Technical Memo

To:	Terry Peterson and Chip Wells	From:	Dendy Lofton, PhD, CLM Anne Wilkinson, PhD, EIT Tom Beneke
	Windemere Township Lake Association, Inc PO Box 292 Sturgeon Lake, MN 55783		Stantec 7500 Olson Memorial Highway Suite 300 Golden Valley MN 55427-4886
File:	Island Lake Diagnostic Study	Date:	July 15, 2022

Reference: Island Lake Diagnostic Study

Island Lake is a large, deep lake in the North Central Hardwood Forrest Ecoregion in Pine County, Minnesota with a maximum depth of 42 feet and a surface area of 536 acres. Island Lake experiences high concentrations of phosphorus during the summer months. The objective of this study is to use existing data to develop a model to estimate watershed and internal phosphorus load contributions to Island Lake and provide recommendations for phosphorus load management in order to improve water quality and protect from future degradation.

Background Data

The Windemere Township Lake Association collected water quality data from the lake and the two primary tributaries from May to October 2021 and May to June 2022. In-lake data collection included water quality profiles, chlorophyll-a (chl-a) concentrations, Secchi depth, and total phosphorus (TP) concentrations at the surface and in the hypolimnion in Island Lake. The water quality profiles consisted of water temperature, DO (dissolved oxygen), and pH measured approximately every meter vertically through the water column. The tributaries, as seen in Figure 1, are referred to as Echo Stream and Large Culvert. Tributary data collection included water temperature, DO, conductivity, pH, streamflow, Total Suspended Solids (TSS), TP, and orthophosphate following rainfall events.

Reference: Island Lake Diagnostic Study

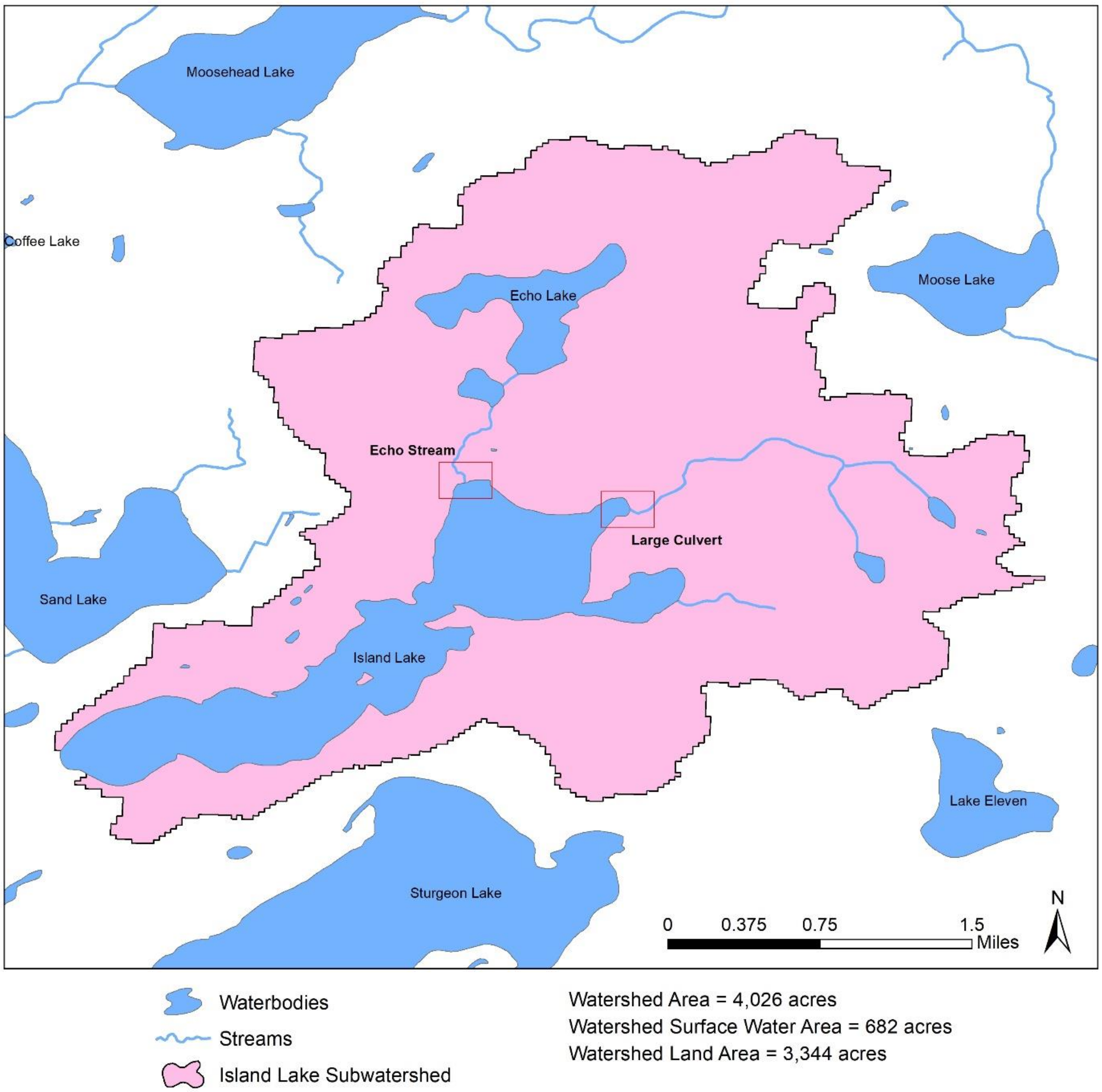

Figure 1. Map of Island Lake watershed boundary based on the corresponding NHDPlus Version 2 catchment boundary. Note the two tributary sites are denoted by red boxes for Echo Stream and Large Culvert.

Figure 2 summarizes Secchi depth, TP and chl-a concentrations in Island Lake compared to the deep lake eutrophication standards for the Northern Hardwood Forests Ecoregion (TP < 40 µg/L; chl-a < 14 µg/L and Secchi depth greater than 1.4 m). Surface TP concentrations increased throughout the season and approached the water quality standards in early fall. The chl-a concentrations exceeded the standard in late summer of 2021 and are likely driven by algae blooms utilizing elevated TP concentrations and warm temperatures. The elevated chl-a is reflected in the decreased Secchi depth during the same time period, which also showed an exceedance of the water quality standard. Additionally, the hypolimnetic TP increases to the highest concentrations during the middle to the end of the summer, indicating internal loading of phosphorus. While the eutrophication standards are not always exceeded throughout the summer, late summer exceedances suggest that Island Lake may become impaired in the future as phosphorus concentrations increase. Consequently, phosphorus load reduction actions should be implemented to improve water quality and protect Island Lake from further degradation and listing on the State's impaired waters list.

Reference: **Island Lake Diagnostic Study**

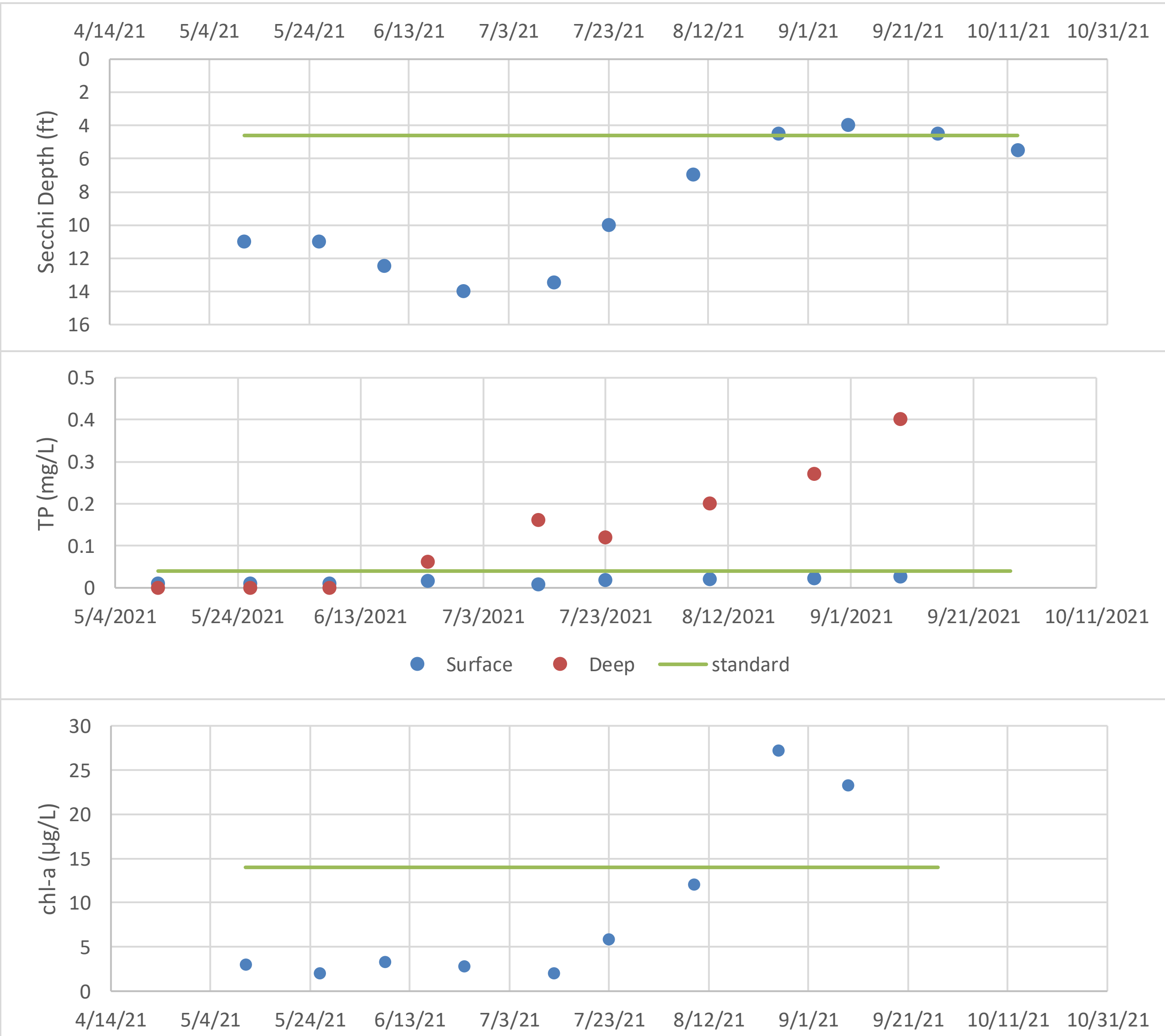

Figure 2. 2021 Island Lake water quality measurements.

In addition to in-lake measurements, data was collected at the two tributary sites, Echo Stream and Large Culvert. Tributary streamflow measurements and water quality samples were collected across four days during the summers of 2021 and 2022. Sample timing and frequency are summarized in Table 1.

Table 1. Summary of tributary streamflow and water quality observations.

Tributary Name	Data Type	Collection Dates
Echo Stream	Streamflow	5/9/2022; 6/2/2022
Echo Stream	Water Quality	6/8/2021; 7/25/2021; 5/9/2022
Large Culvert	Streamflow	5/9/2022; 6/2/2022
Large Culvert	Water Quality	6/8/2021; 7/25/2021; 5/9/2022

The Echo Stream site had an average observed TP concentration of 69 µg/L and an average streamflow of 7.92 cfs. The Large Culvert site had an average observed TP concentration of 160 µg/L and an average streamflow of 3.83 cfs. Tributary TP concentrations are represented by both 2021 and 2022, whereas streamflow measurements are both from 2022. One additional TP sample was taken on June 15, 2022 but the concentration was reported as a "non-detect", meaning that the sample concentration either fell below the minimum reporting level of 200 µg/L or there was an issue with the sample itself. Note that tributary TP concentrations and streamflow values represent conditions following rainfall events and that it was documented that streamflow is intermittent and largely rainfall dependent. This was addressed during calibration in the Lake Response Model Results section below.

Lake Response Model Setup

A lake response model was developed to estimate an average annual TP budget in Island Lake using data from 2021 and 2022. The lake response model selected for this exercise was the Canfield-Bachman lake equation, which predicts in-lake TP concentrations based on established relationships a between in-lake TP concentrations, watershed loads, atmospheric load, morphology of the lake and phosphorus sedimentation rates using data from a wide range of lakes in North America (Canfield and Bachman, 1981). The phosphorus sedimentation rate is an estimate of net phosphorus loss from the water column through sedimentation to the lake bottom, and is used in concert with user supplied lake-specific characteristics such as annual phosphorus loading, mean depth, and hydraulic flushing rate to predict in-lake phosphorus concentrations. Model predictions are then compared to measured data to evaluate how well the model describes the lake system. If necessary, the model parameters are adjusted appropriately to achieve an approximate match to monitored data.

The external TP load to Island Lake is comprised of two components, the landscape load and the tributary load. The landscape load is runoff from upland, non-water land cover classes, that contribute directly to Island Lake. Upland areas draining directly to the two tributaries were excluded from the landscape load as this load is implicitly captured by the tributaries in the model. The landscape TP loading rate of 0.19 lbs/acre/year was determined from the Spatially Referenced Regression on Watershed Attributes Model, or SPARROW model, for the midwestern US. SPARROW was also used to estimate an average annual runoff in the Island Lake watershed of 13.78 inches. The second component of the external TP load, the tributary load, is what comes from streams and culverts directly discharging to the lake. The tributary TP load was estimated using monitoring data from the Echo Stream and Lake Culvert sites.

Internal phosphorus loading from lake sediments can be a major component of a lake's phosphorus budget. Internal loading is typically the result of anoxic (void of oxygen) sediments releasing phosphorus to the water column through complex biogeochemical reactions. To estimate internal loading of phosphorus from the lake sediments in Island Lake, an assumed sediment phosphorus release rate (mg/m^2/day) was multiplied by an anoxic factor calculation (Nürnberg 2004), which estimates the period where anoxic conditions persist over the sediments based on DO profiles and lake morphology. Based on the DO profiles measured in 2021, the estimated anoxic factor was 29 days. Sediment phosphorus release rates were estimated by calculating the observed rate of change in hypolimnetic TP concentrations during the summer growing season for 2021 in which hypolimnion TP samples were collected. Results of these calculations suggest Island Lake has an average sediment phosphorus release rate of 20.5 mg/m^2/day. However, these estimates are relative to other lakes in Minnesota so should be interpreted judiciously. Internal phosphorus loading rates should be better constrained through collection of sediment cores with laboratory incubation to quantify phosphorus release rates.

Finally, atmospheric phosphorus loading to Island Lake was estimated using literature rates for a dry year (<25 inches of rainfall) (Barr Engineering, 2004) since the in-lake observed TP concentrations were from summer of 2021. Atmospheric loading to lakes is typically small compared to other sources and is very difficult, if not impossible, to manage.

Lake Response Model Results

Using a weighted average concentration based on the respective volume of the epilimnion and hypolimnion, the observed in-lake TP concentration was 92.3 µg/L. The uncalibrated model estimated an average annual in-lake TP concentration of 103.3 µg/L, approximately 12% higher than the observed concentration. Due to the intermittent nature of the tributary loading, the calibration factor was applied to reduce tributary loads until the estimated concentration matched the observed concentration. By doing so the model approximates the intermittent nature of those loads. As such, a calibration factor of 0.7 was applied to the tributary loads, meaning that the calibrated model reduced tributary loads to 70% of the initial estimate. This resulted in an estimated in-lake TP concentration of 90.5 µg/L.

An estimated phosphorus budget was created from the calibrated model results to compare loading from different sources (Figure 3). The landscape load is a small percentage of the budget at 6%. The tributary loads from Echo Stream and the Large Culvert represent a larger portion of the budget at 16% and 17%, respectively. However, due to the limited set of observations and the drought conditions during 2021, there is a high degree of uncertainty in the relative contribution of the tributaries versus the landscape. With that in mind, the confidence in the internal load estimate combined with the close match between the estimated and observed in-lake concentrations indicates that the overall magnitude of the external load (the total of the landscape load and tributary load) is reasonable and likely accurate. The model estimates that internal phosphorus loading comprises 58% of the budget to Island Lake with the remaining loads coming from external sources.

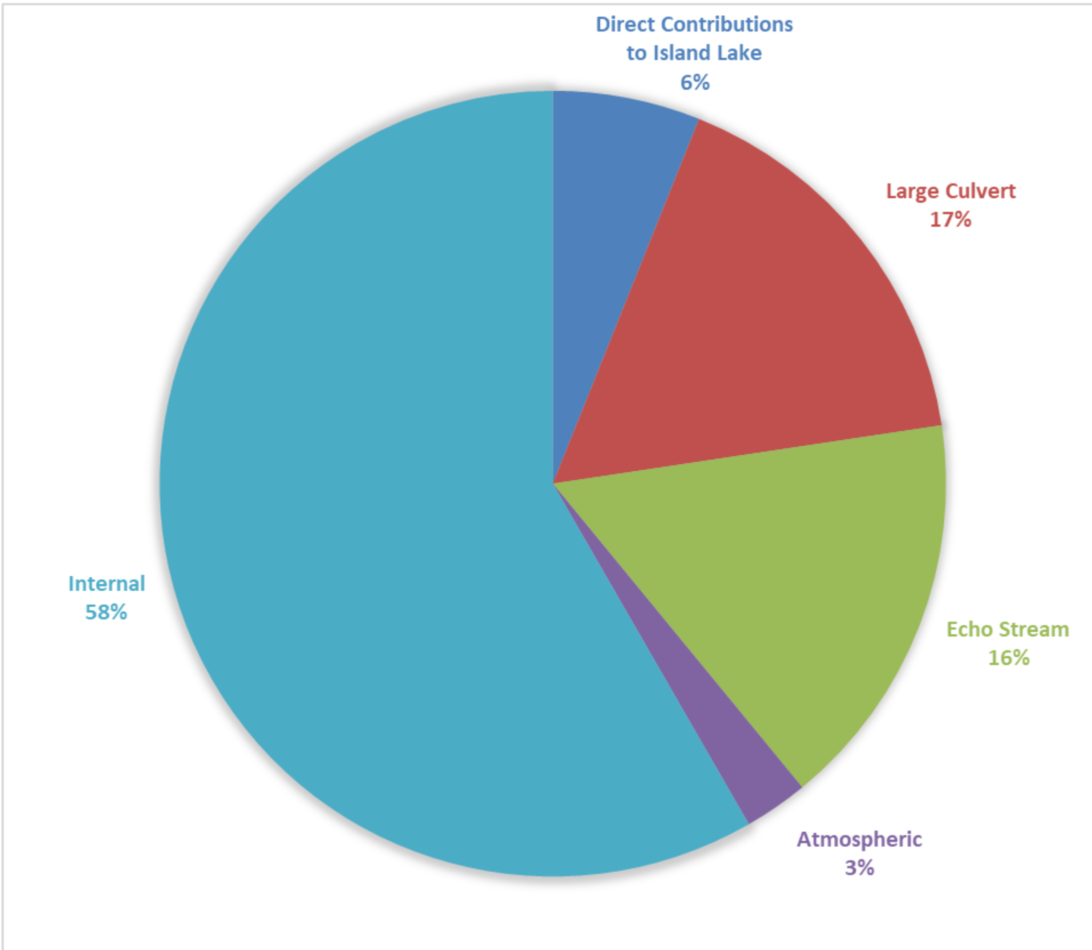

Figure 3. Estimated average annual TP load by source (percent of total load).

Recommendations

Currently, the surface water TP concentrations indicate that Island Lake is meeting the standard but will likely experience exceedances in the future with continued phosphorus loading. This assumption is supported by the accumulation of phosphorus in the hypolimnion under anoxic conditions as shown in Figure 2. When the data were combined into a lake-wide average in support of the lake response model, the average concentration was 90.5 µg/L which does exceed the numeric nutrient standard. While determination of compliance with water quality standards is typically based on surface measurements, and not on lake-wide averages, the observed data and modeling results indicate that Island Lake is close to exceeding the water quality standard such that internal load reductions are needed to protect Island Lake (estimated 58% of the TP budget). This condition is further supported by the increase in chl-a towards the end of the 2021 growing season, which did exceed the State standard.

The model predicts that 58% of the TP budget is derived from internal loading while approximately 42% of the TP load is coming from external sources, primarily from the measured tributary inputs. This means that both internal loading and external loading will need to be reduced in order to improve water quality. Additional subwatershed assessments may need to be conducted to determine where and how to reduce loading from these external sources. Island Lake is in the Kettle River watershed which is just beginning a comprehensive watershed management planning for the Kettle River/Upper St. Croix One Watershed One Plan, which is being led by the Pine County Soil and Water Conservation District and partners. Stantec recommends that the Windemere Township Lake Association engage with watershed partners in this planning effort to manage the Island Lake watershed as part of the larger Kettle River watershed management process.

In-lake treatment methods are available to treat internal loading. Aluminum sulfate (alum) is one of the most common chemicals used for sediment-phosphorus inactivation as the absorption of phosphorus to aluminum is very stable under standard environmental conditions and provides a long-term sink of phosphorus in the lake. Alum is applied to lakes by injection of liquid alum just below the lake water surface. The alum quickly forms a solid precipitate (floc) and settles to the bottom of the lake, which converts highly mobile sediment phosphorus (redox-P) to an immobile phosphorus fraction (aluminum bound-P). This process reduces sediment phosphorus release rates, and ultimately reduces internal phosphorus loading in lakes. The longevity of an alum application to reduce internal loading is largely dependent upon the volume of alum applied and continued extent of external load.

Other in-lake management actions that can mitigate internal phosphorus loading include dredging and hypolimnetic aeration. These latter two options are more expensive than alum treatments and often employed when lakes are experiencing much more dramatic water quality problems than Island Lake. Of the in-lake options, we recommend evaluating the feasibility of an alum treatment to reduce internal phosphorus loading in Island Lake. Note that a feasibility study is required for eligibility of Clean Water Funds for alum treatments.

The next steps towards an alum feasibility study would be to collect sediment cores for quantification of phosphorus release rates in laboratory. Stantec collaborates with UW-Stout and have worked on numerous lake sediment evaluations together. The sediment cores can be used to confirm the phosphorus release rate estimated in this study, quantify the mobile and immobile fractions of sediment phosphorus and estimate the feasibility of an alum dose to mitigate internal phosphorus loads in Island Lake.

References

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