ASSESSING LAKE PRODUCTIVITY IN THE LONG LAKE WATERSHED

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ABSTRACT

The 38,000 acre Long Lake watershed is located in the southeast corner of Washburn County in northwest Wisconsin. Long Lake is a 3,290 acre water resource with over 39 miles of shoreline, a portion of which is undeveloped. The watershed also includes39 lakes over 10 acres in size, and roughly 23,000 acres of the land in the watershed is public land (Washburn County forest). This study was undertaken to gather productivity data, compare trends, and investigate possible sources of nutrients having negative effects on water quality to Long Lake. There has been growing concern from homeowners throughout the watershed of decreasing water quality in Long Lake and other lakes in the watershed through increased productivity. Citizen water monitoring has taken place on Long Lake since the early 1990's through the Wisconsin Department of Natural Resources Self Help program and also through studies by BARR Engineering and UW-Stevens Point Center for Watershed Science and Education.

Comparing previous work with current data, we can draw preliminary conclusions concerning sources of increased productivity on Long Lake. Internal loading of phosphorous in Long Lake appears to be supplying the lake with excess phosphorous for increased productivity. The extent of internal loading in Long Lake is still not fully understood because new findings in 2005 indicate a high concentration of phosphorous in some ground water inputs into the lake.

Introduction: Overview of Lake Productivity

Lake productivity is the amount of biological activity in and ecosystem or maximum growth and development of organisms under optimal conditions (Thienemann 1931). Productivity can vary greatly from lake to lake. Lake systems with high productivity are termed *eutrophic* lakes and are associated with higher nutrient loads high biomass in the accumulation of organic matter. A low productivity lake is termed *oligotrophic*. These lakes often have clear, deep, cooler waters with limited nutrients and low total biomass accumulation.

Lakes naturally change over time and gradually over hundreds if not thousands of years increase, they increase in productivity. This rate of change can be hindered or accelerated in individual lakes according to each lake's own unique characteristics. Humans also can affect the rate at which productivity in a lake can change. Environmental degradation of lakes due to sedimentation and pollution are all human induced accelerators to lake productivity. Productivity in a lake can be good; however problems arise from too much of a good thing. When a lake becomes very productive, it experiences algae blooms more frequently. The loss in clarity can change plant and fish communities. These changes are largely irreversible.

The Long Lake Preservation Association and scientists from the University of Wisconsin-Stevens Point are partners in a long-term project to understand the Long Lake watershed and effectively protect water quality and ecology. There are growing concerns about accelerated rates of productivity due to changes in the watershed. Lake studies have taken place on Long Lake, but little is known about the water quality of smaller lakes throughout the watershed and their affect on Long Lake. Also, most analysis of productivity on Long Lake has focused on phosphorus and secchi disc measurements; though easy to conduct, these measurements are not entirely accurate in measuring how productive a lake actually is.

The purpose of this research was to systematically collect different metrics of lake productivity in the watershed. Results could them be compared with historic lake data to determine any trends in productivity. The study also sought to classify smaller watershed lakes based on their overall trophic status by collecting baseline data on previously untracked lakes.

Methods

Study Area Description

The Long Lake watershed is located in the southeast corner of Washburn County in Northwest Wisconsin. The watershed roughly covers 38,000 square acres in the townships of Long Lake, Madge and Birchwood. Long Lake itself is a 3,290 acre lake with 39 miles of shoreline. Water moves throughout the lake and eventually leaves the system at the dam near the south end of the lake. Long Lake has six established water quality sampling locations that were selected by dividing the lake into six separate basins and locating the deepest hole in each basin.

Ten other “upstream” lakes throughout the watershed were also studied. Little Devils and Big Devils Lake are located in the western half of the watershed. Pepper Creek physically connects these two drainage lakes to Long Lake. Harmon Lake is a seepage lake that is located in the northwestern part of the watershed; it is not physically connected to Long Lake. Slim Lake and Slim Creek Flowage are drainage lakes that start the headwaters for Slim Creek. The creek flows south and drains into the northern basin of Long Lake (Basin A). Loyhead, MacRae, Nick and Bass Lakes are all seepage lakes located in the eastern half of the watershed and are located in the Washburn County forest. Like Harmon Lake, they are only connected to Long Lake through groundwater. Mud Lake is just east of Long Lake and a narrow channel connects it to the north basin of Long Lake near the "narrows". All of the lakes studied were larger then fifty acres. The sampling locations in the lakes were located at the deepest hole.

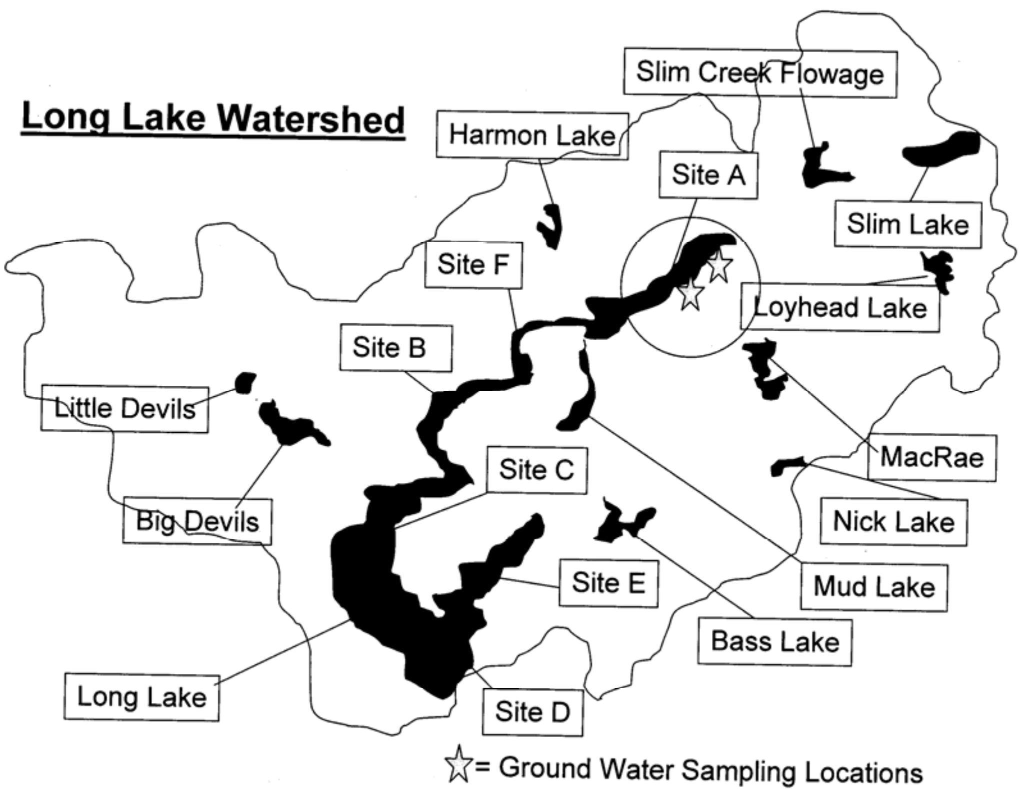

Figure 1. Locations of the sampling locations throughout the Long Lake Watershed, 2005.

Procedures

Secchi disc readings were taken using an 8-inch diameter weighted disc painted black and white. The disc is lowered over the downwind, shaded side of the boat until it just disappears from sight and then raised until it is just visible. The average of the two depths is recorded. Secchi disc readings should be taken on calm, sunny days between 10 a.m. and 2 p.m. since cloud cover, waves, and the sun's angle can affect the reading. (WI DNR 2005)

Total Phosphorous samples were collected using a Kemmerer water sampler to collect surface water samples. Water was collected from directly under the surface to a depth no greater then two feet. The water was acidified to a pH below 2 in a 125ml polyurethane bottle using 1:1 concentrated sulfuric acid. The samples were then analyzed at the University of Wisconsin-Stevens Point in the Water and Environmental Analysis Lab to quantify total phosphorus levels.

A HydroLab Quanta was equipped with the following probes: temperature, depth, dissolved oxygen, conductivity, and pH. It was used to collect these water variables at depth intervals of 2.5 feet. The data was used to ascertain levels of oxygen depletion throughout the hypolimneon.

Secchi and total phosphorous readings were compiled and averaged to yield lake trophic state. Hydrologic maps of each lake were used to determine relative water area at depth intervals. These areas were then related to oxygen concentration to yield areal hypolimnetic oxygen depletions. Calculating these over time gives rates of oxygen depletion. Increased rates of oxygen depletion indicate a more productive lake.

This study was conducted over an intensive 12 week routine. Secchi disk measurements were taken weekly on Long Lake and biweekly on all other watershed lakes. Six samples for total phosphorous from each lake were collected biweekly over a period of three months. Dissolved oxygen profile sampling periodicity was selected to begin as close to ice out as possible and sample at weekly intervals until the lake was stratified, around the middle of July, at which time data was collected biweekly.

Results

Secchi

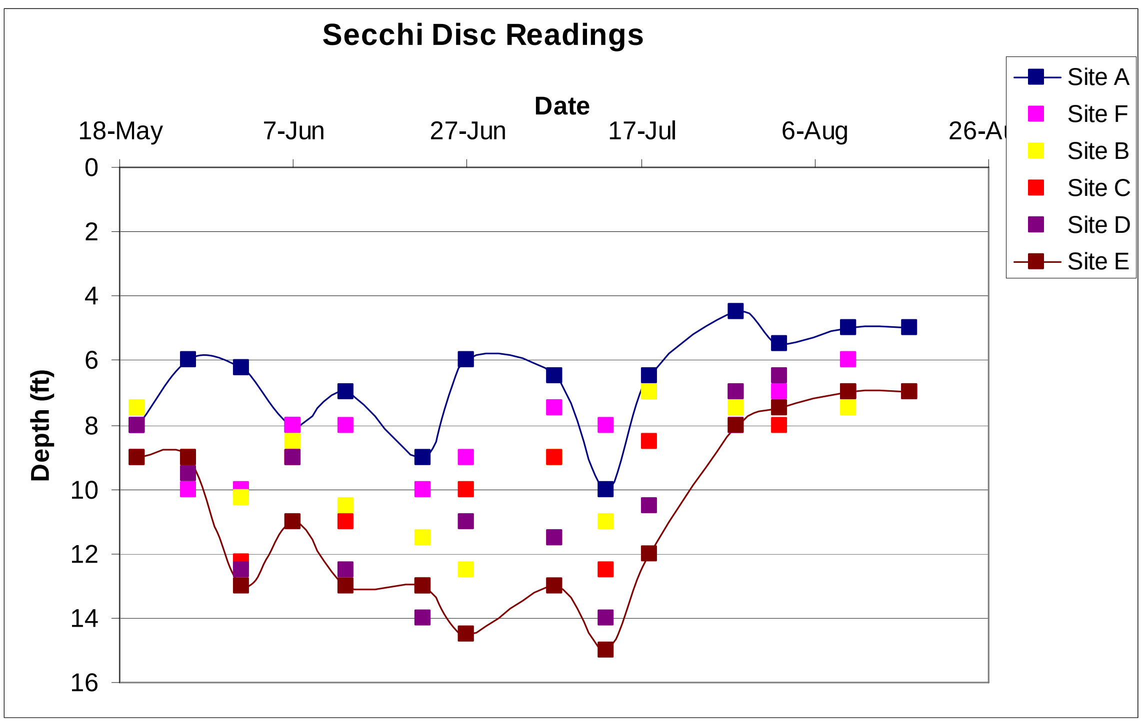

Figure 2. Secchi disc reading from different sites located on Long Lake summer of 2005.

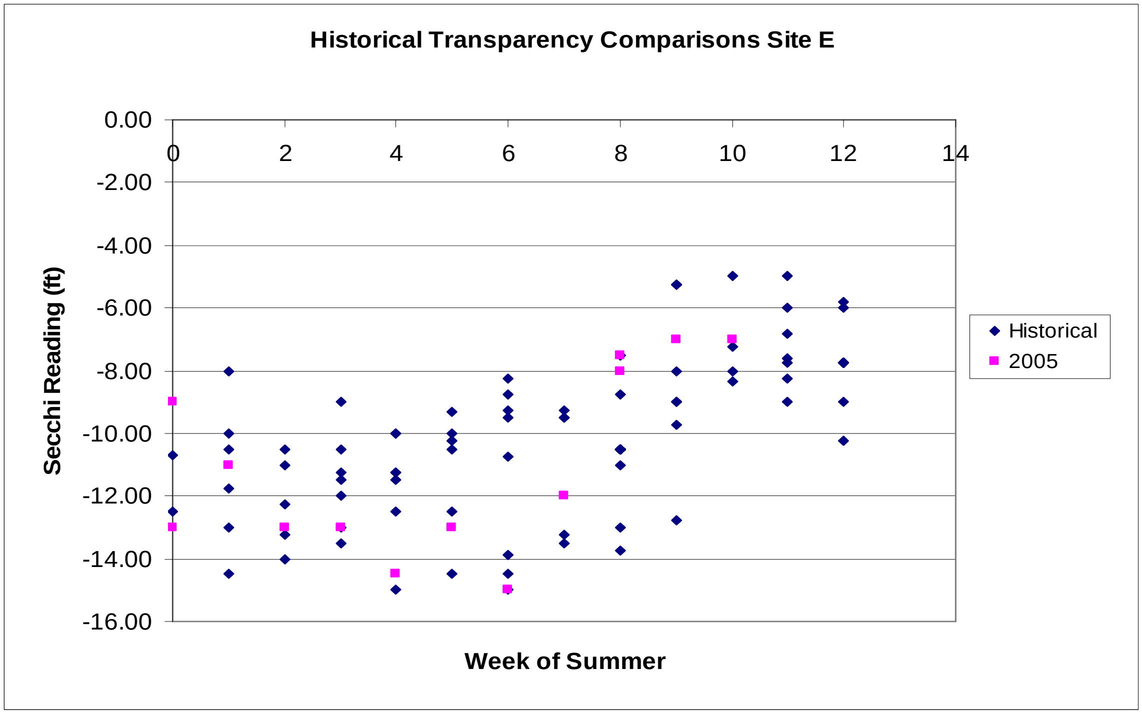

Figure 3. Comparisons of Historical Secchi reading from 1991-2004 and 2005 of Site E Long Lake, Wisconsin.

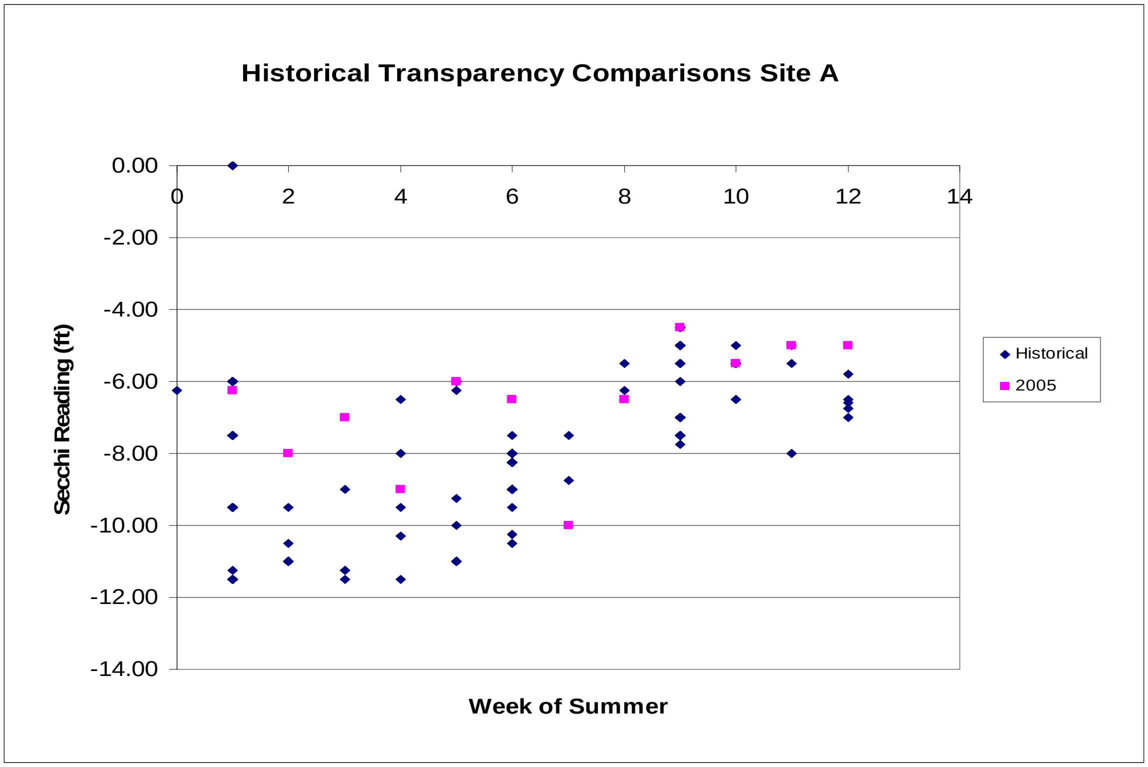

Figure 4.Comparisons of Historical Secchi reading from 1991-2004 and 2005 of Site A Long Lake, Wisconsin.

Table 1. Comparison of average 2005 Secchi disc readings between watershed lakes and Long Lake sites A and E.

Location	Secchi Depth (ft)
Big Devils	12.4
Slim Lake	7.2
Slim Creek Flow	9.9
Loyhead	9.2
Nick	11
Harmon	7.3
Little Devils	10.9
Bass	8.8
Mud	3.6
MacRae	9.2
Long Lake Site E	10.9
Long Lake Site A	7.9

Table 2. Historical comparisons of average Secchi disc at Long Lake and Slim Lake.

Averages Date	**Site A**	**Site E**	**Slim Lake**
Average for 2005	6.6	10.9	7.2
Average from 91-2004	7.5	9.5	8.7

Total Phosphorous

Table 3. Historical Comparison of total phosphorous averages on Long Lake in months of June, July, and August.

Location	**1998-2001**	**2005**
Site A	22	19
Site B	20	19
Site C	19	15
Site D	20	20
Site E	19	20
Site F	20	22
Long Lake	20	19
Slim Lake	29	22

Table 4. Average total phosphorous reading throughout the summer of 2005 for lakes in the Long Lake watershed.

Location	TP (ppb)
Big Devils	15
Slim Lake	22
Little Devils	17
Long Lake Site E	20
Long Lake Site A	19
Mud	97
Bass	20
Nick	8
MacRae	13
Loyhead	11
Slim Creek Flowage	19

Oxygen Depletion

Table 5. Areal Hypolimnetic Oxygen Depletion rates at sampling locations throughout the Long Lake watershed, 2005.

Location	AHOD mg/m^2/day
Bass Lake	482
Big Devil Lake	350
Harmon Lake	44
Little Devil Lake	90
Long Lake	418*
Site A	550
Site B	200
Site C	142
Site D	296
Site E	487
Site F	18
Loyhead Lake	440
MacRae Lake	NA
Mud Lake	NA
Nick Lake	974
Slim Creek Flow.	906
Slim Lake	422

*indicates that Site F was included in the average AHOD for Long Lake

Table 6. Trophic Status Classifications (adapted from Lillie and Mason, 1983 and Cornett and Rigler 1980)

Trophic	**Secchi(ft)**	**AHOD mg/m 2/ day**	**Total P ug/l**
Oligotrophic	>12	50-250	3-10
Mesotrophic	5-12	250-500	10-20
Eutrophic	0-4	500-1000	>20

Table 7. Summary Table of all Results and Historical Comparisons

	Max Depth (feet)	**Historic Summer Secchi (feet)**	**2005 Summer Secchi (feet)**	**Historic Average Total P (ug/l)**	**2005 Average Total P (ug/l)**	**Oxygen Depletion Rate (mg/m^3/ day)**
Bass Lake	66	NA	8.8	12	20	482
Big Devils Lake	75	NA	12.4	24	16	350
Harmon Lake	33	NA	7.3	18	< 8	44
Little Devils Lake	34	NA	10.9	NA	17	90
Long Lake	74	8.4	9	19	19	418*
Basin A	68	7.5	6.6	22	19	550
Basin B	39	8	9	20	19	200
Basin C	30	8.25	9.5	19	15	142
Basin D	49	8.75	10	20	19	296
Basin E	74	9.5	10.8	19	20	487
Basin F	28	8.3	8	20	22	18
Loyhead Lake	35	NA	9.2	NA	11	440
MacRae Lake	58	NA	9.2	NA	13	NA
Mud Lake	13	NA	3.6	71	97	NA
Nick Lake	79	NA	11	NA	8	974
Slim Creek Flow.	27	NA	9.9	26	19	906
Slim Lake	42	8.6	7.2	NA	25	422

Discussion

Transparency

The Secchi disc measurement of transparency is essentially a function of the reflection of light from its surface and therefore influenced by the absorption characteristics of the water and of its dissolved particulate matter (Wetzel 2001). Secchi measurements reflect the consequences of a lake's productivity. The Secchi disc reading for Long Lake had definite trends associated with water transparency. Water color was not a factor when comparing the Long Lake sampling sites since the lake has little or no stain or tannins.

Historically site A has had the most shallow Secchi disc readings and site E has had the deepest. Table 2 shows that in 2005, site A was less clear then it has been historically, indicating higher productivity from previous years. In contrast, site E's 2005 measurements show an increase in water transparency. This would seemingly indicate a decrease in productivity. Figure 2 shows the 2005 changes in transparency throughout the summer. Note the sharp decrease in transparency around July 20th when observations of accelerated algae growth appear on the lake. The algae growth was more noticeable around the north basin at site A; however the effective change was greatest for Secchi depths at site E. Figure 3 shows how summer Secchi readings have changed throughout the summer at site E, with 2005 data highlighted and figure 4 shows the same data for site A. In both cases, late July signals a rapid growth in lake productivity indicated by increased algae growth in the lake's open waters.

Secchi comparisons can also be made on a watershed level. These values are more difficult to interpret for two reasons. First, most lakes in the watershed lack the same historic data of Long Lake. An exception is Slim Lake, and results comparing 2005 with historic averages for this lake are shown in table 2. Secondly, stain and tannins from organic and inorganic sources were observed at different lakes; these chemical qualities of the water affect clarity without representing lake productivity. Referring to table 1 Big Devils Lake had the best average Secchi disc despite a noticeable stain in the lake's water. No observations of an algae bloom on Big Devils were present throughout 2005. Mud Lake, in contrast, was not stained but recorded the lowest Secchi readings for 2005. Observations indicated that this lake had the first algae bloom and was in a continual bloom throughout the summer of 2005.

Secchi disc measurements only reflect situations have already occurred in the system. Understanding nutrients that are available to plants gets us closer to understanding the drivers of lake productivity. To do this, we must more closely analyze the chemical make up of the water found in the watershed lakes. The key limiting nutrient in temperate lakes like those in the Long Lake watershed is phosphorus; the following section looks at this nutrient in more detail.

Total Phosphorous

Phosphorous is the most limiting macronutrient required for aquatic plant growth. Phosphorous is present in water systems in many forms but the most accurate reading for phosphorous concentrations is the reading for both organic and inorganic particulate phosphorous, also referred to as *total phosphorus* or TP. Total phosphorous measurements indicate a precursor to productivity. Higher TP generally means more productivity, hence more algae and declining water clarity. A lake without any phosphorus would have very low productivity.

2005 TP concentrations on the Long Lake were compared to previous years in Table 3. It appears that phosphorous concentrations were close to previous years. There were some exceptions: Site C displayed lower total phosphorus readings in 2005 then historically and site F displayed higher levels. Overall the average for Long Lake historically was 20 ug/l and in 2005 it dropped to 19 ug/l. This average is borderline between a mesotrophic and eutrophic state according to table 6.

With the exception of Slim Lake, this was the first year any total phosphorous readings were collected on smaller watershed lakes. In 2004 Slim Lake had recorded total phosphorous measurements taken. The annual average for 2004 was 29 ug/l and in 2005 the average was 22 ug/l. This decline in total phosphorous concentrations could be possibly linked to limited runoff in the summer of 2005 due to an abnormally dry summer. Mud Lake is a lake with very high TP concentrations compared to other lakes located in the watershed. Mud Lake had an average of 97 ug/l TP in the summer of 2005. These elevated levels of total phosphorous in Mud Lake indicate other sources then sedimentation from runoff.

Water samples were also taken from two sources of ground water upwelling locations. These locations were located on the east side of Long Lake's northern basin (Basin A). The total phosphorous readings were very high, averaging at 114 ug/l. Total phosphorous concentrations in the north basin of Long Lake appear to be affected by this phosphorus-rich ground water.

It is important to recognize that phosphorus levels in lakes change throughout at year, in part due to the absorption of phosphorus by plants and the release of phosphorus by decomposing material at the lake's bottom. The exchange of phosphorous between bottom sediments and the overlying water is a major component of the phosphorous cycle in natural waters (Wetzel 2001). Phosphorus that is temporarily "trapped" in bottom sediments is released throughout the summer season as lakes stratify into cold and warm layers and oxygen is depleted at lower depths. The following section examines this relationship and discusses the implications of oxygen depletion for phosphorus release in the Long Lake watershed.

Dissolved Oxygen

The rate of oxygen loss from the hypolimnion during summer stratification increases not only with depth but also with time during the stratification period (Wetzel 2001). Changing dissolved oxygen concentrations represent both a precursor to increased productivity and a consequence of higher productivity. Though normally dissolved, phosphorous precipitates as a solid and drops out of the water with iron, manganese and carbonates. These elements bind phosphorous and integrate it in the oxidized micro-zone. The ability of a lake's minerals to bind phosphorous in this zone is correlated to the depth at which the sediments can remain in the oxidized state (Wetzel 2001). They remain in the oxidized state when oxygen has the ability to penetrate the sediments at or near the lake's bottom. This can occur if the concentration of oxygen in the overlying water is higher then the concentration of the sediments. When anoxic (oxygen-deprived) conditions predominate, phosphorous is released back into solution and distributes to upper layers of the lake. This is a precursor to greater productivity in the lake's ecosystem.

Tracking areal hypolimnetic oxygen depletion (AHOD) in area lakes was the third method used for determining trophic status in the Long Lake watershed. Long Lake sampling locations provided a variety of results. As seem in Table 5, water columns at sites A and E lose roughly 500 mg of oxygen per square meter per day. These two sites displayed levels of oxygen depletion associated with being on the border of a eutrophic and mesotrophic lake according to table 6. Site F has a level of oxygen depletion around 18 $mg/m^2/day$. This site is the shallowest of the location of Long Lake. This shallow basin along with its orientation in the main lake channel allow for skewed results of oxygen depletion; it is likely that some level of continual mixing of oxygen-rich water from near the lake's surface prevents the complete stratification of this portion of the lake.

Historical data collected by BARR Engineering in 1994 showed that site E lost 390 mg of oxygen per square meter per day. This increase – from 390 to 500 mg of oxygen per square meter per day- indicates that Long Lake is continuing to become more productive and hence more eutrophic. Note that the 2005 total phosphorus readings for site E were consistent with historic levels and that Secchi readings were actually better than recent past. The increased productivity measured by dissolved oxygen depletion rates could very well have been absorbed by macrophyte (non-algal) plant growth. These same plants, however, will continue to contribute to the sediment load at the bottom of the lake as they die annually and decompose.

Throughout the watershed lakes, Nick Lake experienced the greatest loss of oxygen throughout the hypolimnion. Table 6 would put this lake into a eutrophic classification and in 2004 Nick Lake experienced a severe bloom of algae. However, total phosphorous and Secchi readings would place this in a mesotrophic classification. Nick Lake has a rather unique shape, or morphology. The lake is very deep (the deepest in Washburn County) and has a comparatively small surface area and a north-south alignment. As a result, it can be assumed that this lake experiences incomplete mixing in some years. This incomplete mixing can allow for more phosphorous to be cycled in years of more complete mixing and thus increasing productivity in those years.

2005 Climatologic Factors

As mentioned above, the weather in the summer of 2005 was remarkably dry and free of major precipitation events. The months of June, July, and August recorded a deficit of 8 inches of precipitation from the seasonal norm. The lack of rainfall reduced erosion and atmospheric deposition into the lakes and rivers. This lack of storm water influence to the lake systems provides a good representation of internal base flow characteristics. 2005 represents an example of how the watershed would behave in the absence of major surface water runoff nutrient inputs.

Sites of Concern

Three locations were focused on for intense analysis, Mud Lake and Sites A and E of Long Lake. These locations indicate major changes and or concerns. The Secchi readings in the Long Lake sites A and E both show a decrease in Secchi around the time of algae growth. Secchi readings on Mud Lake are poor. Water from Mud Lake feeds Basin A of Long Lake. Mud Lake is a shallow lake only reaching a max depth of 13 feet.

It quickly warms in spring and displays the first bloom of algae and plant growth in the end of May. These factors allow for high production rates. Compounding the problem is the presence of agriculture on the western shore of Mud Lake. Observation of dairy cattle entering the lake and loafing on shoreline habitat is common. These added nutrients to the system only continue to increase productivity and decrease Secchi readings. The total phosphorous readings indicate that the water that eventually leaves Mud Lake and enters Long Lake is rich in phosphorous. This problem will only continue as long as production is fueled by these high phosphorous levels.

Comparisons of conditions on Long Lake can be seen through differences in sites A and site E. Site A began the season with increased productivity in the form of algae growth. Productivity in site A is linked to internal loading of phosphorous. The oxygen disappears from this basin sooner allowing phosphorous to be released from hypolimnetic water up into the epilinion where it becomes available for primary production. This problem will only continue to increase because light will be limited to the depth in which it can penetrate, which in turn will decreases depth at which phytoplankton can thrive.

The effect of ground water rich in phosphorous to the Long Lake system can also be a factor. From 2005 samples, ground water distributed through the north eastern part of the watershed contained high phosphorous levels. Phosphorous levels were also high in Slim Lake, Slim Creek flowage, Mud Lake, Long Lake, and springs at the northeast corner of basin A. This could possibly indicate a flow plume of phosphorous rich ground water into these systems. These sites could all show effects from phosphorous loading from ground water. Phosphorous content is generally low in ground water, averaging 20 ug/l (Wetzel 2001). The values collected from upwelling spring locations averaged 114 ug/l. Land use occurring in the northeast portion of the watershed is solely county forest. A possible source for this phosphorous contamination in ground water is by scattered pockets of glacial deposits rich in phosphorous. Geographic variations in phosphorous concentrations were significant. Water collected in some areas of north central and northwest Wisconsin often had higher concentrations of phosphorus than most of the water collected in southern or eastern Wisconsin (McGinley and Stephens 2004)

The other source for phosphorous in ground water could be from a funneling effect of the scattered small lakes throughout the watershed. These small lakes could act as a funnel delivering rich organic deposits down through the sediments to the ground water.

Secchi disc and total phosphorous levels in the other lakes in the watershed were average for classifications of mesotrophic lakes. There were some borderline measurements into both the eutrophic and oligotrophic levels. There could be some effect of phosphorous being transported through subsurface seepage to Long Lake but this may be negligible if the amount of phosphorous in the ground water is related to glacial deposits.

Investigating watershed dynamics with respect to water quality and analysis is a large task. Many variables change from day to day and from hour to hour. Ideally sampling at locations would occur under identical conditions and unknowns. This is difficult to control over a watershed. Different sites on Long Lake were sampled during a period of 3 hours. Even over this time, sampling conditions changed on the lake. Differences in lake conditions also occurred on the day of week sampled. Early week samples on Long Lake yielded lower Secchi disc reading then late week samples.

Calibration of equipment was accomplished on a weekly basis but slight deviations could occur from location to location. In order for trends to be observed about gains or deteriorations in Long Lakes water quality oxygen depletion profiles should be taken yearly or at maximum biyearly timeline.

Summary and Recommendations

The nutrient status of Long Lake can be compared to a person who has learned that she is genetically predisposed to high cholesterol. All people need to watch their diet and track their cholesterol to avoid heart disease and other health problems, but those with a genetic predisposition need to be extra vigilant. They do not have the physiological freedom to eat cheeseburgers and sit on the couch all day that some people enjoy. If they ignore their condition they run a great risk and can end up paying a grave price.

Similarly, all Wisconsin lakes are subject nutrient loading, but some appear to have higher background inputs from groundwater. If lakes that have a predisposition to higher nutrients are managed as though they are a "typical" lake, then we should not be surprised if they end up paying a grave price through accelerated eutrophication and declining water quality from algae blooms. In an abbreviated amount of time, such a lake could become eutrophic, and the steady and unmanageable flow of groundwater nutrients would likely preempt any attempt to improve water quality and return to a more mesotrophic status.

Two action steps are readily apparent. First, like the person with genetically high cholesterol, Long Lake needs to watch its diet and reduce risks. The LLPA, local governments, Washburn County, and the DNR ought to all exercise vigilance in monitoring and regulating human-caused nutrient inputs. Unmanaged sediment erosion at construction sites require better vigilance and control. Visible erosion near surface waters throughout the watershed should be mitigated and eliminated to the greatest extent possible. All surface water runoff flows associated with impervious surfaces should be redirected into the ground through raingardens and larger infiltration basins.

The second step involves investigating the extent to which Long Lake is predisposed to elevated nutrient levels. Research by Muldoon et al. in nearby Barron and Polk counties found highly variable levels of groundwater phosphorus associated with glacial deposits, ranging from less than 4 to almost 300 ug/l (Muldoon et al. 1990). This work also found a strong relationship between groundwater phosphorus and in-lake nutrient levels. Similar findings were discovered in Little St. Germain Lake in Vilas County. The USGS determined groundwater to be a major source of phosphorus at Little St. Germain, significant enough to keep that 1,000 acre, small-watershed lake in a meso- or eutrophic status even if all other nutrient inputs were radically reduced (Robertson et al, 2004).

This wide-ranging pattern of groundwater phosphorus likely exists in the glacial deposits found in the Long Lake area, but the watershed is located in a somewhat different glacial territory than both the Barron and Polk county studies and the Little St. Germain study. To date, little work has been done in the area to understand the subsurface hydrology and groundwater chemistry in and around the Long Lake watershed. Extending the sort of analysis conducted by Muldoon et al. in Barron and Polk counties to the Long Lake area in Washburn County could help us better understand the degree to which groundwater is contributing to higher nutrient levels, particularly in the northern basin (Basin A) where watershed conditions and lake volume should result in higher water quality than what is observed.

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