean Depth (feet)**	**Acre-Feet**	**Target 2,4-D (ppm a.e.)**	**Navigate Application (pounds)**	**Navigate Dose (pounds/acre)**	**NOTES**
BedAA-17	.11	5.00	0.6	4.0	31.2	284	
BedBLBay-17	.14	5.00	0.7	4.0	39.8	284	Boat Landing
Beds3-3B-17	.33	5.00	1.7	4.0	93.7	284	
Beds4-4B-17	.34	5.50	1.9	4.0	106.2	312.4	
Beds5A-5B-17	.55	5.00	2.8	4.0	156.2	284	
Bed6-17	1.50	5.00	7.5	4.0	426.0	284	Treated in 2016, poor results, high water
Bed9B-17	.44	5.00	2.2	4.0	125.0	284	
BEd10-17	.27	5.00	1.4	4.0	76.7	284	
Bed12-17	.36	5.00	1.8	4.0	102.2	284	
BdBWBay-17	.10	3.50	0.4	3.5	17.4	173.95	
TOTAL	***4.14***		***20.72***		***1174.4***	*276*	

Figure 15 - 2017 Proposed treatment areas (in red): West, Central, and East Basins

A WDNR permit request for herbicide application was completed and approved by the WDNR. Treatment occurred on May 24, 2017 from 2:00-6:00pm. Water temperature was 53 F and air temperature was 60 F. Wind was from the north at 1.5 mph.

FUTURE MANAGEMENT PLANNING ACTIONS

UW-STOUT still needs to revise its initial report on internal loading to reflect the iron and phosphorus data collected from the bottom waters of the lake. This report will further help to define the role of internal loading in the water turning green. Water quality/clarity monitoring in 2017 will be interesting due to the fact that high water levels have been maintained now through 2016 and 2017. The high water will have an impact on the lake and the vegetation in it, the question is will that be a positive impact with better water quality and less HWM, or will it be a negative impact with worsening water quality and an increase in the amount of HWM identified.

Additional flow and volume data needs to be collected from the two main tributaries to the lake at Greatwood Lane and on the SW Shore. Nutrient sampling and flow and volume should be considered at the outlet from Horseshoe to Echo Lake. The amount of water flowing out of the lake and the amount of phosphorus in that water would be needed to determine a water budget, and to better determine a nutrient budget. Drafting a Comprehensive Lake Management Plan with existing and some new data, focused on what could be done to further reduce nutrients, and written in a manner such that it covers the 9-Key Elements now promoted by the WDNR.

HWM management planning and implementation should continue in 2018 and beyond, in an effort to hold its distribution to only a few acres annually. If this is not done, it is likely that HWM will continue to spread into new areas, and increase its density in existing areas.

Continued education of the constituency is important for maintaining lake health in a variety of different categories. As a Lake District, funding is easier to come by when needed to support HWM management, water quality management, and public education and involvement.

With the completion of this grant funded project, additional grant funding could be sought, but at the present time, is not a pressing need. A Clean Boats Clean Waters grant should be sought moving into 2018, but even that is not a pressing need, particularly if the Lake District does not do management supported by grant funds in 2018. No grant funds means the freedom to not do CBCW or other monitoring activities. Maintaining HWM levels in the 5-10 acres range annually can be supported in full by the Lake District.

Future grant funding requests might be better focused on development of a Comprehensive Lake Management Plan focused on water quality.

References

Berg, Matthew S. 2015. Hybrid Eurasian x Northern Water Milfoil Pre/Post-treatment and Fall Bed Mapping Surveys Horseshoe Lake – WBIC 2630100 Polk/Barron County, WI

Berg, Matthew S. 2016. Hybrid Eurasian x Northern Water Milfoil Fall Bed Mapping Survey Horseshoe Lake – WBIC 2630100 Polk/Barron County, WI

Appendix A – 2016 AIS Monitoring End of Season Report

State of Wisconsin
Department of Natural Resources
Wisconsin Lakes Partnership

Aquatic Invasives Surveillance Monitoring
End of Season Report

Form 3200-133 (02/10)

This monitoring is designed to help detect new invasive species on your lake, so DNR can be alerted and lake residents and/or professionals can respond appropriately. The purpose of the DNR collecting this data is to let us know what methods trained citizens and professionals use when actively looking for aquatic invasive species. You are often the ones to alert us of new invasives in our waters. Remember for surveillance monitoring, a report of "no invasive" at a location is just as important as finding an invasive. One cannot confidently state that the invasive is not present in an area if no one has looked and reported their findings. Knowing where invasives are not, as well as where they are, is extremely important in being able to track and understand their spread. Knowing how often monitors are looking for species and what they are finding is very important information.

Notice: Information on this voluntary form is collected under ss. 33.02 and 281.11, Wis. Stats. Personally identifiable information collected on this form will be incorporated into the DNR Surface Water Integrated Monitoring System (SWIMS) Database. It is not intended to be used for any other purposes, but may be made available to requesters under Wisconsin's Open Records laws, ss. 19.32 - 19.39, Wis. Stats.

Data Collectors

Primary Data Collector Name Marie Hauser	Phone Number 612-247-7725	Email mariehauser7@gmail.com
Additional Data Collector Names		
Total Paid Hours Spent (# people x # hours each)	Total Volunteer Hours Spent (# people x # hours each) 38 hrs	

Monitoring Location

Waterbody Name Horseshoe Lake	Township Name 2630100	County Barron/Polk	Boat Landing (if you only monitor at a boat landing)

Dates Monitored

Start Date (when you first monitored this season) 6/6/2016	End Date (when you last monitored this season) 8/27/2016

Did at least some data collectors monitor in... May? June? July? August? (circle all that apply)
May - No, June - Yes, July - Yes, August - Yes

Did you monitor…	Did you…
All Beaches and Boat Landings? [✓ Frequently] Some of the Time Not Often/Never	Walk along the shoreline? Frequently [✓ Some of the Time] Not Often/Never
Perimeter of whole lake? [✓ Frequently] Some of the Time Not Often/Never	Observe entire shallow water area (up to 3 feet deep)? Frequently Some of the Time Not Often/Never
Docks or piers? Frequently [✓ Some of the Time] Not Often/Never	Use rake to extract plant samples? Frequently [✓ Some of the Time] Not Often/Never
Other: ____________	Check underwater solid surfaces (boat hulls, dock legs, rocks)? Frequently [✓ Some of the Time] Not Often/Never
	Other: ____________

Did you find…(even if not a new finding for the lake or stream)

Banded Mystery Snail?	Yes [✓ No] Did not look for	Hydrilla?	Yes No [✓ Did not look for]
Chinese Mystery Snail?	[✓ Yes] No Did not look for	Purple Loosestrife?	[✓ Yes] No Did not look for
Curly-Leaf Pondweed?	Yes [✓ No] Did not look for	Rusty Crayfish?	Yes No [✓ Did not look for]
Eurasian Water Milfoil?	[✓ Yes] No Did not look for	Spiny Waterfleas?	Yes No [✓ Did not look for]
Fishhook Waterfleas?	Yes No [✓ Did not look for]	Zebra Mussels?	Yes [✓ No] Did not look for
Freshwater Jellyfish?	Yes No [✓ Did not look for]	Other?: ____________	

If you find an aquatic invasive
If you find an aquatic invasive and it is not listed at http://dnr.wi.gov/lakes/AIS fill out an incident report for the species. Then bring the form, a voucher specimen if possible, and a map showing where you found it to your regional DNR Citizen Lake Monitoring Coordinator as soon as possible (to facilitate control if control is an option).

If you don't find an aquatic invasive
If you submit your data online, that is all you need to do. Otherwise, please mail a copy to your regional DNR Citizen Lake Monitoring Coordinator. http://dnr.wi.gov/lakes/contacts

Appendix B – HWM Identification and Removal Workshop Flyer

Attention Horseshoe Lake Property Owners & Area Residents

Horseshoe Lake Aquatic Plant and Water Milfoil Identification and Management Workshop

presented by the Horseshoe Lake Improvement Association

WHEN - July 9th, 2016 *from* 10:00 AM-12:15 PM

WHERE - Horseshoe Lake Public Landing

PRESENTED BY - Dave Blumer, Lake Education & Planning Services, LLC

THREE SESSIONS OFFERED

45 MINUTES EACH

Attend as few as one or all that interest you.

Complete descriptions of each session are available at ***hlake.org***

Session 1

10:00 AM to 10:45 AM "Dry Ground Aquatic Plant and Milfoil Identification Training"
Discussion of the importance of aquatic plants, plant samples, identification materials, and hands-on learning.

Session 2

10:45 AM to 11:30 AM "On the Water" identification of aquatic plants in Horseshoe Lake.
FOR THIS WE WILL NEED A FEW PONTOONS TO ACCOMPLISH - PLEASE EMAIL PAM TO OFFER...

Session 3

11:30 AM to 12:15 PM "In and On the Lake Demonstration and Training"
Learn how to remove the bad plants in efficient and environmentally friendly ways. Choose to experience hand-pulling while wading, snorkeling, and even with the aid of the SNUBA underwater diving set-up or rake pulling from a boat.

"NEW OWNERS" - This is a great opportunity to experience what has been done to keep Horseshoe Lake a beautiful body of water. Many have expressed an interest in the snuba wondering how it works. This is your chance to see first hand.

THANK YOU for taking time at the lake to participate. This is a component of our current grant - your attendance in appreciated.

****EXCITING NEWS**** - Beaver Township has approved an offer from Scott Fortune of Highland Floatation Systems, to install a dock at the landing on a "three season free trial" for the remainder of 2016 thru 2018. Scott will maintain it and it does not have to be removed during the winter. He lives on the lake and is an awesome steward of the lake...a heartfelt thanks to Scott and Sarah for their generosity!

THANK YOU! - PAM NELSON, DAVE BLUMER, JOE WALDO, CRAIG AND LAURA NACKERUD AND MANY OTHER VOLUNTEERS!

Appendix C – PowerPoint Presentation from Annual Meeting

Horseshoe Lake Annual Meeting

Saturday May 28, 2016

Business as Usual!!

How Does Work on a Lake Get Done?

- **Lake Association**
  - Members identify concerns and issues, projects to support
  - Annual dues and donations provide initial funding for projects
  - Eligible for grant assistance and seeks grant funding whenever possible
  - Tries to get and keep member involvement in projects
  - Board Members elected by the constituency
  - Listens to all people on the lake, but answer really only to the paying members
  - Relies on volunteers and paid personnel

- **Lake District**
  - Members identify concerns and issues, projects to support
  - Annual tax and donations provide initial funding for projects
  - Eligible for grant assistance and seeks grant funding whenever possible
  - Tries to get and keep member involvement in projects
  - Board Members elected by the constituency
  - Listens to all people on the lake and **has** to answer to **all** people on the lake
  - Relies on volunteers and paid personnel

Either way, things need to and do get done, that does not change!!

So, in terms of lake management, it is business as usual!

Aquatic Invasive Species

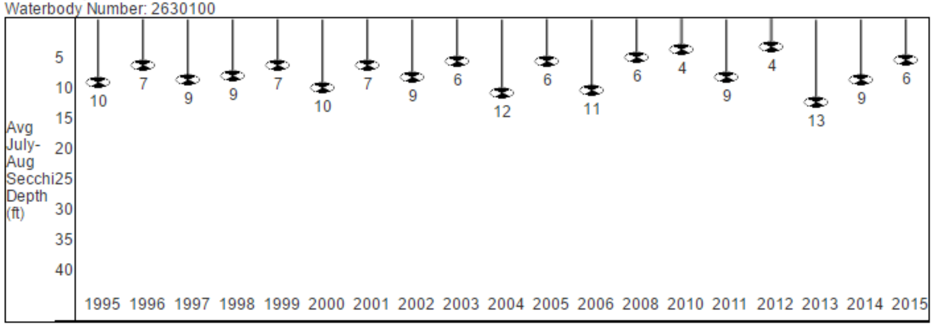
Water Quality

Fun and Games

2016 Lake Management Planning Grant

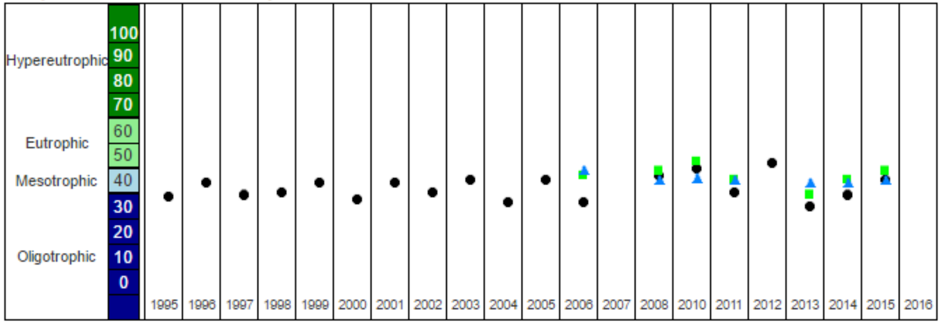
- **Focused on Water Quality**
  - Water quality is the driving factor for lake health.
  - Why does water clarity fluctuate so much year to year?
  - Are any of the sources of phosphorus and other nutrients out of whack?
    - Inflow (watershed)
    - Internal loading
    - Nearshore area
  - Should something be done to address water quality?
  - If so, what?

Horseshoe Lake
Polk County
Waterbody Number: 2630100



Past secchi averages in feet (July and August only).

Trophic State Index Graph



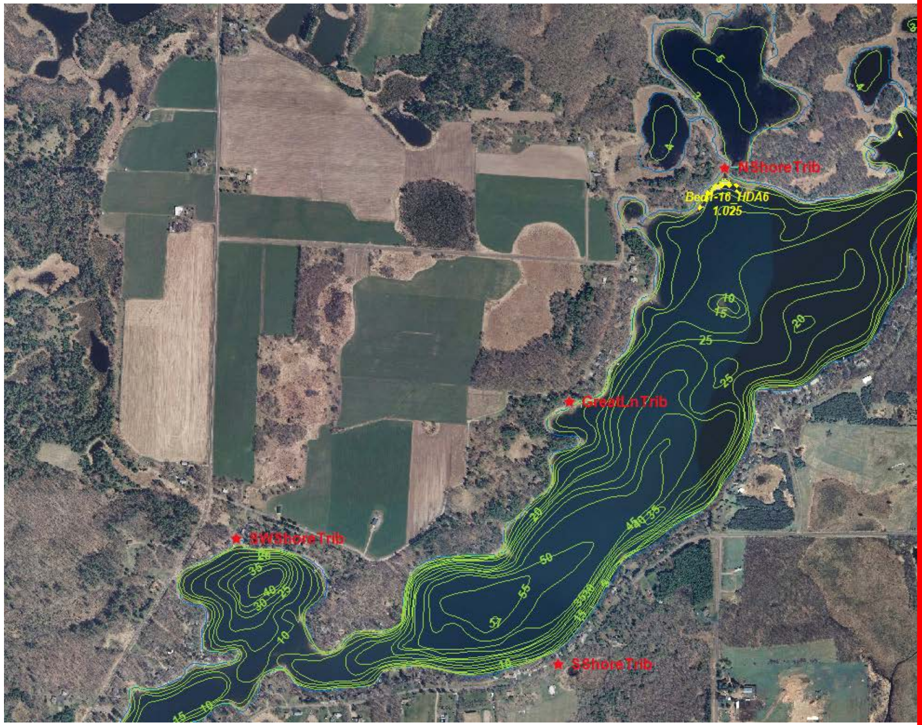
Monitoring Station: Horseshoe Lake - Deep Hole, Polk County
Past Summer (July-August) Trophic State Index (TSI) averages.

Water Quality Actions in the New Grant

- **Lake water quality data**
  - Water clarity, total phosphorus, dissolved phosphorus, iron, chlorophyll, dissolved oxygen, and temperature
  - Surface water and bottom water sampling
  - Twice a month instead of once a month
  - Sediment Release Study completed by UW-STOUT Discovery Center

Tributary Monitoring (Watershed Loading)

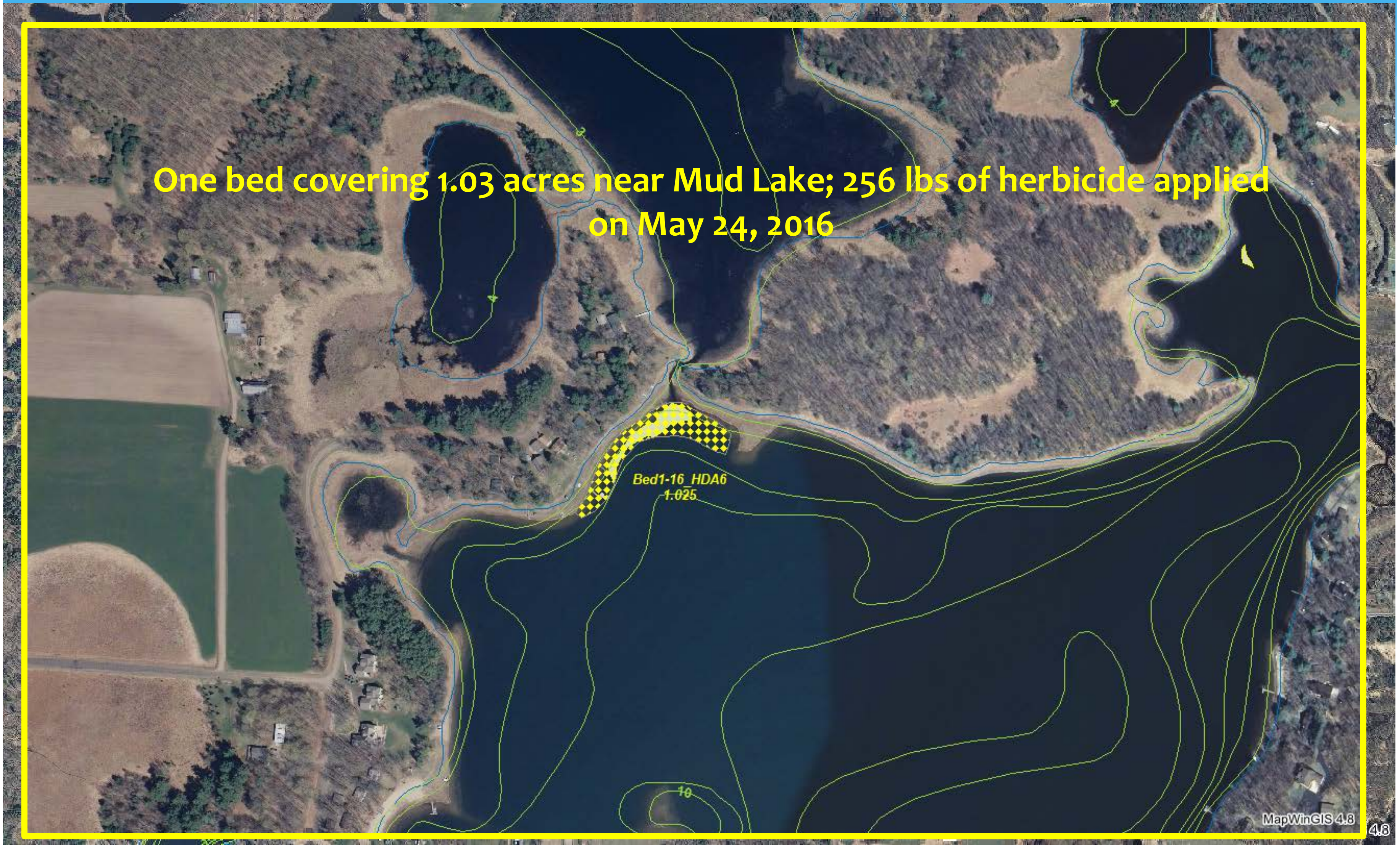
- **Precipitation monitoring**
  - **Lots of rain in the last couple of days, is anyone monitoring it? Someone should be, it's in the grant!**
  - **CoCoRaHS**
    - **Co**mmunity
    - **Co**llaborative
    - **R**ain, **H**ail, and **S**now
    - Network
- **Tributary Monitoring**
  - **Three sites**
  - **Four times**
    - Total phosphorus
    - Dissolved phosphorus
    - Flow and volume



2016 Lake Management Planning Grant

- **Dealing with aquatic invasive species (AIS) is still included in the new project**
  - Hybrid EWM
  - Purple Loosestrife
  - Curly-leaf Pondweed
- **Project includes management planning, AIS education and monitoring, and aquatic plant survey work**
- **Project does not include any funding for actual AIS management (herbicide in the water)**

2016 Hybrid EWM Treatment Preliminary Proposal



One bed covering 1.03 acres near Mud Lake; 256 lbs of herbicide applied on May 24, 2016

EWM Concerns

- What will the normal or high water in the lake do to the distribution and density of EWM?
- More water probably means more habitat to grow EWM.
- Will the water become or stay clear this summer?
  - If it does, EWM could be all over the place.
- Be prepared to complete some physical removal adjacent to your property in shallow water!!
  - Training for identification and physical removal is scheduled for later this summer!

Other things for you to do!

Tasks	Lake Organization Responsibilities	When
1	2016 EWM management planning (8 hrs)	Feb-June
2	Pre-treatment readiness survey (4 hrs, provide a boat and driver)	May
3	NA	NA
4	EWM Identification and Physical Removal Workshop (16 hrs, 6 hrs boat use)	early July
5	AIS Monitoring three times in 2016 (18 hrs, 9hrs boat use)	June, July, Sept
6	June Draining Campaign, 4th of July Landing Blitz (8 hrs)	June, July
7	Plan and coordinate a Lake Fair in 2016 (24 hrs)	August
8	Shoreland Survey: Georeferencing, Parcel Assessment, and Woody Debris Survey; GIS Mapping and Assessment (24 hrs volunteer time for training and collecting of data, [illegible]0 hrs boat use)	June-July
9	NA	NA
10	Tributary monitoring (flow, volume, TP, DRP) (18 hrs training, sample collecting, and assisting the consultant)	snowmelt and three runoff events (Apr-Oct)
11	Precipitation Monitoring/participation in CoCoRaHS (1 volunteer, 8 hrs)	Apr-Oct
12	Lake water sampling (Surface TP, Bottom TP, Bottom iron, Top DRP, Bottom DRP, Secchi, DO, Temp monthly) at the deep hole (56 hrs training, data collection and processing, 21 hrs of boat use)	Apr-Oct
13	Grant Admistration, record keeping, reimbursement requests (40 hrs)	Feb2016 - Jun2017

The End

Appendix D – Woody Habitat Survey Map

Horseshoe Lake Woody Debris Survey

To be considered as woody debris in this survey, wood must be at least 5 feet long and 4 inches in diameter, and in water that is no deeper than 2 feet.

LEAPS
Lake Education and Planning Services

Appendix F – UW-STOUT Sediment Release Study Report

Internal Phosphorus Loading and Sediment Phosphorus Fractionation Analysis for Horseshoe Lake, Wisconsin

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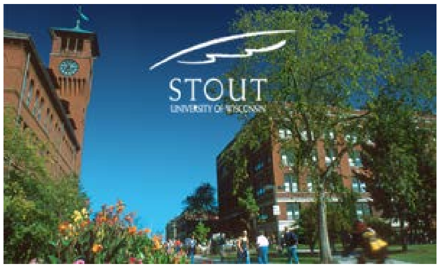
Google Maps

5 December, 2016

University of Wisconsin – Stout
Discovery Center - Sustainability Sciences Institute
Center for Limnological Research and
Rehabilitation
Menomonie, Wisconsin 54751
jamesw@uwstout.edu



SUMMARY

Sediment cores were collected from 3 stations in Horseshoe Lake in Juley, 2016, to examine phosphorus (P) release from sediment under anaerobic conditions and pools of mobile P fractions in the sediment. Overall, rates of P release under anaerobic conditions were moderate, ranging between 2.4 and 3.3 mg/m^2 d. Labile organic P (i.e., sediment P that can be broken down to phosphate by bacteria) dominated the mobile P fraction in the upper 5-cm sediment layer at all stations followed by the iron-bound P fraction. Station 10 and 20 exhibited the highest labile organic and iron-bound P (i.e., subject to release and recycling) concentrations in the upper 5-cm layer. Iron-bound P at these stations fell near the median compared to other lakes. Labile organic P was high at all stations compared to the median. Station 10 and 20 sediment cores exhibited a slight surface concentration maximum in mobile P, suggesting the potential for modest internal P loading. Station 30 mobile P concentrations were relatively constant with increasing sediment depth. This information will need to be combined with information on hypolimnetic anoxia and the Fe:P in order to assess the importance of internal P loading to the P budget and algal blooms in Horseshoe Lake.

BACKGROUND

Phosphorus (P) is a key nutrient that usually limits primary production in freshwater systems. Increased or excess P loading can lead to cultural eutrophication, degradation of water quality, and development of toxic cyanobacterial blooms (Boström et al. 1982, Carpenter et al. 1998, Smith et al. 1998, Cooke et al. 2005, Elser et al. 2007, Havens 2008). Excessive anthropogenic P loading also leads to various problems, such as loss of oxygen, fish kills, and a loss of biodiversity within the lake (Smith and Schindler 2009). Phosphorus sources can originate from the watershed (i.e. external loading) or from P stored as sediment that is later released and recycled into the water column for uptake by algae (i.e. internal loading; Boström 1984, Jeppesen et al. 2005, Mortimer 1941,1942, Nürnberg et al. 1986; Sondergaard et al. 2001). It is important to quantify external and internal P loading in order to identify important P sources for targeted management strategies.

Tributary soluble P loads are immediately available for algal uptake. Particulate P loads can be deposited as sediment and recycled back into the water column through internal P loading mechanisms (Boström et al. 1982; Carey and Rydin 2011, Mortimer 1942, 1971). Recycling of P from the lake sediment to the water column may play an important role in the P budget of lakes, contributing up to 80% of the total P input (Carey & Rydin 2011, Carpenter 2003, 2005, James et al. 2016, Penn et al. 2000). As a result, internal P loading may mask the effects of external nutrient load reductions and delay lake recovery (Ahlgren 1978, Boström 1984, Cooke et al. 2005, Larsen et al. 1981, Rossi and Premazzi 1991, Ryding 1981, Welch et al. 1986).

Mortimer (1942) described a model for sediment P recycling where PO_4^{3-} was initially adsorbed to iron oxyhydroxides or bound as ferric phosphate under aerobic conditions at the thin sediment oxidized microzone (i.e. on the order of mm in thickness) located at the sediment-water interface. Under anaerobic conditions, bacterially mediated reduction of Fe^{3+} to Fe^{2+} resulted in desorption of PO_4^{3-} into pore water and diffusion into the overlying water column. Soluble Fe^{2+} and PO_4^{3-} accumulation in the anoxic hypolimnion over the summer can be accessed directly by vertically migrating algae for growth (James et al. 1992). If there is sufficient Fe relative to P (Fe: P ratio > ~ 3.6:1 mass: mass; Gunnars et al. 2002) in the hypolimnion at turnover, chemical oxidation of Fe during mixing and reaeration is accompanied by adsorption and precipitation of PO_4^{3-} and deposition back to the sediment. Thus, iron oxidation-reduction can regulate P release and availability to algae under this scenario.

However, Hasler and Einsele (1948), Caraco et al. (1991, 1993), Kleeberg and Kozerski (1997), Golterman (2001) and others suggested that reduction of sulfate in sediment and reaction with Fe^{2+} to insoluble and inert $FeS_{x\ (solid)}$ disrupted Fe control of P by burying Fe from further interaction with PO_4^{3-}. As soluble Fe becomes depleted and the Fe: P ratio declines below ~ 3.6: 1 in the hypolimnion, soluble P can become directly entrained into the epilimnion for uptake rather than removed back to the sediment during mixing and reaeration (James et al. 2016).

Fe~(OOH)~PO_4 or redox-sensitive P can be quantified via extraction with a strong reducing agent (dithionite-bicarbonate; BD; Nürnberg 1988). Additionally, biologically-labile P in the form of bacterial polyphosphates and labile organic P compounds and can be recycled to the overlying water column via mineralization and metabolic breakdown and is extracted with a basic solution (0.1 to 1.0 N NaOH; Psenner and Puckso 1988). Thus, the size of the biologically-labile P pool (i.e., redox-P and labile organic P; subject to recycling and internal P loading) in surface sediment can be quantified for evaluation and be compared to other systems to assess the potential importance as a source of P recycling in lakes.

OBJECTIVES

The objectives of this investigation were to determine rates of phosphorus (P) release from sediments under laboratory-controlled anaerobic conditions and to quantify biologically-labile (i.e., subject to recycling) P fractions for sediment collected in Horseshoe Lake, WI. Findings from this research will be important in evaluating the importance of internal P loading to the overall P economy of the lake.

APPROACH

Laboratory-derived rates of P release from sediment under anaerobic conditions: Sediment cores were collected from 3 stations (Figure 1 and Table 1) in Horseshoe Lake in July, 2016, for determination of rates of P release from sediment under anaerobic conditions (Figure 2). 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 the 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 (20 ^{o}C). The oxidation-reduction environment in the overlying water was controlled by gently bubbling nitrogen (anaerobic conditions, 2 replicates per station) through an air stone placed just above the sediment surface in each system (Figure 3). Bubbling action insured complete mixing of the water column but did not disrupt the sediment.

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) 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: Additional sediment cores collected from station 10, 20, and 30 were sectioned vertically over the upper 20-cm layer to evaluate variations in sediment physical-textural and chemical characteristics. These cores were sectioned at 1-cm intervals over the first 6 cm, at 2-cm intervals between 6 and 10 cm, and at 2.5-cm intervals below 10 cm. Sections were analyzed for moisture content (%), sediment density (g/cm^3), loss on ignition (i.e., organic matter content, %), loosely-bound P, iron-bound P, labile organic P, and aluminum-bound 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 550 ^{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; Table 2). 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 represent 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 collectively represent 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. But it provides important background information if an alum treatment is being considered to reduce internal P loading.

RESULTS AND INTERPRETATION

P mass and concentration increased approximately linearly in the overlying water column of sediment systems maintained under anaerobic conditions (Figure 4). Linear increases in P concentration between day 0 and 7 were used in rate calculation. The mean P concentration maximum in the overlying water end of the incubation period was moderate for all stations. It was greatest in station 10 (0.225 mg/L) and 20 (0.231 mg/L) and lower for station 30 (0.115 mg/L) sediment incubation systems (Table 3). The mean rate of P release under anaerobic conditions was also moderate to moderately low, ranging between 2.4 and 3.3 mg/m^2 d (Table 3) but indicative of mesotrophic to eutrophic conditions (Nürnberg 1988). Compared to other lakes in the region, the anaerobic P release rates for Horseshoe Lake sediments fell near but below the median for station 10 and 20 sediment cores (Figure 5). The anaerobic P release rate from station 30 sediments fell below the lower 25% quartile compared to other lakes in the region (Figure 5).

Averaged over the upper 5 cm, sediment moisture content was very high, while wet and dry bulk densities were low (i.e., low mass of sediment per volume), for all stations in Horseshoe Lake, suggesting very flocculent sediments with high porosity (i.e., high volume of interstitial spaces for porewater; Table 4). Organic matter content in the 5-cm surface layer was moderate high, ranging between 33% and 39% (Table 4). Organic matter content reflects labile (i.e., can be used in bacterial metabolism) and refractory (i.e., resistant to bacterial breakdown) organic carbon.

Vertically in the sediment column, sediment moisture content was very high in the surface 1-cm section at all stations, exceeding 95% (Figure 6). Moisture content declined and was relatively constant below 5 cm; however, it exceeded 90% again suggesting very flocculent sediment consisting primarily of porewater. Sediment densities were very low in the upper 5 cm, approaching that of water (i.e., 1 g/cm^3), and increased with increasing sediment depth. This pattern is typical and reflects sediment compaction over time (i.e., compression and consolidation of deeper sediment). Organic matter content tended to be higher in the surface sediments and declined with increasing sediment depth, exhibiting a minimum at ~ 5 to 7 cm, particularly at station 10 and 20. Organic matter content then increased slightly below ~ 7 cm at all stations. This pattern may reflect historical watershed loading patterns to the lake.

The biologically-labile P (i.e., subject to recycling back to the overlying water column; loosely-bound P, iron-bound P, and labile organic P) in the upper 5-cm sediment layer was moderately high, ranging between 1.12 mg/g and 1.24 mg/g at station 10 and 20 and 0.82 at station 30 (Figure 7 and Table 5). Labile organic P accounted for over 50% of the biologically-labile P fraction in the upper 5 cm at all stations, ranging between 0.65 mg/g and 0.74 mg/g (Figure 7). Concentrations of this fraction were also high relative to other lakes in the region (Figure 8). Iron-bound P was the next dominant biologically-labile P fraction (Figure 7) and concentrations fell above the median compared to other lakes in the region, particularly for the upper 5-cm sections from station 10 and 20 (Figure 8). Iron-bound P was much lower in the upper 5 cm of the station 30 sediment core, falling within the lower 25% quartile compared to regional lakes (Figure 7 and 8). Loosely-bound P represented < 1% of the biologically-labile P at all stations (Figure 7) and were relatively low compared to other lakes in the region (Figure 8). Aluminum-bound P concentrations in the upper 5-cm sediment layer were also relatively high (Figure 8). Overall, redox-P concentrations fell near the median while biologically-labile P concentrations were well above the median compared to other lakes in the region (Figure 9). The latter pattern was attributed to high labile organic P.

Vertically in the sediment column, labile organic P was the dominant mobile P fraction at all stations (Figure 10). Concentrations of labile organic P and iron-bound P exhibited a surface peak in the station 10 core. Peak labile organic P concentrations were also observed between 0 and 4 cm at station 20 and at the sediment surface (0 to 1 cm) at station 30. However, iron-bound P concentrations were relatively constant below the sediment surface section at all stations. Overall, vertical profiles in redox-P and biologically-labile P at station 10 suggested only a very modest to no buildup of potentially-mobile P in the upper sediment layer. In contrast, surface P concentration maxima in eutrophic lake sediments reflect high deposition and recycling in excess of diagenesis and burial (Carey and Rydin 2011, Malmaeus et al. 2012). Concentrations of these constituents were nearly constant versus increasing sediment depth at station 20 and 30, suggesting negligible accumulation of potentially mobile P in the surface sediments.

RECOMMENDATIONS

Sediment internal P loading from anaerobic sediment in Horseshoe lake is currently modest but more information is needed to assess the role of this P source in potentially driving summer and fall algal blooms (particularly cyanobacteria). Rates derived from this study can be combined with dissolved oxygen profiles to estimate lake wide internal P loading for comparison with watershed tributary P sources. This analysis will be important in evaluating P sources in the lake that need to be targeted for management.

An unknown is the role of iron in hypolimnetic P availability for algal uptake. Iron oxyhydroxides can adsorb soluble P and keep it trapped in the hypolimnion during turnover and reoxygenation if the Fe:P ratio is high. Under this scenario, availability of internal P loads is usually minor unless algae can vertically migrate into the anoxic hypolimnion for direct P uptake. If the Fe:P ratio is relatively low, there will not be enough iron oxyhydroxide to bind all the soluble P and it will become entrained into the surface waters during mixing periods and assimilated by algae for growth. If watershed tributary P loads are low in the fall but a massive algal bloom occurs during turnover, it is likely that the Fe:P ratio is low. More information is needed on summer iron and dissolved oxygen patterns in Horseshoe Lake to evaluate the availability of internal P loads for algal uptake.

I recommend that a vertical water sampling profile (i.e., 1-m intervals from the surface to the bottom at station 10 and 20) be collected in late August for analysis of soluble iron and phosphorus in the anoxic hypolimnion to determine the Fe:P ratio and potential for entrainment of soluble P during mixing periods. I also recommend collecting samples for chlorophyll analysis in August to evaluate the potential for vertical migration into the hypolimnion.

Additionally, it would be valuable to attempt to construct a hydrological and P budget for the lake to evaluate important P sources contributing to algal blooms. Dominant P sources can then be targeted for management. Simple empirical modeling can be conducted to assess the impact of P loading reduction on mean summer water quality. Water quality goals can be established and management scenarios developed to improve Horseshoe Lake.

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Table 1. Sediment sampling locations in Horseshoe Lake.

Station	Water depth		East	North
	(ft)	(m)	(Dec Deg)	
10	40	12	45.43650	-92.17460
20	51	16	45.43604	-92.16560
30	35	11	45.44157	-92.15822

Table 2. Sediment sequential phosphorus (P) fractionation scheme, extractants used, and definitions of recycling potential.

Variable	Extractant	Recycling Potential
Loosely-bound P	1 M Ammonium Chloride	Biologically labile; Soluble P in interstitial water and adsorbed to $CaCO_3$; Recycled via direct diffusion, eH and pH reactions, and equilibrium processes
Iron-bound P	0.11 M Sodium Bicarbonate-dithionate	Biologically labile; P adsorbed to iron oxyhydroxides (Fe(OOH); Recycled via eH and pH reactions and equilibrium processes
Labile organic P	Persulfate digestion of the NaOH extraction	Biologically labile; Recycled via bacterial mineralization of organic P and mobilization of polyphosphates stored in cells
Aluminum-bound P	0.1 N Sodium Hydroxide	Biologically refractory; Al-P minerals with a low solubility product

Table 3. Mean (1 standard error in parentheses; n = 3) rates of phosphorus (P) release under aerobic and anaerobic conditions for sediments collected in Horseshoe Lake.

Station	Diffusive P Flux	
	Anaerobic	
	(mg m^{-2} d^{-1})	(mg/L)
10	2.52	0.225
20	3.32	0.231
30	2.37	0.115

Table 4. Textural characteristics in the upper 5-cm sediment layer.

Station	Moisture Content (%)	Wet Bulk Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Loss-on-ignition (%)
10	94.8	1.023	0.054	32.8
20	95.4	1.019	0.050	39.4
30	93.2	1.029	0.071	33.5

Table 5. Phosphorus fractions in the upper 5-cm layer of Horseshoe Lake sediments.

Station	Loosely-bound P (mg/g DW)	Iron-bound P (mg/g DW)	Labile organic P (mg/g DW)	Aluminum-bound P (mg/g DW)	Redox-P (mg/g DW)	Bio-labile P (mg/g DW)
10	0.023	0.479	0.736	0.462	0.502	1.238
20	0.016	0.395	0.708	0.435	0.411	1.119
30	0.018	0.159	0.649	0.362	0.177	0.826

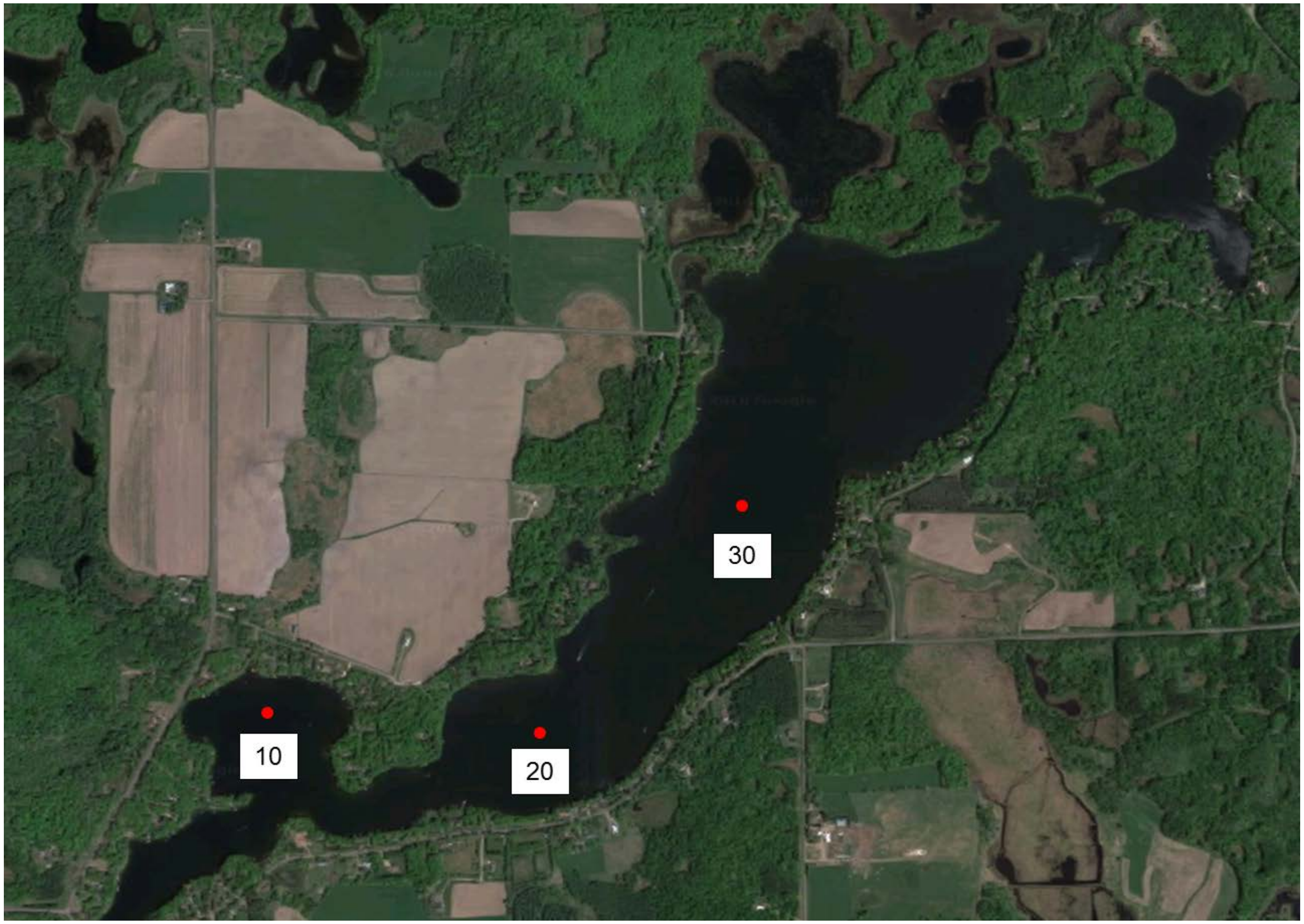

Figure 1. Sediment sampling stations in Horseshoe Lake, WI.

Figure 2. Sediment core apparatus and sediment coring on Horseshoe Lake.

Figure 3. Sediment core incubation systems for determination of laboratory-derived rates of phosphorus release from sediments under anaerobic conditions.

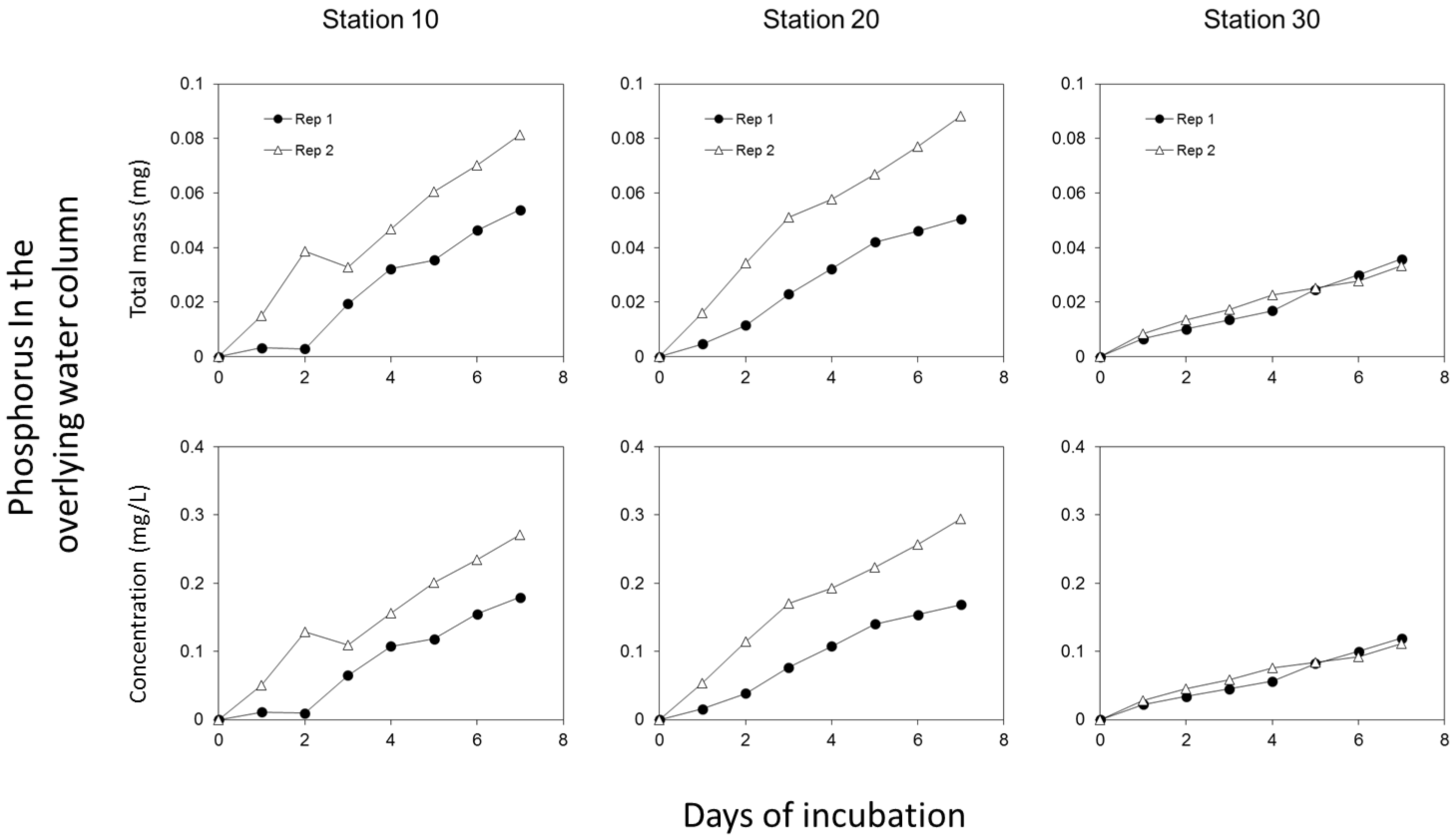

Figure 4. Changes in soluble reactive phosphorus mass (upper panel) and concentration (lower panel) in the overlying water column under anaerobic conditions versus time for sediment cores collected in Horseshoe Lake.

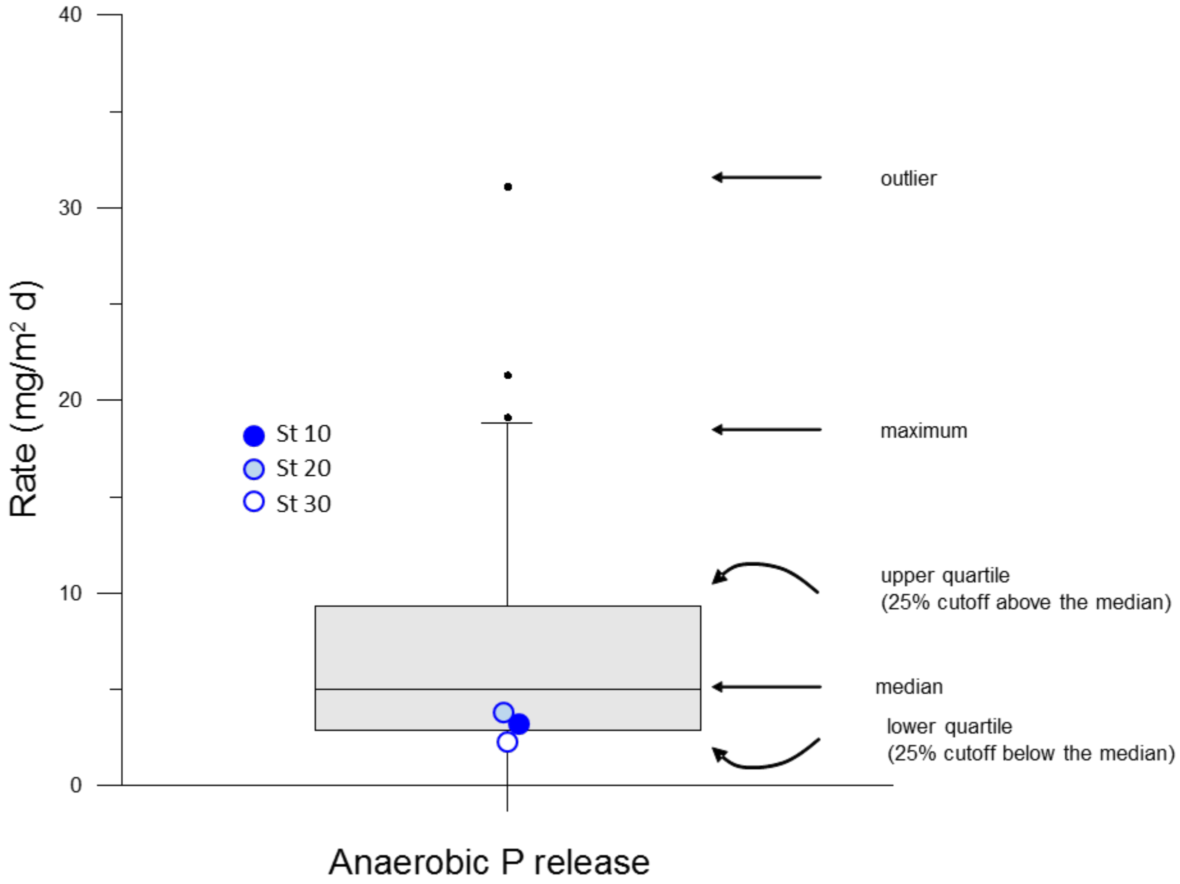

Figure 5. Box and whisker plot comparing the anaerobic phosphorus (P) release rate measured in Horseshoe Lake with statistical ranges for lakes in Minnesota.

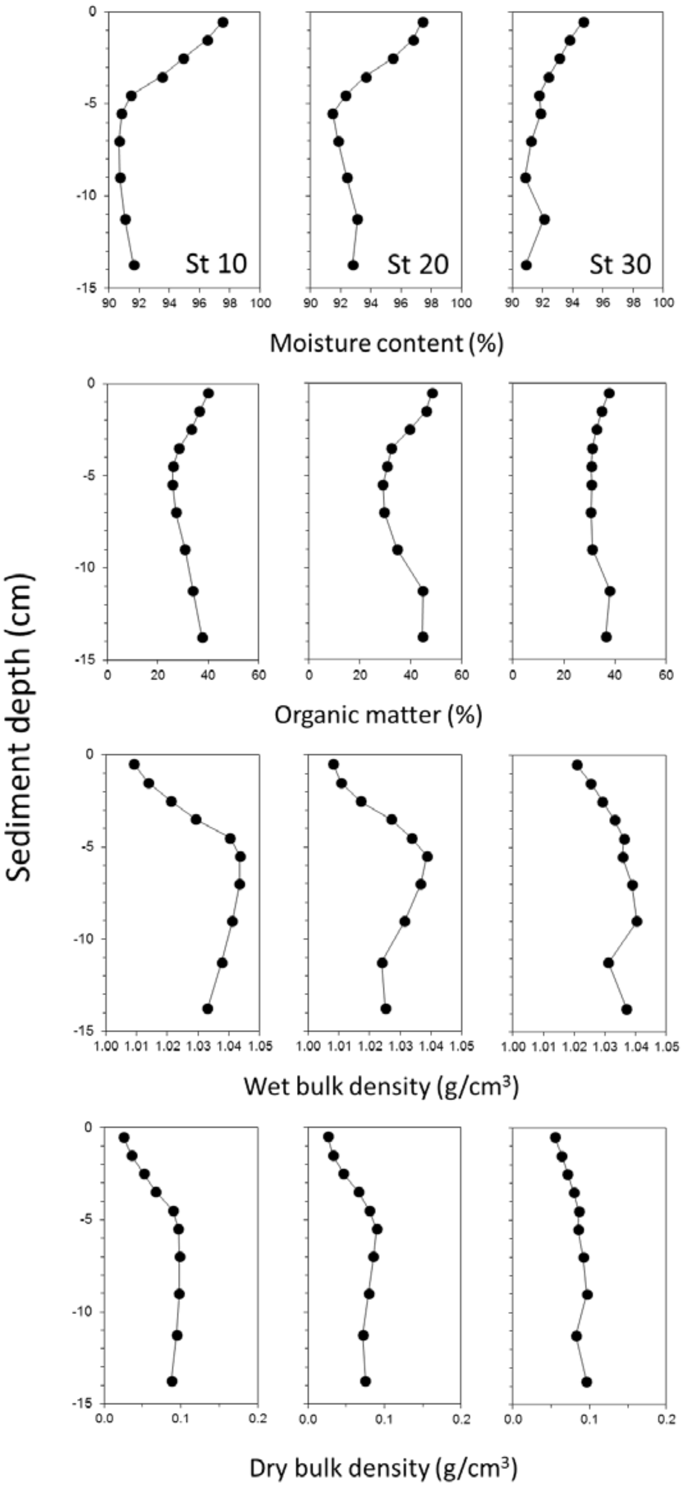

Figure 6. Vertical variations in moisture content, organic matter content, and wet and dry bulk.

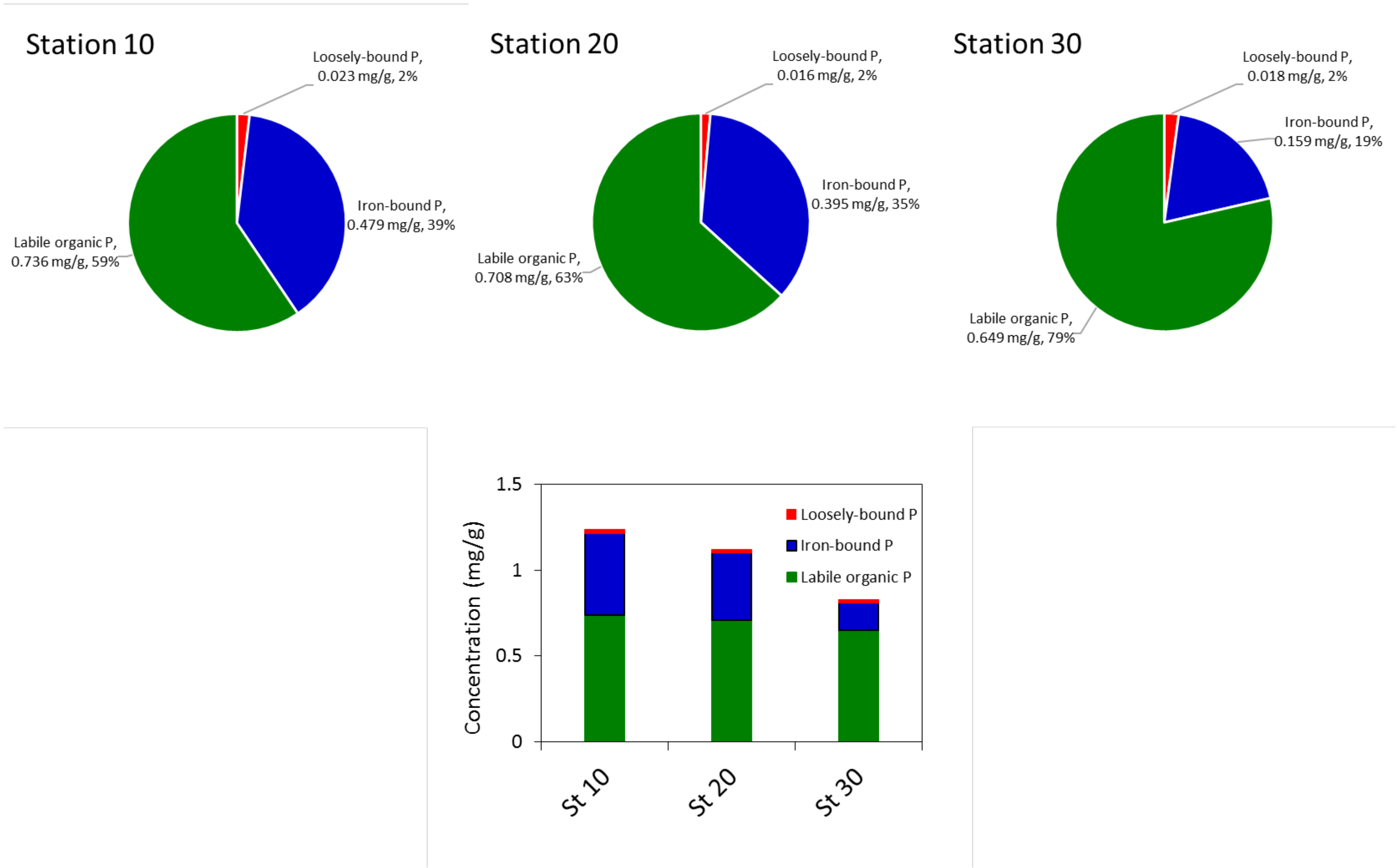

Figure 7. Composition of biologically-labile phosphorus (P) in the upper 5-cm surface sediment layer of Horseshoe Lake. Loosely-bound, iron-bound, and labile organic P are biologically reactive (i.e., subject to recycling). Values next to each label represent concentration (mg/^{1}) and percent of the biologically-labile P concentration, respectively.

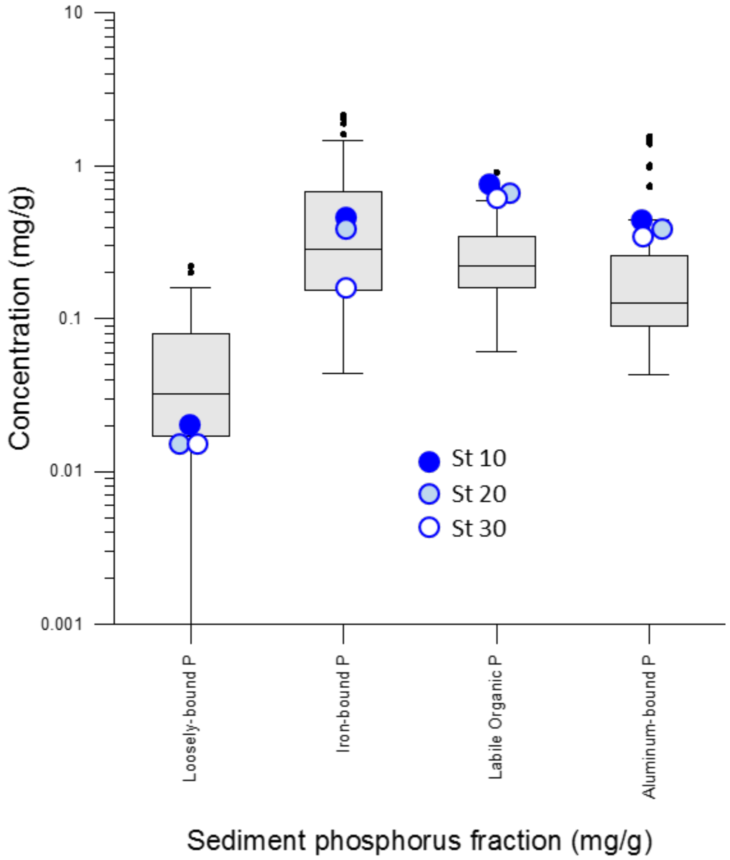

Figure 8. Box and whisker plots comparing various sediment phosphorus (P) fractions measured for sediment collected in Horseshoe Lake, WI, with statistical ranges for lakes in nearby Minnesota. Loosely-bound, iron-bound, and labile organic P are biologically-labile (i.e., subject to recycling) and aluminum-bound, calcium-bound, and refractory organic P are more are more inert to transformation (i.e., subject to burial). Please note the logarithmic scale.

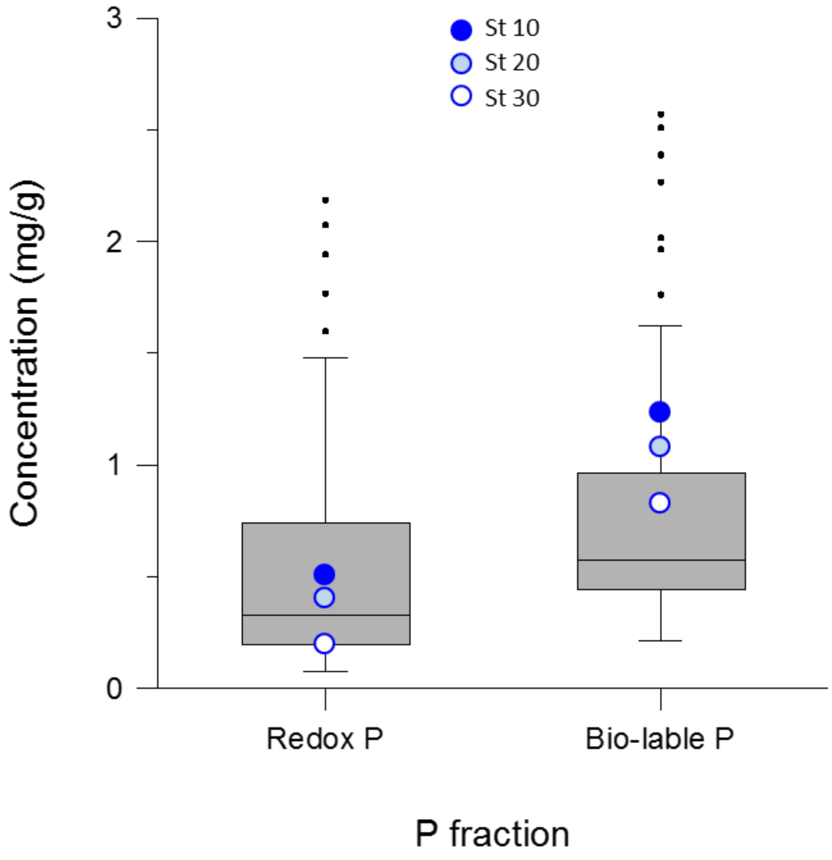

Figure 9. Box and whisker plots comparing redox-P (i.e., sum of the loosely-bound and iron-bound P fractions) and biologically-labile P (i.e., the sum of redox-P and labile organic P fractions) for sediment collected in Horseshoe Lake, WI, with statistical ranges for lakes in nearby Minnesota.

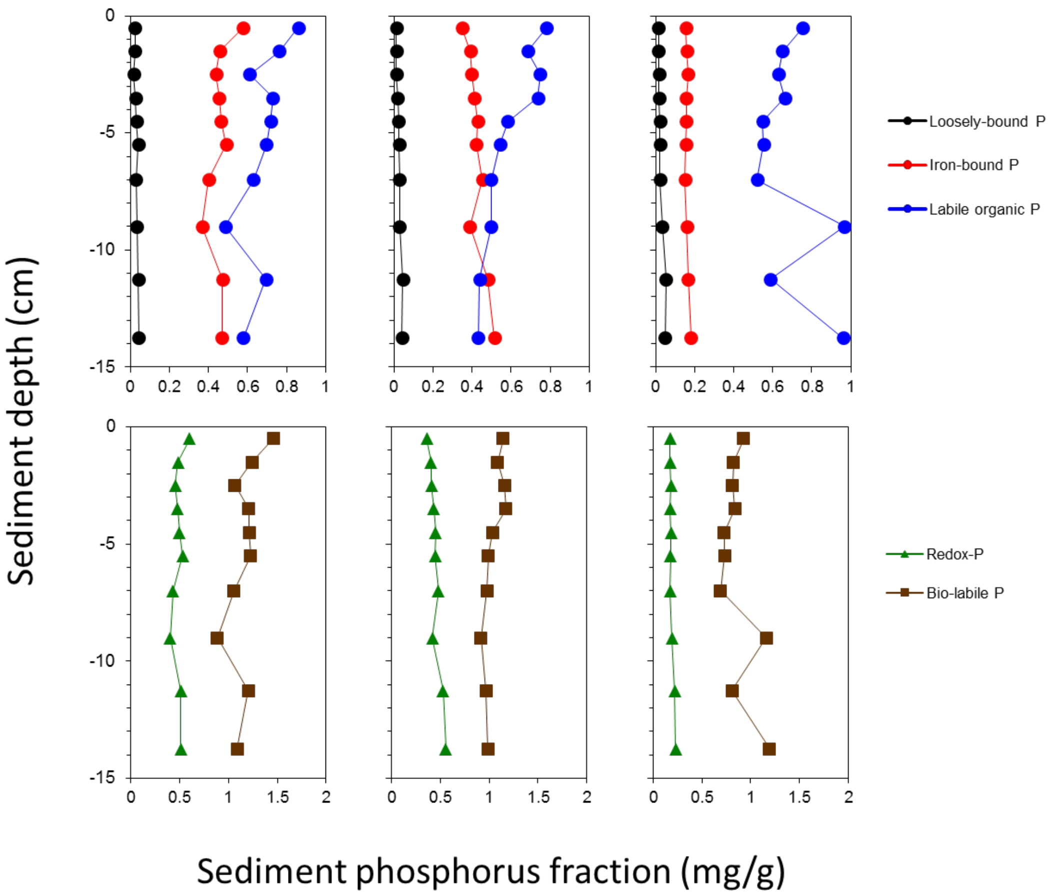

Figure 10. Vertical variations in loosely-bound phosphorus (P), iron-bound P, labile organic P, redox-P, and biologically-labile P