Green Lake (DOW 30013600)
Isanti County, Minnesota

Year 2018

Lake Status Report

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Year 2018
Green Lake Status &
Aquatic Vegetation Report

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Executive Summary

A Lake Status Report was assembled for Green Lake in Isanti County, MN, from multiple sources of data, some going back as far as 1949. While much data has been collected on Green Lake, in general, data quality is low due to either missing information about methodologies, incompleteness, or unclear purposes for collection.

The primary concern by the Green Lake Improvement District (GLID) that prompted the creation of this document was (1) to determine what is necessary to take steps toward getting the lake off of the MPCA impaired waters list (2) to determine steps forward in managing negative impacts from nuisance plants in the lake, primarily the invasive species curlyleaf pondweed and Eurasian watermilfoil.

Historical data leave questions about how important phosphorus is, relative to other limiting nutrients such as nitrogen, to driving water quality conditions in Green Lake. If phosphorus is the primary driving force for water quality, given the small contributing watershed relative to lake size, it is likely that the greatest contributor to phosphorus to the lake is internal lake sediments, but this hypothesis should be verified and tested through targeted and purposeful collection of data to create a sound nutrient budget. If monitoring supports that hypothesis, the next step in reducing eutrophication of Green Lake would likely be to develop grant applications and raise money to reduce internal loading through (1) alum treatments, (2) deep water withdrawal or (3) deep-water aeration. Costs associated with collection of useful data to the end of developing a sound nutrient budget and to test hypotheses about sources and sinks is estimated to be \$25,000-\$30,000. The money required to treat impaired water in a serious way is likely outside the ability of GLID to pay and subsequently will require grant applications for cost sharing. Having a high quality and well analyzed set of data to argue for funding would be valuable.

Managing nuisance curlyleaf pondweed and Eurasian watermilfoil likely will be best done using chemical methods. Because mechanical harvesting does not remove or else kill plants but only removes the canopy, we do not recommend using it as a control method. Removing the canopy will allow increased light penetration and nutrient availability to plants that remain behind. Those plants left behind will grow at a higher rate than before harvest. Research indicates that treatment of areas where both curlyleaf and Eurasian watermilfoil coexist has been successful using a low dose mixture of endothall and 2,4D as soon as possible after ice out with the goal of keeping plants from growing, particular with curlyleaf pondweed producing turions. It is highly unlikely that either of these invasives species will be eradicated, and it is somewhat likely that additional invasive species will make their way at some time to Green Lake. It is important that GLID recognize that the goal for managing invasives species already in the lake is to control them to the point that users of the lake can enjoy recreational benefits by targeted treatment of areas important to that end rather than trying to get rid of the plants.

Specific Recommendations

1. **Complete water and nutrient budget to determine nature and sources of nutrients. Ideally, all of these steps are done during the same year. Estimated cost to get a good nutrient budget would be $15,000 – 20,000 broken down as follows:**

   A. Annual participation in Citizen's Lake Monitoring Program (CLMP) from May – September to collect water samples for chlorophyll *a* and total phosphorus measurements while at the same time getting Secchi depth. Be sure volunteers receive adequate training, particularly regarding clean methods in the field when collecting water. Approximate cost $300 for one year.

   B. One year of total nitrogen analysis collected at the same location as samples collected for the CLMP. We are suggesting this test because it is not clear based on available data that phosphorus is the limiting nutrient in Green Lake (see below). The test for this nutrient cost around $45 per test for a one year total of $225 and the water chemistry lab can test the same water that you collect for chlorophyll *a* and phosphorus. Approximate cost $225 for one year.

   C. One year of flow and chemistry (i.e., phosphorus and nitrogen) data at each of the main inlets for Wyanett Creek, North Brook Creek, Bratlin Creek, Old Judges' Creek and one unnamed tributary coming in on the south part of Green Lake, and most importantly at the outlet named Green Brook. Five baseflow measurements from May – September plus three storm-events at each location. Chemistry cost would be estimated at $68 for both TP and TN for eight flows x eight times for a total of $4352. Cross-sections for each stream will need to be made, flow measured with a flowmeter, and water samples collected eight times. Estimated field costs for one year collection eight times is $5,000. Total estimated cost with water chemistry and field work would be $9,352 for one year.

   D. Sediment cores extracted for the analysis of total phosphorus in order to determine likely P-release rates for internal load estimation. Approximately cost $2,000 for one year.

   E. All data need to be analyzed with reduction scenarios modeled to determine best management practices moving forward. Approximate cost is $5,000 for one year.

2. **Complete biological survey to estimate contribution of fish (indirectly), zooplankton and algae to water quality at a total cost of ~$1,500**. These data will help us to understand what contribution biology is making to the eutrophication process rather than the addition of nutrients to the lake. Approximate cost would be $300 per sample for combination of zooplankton and algae ID and if five samples are taken, one per month for five months would be around $1,500 for the year.

3. **Complete an aquatic plant survey during peak of growing season (July 15-August 15) to estimate coverage, biomass, and community structure of native plant community and to map current distribution of Eurasian watermilfoil at ~ $1,500 for the year**.

4. **Chemically treat curlyleaf pondweed and Eurasian watermilfoil in early spring with mixture of endothall and 2,4-D.** Do this as soon as possible after ice out before it has started rapid growth and target areas with both CLP and EWM. Treatments will be most effective when the plants are small. Budget variable dependent upon desired area to treat.

INTRODUCTION

This report describes the status of Green Lake in Isanti County as of August 2018 and proposes monitoring plans in support of future management decisions for the lake.

The primary concern about Green Lake is that it is eutrophic, which is expressed in early season excessive growth of the invasive plant species curlyleaf pondweed followed by poor water quality due to cloudy conditions resulting from algal growth.

This lake status report will review issues of highest concern to most lake user groups but focus on the two issues that are a primarily concern in 2018, namely (1) clearing up water to a point that it can be taken off the impaired lakes list and (2) addressing the need and strategy for treating curlyleaf pondweed and Eurasian watermilfoil in the lake.

Our lake status reports will include some information on general lake and watershed characteristics, lake and watershed maps, water quality trend analyses, comparison to other lakes in the ecoregion, land use analysis, connectivity and invasive species risk, and runoff potential and theoretical phosphorus loading, and a fisheries summary and analysis. Data sources used in putting this report together are included at the end of the report as an appendix.

LAKE DESCRIPTION

Green Lake is in the southern portion of the Rum River watershed with Mille Lacs Lake being the largest lake at the head of the watershed (Fig. 1). Green Lake itself does not receive direct inflow from the Rum River, and as such, operates much like a head water lake with few inputs. Green Lake does, however, contribute to the Rum River and downstream receiving waters from it. The lake has a relatively small contributing lakeshed (15,875 acres, which is less than 2% of the 1,584 square mile area of the watershed) dominated by agricultural uses (Fig. 2). The drainage basin: lake area (DB:LA) size ratio can vary from near 0 to over 1,000 and Green Lake's is approximately 20, which is small. Lakes with small DB:LA ratios tend to be deeper with less external nutrient inflow than lakes with higher values. Small DB:LA lakes tend to have water budgets dominated by groundwater flow and long nutrient retention

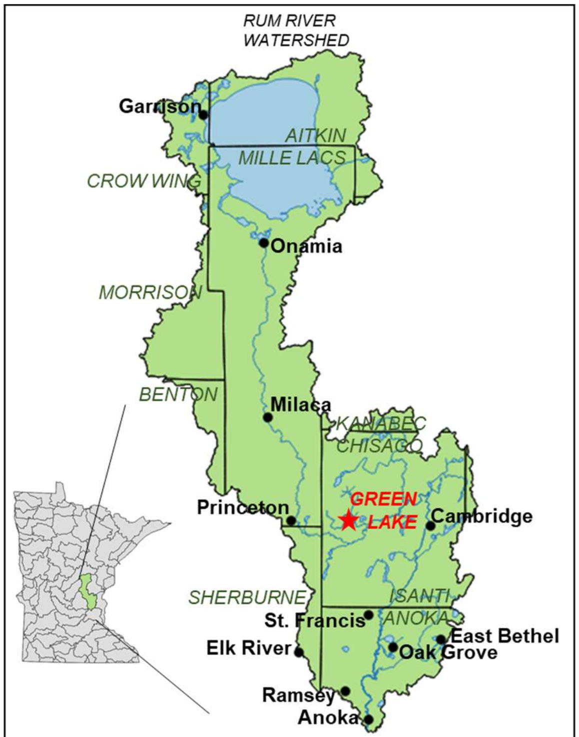

Fig. 1. Green Lake location within Minnesota and the Rum River watershed. Rum River flows out of Mille Lacs lake through Onamia, Milaca and south. The Rum River does not flow directly into Green Lake but Green Lake contributes flow to it.

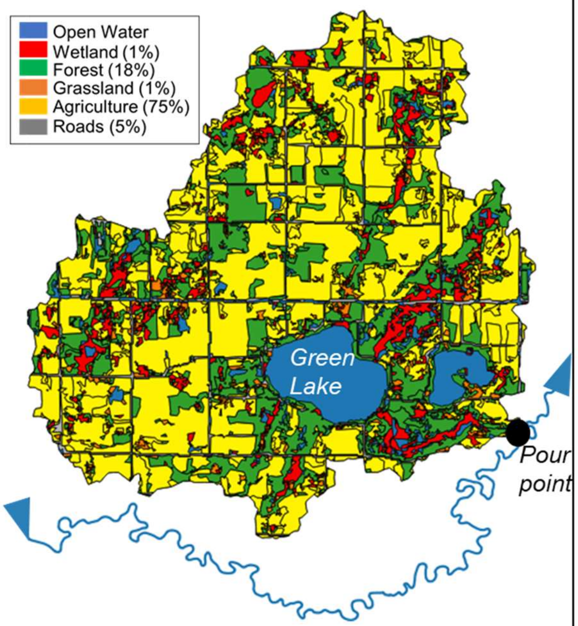

Fig. 2. Land directly contributing materials to Green Lake (i.e., Green Lake "Lakeshed"). Data come from the most recent NLCD 2011 landuse layer. Some categories have been combined (e.g., agriculture includes crop, pasture, hay, and feedlots). A new layer based on 2016 is due out in December 2018. Percentages indicate is of the total lakeshed excluding open water. Blue line to the south is the Rum River that generally flows around the lakeshed with the pour point indicated outflow to Rum River.

times. It is also notable that Green Lake has legacy sediments from Glacial Lake Grantsburg (Fig. 3). Glacial lake sediments are naturally high in clay and nutrient contents even before accounting for influx from agriculture lands.

Green Lake is the largest and deepest lake in Isanti County and also has a large fetch, which is the distance wind blows across the lake and correlates to annual wave energy (Table 1). Lakes with high wind energy have high concentrations of suspended sediments due to bottom disturbance in shallow areas.

Green Lake is highly developed, particularly along the northeast and northwest shorelines

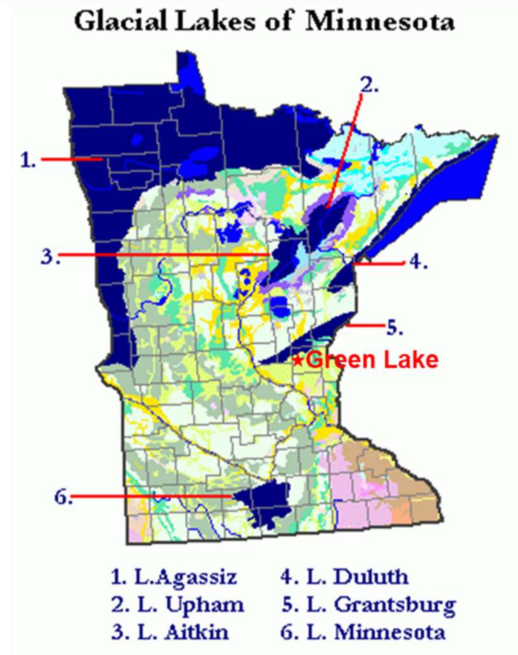

Fig. 3. Location of Green Lake relative to glacial Lake Grantsburg

(Fig. 4). To our knowledge there are no operating resorts on the lake.

WATER QUALITY

Base-line water quality is typically assessed with measures of total phosphorus,

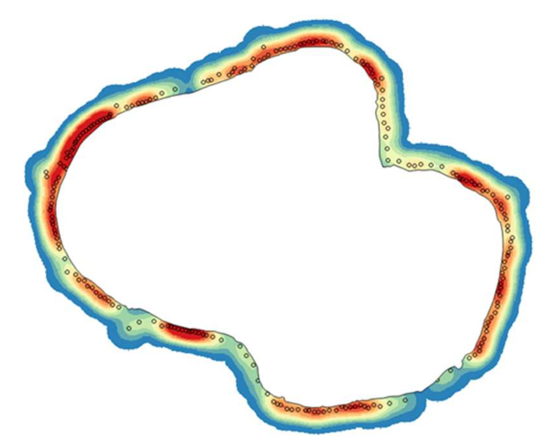

Fig. 4. Shoreline occupancy of Green Lake. The points represent individual properties and colors indicate statistical density map with blue being least developed to red being the most.

Table 1. Green Lake characteristics compared to measured lakes in Minnesota. Comparisons are made to other lakes in the Northern Hardwood ecoregion, Rum River watershed, and Itasca county. Numbers after the "*n*" indicate the number of lakes compared. The values are the percentiles. For example, the 85% percentile for surface area compared to all lakes means that 85% of lakes measured have a smaller surface area, and 3% percentile for littoral percentage means that 3% have less littoral zone as a percentage or 97% of lakes measured have a higher littoral zone percentage.

		Percentile Comparison			
	Green Lake	All *n*=1,888	Ecoregion *n*=760	Watershed *n*=34	County *n*=14
Surface area (acres)	833	85	86	94	100
Littoral (%)	16	3	1	6	8
Depth, maximum (feet)	28	45	46	55	69
Depth, average (feet)	16.51	72	77	85	100
Slope, average (%)	0.82	22	21	30	38
Fetch (feet)	8325	72	79	67	77
Volume (thousand acre-feet)	13.75	85	89	91	100
Shoreline development	1.14	5	7	6	0

chlorophyll *a*, and water clarity as measured by Secchi depth readings. In general, phosphorus is a limiting nutrient for algae growth and algae in turn influence water clarity by not allowing light to transmit.

Algae are microscopic photosynthetic organisms that are a primary (but not only) cause of water turning cloudy or greenish (Fig. 5). The cloudy-green coloring comes from a pigment within the algae cells called chlorophyll *a*. There is a direct relationship between the amount of chlorophyll a and algae in water. Chlorophyll *a* is relatively simple to analyze using standard water chemistry techniques while algae counts and biomass measurements are laborious and time consuming. Subsequently, chlorophyll *a* becomes a substitute for measuring the amount of algae in a lake.

Algae are produced when solar energy is used to put together nutrients in the water to build cells. While there are dozens of nutrients that are required to construct algae cells, phosphorus is considered a "limiting" nutrient. This means that the amount of algae (and subsequently chlorophyll *a*) is most often directly regulated by the amount of phosphorus in a lake.

A metaphor helpful in understanding the idea of limiting nutrients is useful (Fig. 6). Consider making a bologna sandwich that requires exactly two slices of bread, one slice of cheese, and one slice of bologna. If you were presented with a loaf of bread, a package of 10 bologna slices and five cheese

Fig. 5. Typical algae collected from lake water magnified under a microscope.

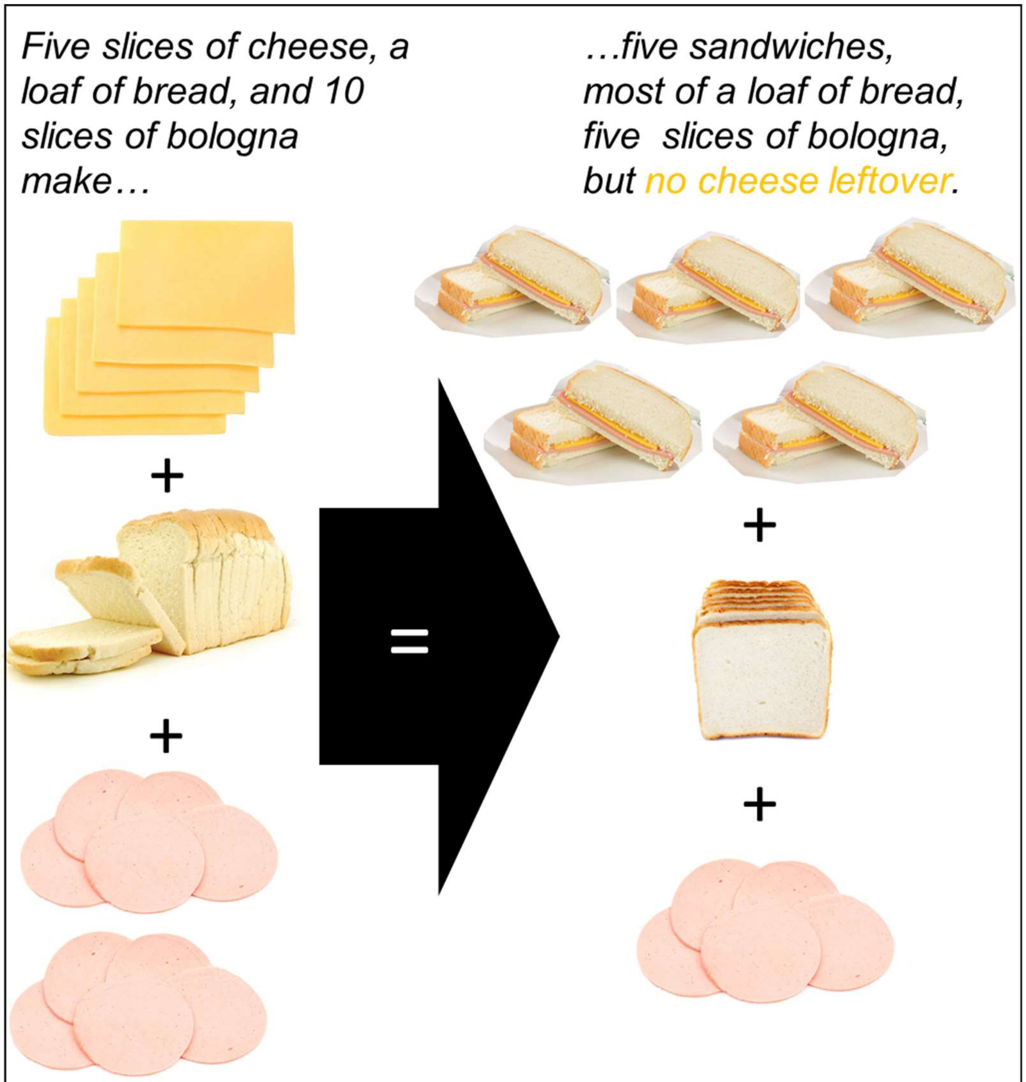

Fig. 6. Illustration of limiting factors. In this example, cheese is a limiting factor. The only way to make more than five bologna sandwiches, assuming each uses exactly two slices of bread, one slice of bologna, and one slice of cheese, is to buy or add more cheese to the equation. Until we find more cheese, even though there is plenty of bread and bologna, we cannot make more sandwiches. Building algae is much like building bologna sandwiches. Each cell is made of a relatively fixed amount of nutrients, and the nutrient that is in lowest supply relative to demand is the limiting nutrient. In the vast majority of lakes, the limiting nutrient is phosphorus.

slices, how many sandwiches could be made? If you said "five" you are correct. You can make five sandwiches with 10 bologna slices left over and nearly a whole loaf of bread but no cheese left over. You cannot make more sandwiches until presented with more cheese. In this case, "cheese" is the limiting factor. Because we have left over bread and bologna, we say these factors are in surplus, and thus not limiting.

Phosphorus is like the *cheese* in the metaphor. It limits growth of algae while the other nutrients are in excess. This means that you can add more carbon or nitrogen or potassium or anything else to the lake that algae use to build themselves but it will not result in more algae. Only by adding more phosphorus will you grow more algae.

It is not a given that phosphorus is the limiting nutrient or that other nutrients may not become temporarily limiting, but science tells us that in most lakes, most of the time, phosphorus is the limiting nutrients. One other contender for that role is nitrogen. These two nutrients are generally in shortest supply in the environment relative to demand for building algae; however, it is phosphorus that we typically focus on unless there is evidence to the contrary. Why? Both nitrogen and phosphorus are used in agricultural fertilizers, but whereas nitrogen easily dissolves in water and is carried to the lake through run-off, phosphorus is sticky to the dirt. This means that less of it dissolves in water and reaches the lake so that lakes in general are phosphorus starved relative to other nutrients.

A precise relationship between phosphorus, algae (as measured by chlorophyll *a*), and water clarity has been long established in many lakes such that an increase in phosphorus leads to an increase in algae, which leads to a decrease in water clarity (as measured by the Secchi depth). Phosphorus causes algae to grow, which causes water clarity to be reduced. Scientists can and have measured in lots of different lakes how much chlorophyll *a* should be expected based on a given amount of phosphorus and what the effect of that is on water clarity. For example, if a waterbody has a concentration of 40 ppb of total phosphorus, then science tells us we expect it to have 15.28 ppb chlorophyll *a* and a Secchi depth reading of 3.94 ft.

Table 2. Relationship between Secchi depth, total phosphorus (TP), and chlorophyll a (Chl a) established and converted into a Trophic State Index (TSI) by R.E. Carlson (1977). Note that Secchi depth is given in meters, which can be converted to feet by multiplying by 3.28. The general nature of the relationship is that for every 10 point increase in TSI, there is a halving of the Secchi depth in meters, a doubling of total phosphorus, and an approximate tripling in algae.

TSI	Secchi depth (m)	TP (ug/L)	Chl a (ug/L)
0	64	0.75	0.04
10	32	1.5	0.12
20	16	3	0.34
30	8	6	0.94
40	4	12	2.6
50	2	24	6.4
60	1	48	20
70	0.5	96	56
80	0.25	192	154
90	0.12	384	427
100	0.062	768	1183

Due to this exact relationship, a scientist from the University of Minnesota by the name of R.E. Carlson in 1977 developed a Trophic State Index (TSI), which standardizes all of these to a single measure (Table 2). A TSI for 48 ug/L of phosphorus is 60. Because of the exact relationship between total phosphorus, chlorophyll *a*, and Secchi depth this means that a TSI of 60 is also equivalent 20 ug/L chlorophyll *a* and 1-meter (or 3.28 feet) Secchi depth. This relationship is useful because if you can simply measure Secchi depth (inexpensive) you can say something about phosphorus and chlorophyll *a* levels in the lake. Most lakes, including Green Lake, have long histories of Secchi depth readings with sporadic readings for chlorophyll *a* and phosphorus. The TSI is useful and intuitive because for each 10 point increase in value, it relates to a halving in the Secchi depth, a doubling in phosphorus, and an approximate tripling of in algae in a lake (e.g., a lake with TSI 50 has approximately three times as much algae as a lake with TSI 40).

Green Lake was listed as impaired in 2008 based on not reaching minimum numbers for established targets for TSI for deep lakes established by the MPCA. Based on historic data, Green Lake is borderline for Secchi depth (Fig. 7). The lake has historically met the guideline for individual readings approximately 50% of the time. If we average values to give an annual average Secchi depth reading, then Green Lake meets the threshold 62% of years for which data are available. The lake appears to have been improving since 2012 with the clearest conditions ever recorded in the most recent published data year (2017). Year 2017 averaged water clarity of 14.5 feet with an all time high reading on 6/8/2017 of near 28 feet. To be sure, there is seasonality that influences water quality. Many lakes are clearest in the early spring and gradually become more degraded as the summer progresses. Lakes that stratify, which Green Lake does, can get a large pulse of phosphorus released from sediments after fall turnover.

Retrospective analysis for trends of phosphorus and chlorophyll *a* are more difficult due to missing data and difficulties doing water chemistry. There are a handful of water chemistry labs in Minnesota that provide a "lakes package" where they will take a water sample collected from volunteers once a month from May through September and analyze that water sample for phosphorus and chlorophyll *a* for a small cost. Some lakes have more complete data sets than others and being able to compare these three measures: Secchi depth, phosphorus and chlorophyll *a* can be useful. They should all tell the same story about the quality of the water; however, sometimes they do not. For example, we might get

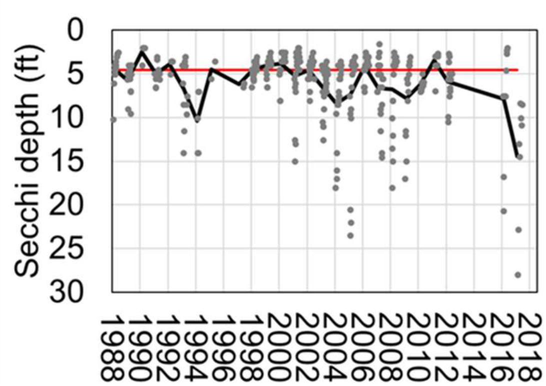

Fig. 7. Historical Secchi depth readings of records obtained from MPCA database. Grey points are individual readings, the solid black line is the annual averages, and red line is the Minnesota clean water goal for deep lakes (<4.60 ft).

significantly higher Secchi depth readings than what would be expected based on phosphorus and chlorophyll *a* levels. This can occur for one or a combination of three reasons: (1) the data collected are in error or (2) phosphorus is not the limiting nutrient or (3) biology is disturbing the relationship.

There is a weaker relationship between the three trophic measures than might be expected for chlorophyll a being predicted by total phosphorus if we assume phosphorus is a limiting nutrient in Green Lake (Fig. 8). We can say that approximately 30% of the increase/decrease in algae in the lake can be associated with total phosphorus in the lake as measured. This means that upwards of 70% of the increase/decrease algae is due to something else (e.g., light or nitrogen). Alternatively, these data may reflect errors in collection or analysis (see below).

The water clarity acts much more as expected, showing that about 60-70% of the variability in Secchi depth readings coming from algae concentrations. The remaining unexplained 30% could come from

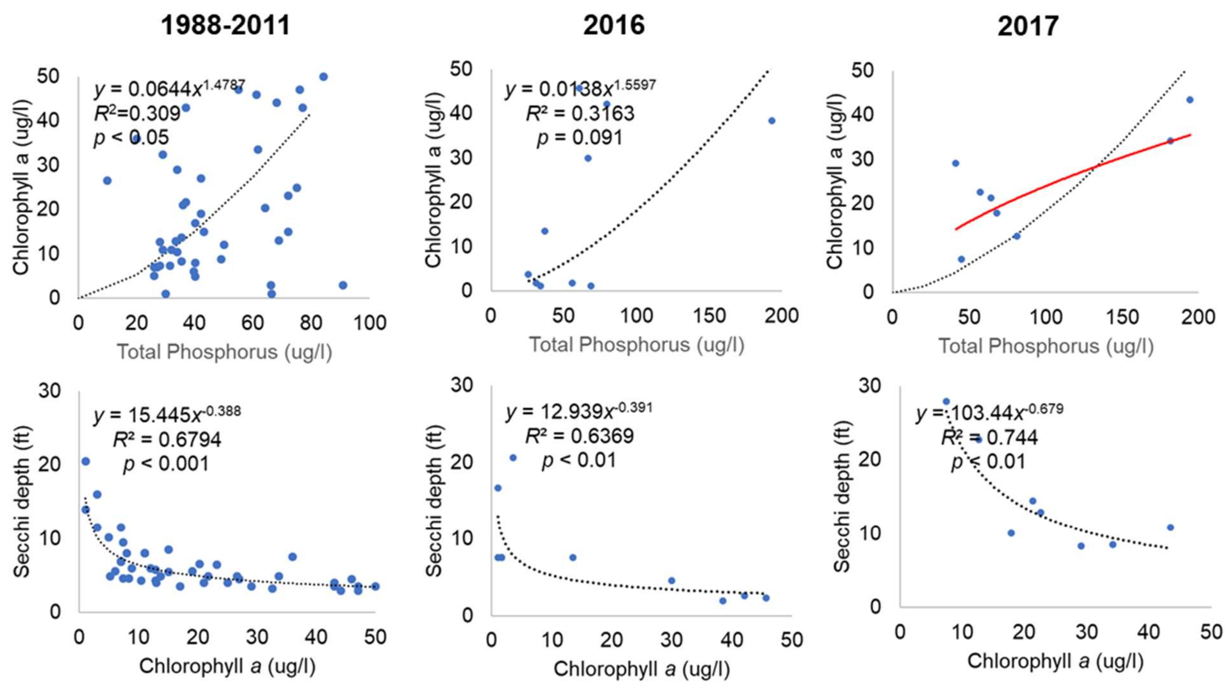

Fig. 8. Comparison of the three factors that get converted to a trophic state index. If relationships become as expected, then points will fall directly on the dashed line. The R^2 value indicates the proportion of one measure explained by another. For example, in the upper right plot Total Phosphorus predicts 30.9% of the chlorophyll a measurements made between 1988-2011. Thought about another way, it means 61.9% of algae growth is due to some other(s) factors ***IF*** the there were not systematic errors in how water samples were collected and analyzed. The "p-value" is a statistical measure used in science that gives the probability that we would have collected these data if there was absolutely no relationship between the two measures compared. For example, in the upper left plot, "$p < 0.05$" means there is less than a 5% chance that we are wrong to say that chlorophyll a is related to total phosphorus. Scientist typically accept any probably as less than 5% as enough evidence to suggest a relationship exists. In the upper middle plot, "$p = 0.091$", meaning there is a 9.1% chance we would be wrong to conclude chlorophyll a and total phosphorus were related. Since 9.1% is more than 5%, from a scientific perspective we would say there is not enough evidence to say chlorophyll a and total phosphorus were related in 2016 even though the analysis suggests about 32% of chlorophyll a is related to total phosphorus. Note that we deleted the six highest total phosphorus values from the 1988-2011 data, which looked to be erroneous. For the upper right plot, the 2017 data comparing total phosphorus to chlorophyll a were so variabile that we could not fit a sensible curve. The red line shows the curve, which does not match known associations between total phosphorus and chlorophyll. The dashed black line in that plot is the same as from 2016 just to show a comparison.

suspended sediments and/or differences in how individuals make their readings.

Phosphorus is difficult to analyze, particularly in lakes where the concentrations are low. Not only are there many chemistry steps in the lab that can introduce error into readings, built phosphorus analysis requires extremely clean conditions. Even slightly dirty glassware, chemical reagents, or sampling gear can introduce phosphorus into the water sample to cause error. Of all the trophic state variables, phosphorus readings most difficult to accurately determine and as such are least to be trusted if they do not agree with chlorophyll *a* and Secchi depth readings. Chlorophyll *a* readings are susceptible to the same sources of error, except that they are not nearly as sensitive as phosphorus to dirty gear or glassware. Still a number of steps are required in the lab to get chlorophyll *a* readings and error can be introduced at any of them. Secchi depth readings are most to be trusted. These are only subject to human error in making readings. There are no chemistry steps that can potentially introduce error.

When trophic state index values do not match for phosphorus, chlorophyll *a*, and Secchi depth, a first step should be to rule out errors in collection or chemistry. This can be done, for example, by either having multiple pieces of equipment take water samples to be sure they all match, having two or more water chemistry labs analyze the same. Data integrity can also be improved by having professionals collect samples rather than individuals. Exact steps toward validating data for a year will depend on budgetary constraints.

If data integrity can be determined to be valid, there may be real system explanations, including different limiting nutrients besides phosphorus controlling growth (e.g., nitrogen) or biological reasons to explain differences.

A convenient and conventional way to analyze all three variables on a single graph is by plotting the difference of the trophic state index for chlorophyll a (TSI(CHL)) from the trophic state index resulting from Secchi depth readings. (TSI(SD)) or

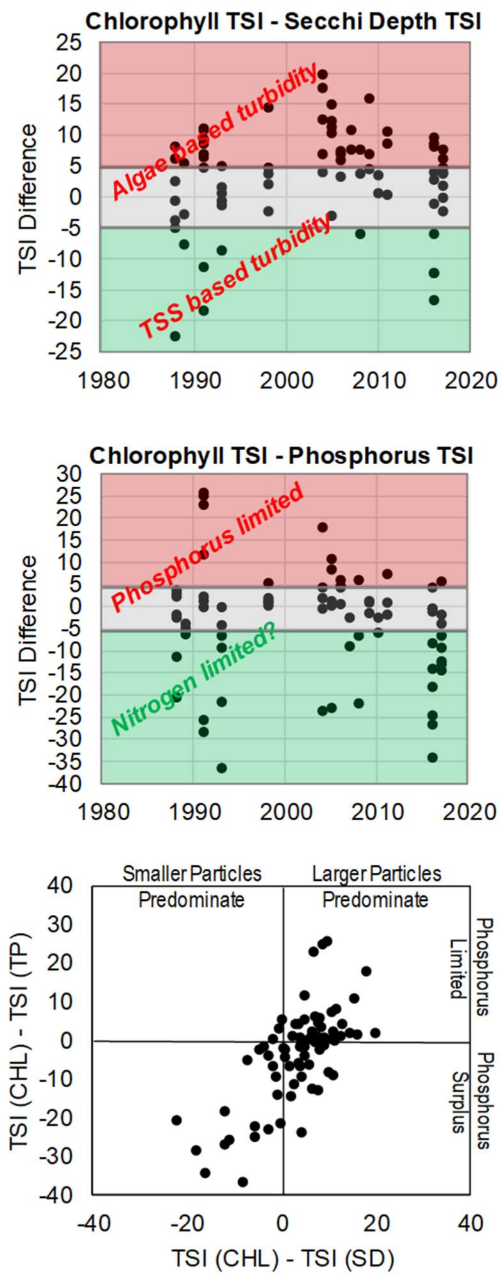

Fig. 9. Differences in TSI values for Green Lake. Expectation is that differences would be zero. Deviations from zero indicate either (a) poor data, (b) something other than phosphorus limiting algae, or (c) water clarity modified by biology (i.e., fish and zooplankton communities).

TSI(CHL)-TSI(SD). If this number is zero, things match up just as expected. If the number is much higher than 0, it says there is more algae in the water than expected based on water clarity and if the number is much

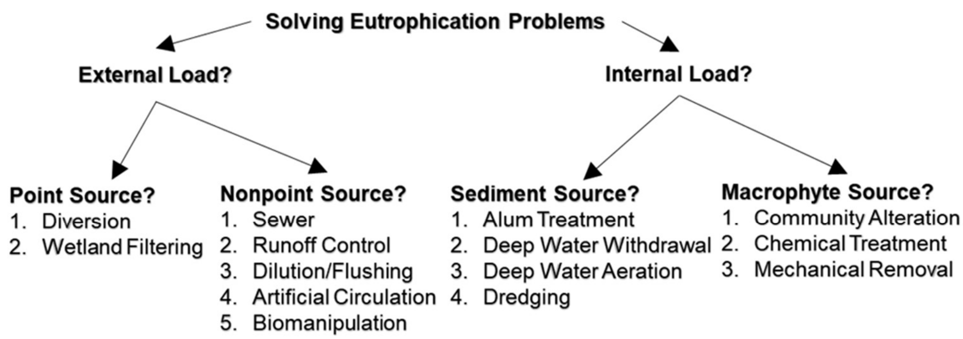

Fig. 10. Common methods for lake restoration from eutrophication (modified from Cooke et al. 1993. Restoration and Management of Lakes and Reservoirs. Boca Raton: CRC Press, Inc.

lower than 0 it suggests that something other than algae is making the water cloudy (e.g., suspended sediments). For Green Lake, there is significant deviations when TSI measures are compared to one another (Fig 9). Recall that an increase in 10 TSI points indicates a doubling in phosphorus, a halving of Secchi depth, and a 2-3X increase in chlorophyll a. Some of the deviations in TSI readings for Green Lake are as much as 30 – 40 points, which is extremely high and needs rectifying. Either there are data errors or phosphorus is not always the most important regulator of water quality in Green Lake.

Eutrophication can be thought of as analogous to obesity in human health. It is a chronic condition brought on by the lake consuming or receiving more nutrients than can be processed. Nutrients are processed through sedimentation and buildup of organism tissue, particularly macrophytes (plants) and algae. The lake can process a certain amount of algae through grazing algae eaters, namely large bodied zooplankton, but if more nutrients build algal tissue beyond what zooplankton can keep up to graze, a lake become cloudy. In order to control eutrophication, either nutrients coming into the lake and being made available needs to decrease and/or the biology of the lake needs to be manipulated to favor growth of more zooplankton that can keep up with the metabolic demands made by growing algae.

Eutrophication has multiple causes. The four major categories of influences are location on the planet (latitude, longitude, and altitude), topography, geological formation, and human influence. Not all factors influencing eutrophication can be controlled but both in Europe and in North America lake restoration has been somewhat successful and processes to diagnose and treat problems have been tested (Fig. 10).

To initialize a control plan, a determination of the likely source of nutrients needs to be determined. Nutrients can come from outside of the lake as rain water washes them off of the landscape, into rivers and streams, which then flow into the lake. These are “external sources” that are classified as “Point” or “Nonpoint” sources. A point source is a source of nutrients that can be clearly identified. The classic example is a waste water treatment facility that dumps processed water through a pipe directly into a stream. Other point sources can include industries are identifiable agricultural properties; however, in the case of agriculture in watersheds where there are multiple farms operating, determining sources becomes difficult. If the source of the nutrients cannot be determined, we call it a nonpoint source. Sometimes we can identify nonpoint sources by using a sequential monitoring program, which finds a stream dumping into the lake and them moving upstream at various places to find out where nutrients become prominent. The type of treatment to apply for external control depends on whether the source is a point or nonpoint source. There are limits to controlling output from identified sources that come from private properties. Often the best solution is to somehow intercept suspect waters and either treat them or divert them.

Internal sources of nutrients are those that do not come from rain or stream flow but nutrients that have accumulated over time in sediments or in lake weeds. Lakes act as a sink for phosphorus, the primary nutrient responsible for eutrophication. This means that there are more nutrients that flow in externally than flows out of the lake. The difference gets stored in lake sediments where it either remains or is taken up into plant tissue and stored. When plants die and decompose they release the stored nutrients which provides food for algae and green growth. Lake sediments also have an interesting chemistry regarding phosphorus. When there is lots of oxygen in the lake, chemicals in the lake, particularly iron locks up or holds on to phosphorus. This effectively removes it from being used. Over time, there can get to be quite a buildup of locked up phosphorus in the sediments. The interesting chemistry is when deeper lakes lose oxygen in deeper areas. When oxygen levels decrease, the locked-up phosphorus is

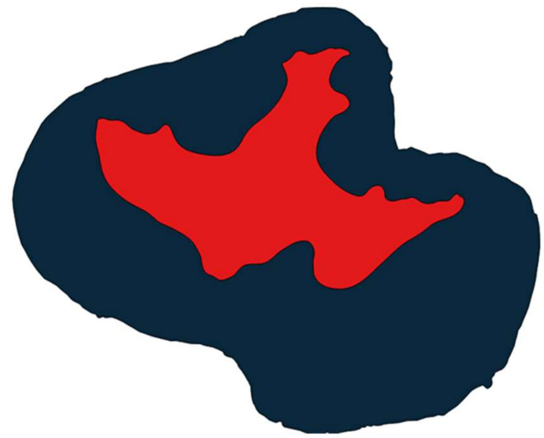

Fig. 11. Green Lake summer anoxic zone. The red color indicates the estimated area of the lake that goes anoxic during the summer. Anoxia is determined as the water above lake bottom to 1 meter falling below 2 mg/l dissolved oxygen (DO). The oxycline was determined from 2016-17 DO profiles, which indicated the oxycline depth is 23 ft. The total anoxic area is 206 acres (or 25% of the lake). Models combined with data indicate that on average the lake goes anoxic around May 4 and turns over on September 3, which gives an duration of 122 days. Internal phosphorus loading can be estimated as the product of the **anoxic zone area x duration x average loading rate** given in the literature. Green Lake estimates for phosphorus loading gives 2,691 pounds TP per year. Nurberg (1984a, 1984b), Demers and Kalff (1993).

released from the iron and goes back into the water column where it can be used. Based on monitoring data from 2016 and 2017 we estimated the oxycline (depth at which deep water oxygen goes to below 2 mg/l) and the hypolimnetic anoxic zone, which was approximately 206 acres or 25% of the lake (Fig. 11).

Alum, a chemical sometimes added to reduce phosphorus from anoxic water, acts in much the same way as iron except that the locking up is not as dependent on oxygen. Once alum locks up the phosphorus it remains locked up. A recent success for a lake using alum of similar size in the metro is Bald Eagle Lake in Ramsey County (see MPCA story in the appendix). Bald Eagle Lake was impaired by

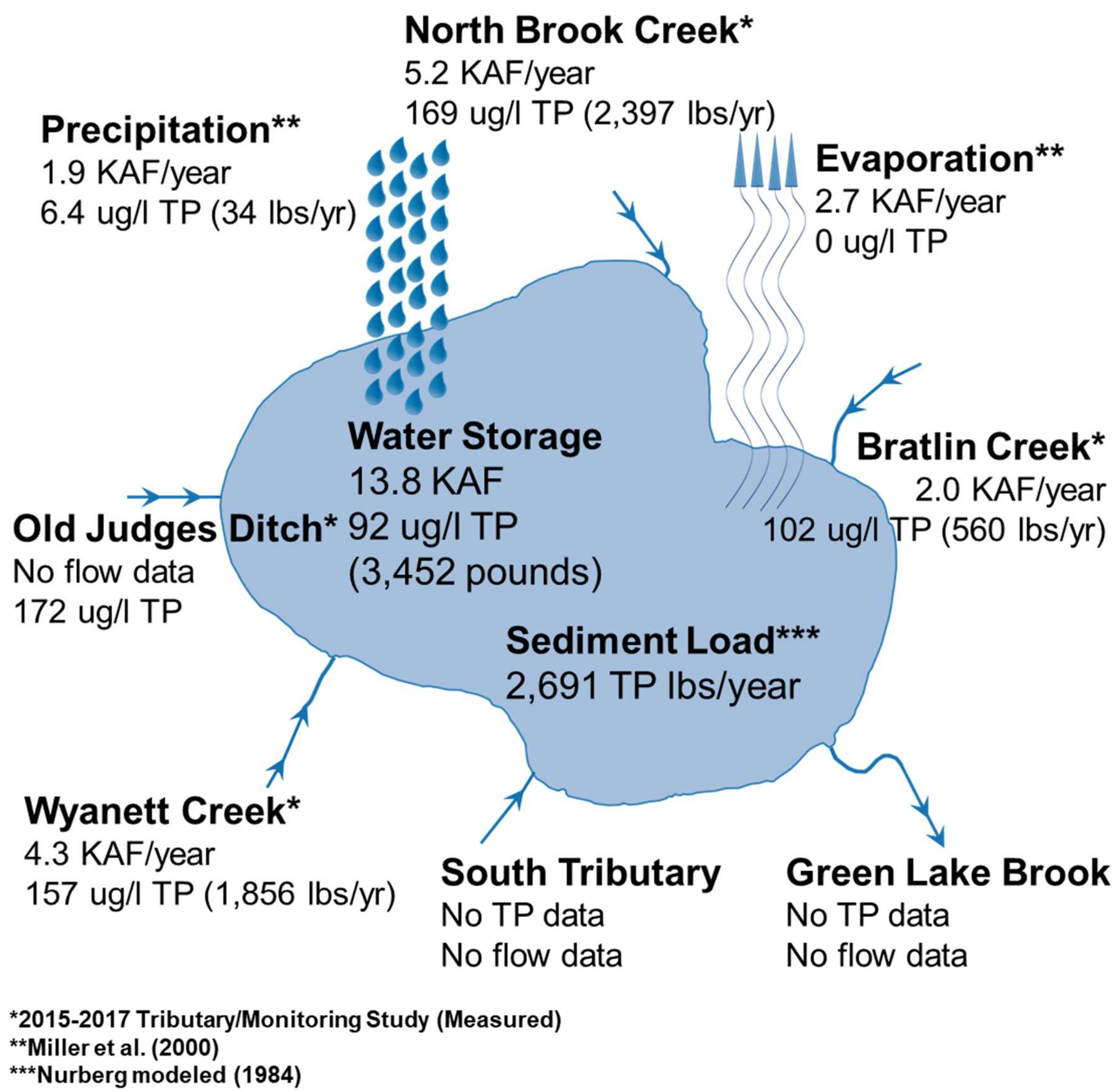

Fig. 12. Existing and missing water and nutrient data for constructing budgets on Green Lake in order to determine eutrophication mitigation strategies.

the same criteria used by MPCA for Green Lake and has a similar size to Green Lake with a surface area of 1,073 acres and maximum depth of 39 feet, draining a watershed of approximately 11,000 acres. The cost was $1,732,100. This was funded through the watershed district, Clean Water fund Grant and Lakeshore tax. The path toward getting funding to improve the lake was long and involved targeted monitoring to make a proper diagnosis and reasonable guess about what methods might be useful.

There are not enough data to determine nutrient sources to Green Lake (Fig. 12). The most important piece of missing data is outlet monitoring. Both discharge and total phosphorus measurements are required to balance the nutrient budget. Unless there is high confidence that neither Old Judges Ditch or the South Tributary contribute important amounts of phosphorus to the lake, these too would require additional monitoring. Ideally, all sources and flows

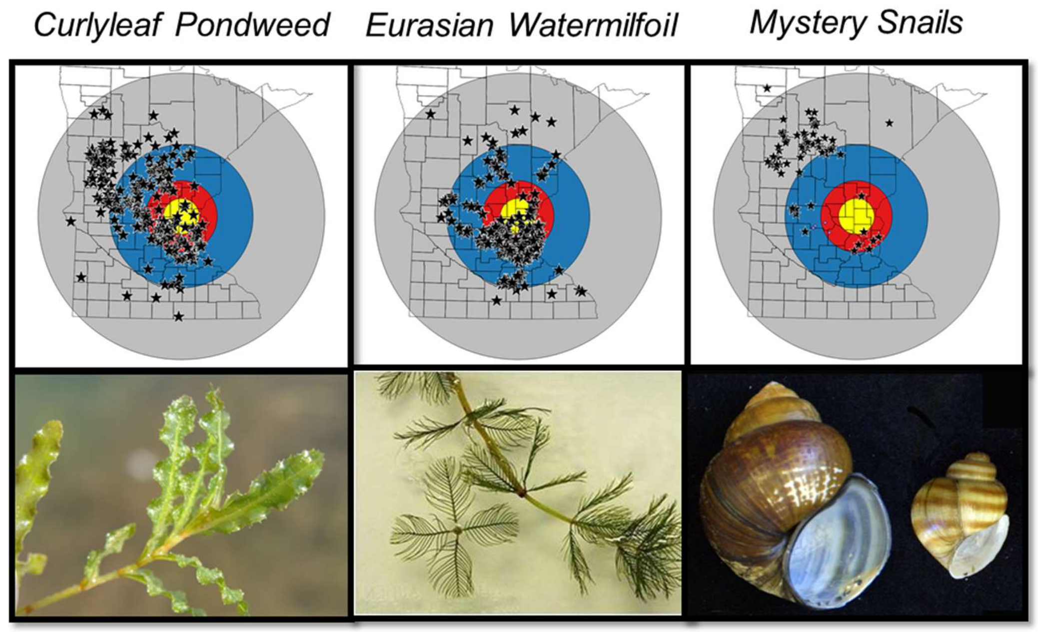

Fig. 13. Invasive species known to occur in Green Lake as of August 2018. Maps show stars where each species is currently known to exist. Bullseye is centered at Green Lake with yellow ring showing 25 mile radius, yellow+red ring showing 50 mile radius, yellow+red+blue ring showing 100 mile radius, and yellow+red+blue+gray showing 200 mile radius. Photo credits: Orange County (CA), USGS, MN DNR.

would be monitored for the whole year to develop a proper budget. Given phosphorus seems to be only a minor determinate for algae growth in the lake, we also recommend simultaneous measurements of total nitrogen.

AQUATIC INVASIVE SPECIES

Green Lake is currently known to be infested with curlyleaf pondweed (CLP), Eurasian water milfoil (EWM), and banded mystery snails (Fig. 13).

Curlyleaf pondweed. CLP has greatly expanded from occupying approximately 4% in 2005 to 35% in 2012 to 44% of the littoral zone in 2018. Long-term management for control should be expected. Unfortunately, there are no current systematic herbicides, which would go toward killing plant, allowed by the MN DNR to treat CLP.

Late ice-out in 2018 meant treatment occurred after most growth of CLP had occurred and was abundant in the lake. Lake property owners noted dying plants accumulating on shoreline from the treatments. This problem can be partly solved by treating areas much earlier in the year before plants have reached maximal growth. This would have additional benefits of removing plants prior to producing turions and adding to the turion bank in the sediment.

Eurasian watermilfoil. A 2005 survey indicated 34% coverage of Green Lake with Eurasian watermilfoil by mid-June. The 2012 MN DNR plant survey indicated mid-June coverage of 28%. The 2018 Limnopro survey occurred in mid-May, well before most of EWM would be detected in the lake. Even so, it found EWM at approximately 5% of sites. It is likely the EWM is much more prevalent on the late as the summer

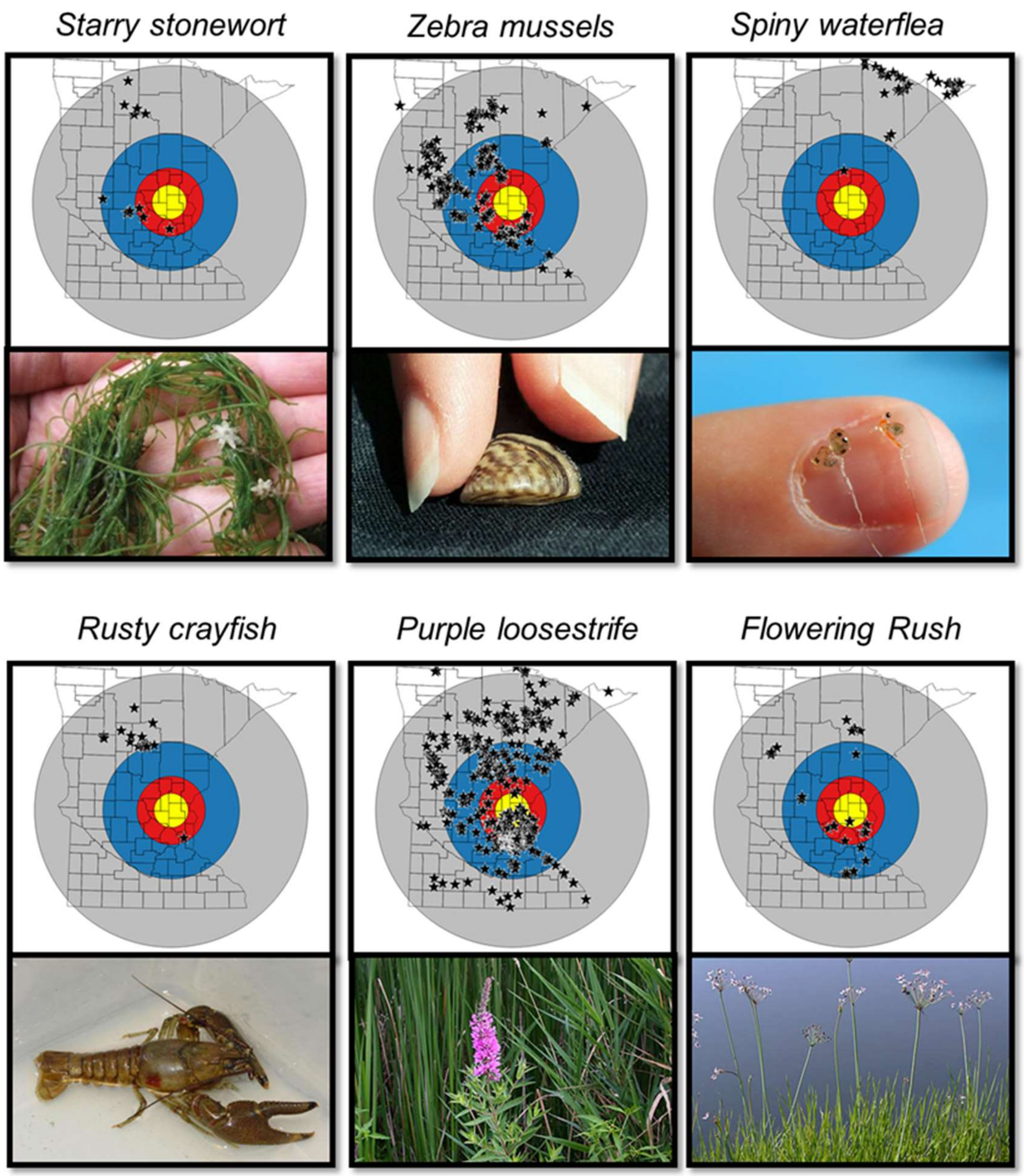

Fig. 14. Invasive species **NOT** known to occur in Green Lake as of August 2018. Maps show stars where each species is currently known to exist. Bullseye is centered at Green Lake with yellow ring showing 25 mile radius, yellow+red ring showing 50 mile radius, yellow+red+blue ring showing 100 mile radius, and yellow+red+blue+gray showing 200 mile radius. Michigan DNR, NY Dept. of Env. Conservation,

progresses and that it creates surface matting in some areas. EWM can become even a greater problem for recreational users of the lake because it is persistent, lasting much longer into the summer than CLP, which naturally dies off at the beginning of July. We are unaware whether any targeted treatments have occurred for EWM, but this is a species that is often chemically controlled. MN DNR allows EWM treatment with the systematic herbicides 2,4-D and triclopyr, both systematic herbicides that may provide longer-term control. Studies do not show differences in which of these two chemicals works better, and because 2,4-D tends to be less expensive it is more often used in control of EWM.

One successful way to treat lakes with populations of both CLP and EWM is by apply in a cocktail mixture of low doses of enthothall and 2,4-D in the early spring. Endothall controls both CLP and EWM, while 2,4-D only impacts EWM. If treatments are done as early as possible in the spring it would improve effectiveness and prevent large plant mats from washing up on shore. A plant management plan that includes control measures for EWM would require an up-to-date mapping of EWM during mid to late summer when it reaches peak standing stock biomass.

Mystery snails. While not currently registered and reported with the MN DNR, Limnopro found several banded mystery snails during the early season CLP survey. These snails are probably more distributed than reported on MN DNR maps, but they do not appear in such lists because they are not being looked for. Some evidence suggests that mystery snails eat fish eggs and compete with native snails to eat algae and detritus, but mystery snails are no known to have large scale impacts to lakes. There is currently no MN DNR allowed treatment for the banded mystery snails.

AIS on the Horizon. Some of the AIS not yet detected in Green Lake but existing in Minnesota and to be looked out for include starry stonewort, zebra mussels, spiny waterfleas, rusty crayfish, purple loosestrife and flowering rush (Fig. 14).

Starry stonewort is a macroalgae first detected in Minnesota in Lake Koronis (Stearns County) in 2015. Seven new lakes were listed in 2016, two in 2017 and so far two in 2018. Of these 12 infestations, three are within 50 miles of Green Lake (Grand, West Sylvia, and Medicine Lake). Another six of these lakes are within 100 miles, occurring in Stearns, Wright or Pope counties. The remaining five lakes occur north in Beltrami County. Costs of treating starry stonewort are high and effectiveness in control is difficult. Lake Koronis has spent upwards of a million dollars on the problem. The best time to search for starry stonewort is August-September when they produce their characteristics white starshaped bulbils. The MN DNR has a program called the Starry Trek, where volunteers will perform spot checks during this time. Purposeful searching from volunteers or professionals each fall is highly recommended in order to launch a rapid response should it be found.

Zebra Mussels are listed as being found in nearly 1,000 lakes, rivers and streams in the state of Minnesota. Last year alone 14 new lakes were listed with nearly half of those from Kandiyohi County. Other counties that had new listings included Crow Wing, Otter Tail, and Itasca. Zebra mussels can and most often do drastically increase clarity in lakes, which also provides greater habitat for aquatic plants, including invasive species. There would be a high likeihood that should Green lake become infested with zebra mussels that water would clear and both curlyleaf and Eurasian watermilfoil would expand in the lake. Zebra mussels also become numerous enough that their shells create sharp bottom, which makes swimming difficult. While some experimental methods are being tried around the state to control new infestations, there has yet to be approved any effective way to remove zebra mussels once they get into a lake.

Spiny waterflea are microscopic zooplankton that so far are concentrated in the arrowhead region of the Minnesota; however, they are known to occur in the Rum River watershed in Mille Lac Lake. These animals can be problematic because they compete with native zooplankton and can replace them. While native zooplankton are a favorite food for young of the year fish, spiny waterflea are difficult for young of the year fish to eat. Consequently, spiny waterflea may reduce fish recruitment in a lake. There is currently no effective way to remove spiny waterflea from lakes.

Rusty crayfish are an invasive that can replace native crayfish. They have a higher metabolic rate, meaning they need to feed much more than native crayfish, and tend to forage during day, which is not common for native crayfish. Rusty crayfish eat plants among other things and as such they can reduce lake plants. When lake plants are reduced, sediments become suspended and nutrients introduce to the water, which can lead to algae blooms. Rusty crayfish can have similar effects as carp in that respect. Currently (August 2018) rusty crayfish occurs in concentrated areas of Cass and Hubbard counties. There is currently no effective way to control for rusty crayfish once they get into a lake.

Two emergent plant species that have been causing problems in Minnesota include ***purple loosestrife*** and ***flowering rush***. Both can outcompete native emergent plants such as cattails and bulrush, creating near monocultures. This reduction in biodiversity

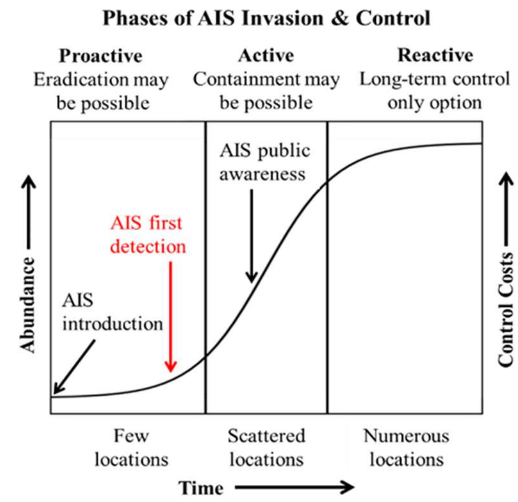

Fig. 15. AIS invasive species curve demonstrating the importance of early, purposeful activities to detect them early for better control. By the time someone "bumps" into AIS accidently they are typically well established.

can impact nutrient cycling and wildlife habitat. A number of invasive fishes exist in Minnesota lakes and include several carp species (***bighead***, ***silver***, and ***grass***), ***round goby***, ***ruffe***, and ***white perch***. Other, less known probably less distributed aquatic invasive species known to exist in Minnesota lakes include ***brit1tle naiad***, ***faucet snails***, ***New Zealand mud snails***, and ***red swamp crayfish***.

Managing invasives species risks is best done when infestations are new and not widespread (Fig. 15). This demands purposeful searching for new infestations, which can be done through specific early detection activities or plant searches.

FISH COMMUNITY

MN DNR fisheries surveys have been done approximately every five years (1979, 1982,

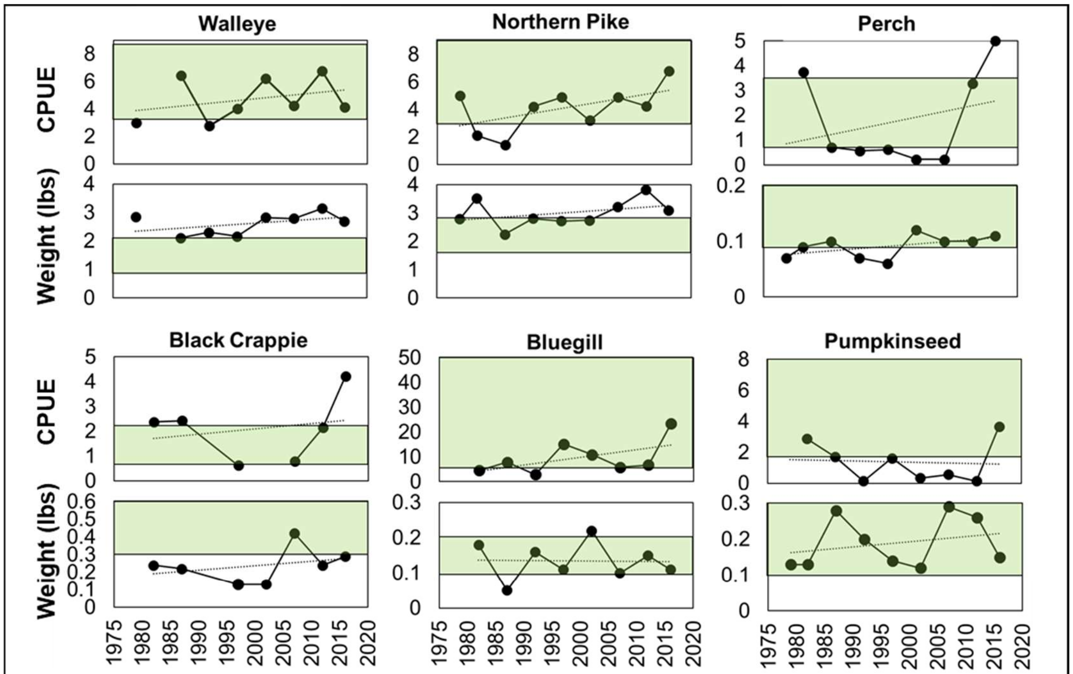

Fig. 16. DNR Fisheries historical data for catch rate (i.e., CPUE = Catch Per Unit Effort) and average weight of a fish caught during the survey. Walleye and northern pike data are from gill nets and everything else is from trap net data. Green boxes inside each plot represent the "normal range" (i.e., interquartile range) for similar lakes to Green Lake.

1987, 1992, 1997, 2002, 2007, 2012, and 2016) since at least 1979. Gill nets and trap nets have been used for standard assessments with a few special assessments using seines and/or electrofishing. The fisheries community appears to be in relatively good health (Fig. 16). Historically adult walleye and northern pike catch rates have fallen within the normal range with average weights of both being on the high end, outside the normal range for most years recorded. Perch, an important food for adult game fish, have historically been low and small, but in the most recent 2016 survey have been more abundant and heavier than normal. Bluegill and pumpkinseed catch rates have both have been on the low end of normal historically but of average size. Black crappie tend to be on the smaller than normal with average weights. The 2016 survey indicated much higher catch rates than historically has been the case.

We also compared the most recent fisheries survey (2016) to normal ranges (Table 3). For the most recent fish survey, Green Lake had more crappies than normal similar lakes but fewer bass. Average size of crappie and yellow perch were below normal but both walleye and northern pike were above normal compared with similar lakes.

We also compared the most recent (2016) fish survey results to the most recent fisheries surveys for Outdoor News designated "Great Eight" fishing lakes in Minnesota (Table 4). That publication lists the following lakes to make up the Great Eight: Mille Lacs, Lake of the Woods, Lake Minnetonka, Lake Vermillion, Lake Winnibigoshish, Leech Lake, Rainy Lake and Red Lake. We added

Table 4. DNR Fisheries most recent 2016 survey for catch rate (i.e., CPUE = Catch Per Unit Effort) and average weight of a fish caught during the survey compared with Outdoor News' designation of Minnesota "Great Eight" fishing lakes. Walleye and northern pike data are from gill nets and everything else is from trap net data.

			Minnesota's "Great Eight" Fishing Lakes							
Fish	**Green**	**Rank**	**Mille Lacs**	**LOW**	**Minnetonka**	**Vermillion**	**Winnibigoshish**	**Leech**	**Rainy**	**Red**
					Numbers (Fish Caught Per Unit Effort)					
black crappie	26.44	1	0.08	0.09	7.38	8.11	0.05	0.28	0.46	0.60
bass	0.22	5	1.02	0.14	0.58	0.56		0.14	0.92	
northern pike	6.78	4	0.58	1.59	13.75	7.78	12.64	3.94	2.29	0.95
walleye	4.11	6	12.77	5.45	3.25	2.56	2.86	9.08	5.71	36.80
yellow perch	32.67	3	17.35	12.98	110.80	23.00	49.68	9.42	6.58	7.30
					Weight (Average Pounds of Fish Caught Per Unit Effort)					
black crappie	0.2	8	0.32	0.53	0.17	0.29	0.54	0.53	0.23	1.25
bass	1.09	5	1.83	2.03	1.40	1.33		0.43	0.74	
northern pike	3.1	4	5.38	4.68	2.63	2.23	2.45	2.07	2.98	4.04
walleye	2.69	1	1.71	2.34	2.43	1.69	2.09	1.61	1.20	1.10
yellow perch	0.05	9	0.22	0.37	0.11	0.09	0.17	0.24	0.31	0.38

Green Lake to the fix to make a "Great Nine" and then ranked each lake from "best" (1) to "worst" (9) within the group. Notably, Green Lake ranks as #1 for crappie numbers (i.e., it has a catch rate for black crappie higher than all "Great Eight" lakes) and for average size of walleye (i.e., Green Lake has a higher average walleye size than any of the Great Eight lakes. On the other end, Green Lake has the lowest yellow perch size and second to lowest black crappie size. With respect to bass, and northern pike, it has numbers somewhere in the middle. One of the ways to monitor the health of Green Lake Fisheries would be to redo this analysis every five years when the MN DNR does it fisheries survey. An increase or decrease in rankings would indicate change over and above that which is natural and no related to Green Lake management, which includes stocking activities and fishing pressure.

CONCLUSION/SUMMARY

This lake status report addressed what is currently known about the health of Green Lake. While lakes are complex systems, topics of most concern to the majority of lakes users were addressed. We looked at general lake and watershed characteristics, water quality, aquatic invasive species, and status and trends of fisheries. Improving water quality and controlling current and future AIS will require effort. Based on our in-depth review of current data and information, much of which is in this report, and other information reviewed in the process of putting it together, we provide several recommendations that have been conveniently summarized on a single page at the beginning of this document. Please direct any further questions or concerns about this report to us at Limnopro Aquatic Science, Inc. Thanks for what you do for Minnesota lakes.

Dan McEwen, Ph.D.
8/20/2018

APPENDICES

Green Lake Data Sources

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2. Ramthun, R. 1992. 1991 Lake Assessment Program. MPCA. 91 pages.
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10. Isanti County SWCD. Green Lake Monitoring Report 2016. 5pp.
11. Isanti County SWCD. Green Lake Tributary Report 2017. 6 pp.
12. Isanti County SWCD. Green Lake Monitoring Report 2016. 5 pp.
13. Green Lake Improvement District. 2012. Residents Survey.
14. Green Lake Improvement District. 2012. Residents Survey Responses
15. MN DNR Fisheries Reports: 1949, 1957, 1971, 1982, 2002, 2007 (Provided by MN DNR Deb Sewell, Hinkley on 12/18/2017)
16. Partial Green Lake Inflow Data (Spreadsheet provided by Isanti County SWCD Todd Kulaf)
17. Green Lake Subatershed Retrofit Analysis. 2014 (Provided by Isanti County SWCD Todd Kulaf)
18. MPCA water quality data (Accessed 2017-2018)
19. DNR Lake Finder (Accessed 2017-2018)
20. Minnesota Geospatial Commons Data (Accessed 2017-2018)

Bald Eagle Lake now meets water quality standards

Thanks to many partners and funding sources, Bald Eagle Lake in the northern Twin Cities is meeting state water quality standards for the first time since 1980. Once plagued by algal blooms and murky water, this lake near Hugo is now much healthier for recreation. "This is an example of good science, strong collaboration, and fiscal responsibility resulting in a successful restoration project," said Bryan Bear, Hugo city administrator.

The Rice Creek Watershed District worked with several partners and tapped many funding resources for the $1.7 million project, including:

- $497,000 from the Minnesota Board of Water and Soil Resources' Clean Water Fund, established by the 2008 Legacy Amendment.
- $400,000 Clean Water Partnership loan from the Minnesota Pollution Control Agency.
- Remainder from the watershed district and Bald Eagle Lake Water Management District, a special tax for lakeshore owners that was initiated by the property owners themselves.

Partners in the lake restoration included the City of Hugo, lakeshore property owners, and a local golf course. Following the implementation of the project, phosphorus and algae decreased by 67% and 69%, respectively, and clarity improved by 63%. Bald Eagle Lake is meeting state water quality standards for nutrients, algae, and clarity for the first time since 1980, when data collection began. "Today we have more than 5 feet of water clarity on Bald Eagle Lake. I think it was closer to 8 or 10 feet this year in August. Three years ago, we were lucky to have 1 foot. I no longer need to worry about my grandsons swimming in a toxic algae bloom!" said Gary Krejcarek. He has lived on or near the lake for 40 years and is president of the Bald Eagle Area Association.

This project used a three-pronged approach to improve water quality in the lake. First, the lake was treated with aluminum sulfate, or "alum." Alum is a non-toxic material that attaches itself to phosphorus. Once alum and phosphorus are combined, phosphorus is no longer available to stimulate algae growth. This was Minnesota's largest full lake alum treatment.

Second, the local Oneka Ridge Golf Course installed a system that captures stormwater and reuses it for watering the golf course. This reduces the amount of stormwater flowing to the lake and reduces the use of groundwater for irrigation.

Finally, 10 residential rain gardens were installed and 6 shoreline areas restored. They capture stormwater and reduce runoff that carries phosphorous into the lake. The results may help the lake move off the impaired waters list, a rare accomplishment and a long-term process.

The project earned the Rice Creek Watershed District a special award in 2016 from the Minnesota Association of Watershed Districts. "This is particularly satisfying because the award is heavily based on the measurable results in the lake. The fact that the homeowners are pleased makes it even more gratifying," said Matt Kocian, the district's lake and stream specialist.

The Rice Creek Watershed District encompasses about 186 square miles of urban and rural lands in Anoka, Hennepin, Ramsey, and Washington Counties with the purpose of conserving and restoring water resources for the beneficial use of current and future generations.

MPCA: *Tuesday, March 28, 2017*