Water and Nutrient Budget Analysis

Spider Chain of Lakes, Sawyer County WI

(Clear Lake WBIC: 2435800, Fawn Lake WBIC: 2435900, North Lake WBIC: 2436000 and Spider Lake WBIC: 2435700)

Sponsored by the Spider Chain of Lakes Association and Wisconsin Dept. of Natural Resources.

Analysis conducted by Ecological Integrity Service, LLC

Analysis Summary

A water quality analysis which includes a water and nutrient budget was conducted on the Spider Chain of Lakes, in Sawyer County Wisconsin in 2020. The Spider Chain of Lakes is comprised of four lakes interconnected. There are no perennial tributaries flowing into these lakes and the system is drained via the Spider Creek outlet. Water quality data including total phosphorus, chlorophyll-a, and Secchi depth were collected monthly from June through September in Clear Lake, Fawn Lake, North Lake, and in two locations in Spider Lake. A total phosphorus profile from the surface to near the bottom was also collected in the two Spider Lake locations. Dissolved oxygen and temperature profiles were also collected monthly and a transducer to measure flow was installed to measure the outflow volume. The watershed was adjusted to evaluate the direct drainage portion of the watershed. The vast majority of the land cover in the Spider Chain of Lakes watershed is forested.

The sampling data indicates all four lakes have a mesotrophic trophic state. The area-weighted mean for total phosphorus in the chain of lakes was 14.9 µg/L. The mean chlorophyll-a concentration was 4.3 µg/L and the mean Secchi depth was 2.8 meters. The water budget estimate indicated that 50% of the inflowing water was from groundwater, 41% from precipitation onto the lake, and 9% from overland runoff from the watershed. The nutrient (phosphorus) budget determined that 47.7% of the phosphorus is coming from the sub-watershed runoff around the lakes, 31.2% is from atmospheric deposition, 18.4% from groundwater discharge into the lakes, and 2.7% from septic systems. Sediment release of phosphorus was determined to occur and was estimated at 22 kg in Spider Lake only (not evaluated in the other lakes). Dissolved oxygen and temperature profiles indicate Spider Lake remained stratified well into September providing evidence that little or no mixing occurred.

The sub-watershed draining into Clear Lake was determined to be the biggest contributor of phosphorus (23.6%) compared to the sub-watersheds of Fawn Lake, North Lake, and Spider Lake (followed by Spider Lake at 16.5%).

A load response indicates that reducing and increasing the total phosphorus load from runoff, groundwater, and septic systems could result in fairly significant changes. A 20% reduction in total phosphorus loading would reduce the mean total phosphorus concentration from 14.9 µg/L to 13.3 µg/L, and a mean chlorophyll-a concentration from 4.3 µg/L to 3.7 µg/L. Other load responses were used to determine changes from more specific sources of phosphorus and indicated potential reductions in loading would result in improved water quality.

Introduction

The Spider Chain of Lakes is located in Sawyer County Wisconsin and is comprised of five hydrologically connected lakes. The lakes in the system include Clear Lake, Fawn Lake, North Lake, and Spider Lake (some refer to as two lakes Big and Little Spider Lakes). The morphology data of the lakes are listed in Table 1.

Lake	**Area** (km^2)	**Maximum depth** (ft)	**Mean depth** (ft)	**DNR trophic status**
Clear Lake	254.8	30	5.8	Mesotrophic
Fawn Lake	30.3	35	11.2	Eutrophic
North Lake	139.6	30	12.7	Eutrophic
Spider Lake	1232.8	64	14.7	Mesotrophic

Table 1: Morphological data of the four lakes in the Spider Chain of Lakes.

The chain of lakes is a complex hydrological system that consists of four lakes (five if separating Spider Lake into Big Spider and Little Spider). The northernmost lake, North Lake, drains into the small Fawn Lake. Fawn Lake flows into Spider Lake. Clear Lake, to the west, drains into Spider Lake as well. The lakes connect with quite narrow channels, that likely restrict the dispersive movement of the water. Spider Lake drains out via Spider Creek. North Lake, Fawn Lake, and Spider Lake all have large areas of wetlands in the riparian zone. The complexity of this system makes modeling the water budget and nutrient budget challenging with limited data.

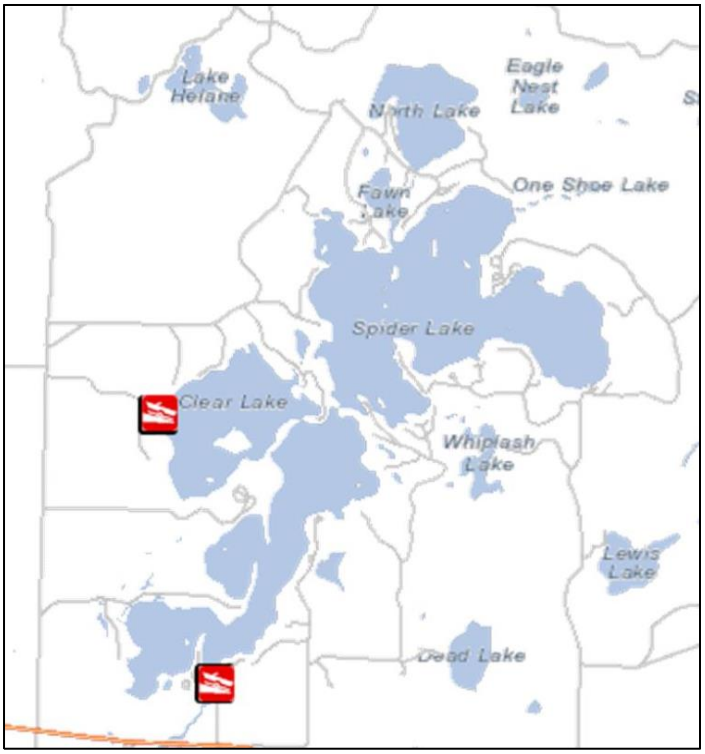

Figure 1: Map of the Spider Chain of Lakes showing the four lakes in the chain.

As part of a comprehensive lake management plan development, the Spider Chain of Lakes Association along with the Wisconsin DNR sought to evaluate the nutrient budget and water quality for the Spider Chain of Lakes. This analysis involved numerous water quality data, as well as measurements of outflow to determine the nutrient budget of the chain of lakes. In this analysis, the water quality of each of the five lakes was evaluated and the nutrient budget was estimated for each. The information was entered into the empirical model Bathtub which was used to predict outcomes of reducing nutrient loads.

The nutrient of focus in each of these lakes is phosphorus. The total nitrogen to total phosphorus ratio is much greater than 10 to 1 in each lake. This indicates that phosphorus is the limiting nutrient in these lakes, which determines the amounts of algae that grows in the water. Therefore, the nutrient data collected as total phosphorus. Total phosphorus tests for all forms of phosphorus. The useable form of phosphorus is soluble reactive phosphorus as phosphate. Various forms of phosphorus can be converted into the useable phosphate form, so total phosphorus reflects the potentially available phosphorus.

Sources of phosphorus include atmospheric deposition (precipitation and dry deposition from pollen and dust), runoff from the land within the watershed of the lake, groundwater, and septic systems. Another source of phosphorus in some lakes is the release of phosphorus from lake bottom sediments. This is referred to as the internal loading of phosphorus.

Figure 2: Entire watershed boundary for the Spider Chain of Lakes. This includes internally drained portions of the watershed.

The watershed of the Spider Chain of Lakes covers approximately 38.7 square kilometers. The majority of the land cover is forested, with fairly large areas of wetlands around the lakes.

To quantify the amount of phosphorus that enters a lake, various data are collected. These include periodic in-lake phosphorus concentrations to determine how much phosphorus is in the lake and the increase/decrease in phosphorus content. Chlorophyll-a was also measured to evaluate the growth of algae from the phosphorus in the lakes. More phosphorus can result in more algae growth and therefore higher chlorophyll-a concentrations. The watershed is delineated around the lake to determine the land cover and the area from which runoff can occur. Precipitation amounts are used to determine runoff potential and atmospheric deposition. The number of residences and occupants is used to estimate septic system contributions[1]. Lastly, the outflow volume is measured daily. This data estimates the water budget, which can be used to estimate the groundwater discharge into the lakes, and the runoff amounts. Evaporation of water from the lake surface is determined from rates determined in other lake studies in northern Wisconsin (Lenters, 2005).

In this analysis, data were collected to estimate the water budget into and out of the Spider Chain of Lakes. The phosphorus budget was also estimated to indicate the main sources of phosphorus in each lake. These data were then used to create an empirical model of the lakes to estimate the phosphorus, chlorophyll (algae), and Secchi depths that could be expected if nutrient loading is increased or decreased. Land cover changes and human activity can lead to increased phosphorus loading, and management practices can lower phosphorus loading.

Methods

In the analysis of the water budget and nutrient budget for the Spider Chain of Lakes, each lake was separated as a segment in the overall system. The inputs of water and nutrients were determined for each segment with dispersion into lakes downstream in the chain. Each lake's (segment) catchment (watershed) was separated as sub-watersheds from the entire Spider Chain of Lakes watershed.

The watershed boundaries were acquired from the Wisconsin DNR Presto tool available in the surface water viewer. The direct drainage portion of the catchment was isolated to eliminate the internally drained areas. Internally drained areas of the watershed do not drain directly into the lake, thus do not contribute to runoff during storm events. They can affect the shallow groundwater flow and nutrients. The land cover data was also obtained from the Presto data files. The source of the land cover is the North American Land Cover Database with the US Geologic Survey from 2006.

Monthly (June through September) water samples were collected in Clear Lake, Fawn Lake, and North Lake using an integrated water sampler that samples water from 0-2 meters. The samples were analyzed for total phosphorus and chlorophyll-a. Dissolved oxygen, temperature, and specific conductance profiles were completed in each of the listed lakes from the surface to the bottom. Secchi depth was also measured. For Spider Lake (Big and Little), the data from the Citizens Lake Monitoring sampling were used. Total phosphorus, chlorophyll-a, and Secchi depth were measured by volunteers. Profiles of dissolved oxygen and temperature were also collected.

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[1] Information from the Spider Chain of Lakes Shoreline Property Owners Survey Report, 2020.

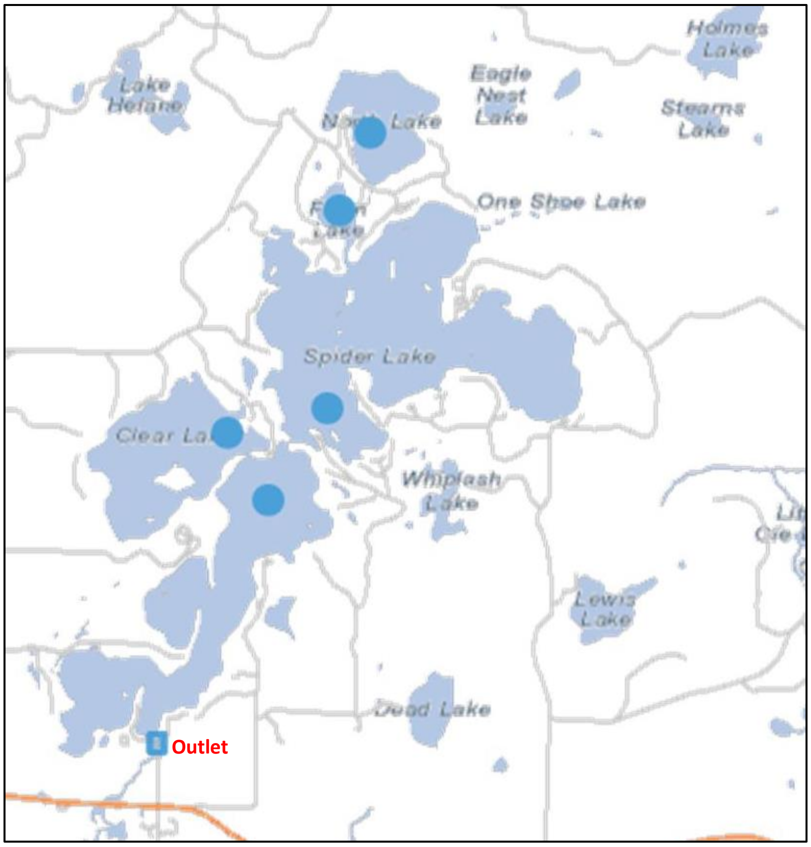

Figure 3: Location of water sample collection in each lake. The discharge was measured at the southern end of the chain (outlet).

To determine the water budget, the outflow from Spider Lake was monitored for flow by installing a pressure transducer in the outlet flume (in a slow flow area that won't affect pressure readings). Six flows were measured throughout the spring, summer, fall and winter using velocity (ft/s) and flume cross-section (ft^2) and recorded in ft^3/s. The flows were then correlated with the transducer stream gage to create a flow curve. The flow curve was then used to calculate flow based upon the stream gauge height every hour. A mean daily flow was then calculated for the outflow from April 20 until January 31. The flow during the winter months, when evaporation and precipitation do not impact the lake level (or very little) determines the base outflow. This base outflow is a decent estimate of the groundwater discharge into the lakes (Arnold, 1999). A lake staff gage was also installed near the outlet (in the lake) to measure the change in the lake stage which is factored into the water budget.

To estimate the groundwater discharge into the lakes, the base flow of the outlet was used. During the ice-on months, the base flow is determined when little to no precipitation (since frozen) is adding to flow and evaporation is not a component of outflow. This baseflow was used in addition to the baseflow during the growing season to estimate the mean baseflow. The groundwater discharge was estimated from this baseflow and applied during the sampling period. Note that there can be variability in groundwater discharge. Also, there is some evidence in the lake stage and outflow data that the lake level was changed manually at the outlet. The dam level can be adjusted to maintain lake levels. These changes were accounted for in the estimates. Groundwater data was not collected so this is an estimate to implement groundwater into the lake model.

Precipitation data was obtained from the NOAA data available at the Hayward airport, near Hayward Wisconsin. Evaporation was estimated using data obtained during other lake analyses in northern Wisconsin (Lenters, 2005). Precipitation amounts and intensity of rainfalls may have been different onsite compared to the values used. This could be true of the evaporation rate as well. The overland runoff water volumes were estimated using a mass balance approach where the inflow of water equals the outflow of water. The following equation is the basis for this approach: (ΔS is the change in lake stage (level))

ΔS = (groundwater inflow + precipitation + runoff from watershed) – (groundwater outflow + evaporation + groundwater outflow + tributary outflow)

The phosphorus loading was estimated using a steady-state, mass balanced model. Since all of the lakes are connected hydrologically, the lakes were modeled as one system but separate "segments". The Canfield-Bachman equation was used within the Bathtub model (US Army Corp of Engineers) to determine the phosphorus loading into each lake. This equation typically works well for northern Wisconsin natural lakes. The equation is as follows (Canfield, 1981):

$$P = \frac{L}{z(0.162(L/z)^{0.458} + p)}$$

Where P is the predicted mixed lake phosphorus concentration (µg/L or mg/m^3), z is the mean depth, L is the aerial total phosphorus load (mg/m^2/yr. for the entire lake surface area), and p is the lake flushing rate (yr^{-1}). The mass balance assumes the phosphorus inflow will equal the phosphorus outflow. A key factor for a good model fit is the rate at which phosphorus settles into the sediment (sedimentation rate). The sedimentation rate factor is one reason the Canfield-Bachman equation works well in northern Wisconsin lakes (Robertson, 2009). The incorrect sedimentation rate can over-estimate phosphorus loads in Bathtub, so this rate can be calibrated to match lake concentrations.

The precipitation (atmospheric deposition) phosphorus concentration was determined in another lake water analysis in northwest Wisconsin at 7 µg/L (Rose, 1989). Another, more recent analysis measured the precipitation concentration at 16 µg/L (Robertson, 2009). This analysis cited the significance of dry loading from tree pollen. The loading from tree pollen into lakes surrounded by forest land cover is often underestimated or even ignored. Some studies in pollen phosphorus loading show it can be quite significant (Banks, n.d.). In Lake Owen, Bayfield County there was evidence this load was upwards of 55 kg/year. Since the Spider Chain of Lakes is surrounded by dense forest, the 16 µg/L value was used to allow for some pollen deposition.

The concentration of phosphorus in groundwater is not available for these lakes. In US EPA's Spreadsheet Tool for the Estimation of Pollutant Load (STEPL) model, the Sawyer County default value is 9 µg/L which was used in this analysis. This may not be an accurate value as groundwater phosphorus concentration can vary greatly. Typically, groundwater from forest land covers has a low concentration of phosphorus (Robertson, 2009). Higher or lower concentrations will affect the total phosphorus load into a lake. Human activity, such as septic systems, can increase this concentration. However, septic system load was estimated separately which should reduce the groundwater flux error.

The septic system loading was estimated using the STEPL model as well as WILMS (Wisconsin DNR). These estimates are based on the number of residences (septic systems), the number of days the systems are used, and the number of people using the systems.

Septic system load equation from the Wisconsin Lakes Modeling Suite: ***L=E*P*(1-R),*** where L is the annual load of phosphorus from septic systems, E is the export rate of phosphorus (0.8kg/person/year), P is the number of people using systems (considers number of residences and the time of use such as annual residents, summers only, weekends only, etc.) and R is the phosphorus retention coefficient for the soil (0.9)

These values are combined to estimate the per capita septic use per year. The soil retention coefficient estimates the ability of the soil to retain nutrients and allows an estimate for septic system discharge into the lake. Little is known about the age, design, and accurate numbers of residents using the systems. Therefore, this information has the potential for large error. Both the STEPL and WILMS models predicted similar loads. The total septic load was separated into each segment based upon the percent of the total residents occurring in a particular lake. The total is based on the total per capita septic system use per year. This allows for the consideration of an estimated septic load into each lake.

The watershed area from the watershed map, land cover types, and the difference between outflow volume and known inflow volumes were used to determine runoff values into the lakes. The runoff values were adjusted until the model predicted growing season mean total phosphorus concentration matched the in-lake total phosphorus measurements. This resulted in an estimate of phosphorus loading from the direct drainage watershed. The model predicted a nearly perfect fit for total phosphorus within each lake.

Potential internal loading in Big Spider Lake and Little Spider was also evaluated. Lake dissolved oxygen and temperature profiles were used in each lake to determine the degree and length of time stratification occurred. Two total phosphorus concentration profiles were conducted (early summer and late summer) to determine if sediments released phosphorus in an anoxic hypolimnion and estimate how much is released if internal loading appeared to occur.

Within the Bathtub model, the Jones-Bachman model (Jones, 1977) for chlorophyll-a prediction was utilized. Based upon the total phosphorus values, the chlorophyll-a concentration predictions were close to the actual in-lake concentrations during the growing season in 2020. The best predictor of Secchi depth was using the total phosphorus trophic state index (TSI) model. This fit was not as close, but can be calibrated to fit each lake. Some readings were predicted to low (Fawn Lake and North Lake), while the readings in Clear Lake and Spider were too high. Once the model was calibrated to reflect the observed values in the lake, predictions can be made by changing the nutrient loads and the resulting phosphorus and chlorophyll-a concentrations as well as Secchi depth.

The total phosphorus and chlorophyll-a predicted from the model were close to the in-lake readings so limited calibration was needed. The Secchi depth needed to be calibrated more substantially to reflect the in-lake measurements from 2020. The model was then calibrated and run to predict total phosphorus, chlorophyll-a, and Secchi depth for an average precipitation year at the Spider Chain of Lakes. This allows the model to be used to change loading intensity (reduction and increases) in phosphorus loading to predict what the lake total phosphorus, chlorophyll-a and Secchi depth would be with these changes.

Results

Watershed delineation and land cover

The watershed boundary was reduced to the direct-drainage catchment for each lake. The land cover was also determined (by area) based upon the listed land cover by percent of the total. The following map shows the direct-drainage catchment for each lake and the land cover within those catchments.

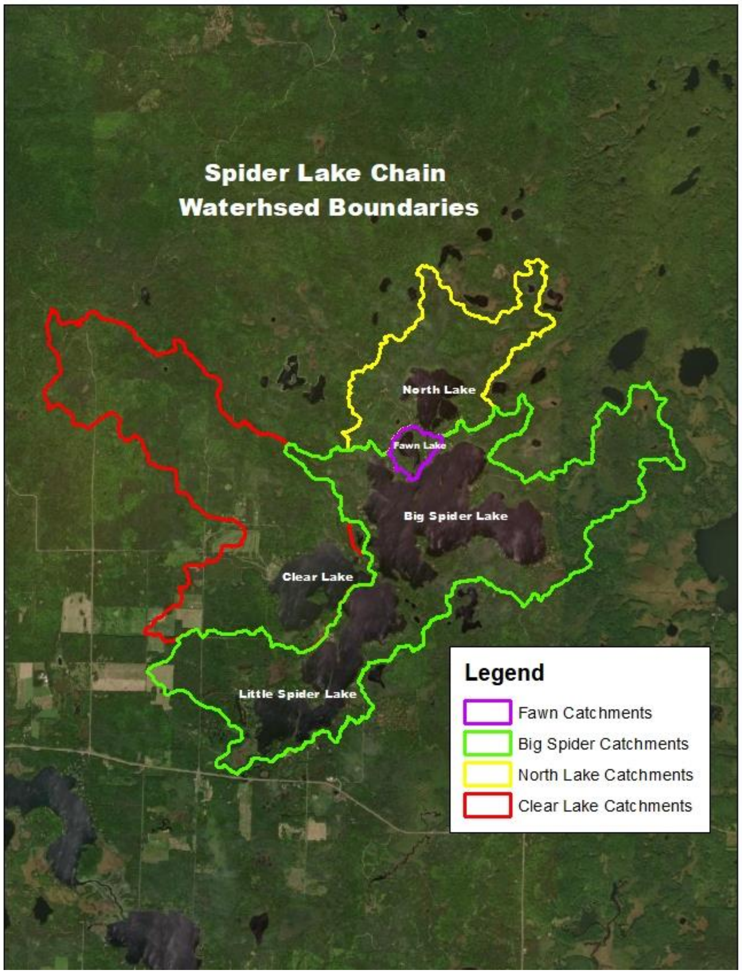

Figure 4: Map of sub-watershed boundaries for each lake in the chain.

These catchments are from the Wisconsin DNR Presto tool and are assumed to be accurately delineated.

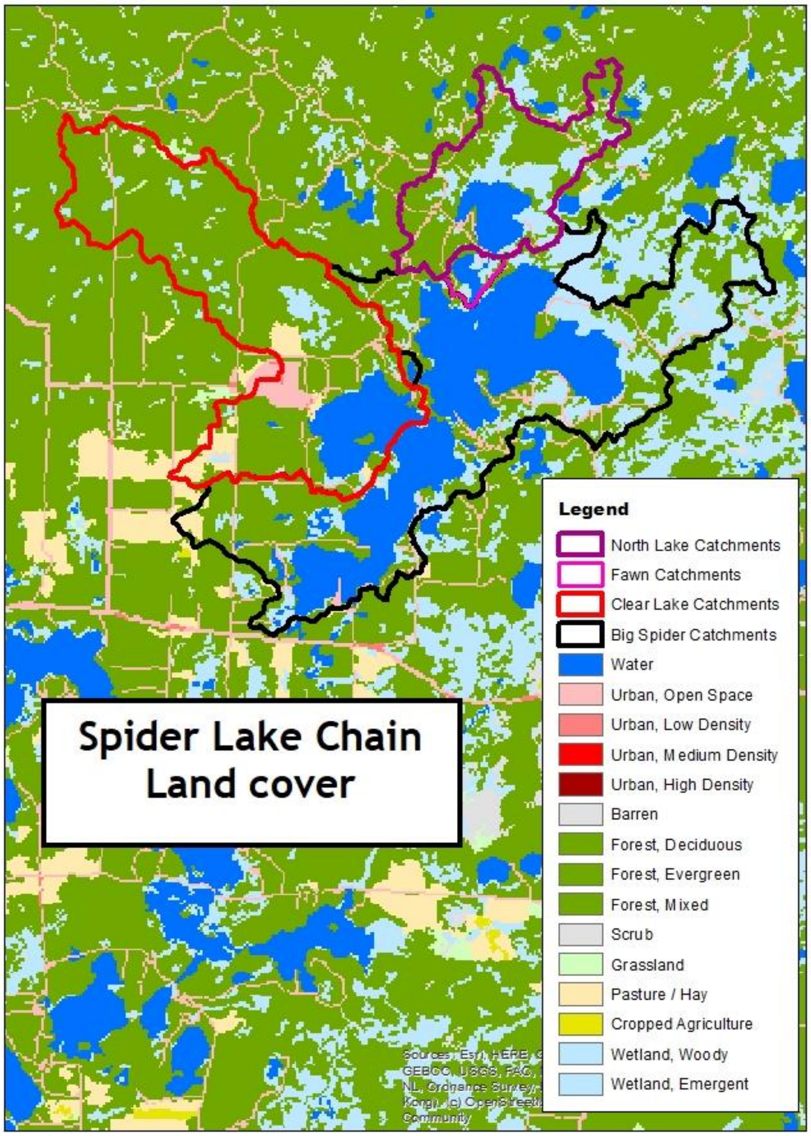

Figure 5: A land cover map for each sub-watershed.

Table 2 shows the breakdown of each catchment by area and percent land cover within each catchment.

Lake Catchment	**Area (km^2)**	**% forest** (all types)	**% wetland** (all types)	**% developed ("urban")***	**% agriculture**	**% barren**	**% grassland**	**% open water**
Clear Lake	8.9	79%	6%	7%	6%	1.4%	0.6%	0%
Fawn Lake	0.26	40%	40%	10%	10%	0%	0%	0%
North Lake	3.6	58.4%	21.2%	6%	0%	0%	0%	14.4%
Spider Lake	12.4	35.2%	20.6%	5%	1.0%	0%	0.07%	38.13%

*It does not appear that the land cover record accurately accounts for developed areas near the lake. The developed land cover was combined, but in the listed land cover % there was 0% listed a having any structures. This is not correct.

Table 2: Landcover of each sub-watershed within each lake in the Spider Chain of Lakes.

Water budget

The water budget balanced with the inflows equaling the outflows. The amount of groundwater outflow is not known. Some water likely discharges into the groundwater table, even via some of the wetland areas around the lake. Since the Spider Chain of Lakes is contained in the headwaters of Spider Creek, this amount may be low. The mass of water balanced, so the groundwater outflow was considered to be zero. This is unlikely but the water budget data does not allow for a valid estimate. Table 3 summarizes the inflow and outflow volumes of water into the entire Spider Chain of Lakes in cubic hectometers.

Inflows	Volume (hm^3)	**Outflows**	Volume (hm^3)
Precipitation	5.8	Evaporation	3.85
Groundwater	7.1	Spider Creek	10.35
Overland runoff	1.3		

Table 3: Water inflows and outflows from the water budget analysis.

The hydraulic residence time for the Spider Chain of Lakes is 2.6 years.

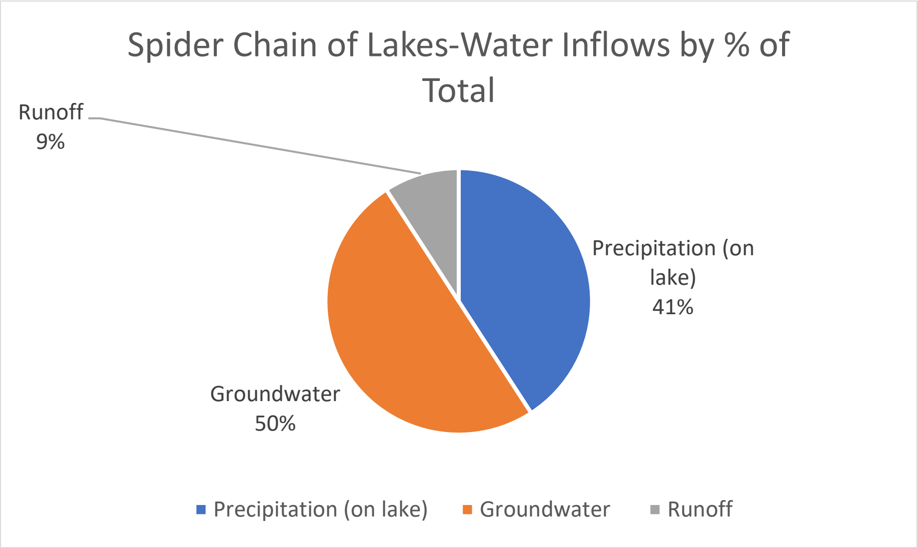

Figure 6: Water budget inflows by % of the total.

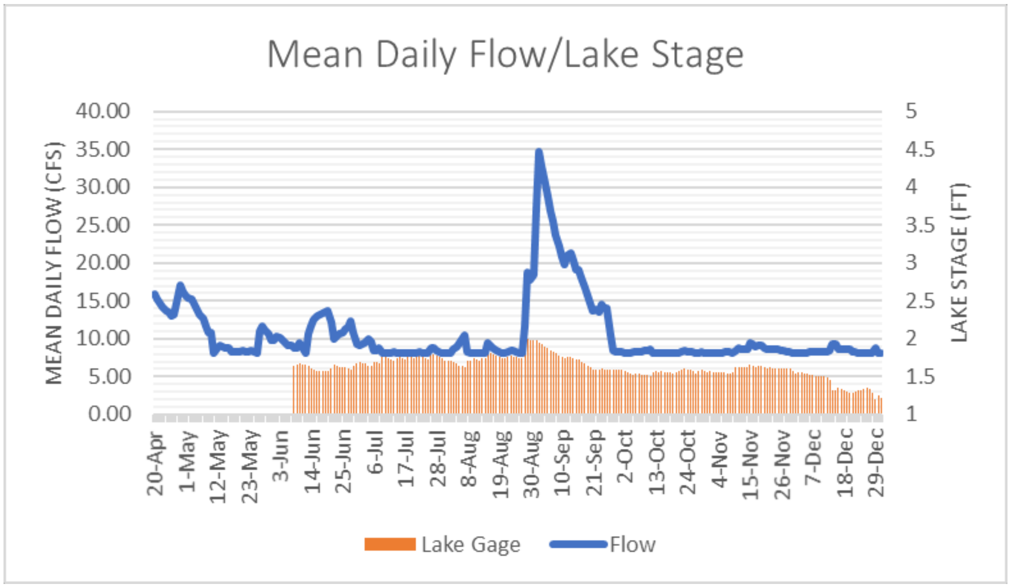

Figure 7: Hydrograph of water discharge out of Spider Lake into Spider Creek. Lake stage is also shown as well. The stage is the depth of water at the gage location and has not been changed to the elevation of water. This was in place to determine the depth change of the water for the water-budget. Lake stage gage was not installed until June, 2020.

Nutrient Data and trophic state

The summer water chemistry can be used to indicate the trophic state of each lake. The three measurements collected in all five lakes were total phosphorus, chlorophyll-a, and Secchi depth. Those amounts are listed in Table 4.

2020 Data by Lake	**In-lake Mean total P (µg/L)**	**Model Estimate**	**The difference in µg/L (%)**	**In-lake Mean Chl-a (µg/L)**	**Model Estimate**	**The difference in µg/L (%)**	**In-lake Mean Secchi Depths (m)**
Clear Lake	17.2*	17.2	0(0%)	4.9	5.1	0.3(6.1%)	2.4
Fawn Lake	18.6*	18.7	0.1(0.5%)	7.0	5.3	-1.2(17.1%)	2.7
North Lake	19.7*	19.5	-0.2(1.0%)	6.1	6.2	0.2(3.3%)	2.2
Spider Lake (Big and Little values combined)	13.8*	13.7	-0.1(0.7%)	4.0	3.7	-0.5(12.5%)	2.9
Entire Chain of Lakes (weighted mean)	14.9*	14.8	-0.1(0.7%)	4.3	4.2	-0.3(7.0%)	2.7

*All total phosphorus measurements fell between the LOD (8 µg/L) and the LOQ (28 µg/L)[2]

Table 4: Summary of water quality data observed and predicted means from the nutrient budget model.

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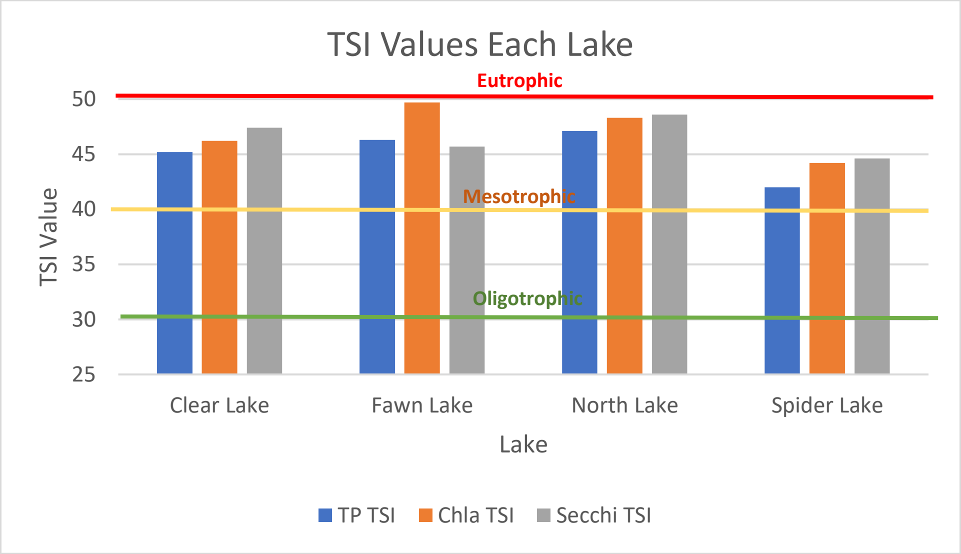
[2] LOD is the level of detection, which is the smallest concentration the analysis will detect. The LOQ is the level of quantification, which is the minimal concentration that the analysis is precise enough to state concentration with validity. This indicates that the values reported lack in accuracy when below the LOQ.

A value known as the Carlson Trophic State Index (TSI), indicates the trophic state of a lake based upon the total phosphorus, chlorophyll-a, and Secchi depth values (Carlson, 1977). The greater the TSI, the more nutritive (eutrophic) the lake. Table 5 shows the TSI values for each lake based upon the measured values for each lake in the growing season 2020. The North American Lake Management Society recommends focusing on the chlorophyll TSI value as it is the best indicator of algal biomass, which is of importance for water quality. The chlorophyll TSI is the orange bar on the graph (Figure 8).

Lake	**Total phosphorus TSI**	**Chlorophyll-a TSI**	**Secchi Depth TSI**
Clear Lake	45.2	46.2	47.4
Fawn Lake	46.3	49.7	45.7
North Lake	47.1	48.3	48.6
Spider Lake	42.0	44.2	44.6

Table 5: Trophic state index values for total phosphorus, chlorophyll-a, and Secchi depth.



30-40	Oligotrophic = very low nutrients and productivity
40-50	Mesotrophic = moderate nutrients and productivity
50-60	Mild Eutrophic =moderately high nutrients and productivity
60-70	Eutrophic = high nutrients and productivity
70-80	Hyper Eutrophic = very high nutrients and productivity

Figure 8: Graph showing the trophic state for each water quality parameter in each lake.

As Figure 8 shows, all of the lakes are in the middle of the mesotrophic state for all parameters (except for Fawn Lake chlorophyll-a value). The chlorophyll-a concentration in Fawn Lake is just below the eutrophic cutoff. Spider Lake has the lowest TSI, with total phosphorus concentration in the lower portion of the mesotrophic state. If the total phosphorus concentrations were to increase in Fawn Lake and North Lake, they could fall into the eutrophic state. Interestingly the Wisconsin DNR has Fawn Lake and North Lake classified as eutrophic. The only parameter that has been measured historically in these two lakes was Secchi Depth so it must be based on the Secchi depth.

Phosphorus budget

The estimated total load of phosphorus into the Spider Chain of Lakes (all lakes) was determined to be 344.1 kg/yr. This modeled amount is the mean of an estimated range. This load is predicted by the model-based upon a growing season mean (area-weighted) of 14.9 µg/L in the entire chain of lakes.

The Canfield-Bachman model equation is a good fit with the predicted total phosphorus concentrations and a close match with the actual in-lake concentrations measured in the summer of 2020. Fawn Lake had the greatest deviation between predicted and observed concentration, possibly due to the extremely small sub-watershed as well as the model inadequately predicting dispersion from North Lake. Since Fawn Lake is so small by area and volume in the entire system, this deviation is not a concern. The deviation between predicted and observed for the entire change was less than 1%, which is an excellent fit. To predict the response to greater and lesser phosphorus loads, the total phosphorus concentrations within each lake were calibrated so the values matched the observed concentrations.

Entire Spider Chain of Lakes Load Estimates	**Atmospheric deposition (kg/yr)**	**Groundwater discharge (kg/yr)**	**Septic systems (kg/yr)**	**Clear Lake Sub-watershed (kg/yr)**	**Fawn Lake Sub-watershed (kg/yr)**	**North Lake Sub-watershed (kg/yr)**	**Spider Lakes Sub-watershed (kg/yr)**	**Total Load (kg/yr.)**
Phosphorus Load (kg/yr)	107.2	63.2	9.2	81	1.9	25.0	56.6	**344.1**

Table 6: Phosphorus sources by mass from various sources determined in the nutrient model.

For the sake of management, it is helpful to estimate the load of phosphorus from various land cover types within a sub-watershed. Table 7 shows the breakdown of each sub-watershed land cover contributions. The forested and wetland land cover was combined largely due to Spider Lake. This sub-watershed has extensive interactions between the forested cover and wetlands, with many portions of the forest adjacent to large areas of wetlands adjacent to the lake. They were combined as the impact of the wetlands on the runoff is not understood in this system. The estimates of all land cover are based upon export coefficient ranges, adjusted to balance the phosphorus loading into the lakes.

	Sub-watershed Estimated Load*			
Landcover	Clear Lake (kg)	Fawn Lake (kg)	North Lake (kg)	Spider Lake (kg)
Forested/Wetland	39.5	0.5	22.3	36
Developed#	9.7	0.2	2.6	16.2
Agriculture	15.9	0.7	0	4.8
Grassland	0.5	0	0.1	0
Golf course	15.4	0	0	0

*Based off of export coefficients within the recommended range from Wisconsin and Minnesota watersheds.

#The land cover data is not precise and it appears some near-shore development is not included in data set.

Internal load

The dissolved oxygen (DO) and temperature profiles indicate stratification in Big Spider Lake and Little Spider Lake throughout the entire summer. North Lake also remained stratified and Fawn Lake fairly stratified over the course of the summer months. The dissolved oxygen profiles also show that anoxic conditions occur in all lakes except Clear Lake throughout at least the second half of the summer period.

The total phosphorus concentration profiles show little accumulation of total phosphorus in the Little Spider Lake hypolimnion (deep layer of cold water). The Big Spider Lake hypolimnion did show some accumulation of total phosphorus. This indicates some internal loading through sediment phosphorus release. Since it was small and the lake did not mix through September, this phosphorus was not available in the euphotic zone (depth with enough light to drive photosynthesis) during the growing season. Concerning phosphorus load during the growing season, the internal load is considered zero. See Figures 9 and 10 for the phosphorus profiles in Little Spider Lake and Big Spider Lake.

Detailed bathymetry data is not available to do a precise estimation of the hypolimnion phosphorus accumulation. However, using the hypolimnion total phosphorus measurements and available hypolimnion volume data, 22 kg of total phosphorus was estimated to accumulate from sediment release from June through August in Big Spider Lake. Little Spider lake did not show a clear accumulation of total phosphorus in the measured hypolimnion (6-9 meters). Regardless, there is no evidence the stratification degraded during the growing season resulting in the mixing of the lake and releasing phosphorus into the upper layer of the lakes.

Both Fawn Lake and North Lake become stratified and may have phosphorus release from the sediment which could result in internal loading. No data was collected, but the near-surface total phosphorus concentration did spike in September. This could be from a release of accumulated hypolimnetic phosphorus from mixing. This could account for the phosphorus being higher in the lake than the model predicted from overland runoff.

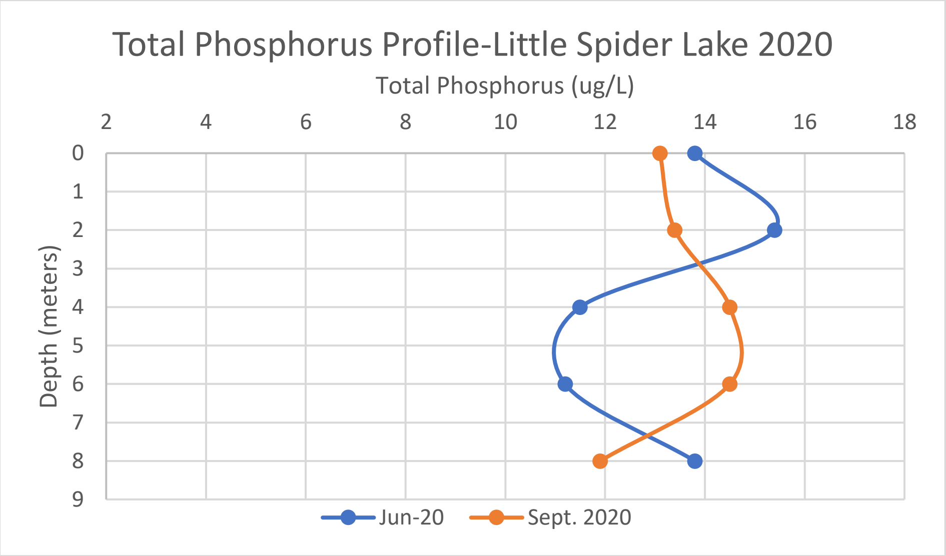


Figure 9: Total phosphorus profile June and August in the southern portion of Spider Lake (Little Spider Lake).

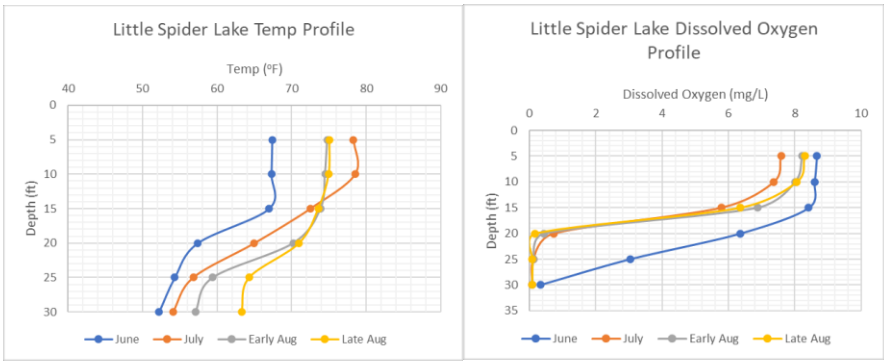
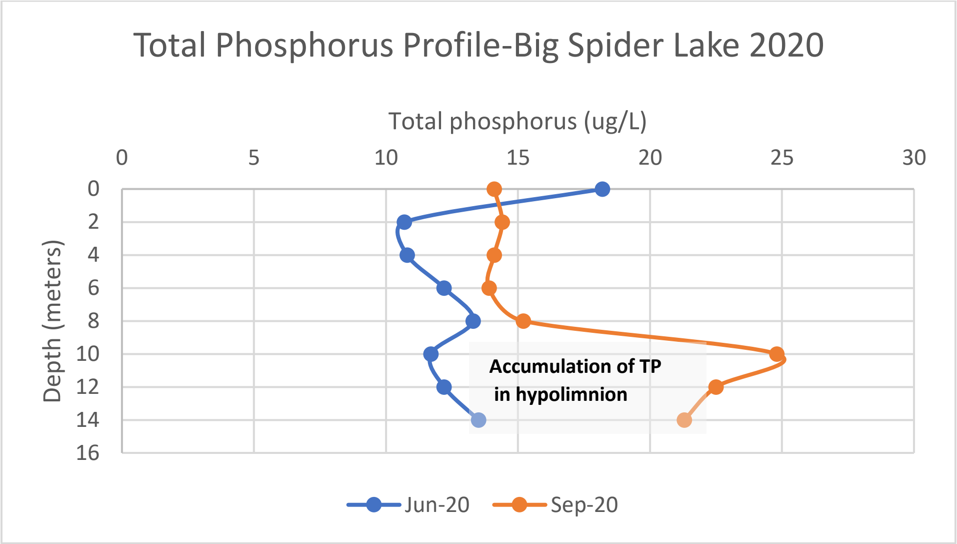


Figure 10: Temperature and dissolved oxygen profiles, southern Spider Lake (Little Spider Lake).



Accumulation of TP in hypolimnion

Figure 11: Total phosphorus profile June and August in the northern portion of Spider Lake (Big Spider Lake).

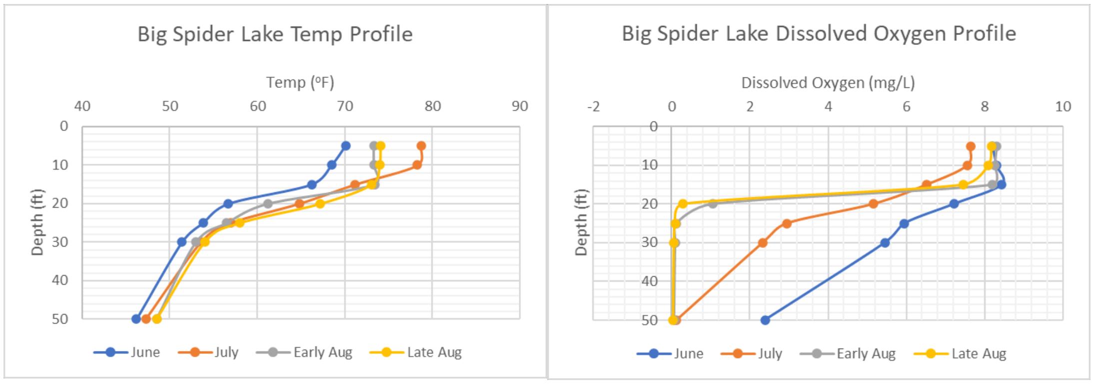


Figure 12: Temperature and dissolved oxygen profiles in northern Spider Lake (Big Spider Lake).

Phosphorus sources

The Bachman-Jones model equation for predicting chlorophyll-a concentrations was also a good fit. The deviation between predicted chlorophyll-a concentrations was 7% for the entire Spider Chain. Again, the largest deviation was in Fawn Lake at 17%. These values were calibrated to fit the observed values exactly to predict the chlorophyll concentration change associated with a change in phosphorus loading.

As Figure 13 shows, the largest source of phosphorus is predicted to be atmospheric deposition. This is followed by the Clear Lake sub-watershed and then groundwater. Although the Spider Lake sub-watershed accounts for the largest sub-watershed by area, this sub-watershed is the fourth-largest contributor of nutrients. These results show that the watershed collectively contributes enough nutrients that reducing phosphorus loading could impact the concentration of total phosphorus and chlorophyll-a in these lakes.

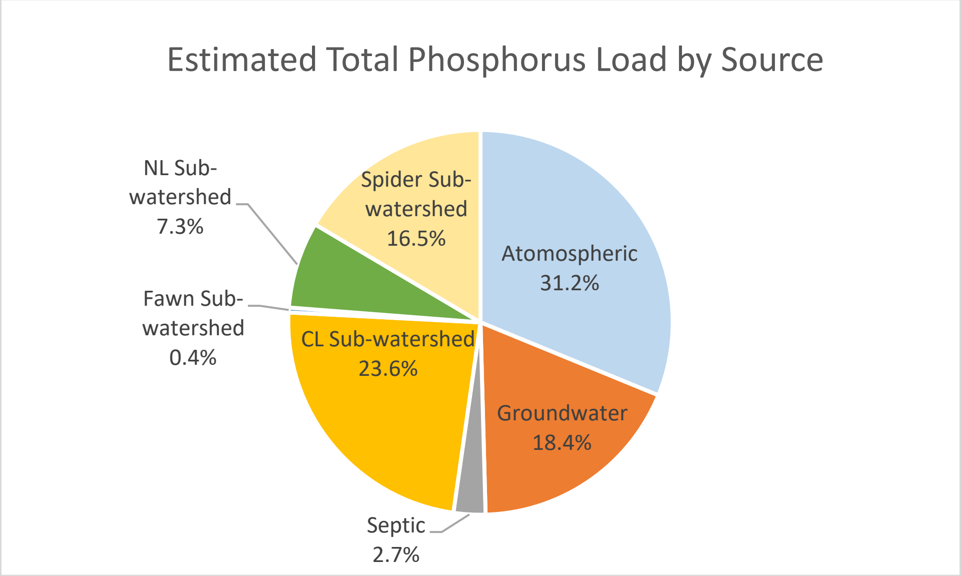


Figure 13: Estimated phosphorus load by the source as a percent of the total.

The loading of phosphorus into the Spider Chain of Lakes from watershed overland runoff is complex, especially for North Lake, Big Spider Lake, and Little Spider Lake. This is because there are large areas of the near lake watershed that are wetlands. Wetlands will slow the water running off from the land before it enters the lake. This can allow nutrients to settle and be reduced before the water enters the lake, reducing the load. If typical export coefficients for various land cover are used, the model overestimates the phosphorus load and would cause the model to predict higher concentrations than observed in these lakes. The loading from these watersheds had to be adjusted to match the observed in-lake phosphorus concentrations.

The Clear Lake sub-watershed was the highest phosphorus loading sub-watershed. This is largely due to land cover with higher loads predicted. One example is the golf course that is in the sub-watershed boundary and has proximity to the lake. Golf courses are largely turf grass which reduces water infiltration and results in higher runoff. Furthermore, golf courses typically apply a large amount of fertilizer, which will increase the concentration of nutrients in the runoff.

Intensity and phosphorus concentration in runoff can vary greatly from the estimates in this analysis. The slope of parcels and the intensity of developed areas around the lake can have a major impact on runoff. The land around the lake that is classified as developed (urban) may have larger lawns, more impervious surfaces, and steeper slopes than other areas designated as the same land cover. These specific differences were not evaluated in this study. Furthermore, the timing and intensity of precipitation/storm events can affect runoff as well. For example, in a given month receiving one two-inch rainfall over a short period, will have much more impact than receiving several small events that total two inches. Individual storm events were not evaluated and all runoff estimates are based upon the entire study period.

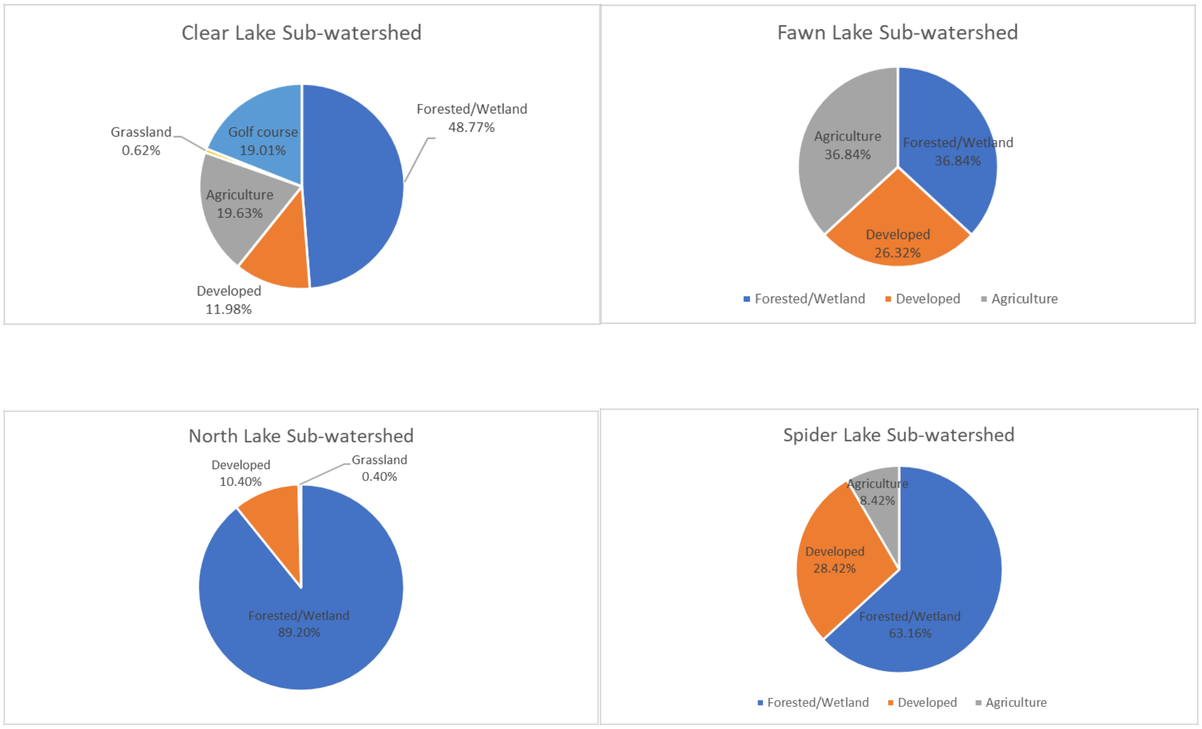


Figure 14: Percent of phosphorus loading by land cover within each sub-watershed. These loads are estimated using published export coefficients and adjusted to fit phosphorus balance.

In addition, the percent of the phosphorus load from the sub-watershed land cover types was evaluated. These estimates are from utilizing export coefficients that are recommend and adjusted to fit the mass balance of phosphorus (such as using the lower or higher amounts within the published range). As Figure 14 shows, the highest contributing land type is forested/wetland. However, this is due to the fact that this land cover makes up the largest percentage of each sub-watershed. Developed areas and agriculture have much higher export coefficients, and therefore contribute more phosphorus per unit area. In Clear Lake, the golf course was separated out by measuring the actual area from a digitized map and applying an export coefficient that was published. Without the nutrient management information about the golf course, this estimate could be inaccurate, but reflects the potential load from this land cover type. Based upon the estimate, this represents 19.0% of the total phosphorus load from the Clear Lake sub-watershed.

Load Analysis

In most cases, the model predictions fit the observed in-lake values well. In 2020, the model was calibrated so the total phosphorus, chlorophyll-a, and Secchi depths matched the in-lake observed data collected. This calibration allows the use of the model to do a load analysis. In a load analysis, the model changes the phosphorus load amounts by a factor and predicts the resulting total phosphorus, chlorophyll-a, and Secchi depth for the lake chosen to view the result of load change. The load factor is applied only to sources other than precipitation and selected for one source such as a single sub-watershed.

Lake organizations often develop goals for nutrient reduction to preserve or improve lake water quality. Since most of the lakes in the Spider Chain are mesotrophic, the values for total phosphorus, chlorophyll-a and Secchi depth that are necessary (at minimum) to achieve an oligotrophic trophic state may be helpful. These are:

Total phosphorus <12 µg/L

Chlorophyll-a <2.5 µg/L

Secchi depth >4 meters

The first load analysis conducted was to change the overall phosphorus load into the entire Spider Chain of Lakes and the resulting area-weighted mean predictions that could result from the change in load. Table 7 shows the load factor, which is the fraction of the present modeled load (for example 0.4 would be a phosphorus load that is 0.4 of the modeled phosphorus loads, or a 60% reduction). The predicted values are for the entire Spider Chain. Compare these values to the present load, represented in the first row with a factor of 1.0.

Load factor (fraction of modeled load) (1 is present load from model)	**Predicted total phosphorus concentration µg/L**	**Predicted chlorophyll-a concentration µg/L**	**Predicted Secchi depth (m)**
1.0	14.9	4.3	2.8
0.4	9.9	2.4	3.8
0.6	11.6	3.0	3.3
0.8	13.3	3.7	3.0
1.2	16.4	5.0	2.6
1.4	17.9	5.7	2.4
1.6	19.3	6.3	2.3

Table 7: Predicted total phosphorus, chlorophyll-a, and Secchi depth as an area-weighted mean for the entire Spider Chain of Lakes with various phosphorus load factors. A load factor of 1 is the present predicted concentration. Numbers less than 1 represent a load reduction and numbers greater than 1 represent increases in loading.

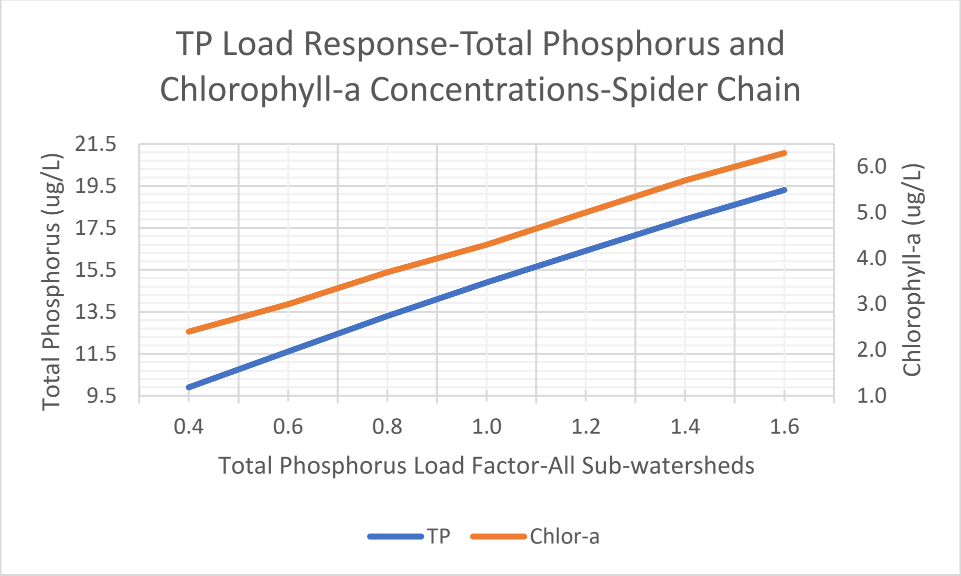


Figure 15: Load response graph showing the predicted change in total phosphorus and chlorophyll-a based upon total phosphorus load factors-Spider Chain of Lakes.

The load analysis for reducing the overall load into the entire Spider Chain of Lakes shows that the water concentrations of total phosphorus and chlorophyll-a would decrease. A 20% reduction in total phosphorus loading, would lower the area-weighted mean of total phosphorus in the entire chain 14.9 µg/L to 13.3 µg/L. The chlorophyll-a is predicted to decrease from 4.3µg/L to 3.7 µg/L overall with the 20% total phosphorus reduction.

As expected, an increase in phosphorus load will cause an increase in total phosphorus and chlorophyll-a concentrations in the lakes. A 20% increase in phosphorus load results in a predicted total phosphorus concentration of 16.4 µg/L and a chlorophyll-a concentration of 5.0 µg/L (compared to 14.9 µg/L and 4.3 µg/L respectively).

Since Big Spider Lake and Little Spider Lake make up the largest area of the Spider Chain of Lakes, predicted values for these two lakes were analyzed. The same load factors for the entire Spider Chain of Lakes were used for these predictions shown in Table 8.

Load factor (fraction of modeled load) (1 is present load from the model)	Predicted total phosphorus concentration µg/L-Spider Lake	Predicted chlorophyll-a concentration µg/L-Spider Lake	Predicted Secchi depth (m) Spider Lake
1.0	13.8	3.9	2.9
0.4	9.4	2.2	3.9
0.6	10.9	2.8	3.5
0.8	12.4	3.4	3.2
1.2	15.1	4.5	2.7
1.4	16.4	5.0	2.6
1.6	17.6	5.6	2.4

Table 8: Predicted total phosphorus, chlorophyll-a, and Secchi depth in Spider Lake with a

change in the overall phosphorus loading in the Spider Chain (all segments).

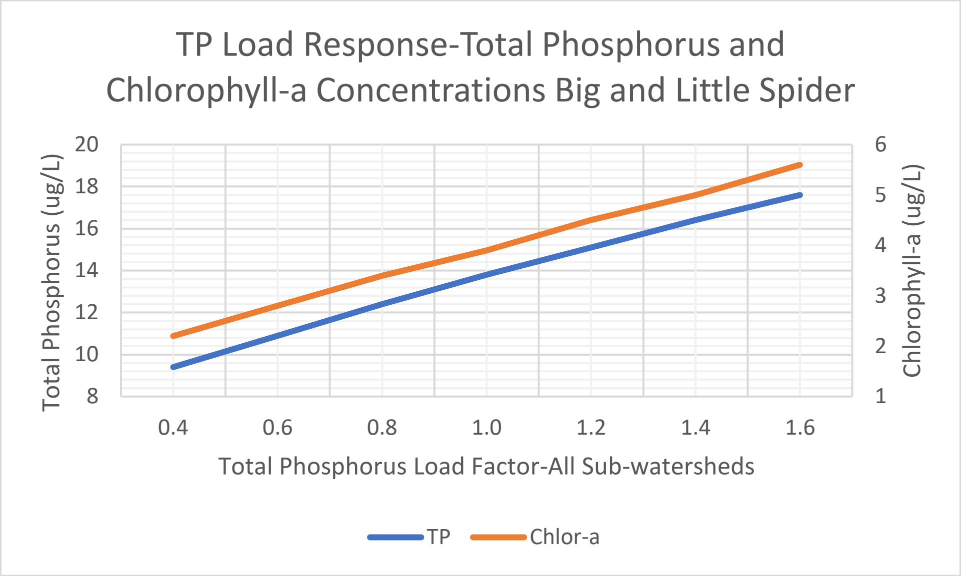


Figure 16: Graph showing predicted total phosphorus and chlorophyll-a in Spider Lake with a total phosphorus load factor changes in the Spider Chain of Lakes.

A 20% reduction in phosphorus loading from the entire watershed is predicted to reduce the total phosphorus concentration in Spider Lake from 13.8 µg/L to 12.4 ug/L. The predicted chlorophyll-a concentration would decrease from 3.9 µg/L to 3.4 µg/L. A 20% increase is predicted to increase total phosphorus to 15.1 µg/L and the chlorophyll-a concentration to 4.5 µg/L.

The Clear Lake sub-watershed is the predicted largest contributing sub-watershed of phosphorus of all the sub-watersheds. For this reason, a load analysis was conducted to evaluate the predicted values from changing the loading from just the Clear Lake sub-watershed. The predicted values are for both Clear Lake as well as Big Spider Lake and Little Spider Lake.

A 20% reduction in phosphorus loading from the Clear Lake sub-watershed only is predicted to result in a decrease from 17.2 µg/L total phosphorus concentration to 16.0 µg/L in Clear Lake. The load analysis also predicts a chlorophyll-a concentration decrease from 5.0 µg/L to 4.5 µg/L in Clear Lake. Should a 20% increase in phosphorus load occur, the load analysis predicts a total phosphorus concentration of 18.4 µg/L and chlorophyll-a concentration of 5.5 µg/L.

Load factor (fraction of modeled load) (1 is present load from the model)	**Predicted total phosphorus concentration µg/L-Clear Lake**	**Predicted chlorophyll-a concentration µg/L-Clear Lake**	**Predicted Secchi depth (m) Clear Lake**	**Predicted total phosphorus concentration µg/L-Spider Lakes**	**Predicted chlorophyll-a concentration µg/L-Spider Lakes**	**Predicted Secchi depth (m) Spider Lakes**
1.0	17.2	5.0	2.4	13.8	3.9	2.9
0.4	13.6	3.5	2.8	12.4	3.4	3.2
0.6	14.8	4.0	2.6	12.9	3.5	3.1
0.8	16.0	4.5	2.5	13.3	3.7	3.0
1.2	18.4	5.5	2.2	14.2	4.1	2.8
1.4	19.6	6.1	2.1	14.7	4.3	2.7
1.6	20.8	6.6	2.0	15.1	4.5	2.7

Table 9: Predicted total phosphorus, chlorophyll-a, and Secchi depth for Clear Lake and Spider Lake with phosphorus load factors for the Clear Lake sub-watershed only.

Clear Lake is connected to Spider Lake. Therefore, a change in loading from the Clear Lake sub-watershed can affect Spider Lake concentrations as well. A 20% reduction in phosphorus loading from the Clear Lake sub-watershed is predicted to result in a reduction from 13.8 µg/L total phosphorus to 13.7 µg/L. The chlorophyll-a concentration would decrease from 3.9 µg/L to 3.7 µg/L. An increase by 20% is predicted to result in a total phosphorus concentration of 14.2 µg/L and chlorophyll-a concentration of 4.1 µg/L.

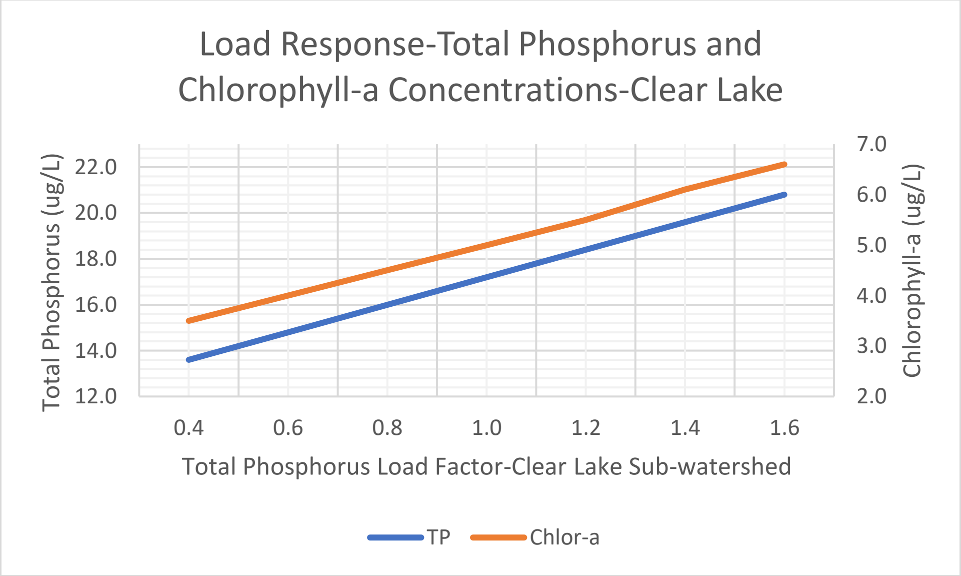


Figure 17: Graph showing predicted total phosphorus and chlorophyll-a in Clear Lake with total phosphorus load factor changes in the Clear Lake sub-watershed.

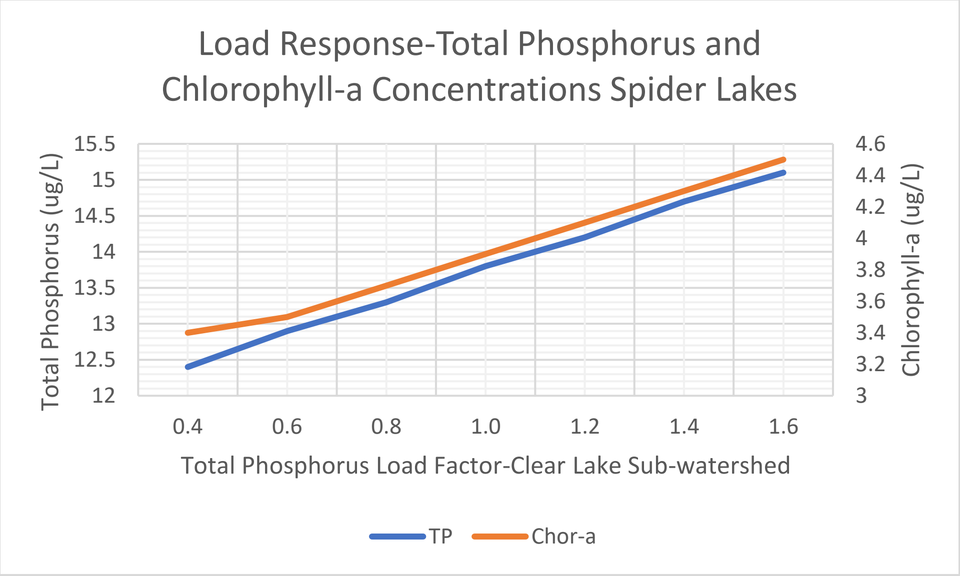


Figure 18: Graph showing predicted total phosphorus and chlorophyll-a in Spider Lake with total phosphorus load factor changes in the Clear Lake sub-watershed.

Lastly, a load analysis was conducted on Spider Lake with predicted values for these lakes combined. Table 10 shows the results of this load analysis. This evaluated changes in the Spider Lake sub-watershed phosphorus load.

In this load analysis, a 20% reduction in phosphorus load a predicted total concentration decreases from 13.8 µg/L to 13.4 µg/L, while the chlorophyll-a concentration is predicted to decrease from 3.9 µg/L to 3.8 µg/L. A 20% increase predicts total phosphorus to increase to 14.2 µg/L and chlorophyll-a to 4.1 µg/L.

Load factor (fraction of modeled load) (1 is present load from the model)	**Predicted total phosphorus concentration µg/L-Spider lakes**	**Predicted chlorophyll-a concentration µg/L-Spider lakes**	**Predicted Secchi depth (m)-Spider lakes**
1.0	13.8	3.9	2.9
0.4	12.6	3.5	3.1
0.6	13.0	3.6	3.0
0.8	13.4	3.8	3.0
1.2	14.2	4.1	2.8
1.4	14.5	4.2	2.8
1.6	14.9	4.4	2.7

Table 10: Predicted total phosphorus, chlorophyll-a, and Secchi depth for Spider Lake from phosphorus load factors for the Spider Lake sub-watershed only.

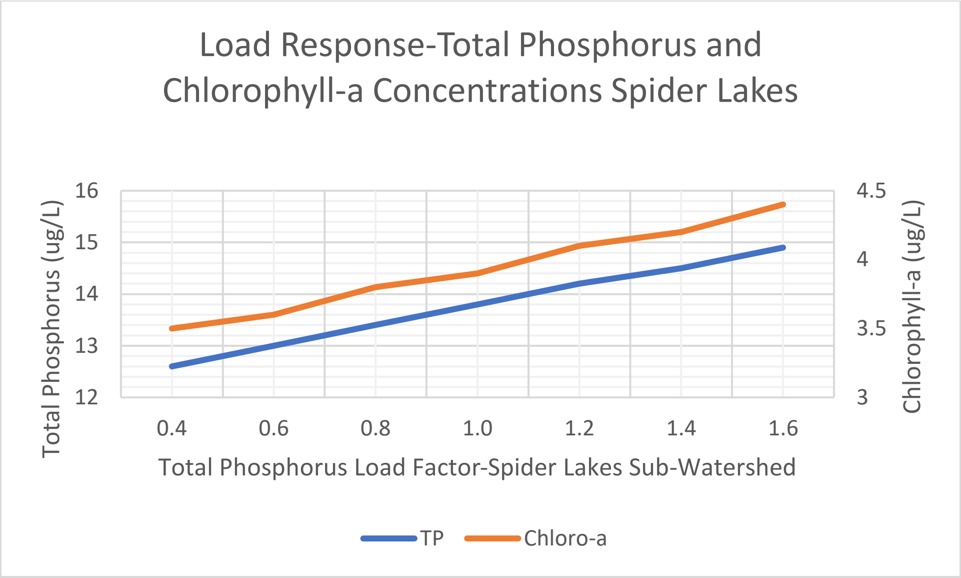


Figure 19: Graph showing predicted total phosphorus, chlorophyll-a, and Secchi depth for Spider Lake from phosphorus load factors for the Spider Lake sub-watershed only.

Discussion

The water quality analysis model showed an excellent fit in predicting the water quality values compared to the observed values in the Spider Chain of Lakes. This indicates that a total load of phosphorus into the Spider Chain of Lakes and the resulting chlorophyll-a concentrations in response should be accurate. Since the atmospheric load and the groundwater load are based upon data from other studies in northern Wisconsin, there is potential for error in the estimations by source. However, since the model fits well, predictions made in the load analysis should be reflective of the expected response to these load changes.

The load analysis shows that reductions and increases in phosphorus loading can result in significant changes in total phosphorus and chlorophyll-a concentrations. A 20% reduction was discussed and this reduction may or may not be attainable depending on the management practices available. Regardless, any reduction could potentially offset increases that could result from increased development around these lakes. Spider Lake in particular is high water quality and reductions from management practices could help preserve the lake quality.

Mitigation of phosphorus loads cannot occur with atmospheric deposition. Land cover can affect the nutrient contents of groundwater. However, since there is little agriculture in this region and most of the nutrients in groundwater are likely tied to septic systems (which have been separated), few mitigation options are likely available for groundwater nutrients. Therefore, the most prudent area to focus on for phosphorus mitigation is overland runoff areas.

The estimated phosphorus loading from the direct drainage watershed into each lake indicates that the Clear Lake sub-watershed has the highest load. Based upon this knowledge, focusing on this sub-watershed for mitigation efforts would be logical. The load analysis shows that even a 20% reduction in phosphorus loading could result in a significant reduction in the in-lake phosphorus and chlorophyll-a concentrations in Clear Lake as well as Big Spider Lake and Little Spider Lake. The focus for mitigation should be on near shoreland cover that has high nutrient load land cover such as large impervious surfaces, residential buildings, and manicured lawns that are also potentially fertilized. Best management practices focused on these areas would likely reduce runoff volumes and nutrient concentrations. The potential management practices can be reviewed in the lake management plan.

Also, the golf course on Clear Lake should be evaluated. The course may have a nutrient management plan in place. If not, one should be established. A review of fertilizer application rates and type could provide more information regarding the potential nutrient load the golf course has on the Spider Chain of Lakes. Buffer zones could be beneficial and reduce loading from the golf course as well.

Since Spider Lake (Big and Little) has the most residents, management practices placed at properties near shore would provide phosphorus reductions. Again, properties managed close to the lake that have large impervious surfaces, large buildings and manicured lawns would provide the largest reductions in phosphorus loading.

Although the septic system loads appear small, they are estimates and it is possible this load may be larger or smaller. Lake residents could be encouraged to have their systems inspected to evaluate any failing systems. The type of systems could also be evaluated as many may be functioning holding tanks or if many are older systems, their impact could vary the load.

North Lake and Fawn Lake have the higher total phosphorus and the highest chlorophyll-a concentrations. The amount of wetland bordering North Lake (which flows into Fawn Lake) the small size of the sub-watershed draining into Fawn Lake makes these in-lake values somewhat puzzling. Wetlands will absorb runoff and typically filter nutrients before the water goes into the lake. The North Lake sub-watershed is quite large in comparison to the lake area, which will increase the impact on the nutrients in the lake. The wetlands are possibly functioning as a nutrient source.

Another part of the lake management plan process was a shoreland survey. Within this survey, data was collected which should allow for the identification of parcels of property that could potentially have the greatest impact on runoff and nutrient loading into these lakes. This survey could be utilized to identify priority areas to implement best management practices to mitigate phosphorus and preserve the water quality in the Spider Chain of Lakes.

Recommendations

The lakes in the Spider Chain of Lakes have good water quality. All lakes are in the mesotrophic state, with Spider Lake (both Big and Little) in the lower-mesotrophic range. Although phosphorus loading may not be big concern at this point in time, future development and increased human activity could increase nutrient loads and degrade the water quality. Reducing phosphorus could offset some of these increases and may be necessary to even maintain the present water quality.

If the Spider Chain of Lakes Association would like to reduce present phosphorus loading and/or reduce future phosphorus loading from human activity the following recommendations would benefit this process.

Identifying/addressing load sources:

1. Focus on identification of potentially high loading areas using this study and the shoreland survey to target areas that management practices would provide a highest reduction. No runoff areas were evaluated as the modeling and this study had a broader target. Since the Clear Lake sub-watershed has the highest contribution form all watersheds and the fact that Clear Lake has higher total phosphorus than Spider Lake, it may be prudent to focus on that sub-watershed first. However, land cover such as the golf course typically produce large phosphorus loads. As stated in study, the nutrient management of this course is unknown so that information would allow for a better evaluation of the actual load from this portion of the watershed. Furthermore, there is some agriculture land within the Clear Lake sub-watershed as well. More information on what type of agriculture and potential runoff in these areas would be helpful. Although Clear Lake has a limited number of residences, near-shore development could also be identified as potential contributors to the lake phosphorus. Clear Lake also has higher TSI values than Spider Lake and contributes some of its phosphorus to Spider Lake, thus increasing Spider Lake's concentration.
2. Once areas are identified, potential best management practices could be evaluated to mitigate phosphorus loading. These could include infiltration devices (especially adjacent to impervious surfaces), rain gardens and/or shoreline buffers.
3. Survey residence about their septic systems. This study shows a small load, but this is estimated based upon literature recommendations. It could be much larger depending on the system's age and type.
4. Evaluate the Fawn Lake and North Lake wetland areas. This would be of lower priority, but these lakes are higher in nutrients compared to Big and Little Spider Lake. The model fit the predicted inputs of phosphorus, but with the amount of wetland around these lakes there is some question about the source. It is possible phosphorus is being released at a higher amount than would typically be expected from a wetland. This information would allow for better understanding of the impact the watershed is having on these lakes.

Additional information that would help better understand the nutrient budget that was not available for this study:

1. Update and more closely evaluate the watershed land cover. The data available was 2006. Although the land cover may not have changed much, the land cover available is not very precise. For example, it appears much of the near-shore developed areas are included in the forested areas round the lake. It is difficult to assess if this is the case, but it appears as such. Focusing just on near-shore development would be a good start and helpful in understanding the impact these properties may have on the budget.
2. An analysis of the phosphorus concentration in groundwater would be beneficial. The water budget for the Spider Chain of Lakes indicates that a large amount of groundwater discharges into these lakes. The concentration used was not tested but was based upon published recommendations. If the actual concentration is higher or lower, it would significantly change the loading amounts from groundwater, which could allow for a better determination of actual phosphorus sources.
3. Analysis of precipitation/atmospheric deposition could also be helpful. The large source of phosphorus in this study (by %) is atmospheric deposition. This is estimated using published

concentrations from other studies. In the case of high nutrient lakes, the impact of this concentration is much less. In lower nutrient lakes, the loading from atmospheric deposition is more significant if lower than expected, the degree of other loading sources can be better evaluated.

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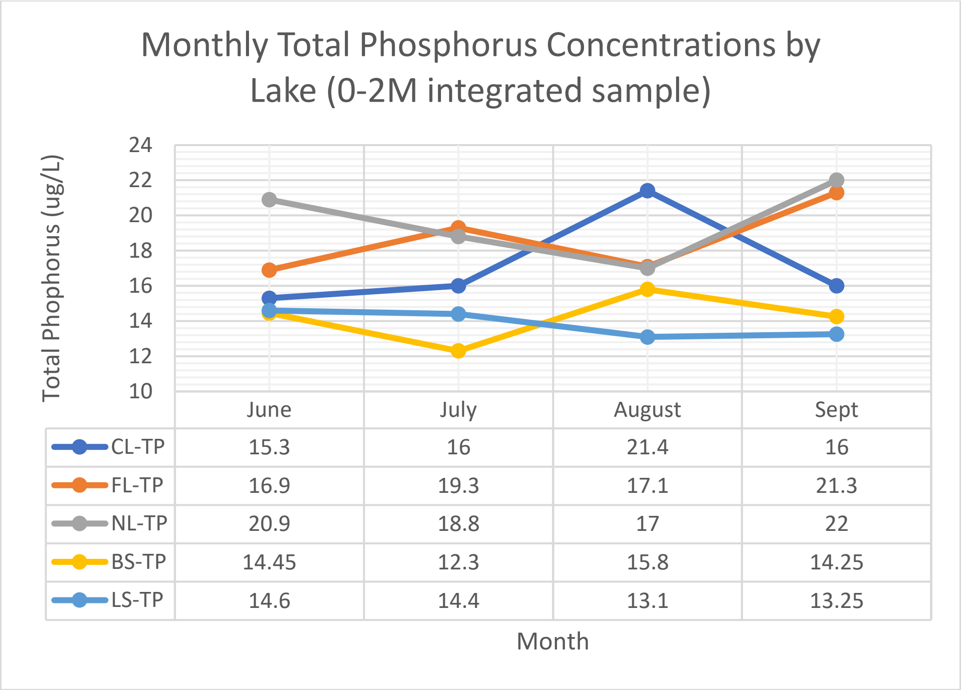
Appendix-A: Data Sets

Water Quality Data from June-Sept. 2020

Clear Lake	**TP (µg/L)**	**Chl-a (µg/L)**	**Fawn Lake**	**TP (µg/L)**	**Chl-a (µg/L)**	**North Lake**	**TP (µg/L)**	**Chl-a (µg/L)**
6/8/2020	15.3		6/8/2020	16.9		6/8/2020	20.9	
7/13/2020	16	4.58	7/13/2020	19.3	3.05	7/13/2020	18.8	2.25
8/10/2020	21.4	6.05	8/10/2020	17.1	3.74	8/10/2020	17	4.3
9/8/2020	16	4	9/8/2020	21.3	14.1	9/8/2020	22	11.8

Little Spider				Big Spider			
Date	**Depth**	**TP (µg/L)**	**Chl-a (µg/L)**	**Date**	**Depth(m)**	**TP (µg/L)**	**Chl-a (µg/L)**
6/8/2020	0	13.8		6/8/2020	0	18.2	
	2	15.4			2	10.7	
	4	11.5			4	10.8	
	6	11.2			6	12.2	
	8	13.8			8	13.3	
6/24/2020	0-2	16.5	3.81		10	11.7	
7/13/2020	0-2				12	12.2	
7/23/2020	0-2	14.4	3.09		14	13.5	
8/23/2020	0-2	13.1	4.64	6/24/2020	0-2	12.1	4.92
9/8/2020	0	13.1		7/13/2020			
	2	13.4		7/23/2020	0-2	12.3	3.55
	4	14.5		8/23/2020		15.8	3.95
	6	14.5		9/8/2020	0	14.1	
	8	11.9			2	14.4	
					4	14.1	
					6	13.9	
					8	15.2	
					10	24.8	
					12	22.5	
					14	21.3	

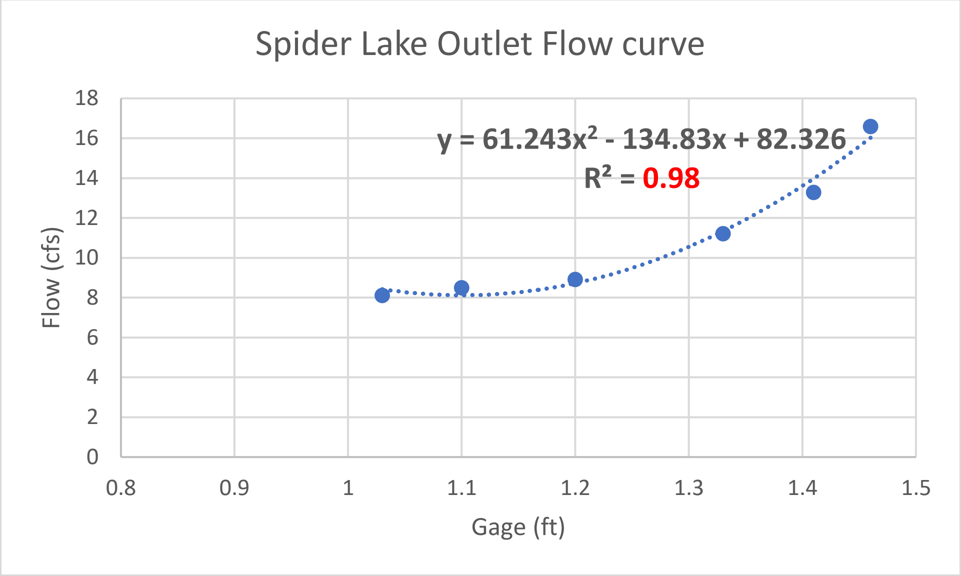


Monthly Total Phosphorus Concentrations by Lake (0-2M integrated sample)

	June	July	August	Sept
CL-TP	15.3	16	21.4	16
FL-TP	16.9	19.3	17.1	21.3
NL-TP	20.9	18.8	17	22
BS-TP	14.45	12.3	15.8	14.25
LS-TP	14.6	14.4	13.1	13.25

Spider (Hayward Airport) 2019-20 Precipitation	
Month	**inches**
Nov('19)	1.56
Dec('19)	2.03
Jan	0.47
Feb	0.12
March	2.04
April	2.68
may	4.23
June	4.09
July	7.34
August	6.62
Sept	1.26
Oct	1.92

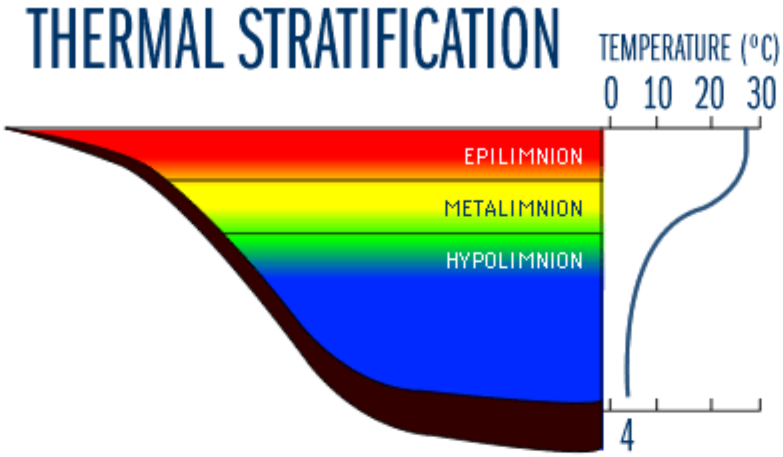
Outflow gage height-flow volume correlation curve

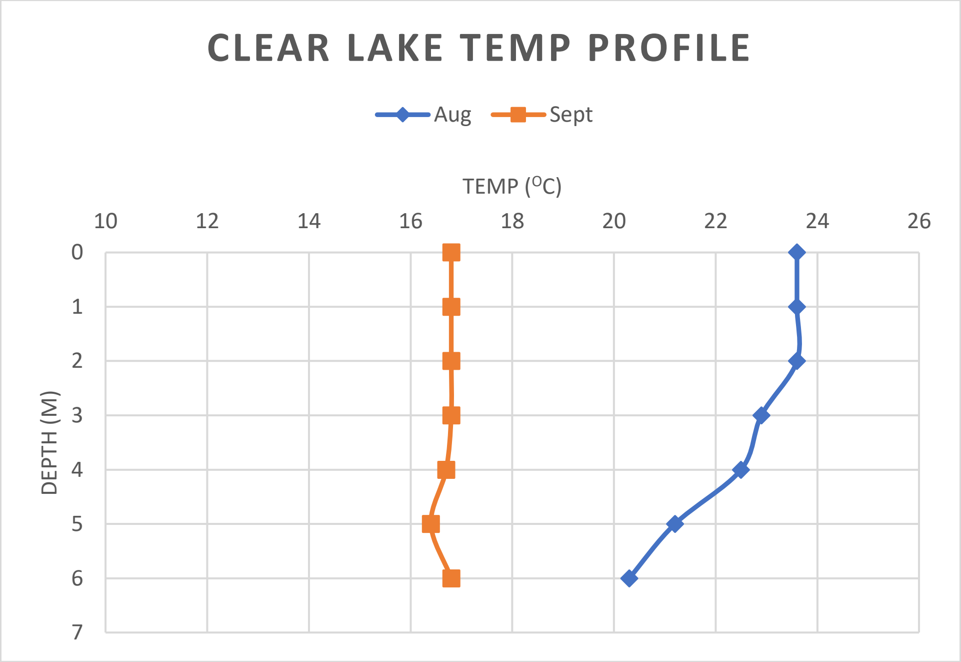


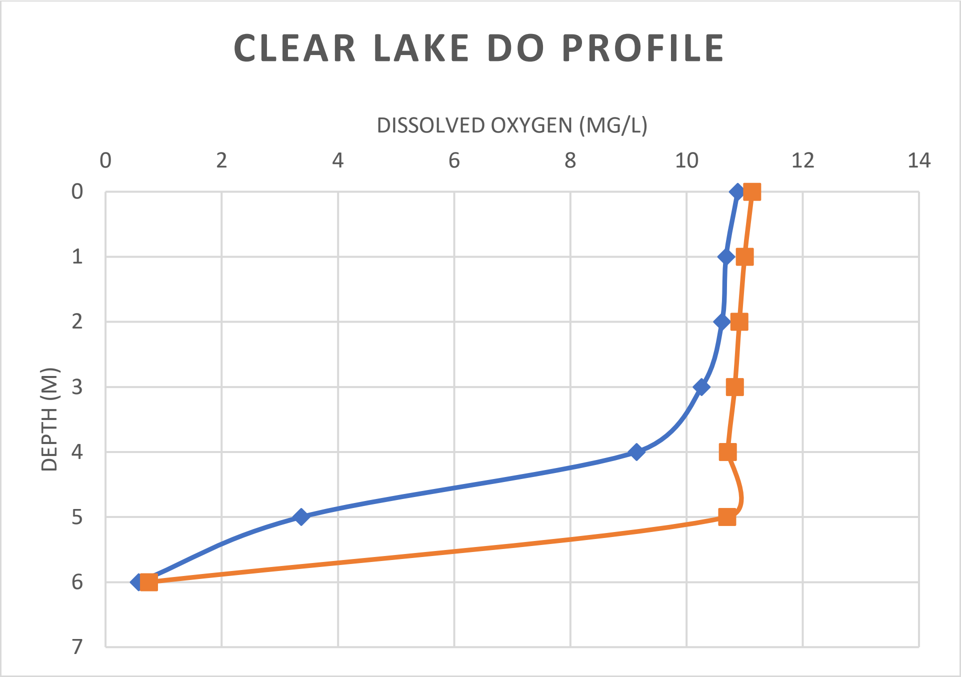
Daily outflow in ft^3/s

Date	Flow	Date	Flow	Date	Flow	Date	Flow	Date	Flow	Date	Flow
20-Apr	15.91	5-Jun	9.42	22-Jul	8.21	7-Sep	25.60	24-Oct	8.31	10-Dec	8.25
21-Apr	15.29	6-Jun	9.05	23-Jul	8.13	8-Sep	23.74	25-Oct	8.28	11-Dec	8.29
22-Apr	14.66	7-Jun	9.05	24-Jul	8.13	9-Sep	22.16	26-Oct	8.20	12-Dec	8.33
23-Apr	14.16	8-Jun	8.75	25-Jul	8.12	10-Sep	20.77	27-Oct	8.12	13-Dec	8.38
24-Apr	13.73	9-Jun	8.78	26-Jul	8.86	11-Sep	19.78	28-Oct	8.18	14-Dec	9.25
25-Apr	13.57	10-Jun	9.44	27-Jul	8.74	12-Sep	20.90	29-Oct	8.27	15-Dec	9.23
26-Apr	13.03	11-Jun	8.88	28-Jul	8.40	13-Sep	21.39	30-Oct	8.15	16-Dec	8.57
27-Apr	13.23	12-Jun	8.12	29-Jul	8.26	14-Sep	20.39	31-Oct	8.12	17-Dec	8.59
28-Apr	14.72	13-Jun	10.73	30-Jul	8.14	15-Sep	19.19	1-Nov	8.14	18-Dec	8.63
29-Apr	17.07	14-Jun	11.73	31-Jul	8.14	16-Sep	19.16	2-Nov	8.12	19-Dec	8.62
30-Apr	16.16	15-Jun	12.48	1-Aug	8.19	17-Sep	18.07	3-Nov	8.12	20-Dec	8.55
1-May	15.71	16-Jun	13.04	2-Aug	8.18	18-Sep	16.80	4-Nov	8.14	21-Dec	8.36
2-May	15.42	17-Jun	13.17	3-Aug	8.59	19-Sep	15.80	5-Nov	8.16	22-Dec	8.36
3-May	15.19	18-Jun	13.42	4-Aug	8.95	20-Sep	14.67	6-Nov	8.21	23-Dec	8.19
4-May	14.53	19-Jun	13.53	5-Aug	9.49	21-Sep	13.74	7-Nov	8.23	24-Dec	8.13
5-May	13.83	20-Jun	13.74	6-Aug	9.93	22-Sep	13.85	8-Nov	8.26	25-Dec	8.13
6-May	13.16	21-Jun	12.14	7-Aug	10.41	23-Sep	13.53	9-Nov	8.13	26-Dec	8.12
7-May	12.61	22-Jun	10.03	8-Aug	8.31	24-Sep	14.61	10-Nov	8.52	27-Dec	8.12
8-May	11.59	23-Jun	10.30	9-Aug	8.15	25-Sep	14.07	11-Nov	8.84	28-Dec	8.18
9-May	10.90	24-Jun	10.68	10-Aug	8.12	26-Sep	14.10	12-Nov	8.70	29-Dec	8.83
10-May	10.76	25-Jun	10.89	11-Aug	8.15	27-Sep	10.47	13-Nov	8.60	30-Dec	8.12
11-May	8.13	26-Jun	11.27	12-Aug	8.17	28-Sep	8.50	14-Nov	8.60	31-Dec	8.12
12-May	8.80	27-Jun	11.43	13-Aug	8.15	29-Sep	8.34	15-Nov	9.45		
13-May	9.07	28-Jun	12.32	14-Aug	8.15	30-Sep	8.36	16-Nov	9.31		
14-May	8.88	29-Jun	10.82	15-Aug	9.40	1-Oct	8.28	17-Nov	8.90		
15-May	8.75	30-Jun	9.25	16-Aug	9.16	2-Oct	8.17	18-Nov	9.06		
16-May	8.73	1-Jul	9.19	17-Aug	8.86	3-Oct	8.12	19-Nov	9.07		
17-May	8.33	2-Jul	9.33	18-Aug	8.52	4-Oct	8.17	20-Nov	8.84		
18-May	8.20	3-Jul	9.44	19-Aug	8.23	5-Oct	8.31	21-Nov	8.54		
19-May	8.26	4-Jul	9.94	20-Aug	8.14	6-Oct	8.26	22-Nov	8.61		
20-May	8.34	5-Jul	9.61	21-Aug	8.15	7-Oct	8.22	23-Nov	8.56		
21-May	8.42	6-Jul	8.41	22-Aug	8.27	8-Oct	8.32	24-Nov	8.56		
22-May	8.35	7-Jul	8.44	23-Aug	8.44	9-Oct	8.43	25-Nov	8.63		
23-May	8.32	8-Jul	8.72	24-Aug	8.38	10-Oct	8.37	26-Nov	8.51		
24-May	8.39	9-Jul	8.19	25-Aug	8.25	11-Oct	8.63	27-Nov	8.38		
25-May	8.21	10-Jul	8.17	26-Aug	8.15	12-Oct	8.12	28-Nov	8.32		
26-May	8.12	11-Jul	8.13	27-Aug	8.16	13-Oct	8.12	29-Nov	8.27		
27-May	10.98	12-Jul	8.12	28-Aug	11.72	14-Oct	8.13	30-Nov	8.16		
28-May	11.62	13-Jul	8.27	29-Aug	18.84	15-Oct	8.15	1-Dec	8.14		
29-May	11.16	14-Jul	8.13	30-Aug	17.80	16-Oct	8.12	2-Dec	8.12		
30-May	10.63	15-Jul	8.16	31-Aug	18.49	17-Oct	8.12	3-Dec	8.12		
31-May	9.88	16-Jul	8.12	1-Sep	27.16	18-Oct	8.13	4-Dec	8.12		
1-Jun	9.78	17-Jul	8.15	2-Sep	34.77	19-Oct	8.15	5-Dec	8.16		
2-Jun	10.30	18-Jul	8.20	3-Sep	32.81	20-Oct	8.13	6-Dec	8.21		
3-Jun	10.11	19-Jul	8.18	4-Sep	30.38	21-Oct	8.18	7-Dec	8.21		
4-Jun	9.77	20-Jul	8.12	5-Sep	28.81	22-Oct	8.30	8-Dec	8.22		
		21-Jul	8.13	6-Sep	26.95	23-Oct	8.51	9-Dec	8.23		

DO/Temp Profiles



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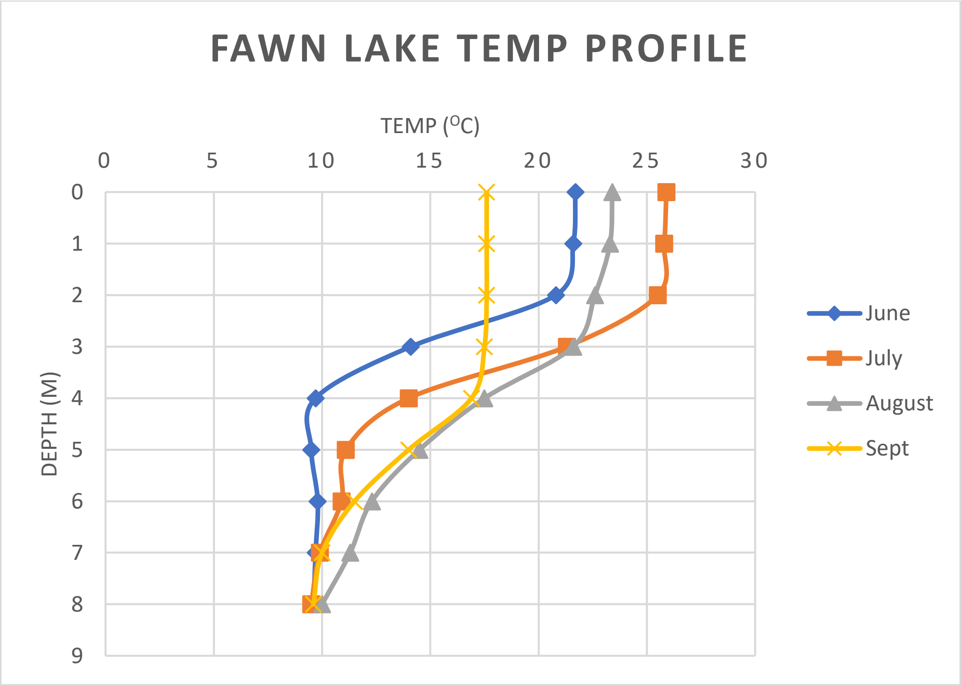
4
6
8
10
12
14
DEPTH (M)
0
1
2
3
4
5
6
7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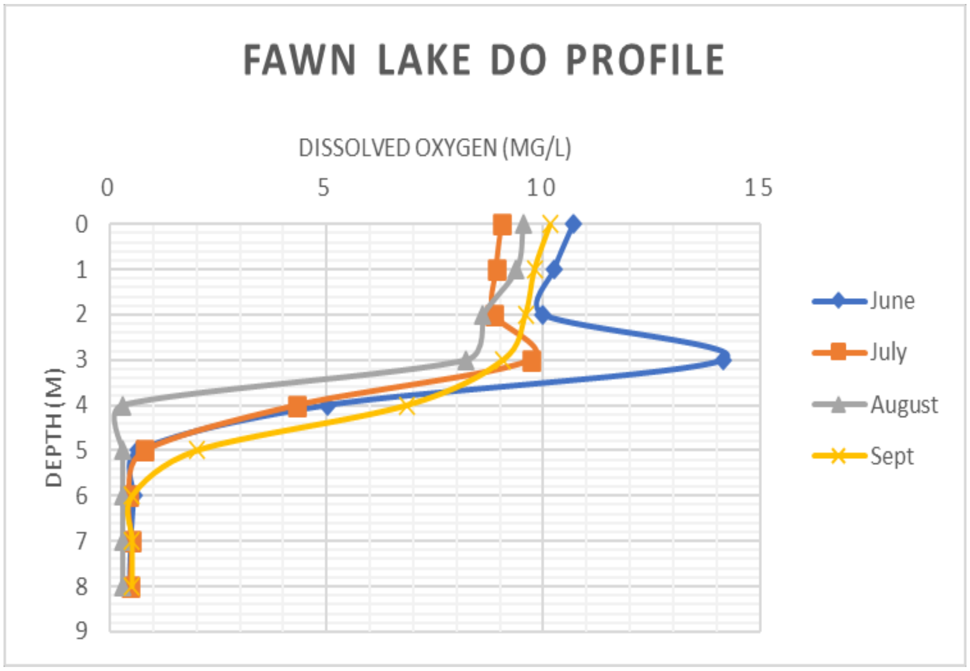
TEMP (^{O}C)
0
5
10
15
20
25
30
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
June
July
August
Sept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DISSOLVED OXYGEN (MG/L)
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5
10
15
DEPTH (M)
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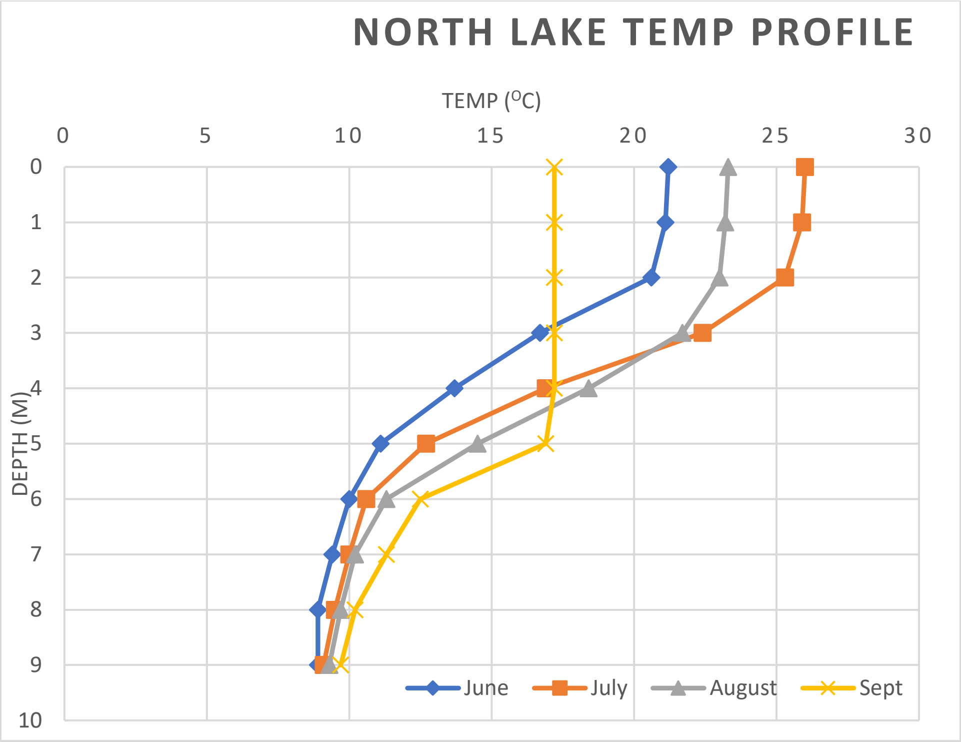
2
3
4
5
6
7
8
9
June
July
August
Sept


NORTH LAKE TEMP PROFILE
TEMP (^{O}C)
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5
10
15
20
25
30
DEPTH (M)
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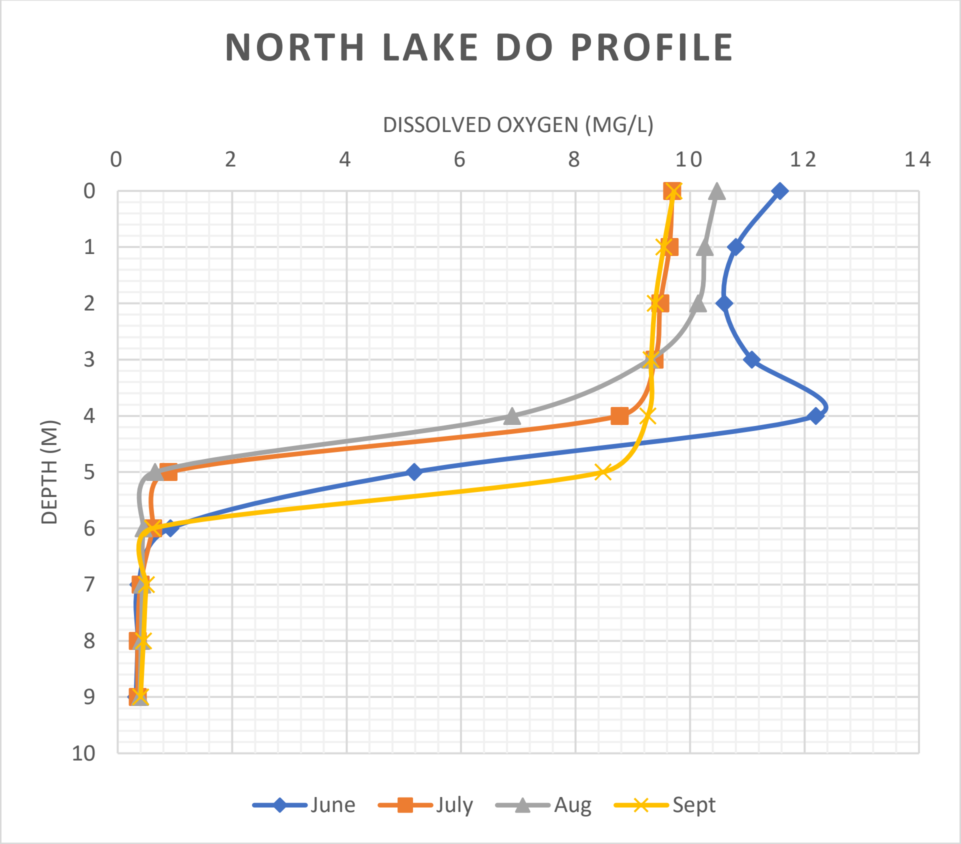
1
2
3
4
5
6
7
8
9
10
June
July
August
Sept


NORTH LAKE DO PROFILE
DISSOLVED OXYGEN (MG/L)
0
2
4
6
8
10
12
14
DEPTH (M)
0
1
2
3
4
5
6
7
8
9
10
June
July
Aug
Sept

Appendix B: Model Information

Overall Water Balance						**Averaging Period =**	**1.00**	**years**
				Area	**Flow**			**Runoff**
Trb	**Type**	**Seg**	**Name**	**km^2**	**hm^3/yr**			**m/yr**
1	1	4	gw spider		5.9			
2	1	1	North Lake Catchment	3.6	0.2			0.06
3	1	2	Fawn Catchment	0.3	0.0			0.04
4	1	3	Clear Lake Catchment	8.9	0.5			0.06
5	1	4	Big/Little Spider Catchment	12.4	0.5			0.04
6	4	4	Spider outlet		10.3			
7	1	1	NL septic		0.0			
8	1	2	Fawn Septic		0.0			
9	1	3	CL septic		0.0			
10	1	4	Spider L septic		0.0			
11	1	3	gw clear lake		0.5			
12	1	1	gw north lake		0.6			
13	1	2	gw fawn lake		0.1			
PRECIPITATION				6.7	5.8			0.87
TRIBUTARY INFLOW				25.1	8.3			0.33
***TOTAL INFLOW				31.8	14.2			0.45
GAUGED OUTFLOW					10.3			
ADVECTIVE OUTFLOW				31.8	0.0			
***TOTAL OUTFLOW				31.8	10.3			0.32
***EVAPORATION					3.8			

Overall Mass Balance Based Upon				Observed		Outflow & Reservoir Concentrations				
Component:				TOTAL P						
				Load					Conc	Export
Trb	Type	Seg	Name	kg/yr	%Total				mg/m^3	kg/km^2/yr
1	1	4	gw spider	52.8	15.4%				9.0	
2	1	1	North Lake Catchment	25.0	7.3%				125.0	7.0
3	1	2	Fawn Catchment	1.9	0.4%				125.0	5.3
4	1	3	Clear Lake Catchment	81.0	23.6%				150.0	9.1
5	1	4	Big/Little Spider Catchment	56.7	16.5%				105.0	4.6
6	4	4	Spider outlet	142.7					13.8	
7	1	1	NL septic	1.2	0.3%				11891.0	
8	1	2	Fawn Septic	0.2	0.1%				2068.0	
9	1	3	CL septic	1.3	0.4%				13442.0	
10	1	4	Spider L septic	6.5	1.9%				65142.0	
11	1	3	gw clear lake	4.2	1.2%				9.0	
12	1	1	gw north lake	5.1	1.5%				9.0	
13	1	2	gw fawn lake	1.1	0.3%				9.0	
PRECIPITATION				107.2	31.2%				18.4	16.0
TRIBUTARY INFLOW				236.6	68.8%				28.4	9.4
***TOTAL INFLOW				343.8	100.0%				24.3	10.8
GAUGED OUTFLOW				142.6	41.5%				13.8	
ADVECTIVE OUTFLOW				0					13.8	
***TOTAL OUTFLOW				142.6	41.5%				13.8	4.5
***RETENTION				201.2	58.5%					
	Overflow Rate (m/yr)			1.5		Nutrient Resid. Time (yrs)			1.16	
	Hydraulic Resid. Time (yrs)			2.59		Turnover Ratio			0.9	
	Reservoir Conc (mg/m3)			15		Retention Coef.			0.585	

Water Balance Terms (hm3/yr)				**Averaging Period =**	**1.00**	**Years**			
			Inflows		**Storage**	**Outflows------>**		**Downstr**	
Seg	**Name**	**External**	**Precip**	**Advect**	**Increase**	**Advect**	**Disch.**	**Exchange**	**Evap**
1.00	North Lake	0.77	0.49	0.00	0.00	0.94	0.00	0.00	0.32
2.00	Fawn Lake	0.13	0.10	0.94	0.00	1.11	0.00	0.00	0.07
3.00	Clear Lake	1.01	0.90	0.00	0.00	1.32	0.00	18.30	0.59
4.00	Big and Little Spider	6.41	4.34	2.43	0.00	-0.01	10.34	0.00	2.84
Net		8.32	5.83	0.00	0.00	-0.01	10.34	0.00	3.82
Mass Balance Terms (kg/yr) Based Upon			**Observed**	**Reservoir & Outflow Concentrations**			**Component:**	**TOTAL P**	
		Inflows-->			**Storage**	**Outflows----->**		**Net**	**Net**
Seg	**Name**	**External**	**Atmos**	**Advect**	**Increase**	**Advect**	**Disch.**	**Exchange**	**Retention**
1.00	North Lake	31.32	8.96	0.00	0.00	18.48	0.00	0.00	21.80
2.00	Fawn Lake	2.66	1.92	18.48	0.00	20.56	0.00	0.00	2.51
3.00	Clear Lake	86.58	16.48	0.00	0.00	22.71	0.00	62.21	18.15
4.00	Big and Little Spider	116.04	79.84	43.26	0.00	0	143.73	-62.21	157.73
Net		236.61	107.20	0.00	0.00	0	143.73	0.00	200.19

Phosphorus export coefficients	**Total phosphorus (kg/km^2/year)**
Forest (all types)	5-9
Wetlands (all types)	2-5
Developed (Rural residential)	10-30
Agriculture	20-40
Grassland	10-17
Golf course	50