Water Quality Analysis/Nutrient Budget

Grindstone Lake, Sawyer County Wisconsin (WBIC: 2391200)

2021

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WISCONSIN DEPT. OF NATURAL RESOURCES

Data and Analysis: Biodiversity People Management Ecological Integrity Service, LLC

Analysis summary

The 2021 Grindstone Lake nutrient analysis resulted in updating the Grindstone Lake watershed and land cover. The watershed evaluated was reduced to a 2122-acre direct-drained catchment. The predominant land cover is forested (65.4%), followed by developed/residential (19.5%) and wetlands (12.7%). The remaining was grassland and commercial. The water budget indicates that most water inflows are similar between precipitation, groundwater, and Grindstone Creek (37%, 32,% and 28% respectively). The phosphorus budget resulted in a 2021 growing season load of 550 kg, with atmospheric deposition being the highest contributor at 32.7%. Using the 2021 model calibrations, the model was adjusted for an average precipitation year, showing a total estimated load of 913.5 kg/yr. This resulted in a predicted in-lake growing season mean phosphorus concentration of 13.7 µg/L, which matches the historical average. This indicates an excellent fit of the model. The contributors of the phosphorus load included atmospheric deposition (28.1%), Grindstone Creek (27.8%), direct-drainage watershed (24.5%), internal load (4.1%), and septic systems (3.8%).

Temperature and dissolved oxygen profiles show the lake became stratified in June and remained stratified the remainder of the growing season. The thermocline moves deeper over the summer. In July, the hypolimnion became anoxic and remained anoxic during the remaining growing season. The phosphorus analysis showed an accumulation of 155 kg of phosphorus in the hypolimnion. The model estimates an internal load (entrainment of phosphorus) of 37.5 kg in 2021. This same internal load was used in the average year model.

The 2021 model was calibrated to match the observed chlorophyll-a concentrations and Secchi depth. These calibrations resulted in an excellent match for the average year model for Secchi depth but had to be further calibrated for chlorophyll-a. The average year model was used to conduct a load analysis.

A load analysis showed that increases and decreases (20% intervals) in the overall phosphorus load and the direct-drainage phosphorus load would result in measurable changes in in-lake total phosphorus concentration, chlorophyll-a concentration, and Secchi depth.

The analysis showed that the water quality of Grindstone Lake is excellent, with limited phosphorus loading. The changes in water quality over several years appear limited, with minor indications of degradation. However, present and future phosphorus mitigation are warranted within the watershed.

Introduction

Grindstone Lake (WBIC: 2391200) is a 3176-acre drainage lake with a maximum depth of 60 feet (18.3 meters) and a mean depth of 30 feet (9.14 meters). The Wisconsin DNR does not classify the overall trophic state. Still, historical data indicates that it is mild-mesotrophic to oligotrophic regarding total phosphorus concentration, chlorophyll-a concentration, and Secchi Depth. Historically, the Secchi depth has suggested that the lake is oligotrophic and both oligotrophic and mild-mesotrophic for chlorophyll-a concentration. The total phosphorus concentration (limited data since 2008) has been in the mesotrophic range. Figure 1 graphs the trophic state in Grindstone Lake since 1993[1].

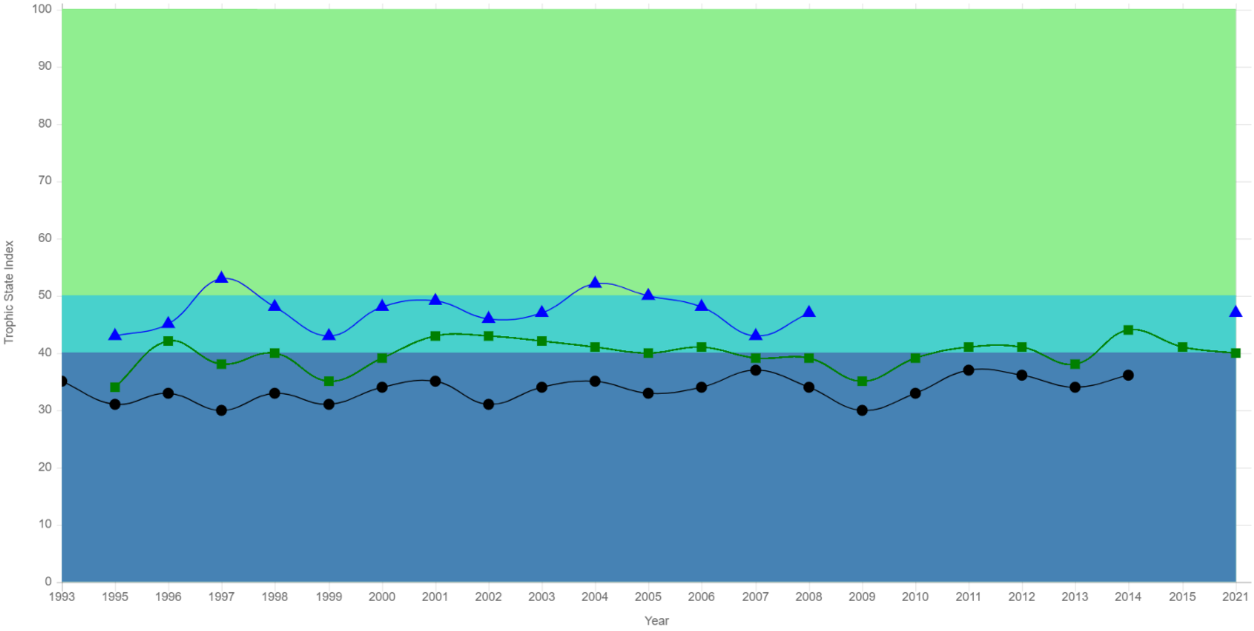

Figure 1: Trophic state index (TSI) graph with total phosphorus, chlorophyll, and Secchi depth values over many years in Grindstone Lake.

Over the years, concern has been expressed over the apparent degradation in water quality, namely related to algae growth and reduced Secchi depth. To address these concerns, two previous analyses of the lake nutrient budget have been conducted in 2000 and 2010. The 2000 analysis was more extensive in data collection. This concern has continued. As a result, the Grindstone Lake Association obtained a Wisconsin DNR surface water grant to re-evaluate the water conditions and analyze the nutrient budget of Grindstone Lake in 2021. This analysis will be utilized to develop a comprehensive lake management plan.

The 2021 analysis involved an extensive data collection of monthly water samples throughout the water column analyzed for total phosphorus and chlorophyll-a in the upper epilimnion layer of the lake from May through September. In addition, the primary inlet Grindstone Creek was monitored hourly for flow along with monthly total phosphorus analysis. The Grindstone Lake outlet was also monitored hourly

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[1] From Wisconsin DNR lake water quality data.

for flow throughout the growing season (May-Sept.). Dissolved oxygen, temperature, and specific conductance profiles were collected from May through Sept each month.

Using a steady-state, mass balance approach, the data was used to establish a water budget and nutrient (phosphorus as assumed to limit productivity) budget. All data was loaded into the empirical model Bathtub to estimate the various sources of phosphorus and conduct a load analysis to predict water quality conditions with increased and decreased phosphorus loading.

Several references will be made in this analysis that may require definitions. The following explains basic topics/concepts that will be referenced:

Trophic state

The trophic state of a lake describes the productivity of the lake. Productivity is the number of algae and/or plant growth that occurs in a lake. There are three classifications. These are oligotrophic, mesotrophic, and eutrophic. Oligotrophic lakes are low in productivity due to having low nutrients. Mesotrophic has a medium amount of productivity followed by eutrophic which have excessive productivity. Clear lakes with limited plant growth are oligotrophic and algae laden or lakes with excessive plant growth are eutrophic. An index is used to determine the trophic state of a lake. This index (TSI) is calculated using total phosphorus concentration, chlorophyll concentration, and Secchi depth. The higher the TSI, the more productive. The following breakdown is used:

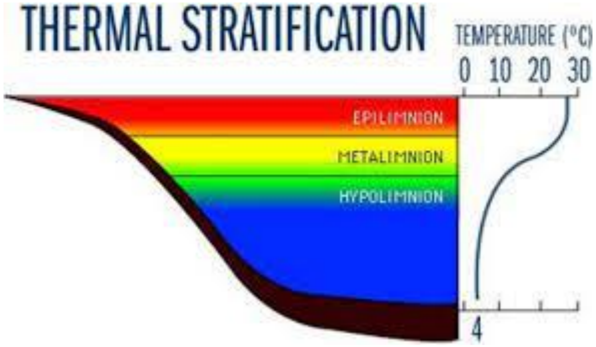
TSI Value	**Trophic State**
30-40	Oligotrophic
40-50	Mesotrophic
50-60	Mild Eutrophic
60-70	Eutrophic
70-80	Hyper Eutrophic

Nutrient loads are the primary cause of increased productivity, typically limited by phosphorus. This means that small changes in phosphorus concentration can lead to large changes in algae and/or plant production in a lake (more productive). Phosphorus sources can be natural from the atmosphere and groundwater (depending to geology). However, human activity can also determine phosphorus loading by developing forested land, installing septic systems, and using fertilizer in agriculture and lawns.

Note: the term total phosphorus refers to all forms of phosphorus dissolved in the water. The useable form of phosphorus (for algae) is soluble reactive phosphorus, which is contained within the measured total phosphorus concentration.

Stratification and Anoxia

Water varies in density when it is at different temperatures. It is most dense at 4 degrees C (about 40 degrees F). For this reason, when water is at or near this temperature, it is most dense and sinks. In deep enough lakes, the lake will undergo stratification. This means that the lake is divided into temperature/density layers vertically. This results in warmer water being near the surface and the colder, denser water at the bottom. The following diagram graphically shows stratification:



This stratification is important because in the summer, the lake can stratify and limit the mixing to the upper layer (epilimnion) since the bottom layer water (hypolimnion) is dense and stable, trapping that water in the bottom. The depth of the thermocline (metalimnion) determines the depth of mixing in the lake.

Another change that can occur in lakes is having the oxygen in the water near the bottom becoming depleted. When it goes below 1-2 mg/L, it is considered anoxic or void of oxygen. Anoxic lake sediments can release phosphorus that became bound in the sediment in oxic conditions. This phosphorus is likely not available in the epilimnion where algae have enough light to grow if the lake remains stratified, trapping the high phosphorus water in the bottom. However, if the lake gets unstable enough through the warming and deepening of the metalimnion, the lake can mix. If it mixes, the bottom water with phosphorus can entrain into the upper layer and be available for tissue growth. This is referred to as internal loading.

Lakes that have strong stratification tend to be dimictic, which means they mix twice (spring and fall). As the cold water in spring warms, it sinks when it reaches 4 degrees C, leading to lake mixing. In the fall, the water cools at the surface and when it reaches about 4 degrees C, it sinks and mixes the lake. Some lakes may stratify but if they are large and have a shallow enough mean depth, they may not remain completely stable and mix in the summer. These lakes are called polymictic, which means they can mix often. This can vary from year to year, depending on air temperature, timing, and storms. The more a lake mixes, the more accumulated hypolimnetic phosphorus will reach the euphotic zone (the zone where photosynthesis can occur), resulting in increased algae growth.

Methods

The procedure for determining the nutrient and water budget for Grindstone Lake depended on numerous data collections and calculations. The methods are separated into the key components that make up the data used to calculate the loads.

Watershed

The watershed boundary for Grindstone Lake and Grindstone Creek was obtained from the Wisconsin DNR via the surface water data viewer map. The catchments that runoff directly into these water bodies was used, and the catchments that appear to drain into other depressions/water bodies were eliminated. These internally drained catchments can contribute to a small degree but are likely minimal except during very high precipitation years. This focuses on the impact of the portion of the watershed that drains directly into the lake.

The catchments for Grindstone Creek were not used in the runoff determination into Grindstone Creek because actual field data for flow and nutrient concentrations were measured in the creek during the analysis period. This results in a better measurement than runoff estimates.

The land cover was also obtained from the Wisconsin DNR. It is from the 2011 National Land Cover Database (USGS), which is still relatively old but is an update from the 2006 version available from the surface water viewer.

Grindstone Creek inflow and Grindstone Lake outflow

Flow measurements had to be completed to determine the contributions of water and phosphorus into Grindstone Lake from Grindstone Creek and the outflow (loss) of water and phosphorus out of Grindstone Lake. A pressure transducer was installed to measure daily flow into the inlet creek and the outlet. These transducers measured the depth (stage) of the water every hour of every day from May 1 until Oct 31. On seven occasions, the flow of each stream was measured by determining the cross-section area of water within the stream (in the culverts at the inlet) by measuring the depth at various width intervals. This data was graphed with the integral of the graph calculated. The velocity was measured using an Onset fluid velocity meter at each width interval. The velocity times the area results in the flow (in ft^3/second). These flow values are then graphed with the stage value of flow determination to create a flow curve. A trendline is implemented into the graph to get a function (model) that calculates flow during each stage logged. The function chosen is the one that will give the highest correlation factor (R^2). Options range from linear, exponential, or polynomial. See the appendix to view the flow curves established from the inlet and the outlet. The total flow is determined from the mean daily flows calculated from the stage and the flow curve function.

The total phosphorus was analyzed in water samples from Grindstone Creek each month. The flow vs. TP concentration scatter-plot was created and revealed there appears to be no correlation between the amount of flow and the phosphorus concentration. Therefore, the mean phosphorus concentration during the monitoring period was used to calculate the phosphorus contributed from the inlet. The mean lake epilimnion phosphorus concentration was used to quantify the phosphorus outflow from Grindstone Lake during the monitoring period.

Water Budget

The water budget was determined by using the following equation:

$\Delta S = \sum \text{inputs} - \sum \text{outputs}$

ΔS is the change in storage (volume of the lake).

Inputs include direct precipitation onto the lake, Grindstone Creek (inlet), runoff from land/wetlands around the lake, and net groundwater inflow.

Outputs include outflow of Grindstone outlet, and evaporation (groundwater outflow is technically included in net groundwater inflow).

Direct precipitation is an absolute value based upon total precipitation onto the know surface area of the lake. The flow calculation from Grindstone Creek is also a measured value. The runoff was estimated using literature obtained runoff coefficients for various land covers and the response of the lake stage to precipitation events.

The inflow from Grindstone Creek was determined using a flow curve (explained earlier in this section) and measuring the hourly stage of the stream.

The outflow was calculated using measured values. The evaporation is estimated using literature obtained from research conducted in other Wisconsin Lakes.

Since groundwater outflow could not be determined directly, the net groundwater inflow was estimated using the volume difference between inputs and outputs. It is assumed that higher groundwater inflows offset any groundwater outflows. The value used is the net contribution of groundwater to Grindstone Lake. The groundwater contributions from Grindstone Creek should be included in the total flow measured.

A water year model estimate was determined. The runoff from the watershed and direct lake precipitation was adjusted by the percent of actual compared to an average year to account for reduced rainfall. The Grindstone Creek inflow was estimated by doubling the baseflow (since only measured for half of one year) in an average year. The runoff into Grindstone Creek was adjusted by the measured divided by average. The estimated net groundwater inflow was doubled to account for an entire year.

Phosphorus Budget

The phosphorus budget was determined using a mass balance approach, where the phosphorus inputs will equal the phosphorus outputs. Inputs include atmospheric deposition, Grindstone Creek, runoff for the surrounding land, and groundwater flux. Outputs include outflow via the outlet of Grindstone Lake, sedimentation of the phosphorus, and biological uptake (absorbed by organisms such as algae). Another input that can contribute phosphorus to the epilimnion where algae can grow is internal loading, which results from sediment release of phosphorus.

The in-lake concentration of phosphorus was determined using monthly total phosphorus samples through vertical sample collection at 2-meter intervals. The emphasis was on the epilimnion concentrations as this layer has enough light penetration for algae growth, affecting water clarity. The vertical profile allows for the evaluation of potential internal loading. Chlorophyll-a and Secchi depth data was collected in monthly intervals as well. The samples were collected with integrated samples (0-2 meters).

Atmospheric deposition

Phosphorus can be loaded into the lake from the atmosphere by wet deposition (rainwater containing phosphorus) and dry residue (dust, pollen, other particles containing phosphorus). An extensive study of lake nutrients in a northwest Wisconsin lake led to data that can be used to extrapolate atmospheric deposition (Roberts and Rose, 2009). It was determined that the rainwater in the summer averaged a phosphorus concentration of 17 µg/L in the summer and 12 µg/L in the winter, with an annual average of 16 µg/L (since most precipitation occurs in the summer months). The dry deposition was differentiated into watersheds with extensive conifer composition and lacking conifer composition in the forested areas. Agriculture has little impact in lakes such as Grindstone Lake as very little agriculture is contained near most northern Wisconsin lakes. The dry deposition for conifer-containing watersheds is highest in the summer months and minimal in winter. The dry deposition coefficients are in lb/mi^2/day. The volume of rain multiplied by the phosphorus concentration allows for the determination of wet deposition. The dry deposition can be calculated using the coefficient multiplied by lake area and the number of days.

Grindstone Creek and Groundwater

The Grindstone Creek phosphorus loading into Grindstone Lake was determined by multiplying the measured volume of water from the inlet by the mean phosphorus concentration. The groundwater load was determined by multiplying the estimated volume of net groundwater input by 12 µg/L, which is a concentration used by similar northern Wisconsin lakes.

Runoff from direct-drainage watershed

The most up-to-date land cover was used to estimate the runoff load. Various land cover types contribute different amounts of phosphorus due to runoff (lack of infiltration) and the tendency to pick up phosphorus from the land. Export coefficients, as well as runoff coefficients published for Wisconsin Lakes, were utilized. Forested land cover has the lowest export coefficient while residential and agriculture have much higher coefficients. The most probable export was used initially and adjusted to match the in-lake concentration. Since export coefficients are based on average conditions each year (precipitation amounts and runoff), these coefficients were adjusted for the actual precipitation amounts. The following coefficients were utilized[2]:

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[2] Export coefficients from Wisconsin DNR lake water database for PRESTO.

Land Cover	Low P ($lb/mi^2/yr$)	Med P ($lb/mi^2/yr$)	High P ($lb/mi^2/yr$)	runoff coefficient (type A soil)
Rural Residential	29	57	143	0.15
Medium Density/Near Lake Development	171	286	457	0.26
High-Density development	571	856	1142	0.5
Pasture/Grass	57	171	286	0.25
Commercial	286	571	1713	0.25
Forest	29	54	103	0.11
Wetland	22	56	85	0.08

Table 1: Export coefficients and runoff coefficients for various land covers. Gray column is what was used.

It is important to understand there can be errors in these estimates. Several factors can affect the runoff intensity and nutrient concentrations of that runoff. These include the degree of slope in surrounding land, the intensity of the storms, the type of soil as well as soil moisture. The estimates are based upon runoff coefficients adjusted for the response the lake showed during precipitation events and soil type. However, a runoff coefficient can be different depending on rain event intensity and topography in specific areas. For example, if four inches of rain is received in a month, there is a big difference if that rain comes in numerous small increments versus a few very intense storms. Also, if there is slope grade is high, the runoff is more intense. In the end, this is an estimate but should allow for a valid comparison to other phosphorus sources.

Septic systems

Human sewage and wastewater are high in nutrients. Although properly designed and functioning septic systems remove much of the nutrients, some can migrate into the lake. Septic system loading was estimated using the following equation:

Total septic load = E_s * (number of capita years) * ($1-S_R$),

Where E_s is the phosphorus export coefficient (0.55 kg/capita/yr was used), the number of capita years is the number of people using the septic system per year. S_R is the soil retention factor (0.90 was higher than the 0.86 used in a previous study since some septic systems have been improved in past years, accommodating this potential improvement). To determine the capita years, seasonal and permanent residents were utilized. In 2010, it was reported that 45% of the residents are year-round, and 55% are seasonal. Three persons per year were used for year-round residents and five persons per year for seasonal with an occupation of 100 days. There are 305 units with septic systems reported in 2007 that can contribute to Grindstone Lake (is this changed in the 2021 social survey?...if so recalculate)

In-lake Phosphorus Concentration and areal load

The biological uptake was not determined. The phosphorus sedimentation from the water column was based on the Canfield and Bachman natural lakes model. This model predicts the growing season's mean phosphorus concentration based on phosphorus loading, sedimentation rate, and output. The Canfield and Bachman model equation is one of the most effective model equations for northern

Wisconsin lakes (Robertson and Rose, 2008). If the inputs reflect the actual load, the in-lake phosphorus concentration will be close to the model prediction. The Canfield and Bachman equation is as follows:

$$\text{Total phosphorus concentration } (\mu g/L) = \frac{L}{0.305 * Z\ (1.62 \times L/Z)^{0.458} + 1/t)}$$

where

L is the annual areal phosphorus-loading rate in mg/m^3,

Z is the lake's mean depth in meters, and

t is the residence time of the water in the lake (in years).

Internal loading

When lakes become anoxic on the bottom, the sediment will release phosphorus. One mechanism is reducing iron-bound phosphate, which leads to the iron casting the phosphate ion, which is released into the bottom water layer (hypolimnion). If the lake is stratified, the layers of water are stable, leading to limited to no mixing of the water column. This traps the phosphorus in the bottom layer and is not available in the upper layer (epilimnion), where light is not limited and can lead to algae production. The internal load is considered zero if sediment release occurs, but not a phosphorus flux into the upper layers (entrainment) due to stable stratification.

Sometimes a lake becomes unstable due to a degradation of the stratification. In that case, the bottom water can move vertically and mix with the upper layers leading to a phosphorus flux (entrainment) in the upper levels allowing for increased algae production. If a lake remains stratified, but the thermocline (also known as the metalimnion, a temperature transition layer between the epilimnion and hypolimnion) increases in-depth, some phosphorus can diffuse upward, leading to a phosphorus flux into the epilimnion. This is less intense than mixing.

An index known as the Osgood index (Osgood, 1988) can predict the likelihood of a lake mixing and leading to internal loading. This equation to predict lake mixing potential ***is calculated as mean depth (m) / (Surface Area) 0.5 (km^2)***. The Osgood index for Grindstone Lake is 2.54, which is considered low (range of 1-5 is considered "low"), which predicts the lake as polymictic, which means the lake can mix more than two times per year. This index value would suggest a reasonably high probability that some of that phosphorus could make it to the epilimnion with sediment release.

To determine the degree of sediment release, monthly dissolved oxygen and temperature profiles were collected to determine if the lake becomes anoxic near the bottom and if the lake becomes and remains stratified throughout the summer. In addition, the monthly phosphorus profiles show the phosphorus concentration at 2-meter intervals to determine if phosphorus increases at various depths. Calculating the phosphorus mass in the hypolimnion before anoxia begins and after anoxia ends allows the estimate of phosphorus released from the sediment due to anoxia.

Mass of phosphorus release = (volume of water in hypolimnion at the end of anoxia X volume-weighted concentration of total phosphorus) – (volume of water in hypolimnion at the beginning of anoxia X volume-weighted concentration of total phosphorus)

Mass balance in the epilimnion was used to quantify the amount of the hypolimnetic phosphorus that was entrained into the epilimnion. All phosphorus inputs are evaluated, and the internal load is considered if an increase in epilimnion phosphorus concentration cannot be accounted for through other sources.

Mass balance budget/Predictions

The empirical model Bathtub (US Army Corp of Engineers, Walker 1994) was used to estimate phosphorus source loads, using a mass balance approach (in which the Canfield and Bachman model for natural lakes was utilized) to match the observed, in-lake phosphorus concentration.

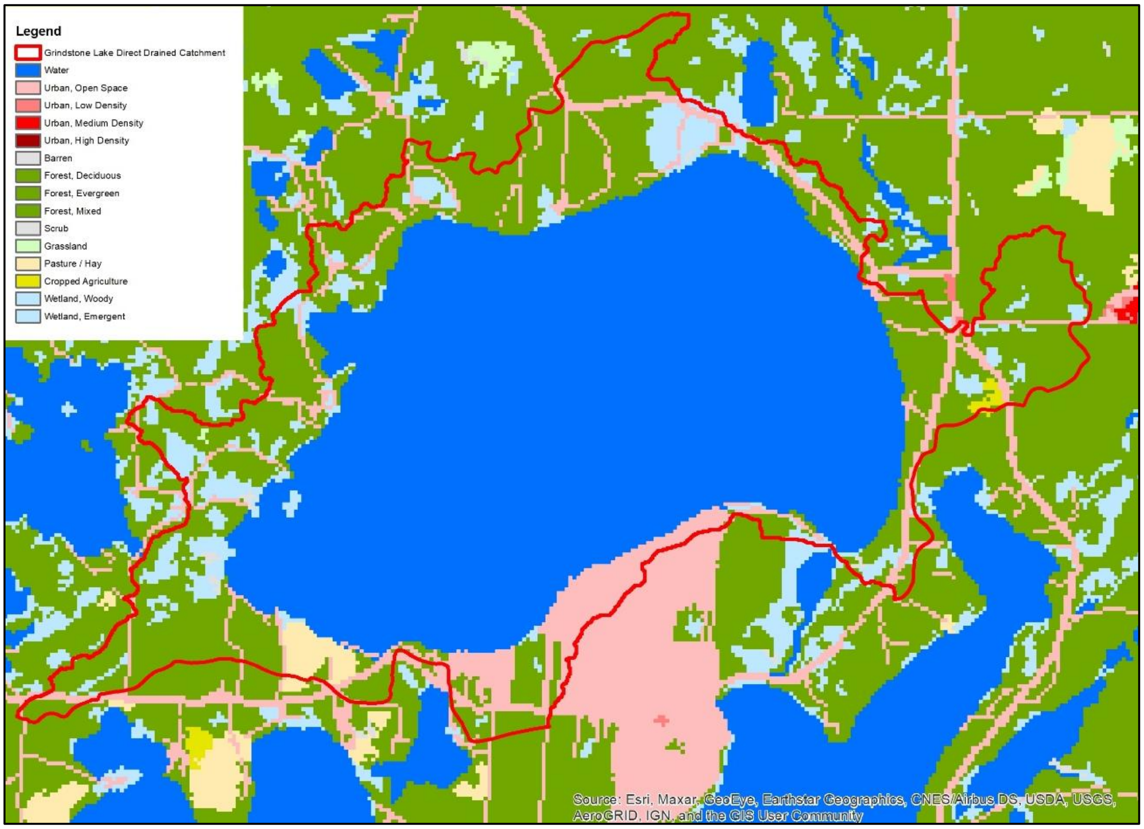
Results

Watershed

The most recent watershed boundary was obtained from the Wisconsin Dept of Natural Resources. The watershed is broken down into catchments. The catchments that appear to drain into low elevations/other bodies of surface that do not appear to flow directly into Grindstone Lake (direct-drainage) were eliminated. The direct-drainage watershed around Grindstone lake measures 2122 acres. In addition, since the inlet (Grindstone Creek) was monitored for flow and nutrient concentrations, the catchments that drain into Grindstone Creek were disregarded in estimating runoff since that is more accurately represented in the flow and nutrient data. Figure 2 is a watershed map showing the direct-drainage (red) line and Grindstone Creek watershed (blue area).

Figure 2: Watershed boundary for direct-drainage watershed around Grindstone Lake (red line) and the Grindstone Creek watershed boundary (blue shaded area).

The land cover utilized to estimate the runoff from the direct-drainage watershed was obtained from the Wisconsin DNR. The land cover was updated in 2011 and came from the National Land Cover Database (NLCD). Figure 3 shows the map of the direct-drainage watershed with land cover types representing different colors. The watershed area to lake area ratio is low in Grindstone Lake, which reduces the impact the watershed has on nutrient loading.



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 3: A land cover map for Grindstone Lake watershed.

Land Cover	**Area (acres)**	**Area (km^2)**	**% of the total area**
Forested (includes deciduous, mixed, and evergreen)	1388.7	5.62	65.4%
Developed/residential	415.1	1.68	19.5%
Wetlands	269.3	1.09	12.7%
Grassland	39.5	0.16	1.9%
Commercial	9.9	0.04	0.5%
Total	***2122.5***	***8.59***	100%

Table 2: Landcover areas for various land cover within the direct-drainage watershed of Grindstone Lake.

As the data shows, forested land cover is the predominant area, followed by developed/residential. Forest land cover has lower runoff and nutrient loading than developed or residential.

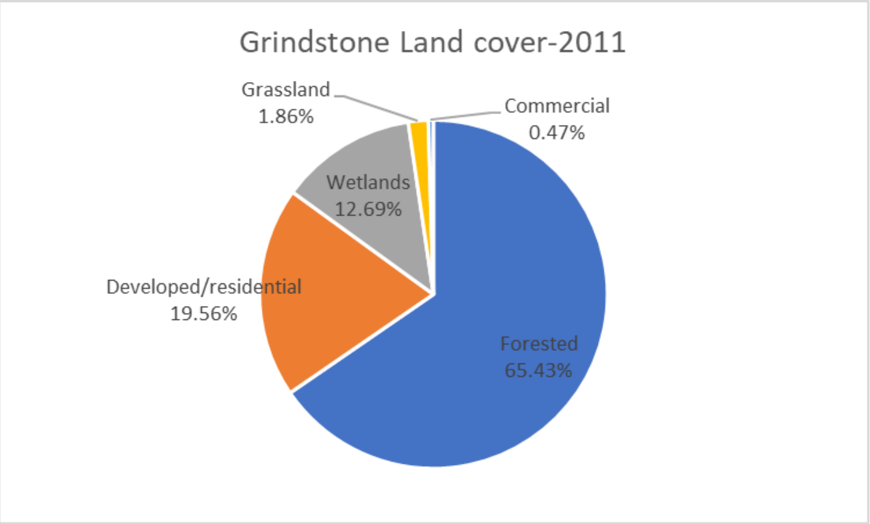


Figure 4: Pie graph of land cover types in the Grindstone Lake watershed.

Water budget

The lake data was monitored from May 1 through Oct 31, 2021. During this time, the area within Grindstone received 17.38 inches of precipitation, which is 64% of normal. For this reason, to analyze a typical year for the Grindstone Lake water budget, the budget needs to be adjusted for a regular precipitation season. This adjustment leads to an estimate because the response to higher precipitation is uncertain in Grindstone Creek. The table below shows the water budget from measured data and calculations for an average season. The rainfall for May 1 thru Oct 31 in 2021 was 58% of the thirty-year average.

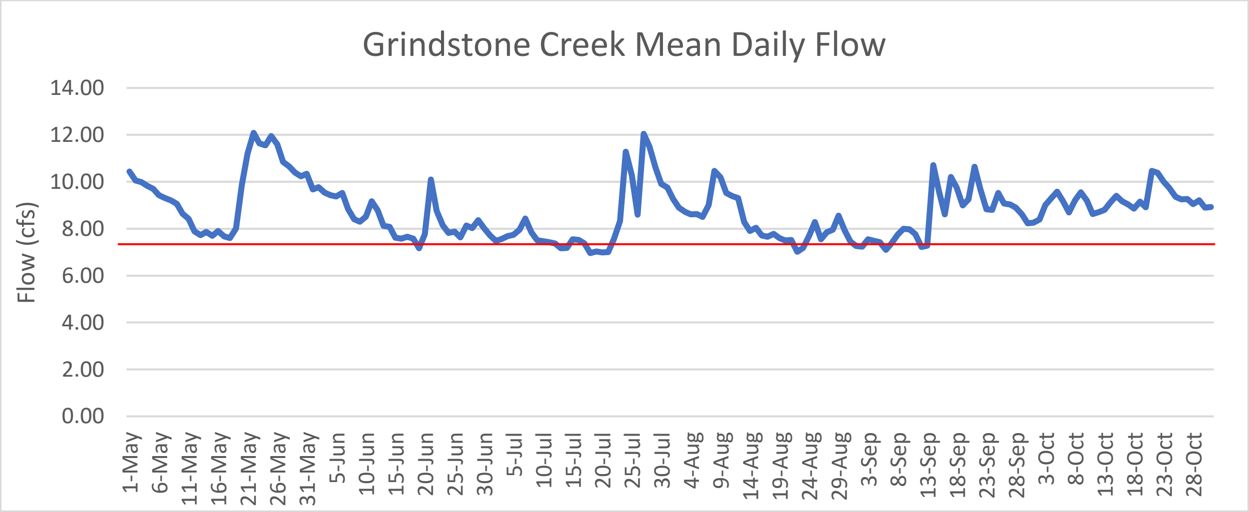


Figure 5: Hydrograph of Grindstone Creek from May 1 to Oct. 31, 2021. The mean base flow was approximately 7.1 ft^3/second (red line shows approximate reference)

Water budget amounts		
Inflows **(hm^3)**	**Using measured data-2021 (growing season)(hm^3)**	**Estimate for average precipitation year (hm^3)**
Direct precipitation on lake	5.7	10.7
Grindstone Creek inlet	4.06	8.2
Net groundwater flow (inflow-outflow)	4.4	9.4
Runoff from direct drained land	0.6	1.0
Outflows **(hm^3/growing season)**	**Using measured data-2021 (growing season)(hm^3)**	**Estimate for average precipitation year (hm^3)**
Out of lake outflow (outlet)	8.4	20.2
Evaporation	8.4	9.1
Change in storage (ΔS)	-2.1	0.0 (assumed)

Table 3: Summary of water sources in the Grindstone Lake water budget. Includes 2021 data and estimates for an average precipitation year.

A groundwater model of Grindstone Springs (Grindstone Creek) in 2007 created by the USGS estimated the baseflow of 8.3 ft3/s. The mean baseflow during the growing season was 7.1 ft^3/s, which is lower. This may be due to the dry year, which lowered the water table and wetlands.

Linear regression data from the Wisconsin DNR PRESTO model for the Grindstone watershed suggests an input of 33 ft^3/s. The estimated water load for the average year was just under 30 ft^3/s, so the water budget is consistent with the regression analysis.

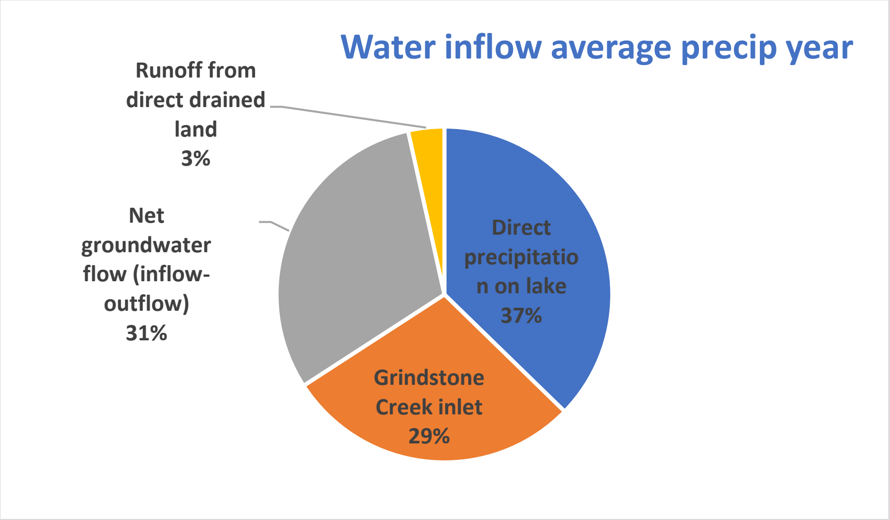


Figure 6: Pie graph showing various water inputs into Grindstone Lake in an average year.

The growing season water budget for Grindstone lake in 2021 gave a water residence time of 3577 days. The estimated growing season residence time through regression analysis is 4000 days (most likely) with a range (90% confidence lower to higher) of 2300 to 8500 days. The water budget is consistent with the regression analysis. The estimated residence time for an average precipitation year is 6.00 years (2190 days).

Nutrient (phosphorus budget)

Using a steady-state, mass balanced approach Canfield and Bachman model, the estimated phosphorus concentration for the 2021 data was close to the in-lake observed epilimnion concentration (12.2 predicted vs. 12.5 observed). To match the in-lake concentration, the model was calibrated by decreasing the sedimentation rate by 2%. The model was re-run using a typical precipitation amount (the growing season for 2021 was substantially lower than normal). Using the 2021 phosphorus calibration, the average year model predicted a growing season mean of 13.7 g/L, the same as the historical average observed (13.7 g/L). Therefore, the model appears to accurately represent the actual phosphorus load that occurs in an average year into Grindstone Lake.

2021 observed	2021 Canfield and Bachman (model) prediction uncalibrated	2021 model prediction Calibrated (reduced sedimentation rate)	Historical observed	Average year model prediction-using 2021 calibration
12.5 µg/L	12.2 µg/L	12.5 µg/L	13.7 µg/L	13.7 µg/L

Table 4: Observed 2021 total phosphorus concentrations (in-lake) and average year, as well as model predictions.

Source-measured 2021 data	kg/growing season	%Total
Direct-drainage watershed	125.3	22.8%
Grindstone Creek	128.7	23.4%
Groundwater	52.8	9.6%
Septic systems	25.8	4.7%
Internal load	37.5	6.8%
Atmospheric deposition	179.9	32.7%
Total	550.0	100.0%

Source-Average year precipitation amount	kg/yr	%Total
Direct-drainage watershed	224.2	24.5%
Grindstone Creek	254.2	27.8%
Groundwater	105.6	11.6%
Septic systems	35	3.8%
Internal load	37.5	4.1%
Atmospheric deposition	257	28.1%
Total	913.5	100%

Table 5: Summary of phosphorus loading sources for 2021 growing season and an average precipitation year into Grindstone Lake.

A breakdown of the sources is shown in Table 5. Atmospheric deposition is the highest of all the sources, followed by Grindstone Creek and the direct-drainage watershed. The loading from Grindstone Creek and the direct-drainage watershed loading can be controlled through management practices. The majority of the direct-drainage watershed load (in kg/m^2) is due to developed land, which would increase run-off through impervious surfaces and other land covers that increase runoff.

The atmospheric loading is due to dry and wet deposition. The dry deposition is relatively high in Grindstone Lake, likely due to high amounts of conifer pollen released in the growing season. Dry deposition can be theoretically controlled by land cover by reducing the dust of agriculture fields.

However, there is little to no agriculture near Grindstone Lake (based upon land cover files), so mitigation of this deposition is unlikely.

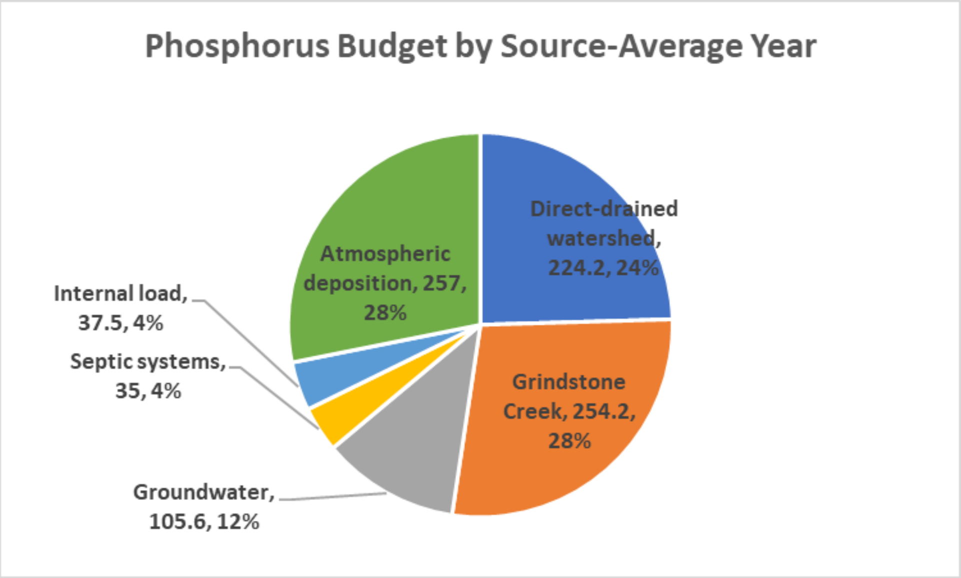


Figure 7: Pie graph of various phosphorus sources into Grindstone Lake (by percent of source) in an average precipitation year.

Sediment Release/Internal Load

The data in 2021 shows that Grindstone Lake was strongly stratified by June and remained that way until October. Profile data in early November found the lake thoroughly mixed. The lake also became anoxic in the hypolimnion between mid-June and mid-July based upon the dissolved oxygen profile and remained this way through September.

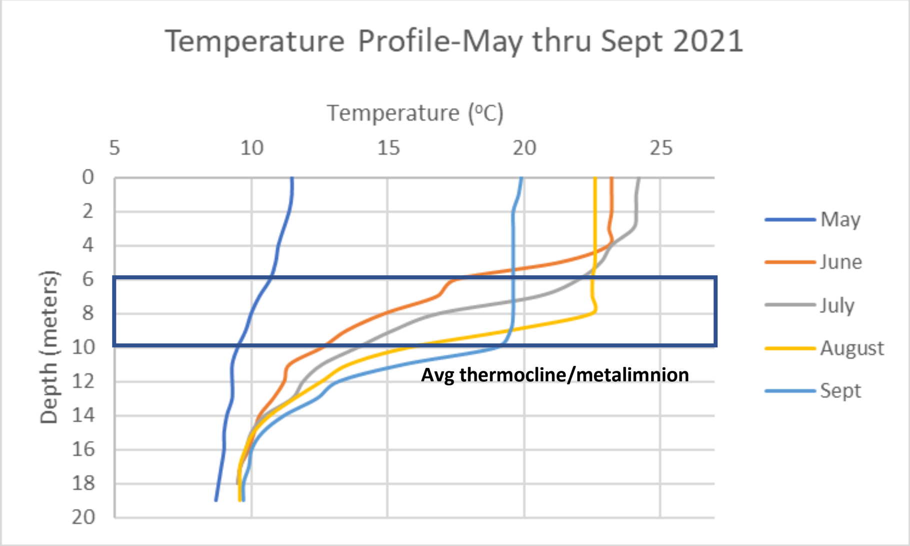


Figure 8: Temperature profile from the surface to near bottom, Grindstone Lake May-Sept 2021.

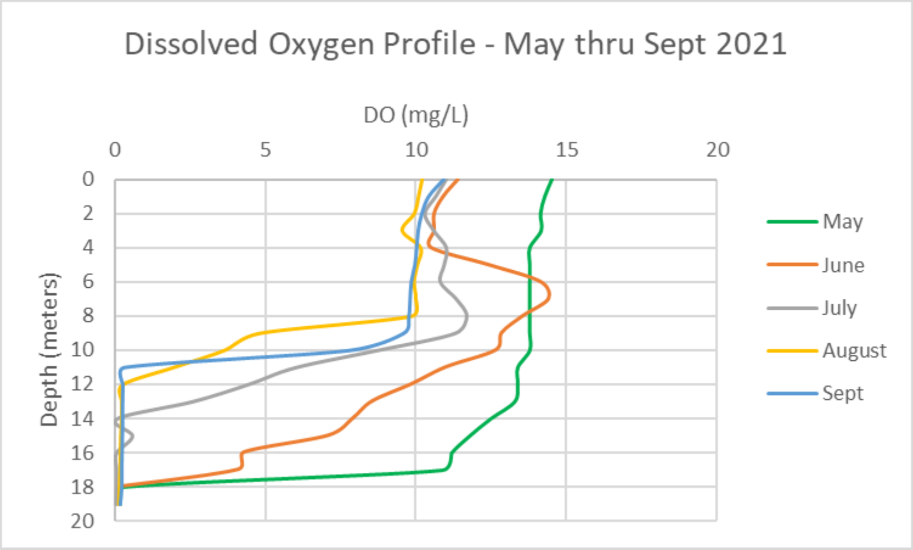


Figure 9: Dissolved oxygen profile from the surface to near bottom, Grindstone Lake May-Sept 2021.

Phosphorus accumulated in the hypolimnion due to bottom sediment release during anoxia in the sediment. Anoxia appears to have occurred in July at 14 meters and in August at 12 meters. The anoxia continued through Sept, with turnover likely occurring in October. As phosphorus accumulated, iron concentration increased in the hypolimnion water, suggesting that the sediment is susceptible to iron reduction in iron-bound phosphate within the deposit. In conditions with oxygen, the residue can readily bind phosphorus. The phosphorus concentration within the hypolimnion increased from May through August, then decreased in September. This decrease could be due to entrainment as the thermocline moved deeper, allowing diffusion of the phosphorus upward, and reduction could be from re-sedimentation into the bottom sediment. Interestingly, the phosphorus decreased in the epilimnion in September (mid), which would indicate that there was significant biological uptake (supported by an increase in chlorophyll-a concentration), the spike from entrainment was missed in data collection or the phosphorus was bound back into the sediment (or a combination of these).

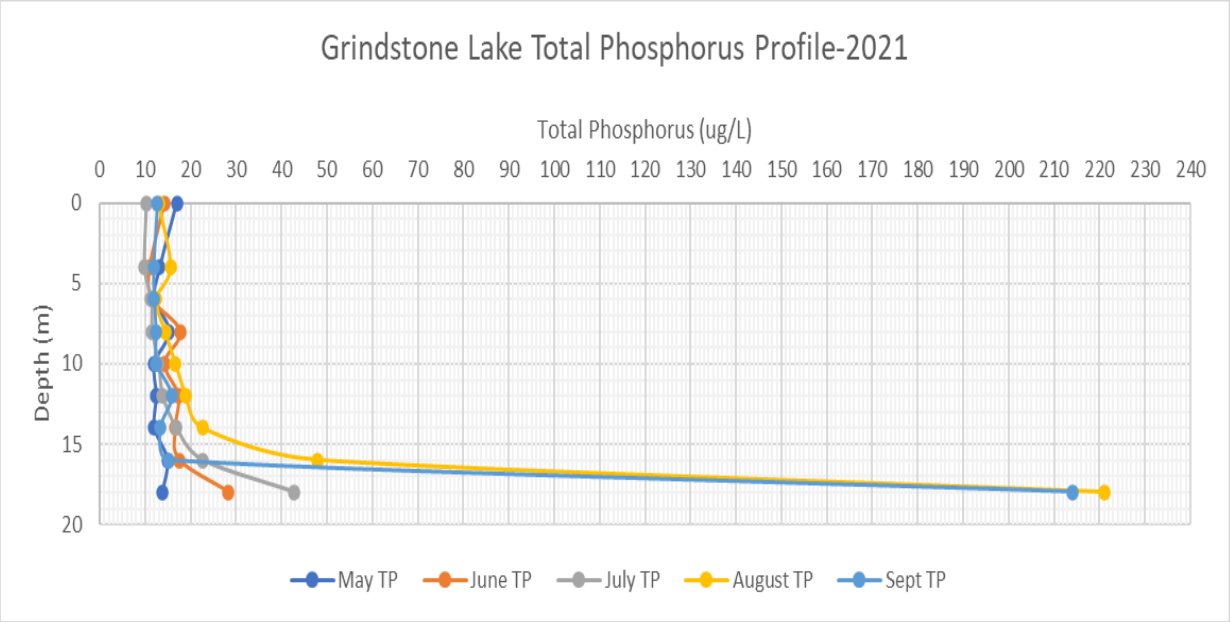


Figure 10: Total phosphorus profile from the surface to near bottom in 2-meter intervals, Grindstone Lake 2021.

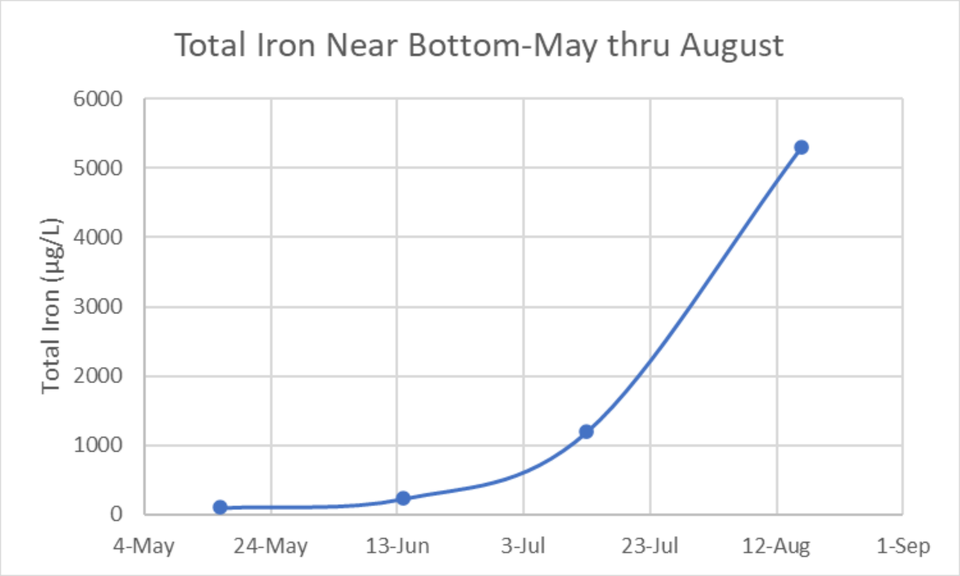


Figure 11: Total iron concentration in hypolimnion (near-bottom) in Grindstone Lake, 2021.

During July through September, there was no evidence of mixing. However, there were limited profile data collected occurring monthly. Entrainment of phosphorus from the hypolimnion did not likely happen due to the mixing of the layers. As the summer progressed, the epilimnion grew deeper, allowing diffusion of some phosphorus into the upper epilimnion layer, leading to an internal phosphorus load. It shows an increase in metalimnion and epilimnion layers in August. Using mass balance (increase in phosphorus that could not be accounted for from other sources), it was calculated that an internal load of ***37.5 kg*** occurred through the entrainment of phosphorus from the hypolimnion.

This load could be higher as this value was based upon what was available to be released as the thermocline deepened but fell short of raising the epilimnion concentration sufficiently to match observed values. However, this could be offset because the most extreme precipitation events occurred from July 15 to August 15, which may have caused a higher than predicted flux of phosphorus from the watershed.

Based upon the data, sediment release of phosphorus occurred. The phosphorus accumulation in the hypolimnion was estimated at 155 kg, primarily due to sediment release in anoxic conditions from July through August. The favorable net release period appears short (July through August) as the phosphorus concentration decreased from mid-August to mid-September in the hypolimnion.

Other water quality parameters

Phosphorus in Grindstone Lake will limit the production of algae. As phosphorus concentrations increase, so too will algae growth. Since algae cells contain chlorophyll, the chlorophyll concentration will reflect changes in algae growth (higher chlorophyll concentration indicates more algae growth). More algae growth will reduce light penetration, resulting in less water clarity and lower Secchi depth values. The models used can predict chlorophyll-a concentrations and Secchi depth, but these models need to be calibrated using observed values. Table 6 shows the calibrating results using 2021 data and the resulting predictions for the average year. The historical average is from previous data looking back to 1998. Using 2021 calibrations, the Secchi depth predictions were nearly perfect, and the chlorophyll-a concentration prediction was 33% higher than observed historically. The chlorophyll-a concentration was re-calibrated for an average year to match the historical data and more accurate load analysis.

Parameter	**2021 observed**	**Predicted model[3]-uncalibrated**	**Predicted model-calibrated**	**Historical observed** (since 2008)	**Predicted model-avg year** (using 2021 calibration)
Chlorophyll-a	2.4	2.8	2.4	2.1	2.8
Secchi depth	6.3	4.3	6.3	5.9	5.8

Table 6: Observed and model predicted chlorophyll-a concentration and Secchi depth.

The chlorophyll-a concentration and Secchi depth are better (lower in the case of chlorophyll-a and higher in the case of Secchi depth) than the total phosphorus concentration would predict. This suggests that zooplankton grazing occurs in the epilimnion of Grindstone Lake, reducing the algae population and thus increasing Secchi depth. The June dissolved oxygen profiles show a significant spike at about 6-7 meters. This suggests more algae growth at this depth, resulting in higher oxygen concentration. This spike is never seen again, maybe due to zooplankton grazing in mid/late summer.

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[3] Chlorophyll-*a* model used Jones-Bachman (1976) and Secchi depth used total phosphorus TSI value.

Comparison to Previous Analysis (2000 and 2010)

It is difficult to establish any changes/trends to the nutrient budget in Grindstone from previous analysis due to differences in modeling procedures. All modeling of lakes involves assumptions related to annual averages such as evaporation, runoff coefficients, etc. This can lead to a fair amount of error/uncertainty compared to the real world. WILMS was used in 2000 and 2010, while Bathtub was used in 2021. While WILMS can be a helpful tool, this model provides estimations with limited data input and broad assumptions, especially related to runoff. The ability to change parameters is more limited. The data input in 2000 appears to be more extensive than in 2010. Using Bathtub, the modeler has more control over calibrating the water budget with field data, thus reducing assumptions. It also provides more latitude in managing various inputs/outputs of nutrients. Also, in 2021 Grindstone Creek and outlet flows were monitored using continuous logging instruments instead of periodic, discreet monitoring in 2000. Although the 2000 analysis included numerous flow readings and was correlated to the stage, the correlation appeared weak. This can lead to more error inflow/outflow estimates, accounting for some differences. Regardless, much of the output data are similar by percent (total loads are quite different due to model use differences in earlier analysis).

Phosphorus sources by %	**2000**	**2010**	**2021**
Atmospheric deposition (dry and wet deposition)	20.7%	24%	28.1%
Grindstone Creek	30.9%	?? (not separated)	27.8%
Runoff from watershed	44.5% (stated to include net groundwater)	71% (assume includes Grindstone Creek and groundwater as this was not separated)	24.5% (36.1% if included with GW as was done in 2000)
Groundwater (GW)	Not separated	Not separated	11.6%
Septic	3.2%	3%	3.8%
Internal loading	0.7%	2%	4.1%

Table 7: Phosphorus source comparison of previous analysis by percent.

One potential positive change in phosphorus loading since 2010 is the acquisition of the commercial cranberry bog. Using the same export coefficients utilized in the 2010 analysis and comparing to the total estimated phosphorus load from the 2021 analysis, it can be estimated that this could reduce 43.5 kg of phosphorus loaded into Grindstone Lake an average year. This amounts to a reduction of 4.5% in the estimated load by taking the cranberry bog out of production and allowing the change in land cover within the bog area (to wetland and grassland). This is a broad calculation and a more precise evaluation would need to utilize a model designed to evaluate the specific property of this type. There may also be residual phosphorus in the bog that is being released, creating a higher load than predicted.

Septic loading was lowered (by mass) in the 2021 analysis to account for described septic updates outlined by the Grindstone Lake Association. The septic load by percent is higher in this model than previous models due to the lower overall loading mass.

Trophic state

The Carlson Trophic State Index (TSI) converts total phosphorus, chlorophyll-a, and Secchi depth into a number representing the trophic state (oligotrophic, mesotrophic, or eutrophic) as it relates to that parameter. Comparing these index values allows for an essential evaluation of what may be occurring within the lake. It also is an excellent method to evaluate the overall quality of the lake. The lower the TSI, the more oligotrophic and thus higher water quality.

Figure 12 shows the TSI values for historical data collected on Grindstone Lake. Note that the TSI is different between the various parameters.

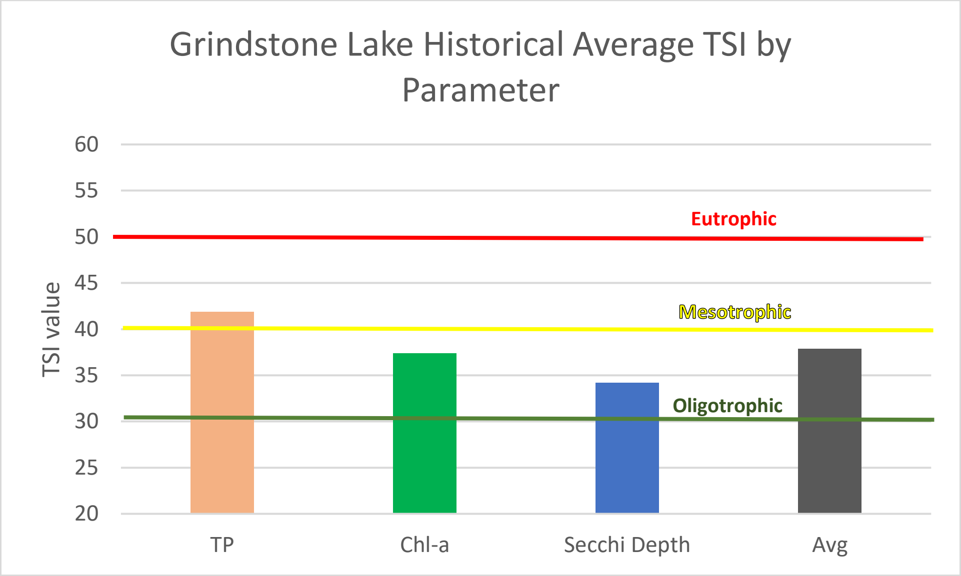


Figure 12: Graph showing the historical average for TSI within each category used in TSI.

When the TSI for phosphorus is higher than the chlorophyll TSI and higher than the Secchi depth TSI, zooplankton grazing is robust in the lake, reducing algae and increasing water clarity.

Load Analysis

For management purposes, empirical lake models can help predict the outcomes of changes in nutrient loading. The average year model was calibrated to match long-term total phosphorus, chlorophyll-a, and Secchi depth data. Although some of the data years may deviate from average conditions, the long-term data set hopefully averages values to reflect the actual values in the lake on an average year.

In the load analysis, the phosphorus loading is changed within sources that can be managed. This would be related to runoff from the watershed since sources such as atmospheric deposition cannot be controlled. The load analysis changed the loading by increasing the probable average year load in 20% increments and decreasing in 20% increments. The resulting output predicts the in-lake total phosphorus and chlorophyll-a concentrations and the Secchi depth during the growing season. Tables 8-10 and figures 13-15 show the predictions from the load analysis.

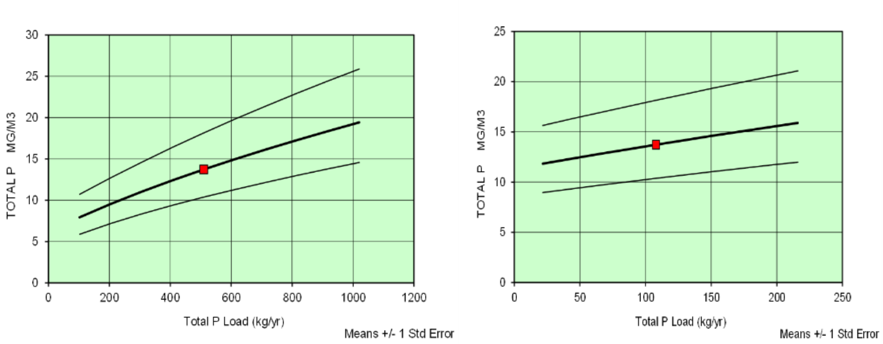


Figure 13: Load analysis graphs showing predicted total phosphorus concentration vs phosphorus load from changes in total load (left) and just the direct-drainage watershed (right).

Total P Load factor (1.0 is present load)	**Estimated GSM TP Concentration-Total load into Grindstone**	**Estimated GSM TP Concentration-Direct Drained Watershed only**
0.6	11	12.8
0.8	12.4	13.3
1.0	13.7	13.7
1.2	15	14.2
1.4	16.1	14.6

Table 8: Total phosphorus concentration prediction based upon TP load analysis.

As figure 13 and table 8 show, the overall total phosphorus concentration will respond to the whole phosphorus load changes. A 20% reduction in phosphorus is predicted to have a most likely in-lake concentration of 12.4 µg/L as opposed to the historical average of 13.7 µg/L, which is a decrease of about 9.5%. Conversely, a 20% increase in total phosphorus load would increase concentration from 13.7 µg/L to 15 µg/L, which is 9.4%.

The most likely potential for phosphorus mitigation would occur in the direct-drainage watershed, especially near-shore development. Load analysis of the direct-drainage watershed only was conducted. It shows less change in the in-lake phosphorus concentration due to lower input. With a 20% decrease in the direct drained loading, the in-lake concentration is estimated at 13.3 µg/L (vs. 13.7 µg/L), representing a decrease of 2.9%. A 20% increase is predicted to result in an in-lake concentration of 14.2 µg/L, representing an increase of 3.6%.

In both cases of load analysis, the more significant the change in loading, the greater the in-lake phosphorus concentration change. Therefore, phosphorus mitigation that can reduce phosphorus loading will decrease in in-lake concentration. Furthermore, reducing the impact in future development would reduce increased loading, preserving present lake water quality.

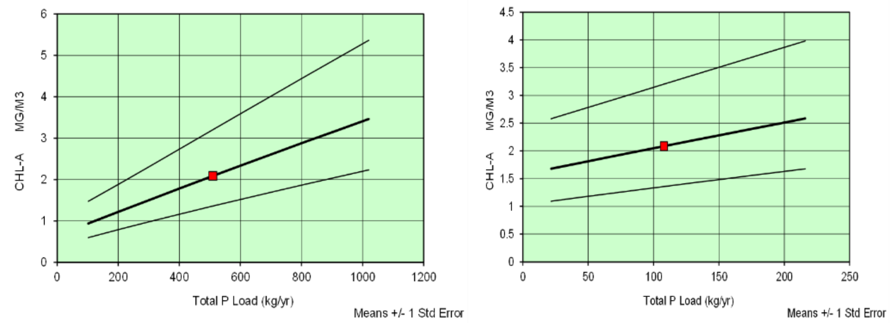


Figure 14: Load analysis graphs showing predicted chlorophyll-a concentration vs phosphorus load from changes in total load (left) and just the direct-drainage watershed (right).

Total P Load factor (1.0 is present load)	**Estimated GSM Chl-a Concentration-Total load into Grindstone**	**Estimated GSM Chl-a Concentration-Direct Drained Watershed only**
0.6	1.5	1.9
0.8	1.8	2.0
1.0	2.1	2.1
1.2	2.4	2.2
1.4	2.6	2.3

Table 9: Predicted chlorophyll-a concentration based upon TP load analysis.

Algae growth is typically limited by available phosphorus in the water. The load analysis allows for predicting the amount of algae growth (represented by the chlorophyll-a concentration). The load analysis shows that a 20% reduction in phosphorus loading (overall) would result in a 0.2 µg/L concentration change in chlorophyll-a concentration (from 2.1 µg/L to 1.8 µg/L). Reducing the direct-drainage phosphorus load by 20% is predicted to lower the chlorophyll-a concentration from 2.1 µg/L to 2.0 µg/L. Figure 14 and Table 9 show the chlorophyll-a concentration load analysis results.

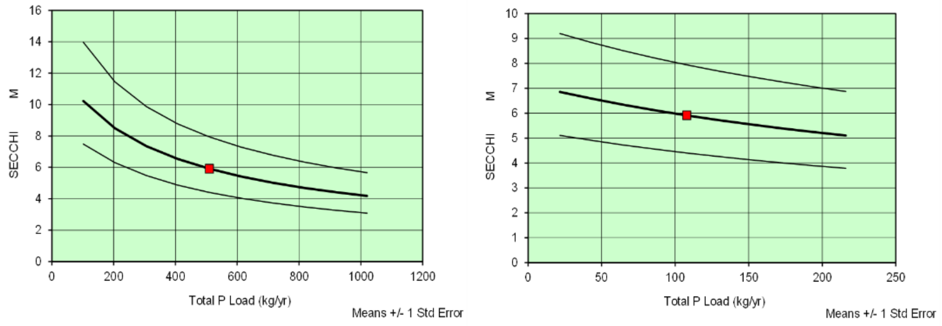


Figure 15: Load analysis graphs showing predicted Secchi depth vs phosphorus load from changes in total load (left) and just the direct-drainage watershed (right).

Total P Load factor (1.0 is present load)	Estimated GSM Secchi depth (m) Concentration-Total load into Grindstone	Estimated GSM Secchi depth (m) Concentration-Direct Drained Watershed only
0.6	7.4	6.3
0.8	6.5	6.1
1.0	5.9	5.9
1.2	5.4	5.7
1.4	5.0	5.5

Table 10: Predicted Secchi depth based upon TP load analysis.

Since algae growth can significantly affect the Secchi depth (water clarity), changing the phosphorus load into Grindstone Lake can be expected to result in a change in Secchi depth. The load analysis from the calibrated average year model predicts an increase in the growing season mean Secchi depth from 5.9 meters to 6.5 meters (1.97 feet) with a 20% reduction in phosphorus loading overall. A 20% reduction in phosphorus loading from jus the direct-drainage watershed would increase the Secchi depth from 5.9 meters to 6.1 meters (0.65 feet). The data also shows that future increases in loading would decrease the Secchi depth measurably.

Discussion

Overall, the historical water quality data indicate that Grindstone Lake has very high-water quality. The total phosphorus concentration is typically in the low-mesotrophic state, and the chlorophyll-a and Secchi TSI's are in the oligotrophic state. Therefore, management should focus on future human impact as the present human impact is not very significant.

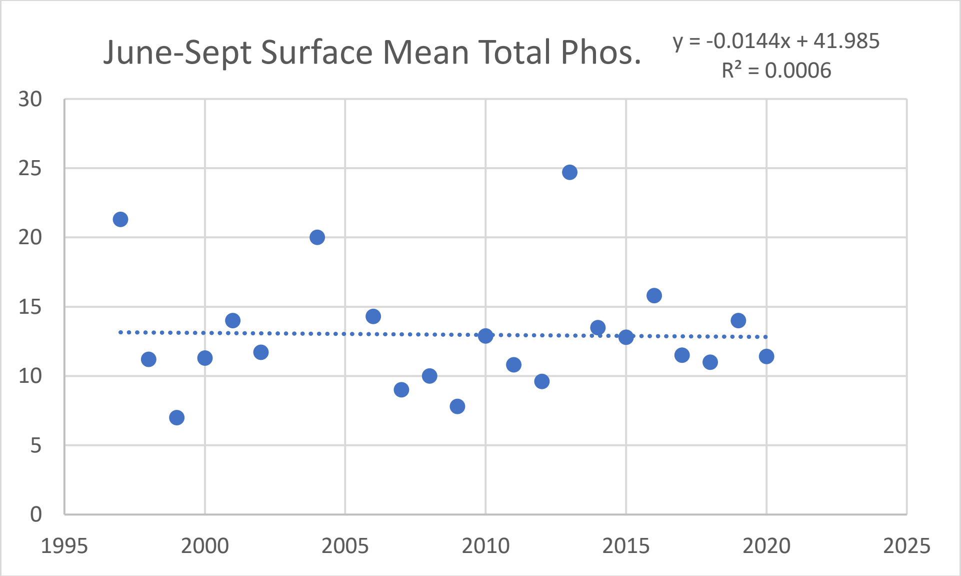
The watershed analysis shows that the direct-drainage portion of the watershed is small around Grindstone Lake. This results in little runoff into Grindstone Lake. Of the watershed, 19.6% of the land cover is developed, with the majority forested land cover. This would indicate that the developed land cover significantly impacts the runoff amount and concentration of phosphorus into Grindstone Lake from the watershed. This is the best portion of the watershed to focus on phosphorus mitigation. Changing forested land into developed land would increase phosphorus loading.

The nutrient model indicates that the direct-drainage watershed and Grindstone Creek contribute significantly to the overall phosphorus budget. However, the overall load is relatively low, so the resulting impact leads to less degraded water quality. Much of the Grindstone Creek flow is due to base flow from groundwater (springs) and wetland draining, with limited influence from the watershed around the creek. Therefore, the most likely effective mitigation would be to focus on near-shore lake development.

Internal load in Grindstone is somewhat complicated to quantify precisely due to various factors. The limited data suggest that although Grindstone Lake has a low Osgood index, which predicts it would tend to mix, there was no evidence of the temperature and dissolved oxygen profiles to suggest the lake became unstable and mixed. This may be because the Osgood index is based upon mean depth and lake area. Grindstone Lake is very large and doesn't have a high mean depth. However, there is a large deep basin that does remain stratified and likely doesn't mix. Therefore, the internal load (entrainment of phosphorus up into the epilimnion) appears to be due to the deepening of the metalimnion during the summer. The data is clear that there is an accumulation of phosphorus from anoxic sediment release, but that too was difficult to precisely quantify because the hypolimnion concentration decreased significantly from August to September, even though there was no evidence of mixing and the hypolimnion was still anoxic. The high iron suggests it may have become rebound in the sediment, but there was no spike in phosphorus in the epilimnion to suggest entrainment. Regardless, it is a small percent of the total load, so mitigation of internal loading is not warranted.

A load analysis predicts that increases and decreases in the overall phosphorus loading into Grindstone Lake could significantly change the algae growth and Secchi depth. The most accessible source to mitigate would be the direct-drainage watershed. The load analysis of this source shows more subtle changes for algae growth and Secchi depth but does show the lake would respond. Since the water quality is already high in Grindstone Lake, future human activity that may adversely affect water quality may need to focus on. If developed areas around the lake increase (converting forested into residential) or the impact of these developed areas (more impervious surfaces such as more buildings, increased building sizes, more driveways/sidewalks, etc.) would increase runoff and nutrient loading, resulting in more algae and less water clarity.

The rationale for an updated nutrient analysis was based upon lake user concerns over observed changes in Grindstone Lake water quality. To address this concern, historical data was used to create a scatter plot of Secchi depth over the years[4]. The mean total phosphorus surface mean value for years 1997 through 2020 is shown in Figure 16. Figure 17 shows this scatter plot of the chlorophyll-a concentrations historically in Grindstone Lake during September (when the lake's productivity is high).



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[4] Most historical data provided by Dan Tyrolt, Lac Courte Oreilles Conservation Dept.

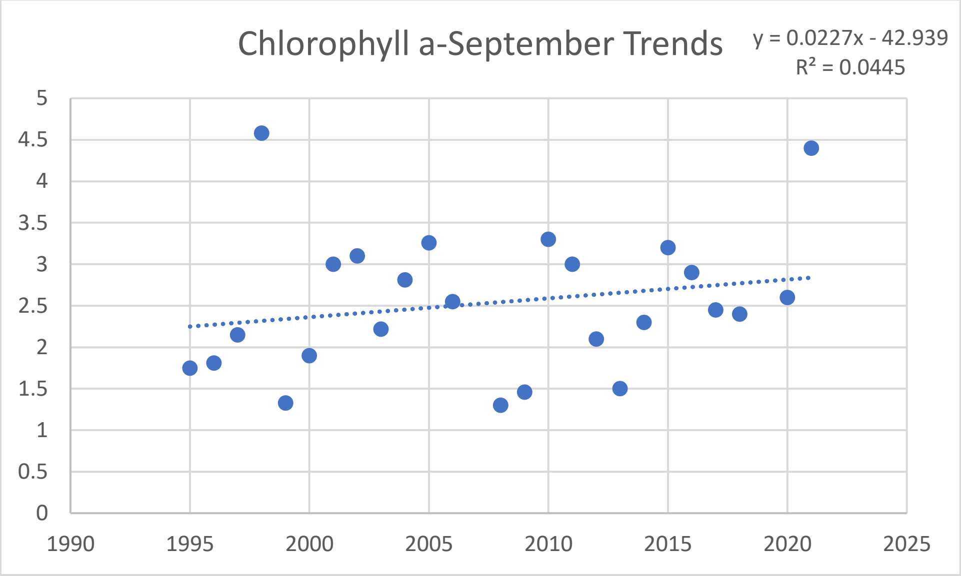

Figure 17: Graph of scatter plot for Sept chlorophyll-a concentration from 1995-2021.

This chart trendline (dotted line) shows a slight increase in September chlorophyll concentration. However, the correlation factor is deficient (0.04), indicating that the trendline is not predicting concentrations over time (accounts for 4% data). Therefore, to conclude that chlorophyll is increasing in concentration would not be a valid conclusion.

A scatter plot of the annual mean (during growing season May-Sept) of the Secchi depth TSI was also created. Figure 18 shows this graph.

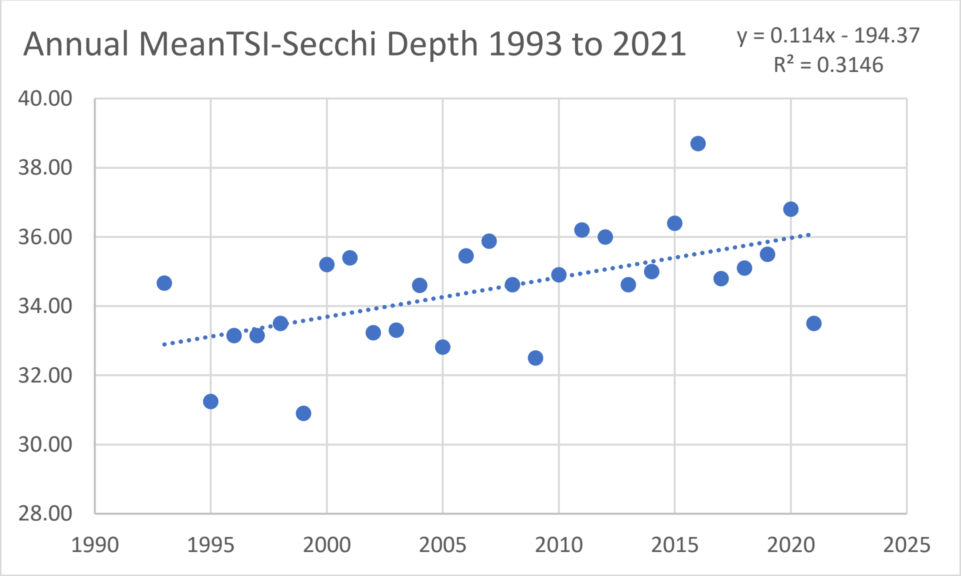

Figure 17: Graph of scatter plot for growing season mean Secchi depth TSI from1993-2021.

This graph trendline does suggest there has been an increase in Secchi depth TSI (meaning the water clarity has decreased). Again, the correlation factor is quite low (0.31), suggesting that concluding Secchi depth is decreasing (TSI increasing) is weak. The correlation factor is higher than that for September chlorophyll concentration but still lacking[5].

The trophic state for total phosphorus, chlorophyll-a, and Secchi historically don't match (TSI values are different). It is possible that the total phosphorus values are not increasing due to biological uptake, resulting in more algae that are being foraged by zooplankton. This would reduce the phosphorus increase measured and the chlorophyll, not increasing, but reducing the Secchi depth due to zooplankton. It is also possible that most of the algae are growing near the thermocline, where more phosphorus would be available. Depending on the thermocline depth, this could reduce the Secchi depth, but the increased chlorophyll is not being captured in near-surface water samples, therefore not increasing.

Regardless, the chlorophyll-a and Secchi depth values are excellent for Grindstone Lake. If these are changing, the change has been limited, so focusing on phosphorus mitigation by limiting increased loading would be warranted to preserve Grindstone Lake water quality.

Likely, the recent mitigation effort through the acquisition of the commercial cranberry bog has significantly reduced the phosphorus loading from that portion of the direct-drainage watershed. Keeping this area out of cranberry production and restoring it into a natural landscape (no development) would continue to help preserve the water quality in Grindstone Lake.

In looking to the future, the potential for increased phosphorus loading would likely be due to a few changes in and around Grindstone Lake. First, since the majority of the direct-drainage watershed is forested and forested land has the lowest runoff coefficient and likely the lowest phosphorus concentration, changing this land cover into other land covers such as residential would hurt Grindstone Lake water quality. Often development leads to significant increases in impervious surfaces and manicured lawn cover, which would significantly increase runoff and nutrients in that runoff. Also, if present developed areas transition into more dense development, the negative impact could increase. For example, small cottages get replaced by much larger homes with larger footprints.

Another potential future negative impact could be climate change. If the trend continues of more intense storms/rain events, the runoff could increase significantly. Furthermore, with more intense storm systems and greater heating of Grindstone Lake, mixing of the lake could increase leading to larger internal loading. This could result in a degradation in water quality with more nutrients and potential algae growth. Since residents and lake users cannot directly control these potential changes, the implementation of management practices that would reduce runoff could help mitigate the impact of more intense storms.

In 2008, a paleolimnological core analysis was completed. This allows for the evaluation of changes in sediment deposition and nutrient changes in a lake going back many years. This analysis indicated that sediment deposition in Grindstone Lake had increased significantly since the late 1970s. It also

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[5] It was reported in XXXXX that there was a statistically significant reduction in Secchi depth of 4 inches from XXXX to XXXX.

suggested that nutrients had increased over time, mostly since the mid-1990s. The analysis did note that the increases are slight. It was suggested in the analysis that near-shore development around Grindstone Lake was likely the source of the sediment and nutrients (Garrison, 2008). Increases in sedimentation could lead to increased phosphorus sediment release since Grindstone Lake does experience hypolimnetic anoxia in the summer months.

Overall, Grindstone Lake still has excellent water quality, but indicators show this may be changing slowly toward a more productive lake. It appears that the changes are likely due to anthropogenic sources such as development in and near the riparian zone.

Recommendations

Since the direct-drainage watershed is a significant contributor to the overall phosphorus load, and the watershed is a source that mitigation can be implemented, specific areas (especially near-lake) should be identified that would invite management practices. The model is broad for the entire watershed, so scrutinizing specific locations that are likely large contributors would be warranted.

Since some limited signs of increased productivity in Grindstone Lake are evident, methods to reduce loading from future development as a form of mitigation are important. This can include reducing the impact of cleared forested areas, increasing the number and or sizes of the buildings, and increasing impervious surfaces. This could include logging practices as well. Public and private land, as well as tribal land, should be included in the management. Increased development appears to have impacted Grindstone Lake somewhat, so future development could increase this trend leading to degraded water quality.

In order to evaluate management practices and changes that may be occurring in Grindstone Lake, a robust monitoring program should be continued. Minimal data collection should include near-surface total phosphorus, chlorophyll-a, Secchi depth (at least monthly), and dissolved oxygen (DO) and temperature profiles in the deep hole. Chlorophyll-a monitoring within the metalimnion (thermocline) may account for differences in surface total phosphorus, chlorophyll-a and Secchi depth TSI values. Monitoring of Grindstone Creek would be desirable on a more consistent basis as well but is not paramount.

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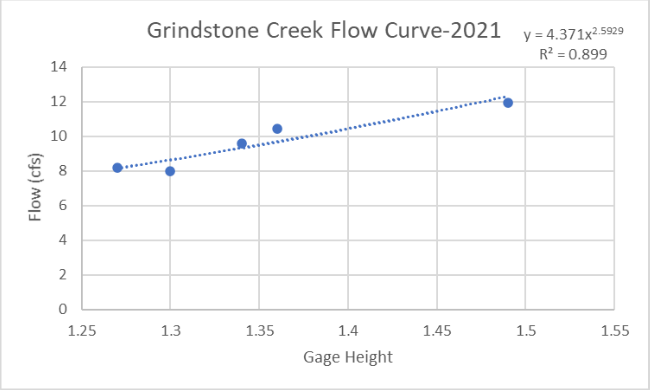
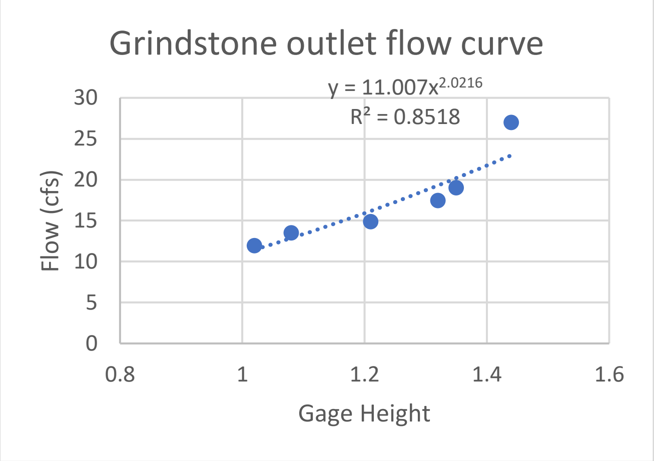
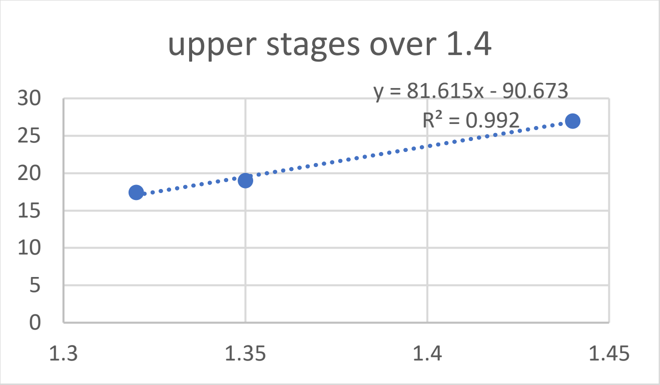
Appendix-Data Set

Flow curves (inlet and outlet)





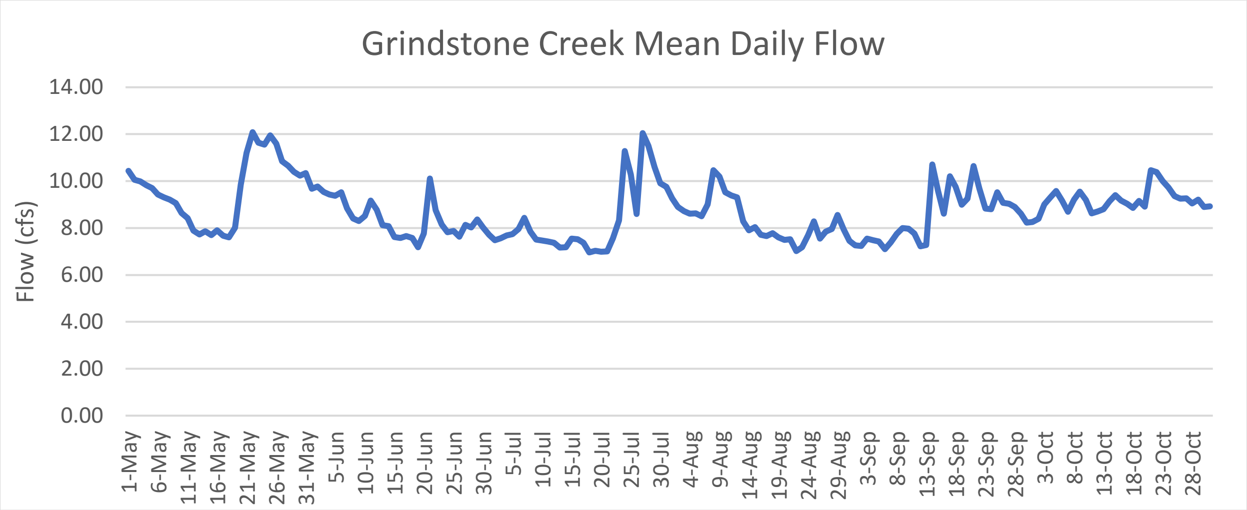


Precipitation record 2021 growing season:

Date	inches	Date	inches	Date	inches
5/1/21 0:00	0.00	7/1/21 0:00	0.00	9/1/21 0:00	0.00
5/2/21 0:00	0.58	7/2/21 0:00	0.00	9/2/21 0:00	0.00
5/3/21 0:00	0.00	7/3/21 0:00	0.00	9/3/21 0:00	0.03
5/4/21 0:00	0.00	7/4/21 0:00	0.00	9/4/21 0:00	0.00
5/5/21 0:00	0.00	7/5/21 0:00	0.00	9/5/21 0:00	0.00
5/6/21 0:00	0.05	7/6/21 0:00	0.19	9/6/21 0:00	0.00
5/7/21 0:00	0.00	7/7/21 0:00	0.00	9/7/21 0:00	0.24
5/8/21 0:00	0.00	7/8/21 0:00	0.00	9/8/21 0:00	0.16
5/9/21 0:00	0.00	7/9/21 0:00	0.00	9/9/21 0:00	0.00
5/10/21 0:00	0.00	7/10/21 0:00	0.00	9/10/21 0:00	0.00
5/11/21 0:00	0.00	7/11/21 0:00	0.00	9/11/21 0:00	0.00
5/12/21 0:00	0.00	7/12/21 0:00	0.00	9/12/21 0:00	0.00
5/13/21 0:00	0.00	7/13/21 0:00	0.00	9/13/21 0:00	0.83
5/14/21 0:00	0.00	7/14/21 0:00	0.14	9/14/21 0:00	0.20
5/15/21 0:00	0.02	7/15/21 0:00	0.05	9/15/21 0:00	0.13
5/16/21 0:00	0.00	7/16/21 0:00	0.00	9/16/21 0:00	0.17
5/17/21 0:00	0.00	7/17/21 0:00	0.00	9/17/21 0:00	0.72
5/18/21 0:00	0.05	7/18/21 0:00	0.00	9/18/21 0:00	0.00
5/19/21 0:00	0.07	7/19/21 0:00	0.00	9/19/21 0:00	0.00
5/20/21 0:00	1.19	7/20/21 0:00	0.00	9/20/21 0:00	1.17
5/21/21 0:00	2.19	7/21/21 0:00	0.00	9/21/21 0:00	0.02
5/22/21 0:00	0.00	7/22/21 0:00	0.02	9/22/21 0:00	0.00
5/23/21 0:00	0.00	7/23/21 0:00	0.06	9/23/21 0:00	0.00
5/24/21 0:00	0.02	7/24/21 0:00	0.84	9/24/21 0:00	0.22
5/25/21 0:00	0.23	7/25/21 0:00	0.89	9/25/21 0:00	0.00
5/26/21 0:00	0.00	7/26/21 0:00	0.68	9/26/21 0:00	0.00
5/27/21 0:00	0.00	7/27/21 0:00	2.08	9/27/21 0:00	0.00
5/28/21 0:00	0.00	7/28/21 0:00	0.09	9/28/21 0:00	0.00
5/29/21 0:00	0.00	7/29/21 0:00	0.00	9/29/21 0:00	0.00
5/30/21 0:00	0.00	7/30/21 0:00	0.00	9/30/21 0:00	0.00
5/31/21 0:00	0.21	7/31/21 0:00	0.01	10/1/21 0:00	0.00

Date	inches	Date	inches	Date	inches
6/1/21 0:00	0.00	8/1/21 0:00	0.00	10/2/21 0:00	0.11
6/2/21 0:00	0.00	8/2/21 0:00	0.00	10/3/21 0:00	0.03
6/3/21 0:00	0.02	8/3/21 0:00	0.00	10/4/21 0:00	0.00
6/4/21 0:00	0.00	8/4/21 0:00	0.00	10/5/21 0:00	0.00
6/5/21 0:00	0.00	8/5/21 0:00	0.03	10/6/21 0:00	0.00
6/6/21 0:00	0.00	8/6/21 0:00	0.00	10/7/21 0:00	0.01
6/7/21 0:00	0.00	8/7/21 0:00	0.26	10/8/21 0:00	0.14
6/8/21 0:00	0.00	8/8/21 0:00	0.37	10/9/21 0:00	0.03
6/9/21 0:00	0.00	8/9/21 0:00	0.00	10/10/21 0:00	0.00
6/10/21 0:00	0.13	8/10/21 0:00	0.05	10/11/21 0:00	0.00
6/11/21 0:00	0.12	8/11/21 0:00	0.21	10/12/21 0:00	0.09
6/12/21 0:00	0.00	8/12/21 0:00	0.01	10/13/21 0:00	0.03
6/13/21 0:00	0.00	8/13/21 0:00	0.00	10/14/21 0:00	0.00
6/14/21 0:00	0.00	8/14/21 0:00	0.00	10/15/21 0:00	0.00
6/15/21 0:00	0.00	8/15/21 0:00	0.00	10/16/21 0:00	0.00
6/16/21 0:00	0.00	8/16/21 0:00	0.00	10/17/21 0:00	0.00
6/17/21 0:00	0.00	8/17/21 0:00	0.00	10/18/21 0:00	0.00
6/18/21 0:00	0.01	8/18/21 0:00	0.00	10/19/21 0:00	0.00
6/19/21 0:00	0.00	8/19/21 0:00	0.00	10/20/21 0:00	0.49
6/20/21 0:00	0.07	8/20/21 0:00	0.00	10/21/21 0:00	0.00
6/21/21 0:00	0.04	8/21/21 0:00	0.01	10/22/21 0:00	0.62
6/22/21 0:00	0.01	8/22/21 0:00	0.00	10/23/21 0:00	0.03
6/23/21 0:00	0.00	8/23/21 0:00	0.00	10/24/21 0:00	0.01
6/24/21 0:00	0.01	8/24/21 0:00	0.26	10/25/21 0:00	0.00
6/25/21 0:00	0.00	8/25/21 0:00	0.00	10/26/21 0:00	0.00
6/26/21 0:00	0.00	8/26/21 0:00	0.03	10/27/21 0:00	0.00
6/27/21 0:00	0.01	8/27/21 0:00	0.03	10/28/21 0:00	0.16
6/28/21 0:00	0.00	8/28/21 0:00	0.22	10/29/21 0:00	0.03
6/29/21 0:00	0.00	8/29/21 0:00	0.13	10/30/21 0:00	0.00
6/30/21 0:00	0.00	8/30/21 0:00	0.00	10/31/21 0:00	0.02
		8/31/21 0:00	0.00	total	17.38 inches

<u>Inlet flow data:</u>



Date	Stage (ft)	Flow (cfs)
1-May	1.376917	10.44
2-May	1.360583	10.05
3-May	1.358	9.99
4-May	1.35175	9.82
5-May	1.347	9.70
6-May	1.337333	9.43
7-May	1.333208	9.31
8-May	1.32975	9.20
9-May	1.325083	9.06
10-May	1.311625	8.64
11-May	1.305125	8.42
12-May	1.28975	7.89
13-May	1.285375	7.73
14-May	1.288917	7.86
15-May	1.2845	7.70
16-May	1.290125	7.90
17-May	1.283833	7.67
18-May	1.282	7.60
19-May	1.293333	8.02
20-May	1.352833	9.85
21-May	1.631583	11.20
22-May	1.536917	12.09
23-May	1.445583	11.63
24-May	1.439625	11.56
25-May	1.47875	11.94
26-May	1.442667	11.59
27-May	1.396	10.85
28-May	1.38675	10.66

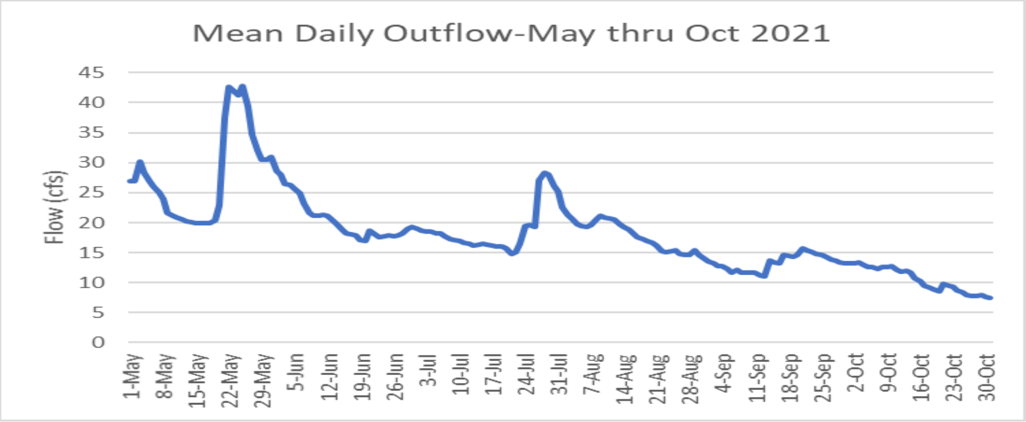
29-May	1.37475	10.39
30-May	1.368	10.23
31-May	1.372583	10.34
1-Jun	1.346208	9.68
2-Jun	1.349833	9.77
3-Jun	1.341417	9.54
4-Jun	1.337333	9.43
5-Jun	1.335667	9.38
6-Jun	1.34075	9.52
7-Jun	1.318042	8.84
8-Jun	1.304833	8.41
9-Jun	1.301292	8.29
10-Jun	1.307792	8.51
11-Jun	1.328458	9.17
12-Jun	1.315667	8.77
13-Jun	1.2965	8.13
14-Jun	1.295208	8.08
15-Jun	1.282292	7.61
16-Jun	1.281083	7.57
17-Jun	1.283333	7.65
18-Jun	1.281375	7.58
19-Jun	1.270708	7.17
20-Jun	1.286417	7.77
21-Jun	1.362625	10.10
22-Jun	1.31525	8.76
23-Jun	1.297042	8.15
24-Jun	1.287875	7.82
25-Jun	1.289333	7.87
26-Jun	1.282667	7.63
27-Jun	1.296875	8.14
28-Jun	1.29375	8.03
29-Jun	1.303375	8.36
30-Jun	1.2935	8.02
1-Jul	1.28475	7.71
2-Jul	1.278875	7.49
3-Jul	1.280875	7.56
4-Jul	1.284167	7.68
5-Jul	1.285542	7.73
6-Jul	1.29175	7.96
7-Jul	1.3055	8.44
8-Jul	1.288542	7.84
9-Jul	1.279292	7.50
10-Jul	1.27825	7.46

11-Jul	1.277208	7.42
12-Jul	1.275875	7.37
13-Jul	1.270375	7.16
14-Jul	1.270833	7.18
15-Jul	1.280667	7.55
16-Jul	1.279708	7.52
17-Jul	1.276	7.38
18-Jul	1.265292	6.96
19-Jul	1.267083	7.03
20-Jul	1.265958	6.99
21-Jul	1.266208	7.00
22-Jul	1.280875	7.56
23-Jul	1.302417	8.33
24-Jul	1.420708	11.28
25-Jul	1.369583	10.27
26-Jul	1.310292	8.59
27-Jul	1.498458	12.05
28-Jul	1.435125	11.50
29-Jul	1.384292	10.60
30-Jul	1.35475	9.90
31-Jul	1.34925	9.76
1-Aug	1.331917	9.27
2-Aug	1.31975	8.90
3-Aug	1.314208	8.72
4-Aug	1.31075	8.61
5-Aug	1.311042	8.62
6-Aug	1.307583	8.51
7-Aug	1.323292	9.01
8-Aug	1.377667	10.46
9-Aug	1.36625	10.19
10-Aug	1.340583	9.52
11-Aug	1.336167	9.39
12-Aug	1.333125	9.30
13-Aug	1.301	8.28
14-Aug	1.29	7.90
15-Aug	1.293917	8.04
16-Aug	1.284875	7.71
17-Aug	1.283583	7.66
18-Aug	1.286708	7.78
19-Aug	1.282125	7.61
20-Aug	1.278917	7.49
21-Aug	1.279708	7.52
22-Aug	1.266792	7.02

23-Aug	1.270917	7.18
24-Aug	1.284583	7.70
25-Aug	1.301125	8.29
26-Aug	1.2805	7.55
27-Aug	1.288542	7.84
28-Aug	1.291625	7.95
29-Aug	1.309292	8.56
30-Aug	1.291125	7.94
31-Aug	1.277875	7.45
1-Sep	1.273042	7.26
2-Sep	1.272208	7.23
3-Sep	1.280417	7.54
4-Sep	1.278542	7.47
5-Sep	1.277167	7.42
6-Sep	1.26875	7.10
7-Sep	1.276083	7.38
8-Sep	1.286208	7.76
9-Sep	1.292958	8.00
10-Sep	1.291958	7.97
11-Sep	1.286458	7.77
12-Sep	1.272042	7.23
13-Sep	1.273458	7.28
14-Sep	1.389	10.70
15-Sep	1.342667	9.58
16-Sep	1.310917	8.62
17-Sep	1.367	10.21
18-Sep	1.349333	9.76
19-Sep	1.322583	8.99
20-Sep	1.331208	9.25
21-Sep	1.385792	10.64
22-Sep	1.346625	9.69
23-Sep	1.317708	8.83
24-Sep	1.316542	8.80
25-Sep	1.34075	9.52
26-Sep	1.32525	9.07
27-Sep	1.324083	9.03
28-Sep	1.319625	8.89
29-Sep	1.310875	8.61
30-Sep	1.299333	8.23
1-Oct	1.300333	8.26
2-Oct	1.30425	8.39
3-Oct	1.323	9.00
4-Oct	1.333208	9.31

5-Oct	1.342583	9.58
6-Oct	1.328292	9.16
7-Oct	1.313333	8.69
8-Oct	1.329958	9.21
9-Oct	1.341917	9.56
10-Oct	1.3295	9.20
11-Oct	1.31125	8.63
12-Oct	1.313875	8.71
13-Oct	1.316792	8.80
14-Oct	1.327458	9.14
15-Oct	1.336667	9.41
16-Oct	1.3285	9.17
17-Oct	1.324167	9.04
18-Oct	1.318417	8.86
19-Oct	1.328333	9.16
20-Oct	1.320292	8.92
21-Oct	1.378167	10.47
22-Oct	1.374458	10.39
23-Oct	1.358333	10.00
24-Oct	1.348375	9.73
25-Oct	1.334875	9.36
26-Oct	1.331125	9.25
27-Oct	1.331958	9.27
28-Oct	1.324667	9.05
29-Oct	1.330083	9.21
30-Oct	1.319875	8.90
31-Oct	1.320542	8.92

Outflow data:



Date	Stage (ft)	Flow (cfs)

1-May	1.44	26.8526
2-May	1.44	26.8526
3-May	1.48	30.16481
4-May	1.46	28.36928
5-May	1.44	26.95632
6-May	1.43	25.95654
7-May	1.42	25.09618
8-May	1.40	23.91276
9-May	1.38	21.6372
10-May	1.37	21.21293
11-May	1.35	20.78992
12-May	1.34	20.46501
13-May	1.34	20.24319
14-May	1.33	20.0295
15-May	1.33	19.98639
16-May	1.33	19.95015
17-May	1.32	19.84642
18-May	1.32	19.9164
19-May	1.34	20.39378
20-May	1.39	22.80926
21-May	1.57	37.56117
22-May	1.63	42.69441
23-May	1.62	41.87316
24-May	1.62	41.31546
25-May	1.64	42.82704
26-May	1.59	39.32609
27-May	1.54	34.70124
28-May	1.50	32.07766
29-May	1.48	30.46576
30-May	1.48	30.48107
31-May	1.49	30.95545
1-Jun	1.46	28.69914
2-Jun	1.45	28.06152
3-Jun	1.44	26.51594
4-Jun	1.43	26.36631
5-Jun	1.43	25.65558
6-Jun	1.42	24.90574
7-Jun	1.40	23.20203
8-Jun	1.38	21.57409
9-Jun	1.36	21.08672
10-Jun	1.36	21.12921
11-Jun	1.37	21.35789
12-Jun	1.37	21.22356

13-Jun	1.34	20.4069
14-Jun	1.32	19.69084
15-Jun	1.29	18.78296
16-Jun	1.27	18.17749
17-Jun	1.26	18.08752
18-Jun	1.26	17.95318
19-Jun	1.23	17.1209
20-Jun	1.22	16.92908
21-Jun	1.28	18.68048
22-Jun	1.26	17.98942
23-Jun	1.25	17.5739
24-Jun	1.25	17.80134
25-Jun	1.26	17.95505
26-Jun	1.25	17.70574
27-Jun	1.26	17.84821
28-Jun	1.27	18.16687
29-Jun	1.29	18.92167
30-Jun	1.30	19.24846
1-Jul	1.29	18.91042
2-Jul	1.28	18.6255
3-Jul	1.28	18.56551
4-Jul	1.28	18.45679
5-Jul	1.27	18.27184
6-Jul	1.27	18.14938
7-Jul	1.25	17.672
8-Jul	1.23	17.20338
9-Jul	1.23	17.06217
10-Jul	1.23	16.97281
11-Jul	1.22	16.63915
12-Jul	1.21	16.46233
13-Jul	1.20	16.25238
14-Jul	1.21	16.41046
15-Jul	1.21	16.5598
16-Jul	1.21	16.38797
17-Jul	1.20	16.1899
18-Jul	1.20	16.03806
19-Jul	1.20	16.07868
20-Jul	1.18	15.6388
21-Jul	1.15	14.79652
22-Jul	1.16	15.02833
23-Jul	1.21	16.4717
24-Jul	1.31	19.48527
25-Jul	1.31	19.54775

26-Jul	1.30	19.23534
27-Jul	1.44	27.00223
28-Jul	1.46	28.27576
29-Jul	1.45	28.00541
30-Jul	1.43	26.20648
31-Jul	1.42	25.17439
1-Aug	1.39	22.52871
2-Aug	1.37	21.25605
3-Aug	1.35	20.63496
4-Aug	1.32	19.81893
5-Aug	1.31	19.43903
6-Aug	1.30	19.22409
7-Aug	1.31	19.559
8-Aug	1.34	20.52812
9-Aug	1.36	21.11358
10-Aug	1.36	20.90114
11-Aug	1.35	20.73056
12-Aug	1.35	20.57998
13-Aug	1.32	19.79581
14-Aug	1.30	19.30594
15-Aug	1.29	18.83482
16-Aug	1.27	18.20186
17-Aug	1.25	17.62889
18-Aug	1.24	17.27211
19-Aug	1.23	17.00843
20-Aug	1.22	16.6479
21-Aug	1.20	16.24426
22-Aug	1.17	15.2539
23-Aug	1.17	15.1633
24-Aug	1.17	15.27389
25-Aug	1.18	15.46009
26-Aug	1.15	14.77528
27-Aug	1.15	14.60657
28-Aug	1.15	14.5772
29-Aug	1.17	15.37949
30-Aug	1.15	14.66343
31-Aug	1.13	14.07171
1-Sep	1.11	13.58872
2-Sep	1.10	13.19507
3-Sep	1.09	12.78518
4-Sep	1.08	12.69271
5-Sep	1.07	12.3453
6-Sep	1.05	11.70297

7-Sep	1.06	12.10474
8-Sep	1.05	11.67485
9-Sep	1.05	11.66111
10-Sep	1.05	11.61549
11-Sep	1.05	11.65048
12-Sep	1.04	11.25496
13-Sep	1.03	11.00628
14-Sep	1.12	13.6562
15-Sep	1.11	13.43126
16-Sep	1.10	13.23881
17-Sep	1.15	14.57095
18-Sep	1.14	14.46786
19-Sep	1.14	14.32602
20-Sep	1.15	14.65843
21-Sep	1.19	15.75689
22-Sep	1.17	15.39261
23-Sep	1.16	15.0652
24-Sep	1.15	14.82401
25-Sep	1.15	14.68093
26-Sep	1.14	14.25979
27-Sep	1.12	13.90301
28-Sep	1.12	13.64058
29-Sep	1.11	13.37752
30-Sep	1.10	13.17695
1-Oct	1.10	13.26943
2-Oct	1.10	13.21194
3-Oct	1.10	13.31004
4-Oct	1.09	12.9114
5-Oct	1.08	12.60398
6-Oct	1.08	12.55462
7-Oct	1.07	12.31593
8-Oct	1.08	12.53837
9-Oct	1.08	12.59023
10-Oct	1.09	12.78768
11-Oct	1.07	12.15347
12-Oct	1.05	11.80857
13-Oct	1.06	11.99977
14-Oct	1.05	11.66298
15-Oct	1.02	10.78884
16-Oct	1.00	10.20774
17-Oct	0.98	9.536673
18-Oct	0.96	9.106787
19-Oct	0.96	8.931209

20-Oct	0.95	8.541938
21-Oct	0.99	9.830344
22-Oct	0.98	9.532924
23-Oct	0.97	9.287364
24-Oct	0.95	8.751882
25-Oct	0.94	8.365735
26-Oct	0.92	7.927727
27-Oct	0.92	7.839625
28-Oct	0.92	7.734029
29-Oct	0.92	7.902734
30-Oct	0.92	7.666547
31-Oct	0.91	7.461601

Water chemistry

Depth	TP-16-May (µg/L)	TP-14-Jun (µg/L)	TP-13-Jul (µg/L)	TP-16-Aug (µg/L)	TP-15-Sep (µg/L)
0	17	14.2	10.2	13	12.7
4	13.2	11	9.8	15.6	11.9
6	12	11.5	11.3	12.5	12
8	15.3	17.7	11.5	14.4	12.4
10	12	14.2	12.9	16.7	12.5
12	12.4	17.3	13.8	19	15.8
14	12	16.6	16.8	22.6	13.4
16	14.9	17.5	22.6	48	15.1
18	13.8	28.3	42.8	221	214
	16-May	14-Jun	13-Jul	16-Aug	15-Sep
Total Iron (near bottom)	100 µg/L	233 µg/L	1200 µg/L	5310 µg/L	
Inlet TP (Grindstone Creek @ Cnty E culvert	24.8 µg/L	41.1 µg/L	33.5 µg/L	27.5 µg/L	21.2 µg/L

	16-May	14-Jun	13-Jul	16-Aug	15-Sep
Chl-a (0-2m @ deep hole)	1.01	2.27	1.54	2.55	4.37

Temperature profiles

May	Depth	June	July	August	Sept
11.5	0	23.2	24.2	22.6	19.9
11.5	1	23.2	24.1	22.6	19.8
11.4	2	23.2	24.1	22.6	19.6
11.2	3	23.1	24	22.6	19.6
11	4	23.1	23.2	22.6	19.6
10.9	5	21.3	22.8	22.6	19.6
10.7	6	17.5	22	22.5	19.6
10.3	7	16.8	20.5	22.5	19.6
10	8	14.9	16.9	22.5	19.6
9.8	9	13.5	15.2	19.5	19.5
9.5	10	12.6	13.9	15.8	19
9.3	11	11.4	12.6	13.6	15.6
9.3	12	11.2	11.9	12.6	13.2
9.3	13	10.8	11.5	11.6	12.4
9.1	14	10.3	10.5	10.7	11.2
9	15	10.1	10	10.1	10.4
9	16	9.9	9.8	9.8	10
8.9	17	9.6	9.6	9.6	9.9
8.8	18	9.5	9.5	9.6	9.7
8.7	19			9.6	9.7

Dissolved oxygen profiles

May	Depth	June	July	August	Sept
14.54	0	11.39	11.03	10.19	10.92
14.3	1	10.9	10.68	10.07	10.42
14.16	2	10.6	10.32	9.93	10.19
14.18	3	10.6	10.61	9.53	10.07
13.8	4	10.5	11.03	10.14	10.02
13.8	5	12.4	10.96	10.03	9.96
13.8	6	14.14	10.83	9.92	9.84
13.8	7	14.4	11.36	9.98	9.8
13.8	8	13.55	11.71	9.85	9.76
13.8	9	12.84	11.33	4.81	9.59
13.8	10	12.65	8.75	3.63	7.8
13.4	11	10.99	6.04	1.94	0.32
13.4	12	9.84	4.44	0.26	0.28
13.3	13	8.54	2.6	0.22	0.27

12.5	14	7.9	0.09	0.22	0.27
11.8	15	7.1	0.6	0.19	0.26
11.2	16	4.27	0.07	0.18	0.25
10.9	17	4.1	0.07	0.17	0.24
0.22	18	0.18	0.07	0.15	0.24
0.17	19		0.06	0.13	0.19

Specific conductance profiles

May	Depth	June	July	August	Sept
125.8	0	115.1	129.1	129.9	127.7
125.8	1	128	129.1	127.3	129.6
125.8	2	128	128.9	127.2	129
125.7	3	128	128.8	127.1	129
125.9	4	127.9	128.4	127	129
125.9	5	128.1	128.3	127.2	128.9
125.8	6	126	128.6	127.1	128.8
125.8	7	125.9	128.5	127.1	128.7
125.7	8	126.3	127.5	127.1	128.7
125.7	9	126.6	127	129.5	128.8
125.6	10	126.6	127.2	128.7	129
125.7	11	126.9	127.6	127.8	129
125.7	12	127.4	127.9	127.3	129.9
125.7	13	128.1	128.9	132.8	130.3
126.1	14	128.2	129.9	133.2	138.7
126.2	15	128.6	132.3	151.6	159.7
126.3	16	129.9	139.5	158.8	165.7
126.5	17	130.4	146.5	163.4	168.4
140.2	18	130.7	151.1	207.2	206.6
141	19		193.6	208.8	214.5

Overall Water & Nutrient Balances-2021 model output										
Overall Water Balance										
				Area	**Flow**	**Variance**	**CV**	**Runoff**		
Trb	**Type**	**Seg**	**Name**	**km^2**	**hm^3/yr**	**(hm3/yr)^2**	**-**	**m/yr**		
1	2	1	Direct drained watershed	8.6	0.6	0.00E+00	0.00	0.06		
2	1	1	Grindstone Creek	9.3	4.1	0.00E+00	0.00	0.44		
3	1	1	Groundwater		4.4	0.00E+00	0.00			
4	4	1	Grindstone Outlfow		8.4	0.00E+00	0.00			
5	1	1	Septic systems		0.0	0.00E+00	0.00			
PRECIPITATION				12.9	5.7	0.00E+00	0.00	0.44		
TRIBUTARY INFLOW				9.3	8.5	0.00E+00	0.00	0.91		
NONPOINT INFLOW				8.6	0.6	0.00E+00	0.00	0.06		
***TOTAL INFLOW				30.7	14.7	0.00E+00	0.00	0.48		
GAUGED OUTFLOW					8.4	0.00E+00	0.00			
ADVECTIVE OUTFLOW				30.7	0.0	0.00E+00	0.00			
***TOTAL OUTFLOW				30.7	8.4	0.00E+00	0.00	0.27		
***EVAPORATION					8.4	0.00E+00	0.00			
***STORAGE INCREASE					-2.1	0.00E+00	0.00			
Overall Mass Balance Based Upon				**Observed**		**Outflow & Reservoir Concentrations**				
Component:				**TOTAL P**						
				Load		**Load Variance**			**Conc**	**Export**
Trb	**Type**	**Seg**	**Name**	**kg/yr**	**%Total**	**(kg/yr)^2**	**%Total**	**CV**	**mg/m^3**	**kg/km^2/yr**
1	2	1	Direct drained watershed	125.3	22.8%	0.00E+00		0.00	227.4	14.6
2	1	1	Grindstone Creek	128.7	23.4%	0.00E+00		0.00	31.7	13.9
3	1	1	Groundwater	52.8	9.6%	0.00E+00		0.00	12.0	
4	4	1	Grindstone Outlfow	105.1		1.66E+03		0.39	12.5	
5	1	1	Septic systems	25.8	4.7%	0.00E+00		0.00	25800.0	
PRECIPITATION				179.9	32.7%	8.09E+03	100.0%	0.50	31.8	14.0

INTERNAL LOAD	37.5	6.8%	0.00E+00		0.00		
TRIBUTARY INFLOW	207.3	37.7%	0.00E+00		0.00	24.5	22.3
NONPOINT INFLOW	125.3	22.8%	0.00E+00		0.00	227.4	14.6
***TOTAL INFLOW	550.0	100.0%	8.09E+03	100.0%	0.16	37.5	17.9
GAUGED OUTFLOW	105.1	19.1%	0.00E+00		0.00	12.5	
ADVECTIVE OUTFLOW	-0.3		0.00E+00		0.00	12.5	
***TOTAL OUTFLOW	104.9	19.1%	0.00E+00		0.00	12.5	3.4
***STORAGE INCREASE	-25.7		9.99E+01		0.39	12.5	
***RETENTION	470.9	85.6%	8.65E+03		0.20		
Overflow Rate (m/yr)	0.5		Nutrient Resid. Time (yrs)			2.6785	
Hydraulic Resid. Time (yrs)	9.8		Turnover Ratio			0.4	
Reservoir Conc (mg/m3)	13		Retention Coef.			0.856	

Segment:	**1**	**Grindstone Lake**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	12.5	0.39	6.8%	12.5		6.8%
CHL-A MG/M3	2.4	0.62	3.8%	2.3		3.6%
SECCHI M	6.3	0.41	99.0%	6.3		99.0%
HOD-V MG/M3-DAY	61.9	0.35	38.5%			
MOD-V MG/M3-DAY	48.9	0.41	32.2%			
ANTILOG PC-1	12.3	0.93	1.1%	12.1		1.1%
ANTILOG PC-2	10.3	0.21	81.3%	10.1		80.7%
ZMIX / SECCHI	1.1	0.40	0.6%	1.1		0.6%
CHL-A * SECCHI	15.1	0.33	71.0%	14.8		70.1%
CHL-A / TOTAL P	0.2	0.32	48.6%	0.2		47.2%
FREQ(CHL-a>10) %	0.4	2.83	3.8%	0.4		3.6%
FREQ(CHL-a>20) %	0.0	3.77	3.8%	0.0		3.6%
FREQ(CHL-a>30) %	0.0	4.33	3.8%	0.0		3.6%

FREQ(CHL-a>40) %	0.0	4.72	3.8%	0.0		3.6%
FREQ(CHL-a>50) %	0.0	5.02	3.8%	0.0		3.6%
FREQ(CHL-a>60) %	0.0	5.27	3.8%	0.0		3.6%
CARLSON TSI-P	40.6	0.14	6.8%	40.6		6.8%
CARLSON TSI-CHLA	39.2	0.16	3.8%	39.0		3.6%
CARLSON TSI-SEC	33.5	0.17	1.0%	33.5		1.0%

Average year model output:

Overall Water & Nutrient Balances											
Overall Water Balance						**Averaging Period =**	**1.00**	**years**			
				Area	**Flow**	**Variance**	**CV**	**Runoff**			
Trb	**Type**	**Seg**	**Name**	**km^2**	**hm^3/yr**	**(hm3/yr)^2**	**-**	**m/yr**			
1	2	1	Direct drained watershed		1.0	0.00E+00	0.00				
2	1	1	Grindstone Creek		8.2	0.00E+00	0.00				
3	1	1	Groundwater		8.8	0.00E+00	0.00				
4	1	1	Septic systems		0.0	0.00E+00	0.00				
PRECIPITATION				12.9	10.7	0.00E+00	0.00	0.83			
TRIBUTARY INFLOW					17.0	0.00E+00	0.00				
NONPOINT INFLOW					1.0	0.00E+00	0.00				
***TOTAL INFLOW				12.9	28.7	0.00E+00	0.00	2.23			
ADVECTIVE OUTFLOW				12.9	19.6	0.00E+00	0.00	1.52			
***TOTAL OUTFLOW				12.9	19.6	0.00E+00	0.00	1.52			
***EVAPORATION					9.1	0.00E+00	0.00				
Overall Mass Balance Based Upon				**Predicted**		**Outflow & Reservoir Concentrations**					
Component:				**TOTAL P**							
				Load		**Load Variance**			**Conc**	**Export**	
Trb	**Type**	**Seg**	**Name**	**kg/yr**	**%Total**	**(kg/yr)^2**	**%Total**	**CV**	**mg/m^3**	**kg/km^2/yr**	
1	2	1	Direct drained watershed	224.2	24.5%	0.00E+00		0.00	216.2		

2	1	1	Grindstone Creek	254.2	27.8%	0.00E+00		0.00	31.0		
3	1	1	Groundwater	105.6	11.6%	0.00E+00		0.00	12.0		
4	1	1	Septic systems	35.0	3.8%	0.00E+00		0.00	35000.0		
PRECIPITATION				257.0	28.1%	1.65E+04	100.0%	0.50	24.1	20.0	
INTERNAL LOAD				37.5	4.1%	0.00E+00		0.00			
TRIBUTARY INFLOW				394.8	43.2%	0.00E+00		0.00	23.2		
NONPOINT INFLOW				224.2	24.5%	0.00E+00		0.00	216.2		
***TOTAL INFLOW				913.5	100.0%	1.65E+04	100.0%	0.14	31.8	71.1	
ADVECTIVE OUTFLOW				267.6	29.3%	7.60E+03		0.33	13.7	20.8	
***TOTAL OUTFLOW				267.6	29.3%	7.60E+03		0.33	13.7	20.8	
***RETENTION				645.9	70.7%	1.76E+04		0.21			
	Overflow Rate (m/yr)			1.5		Nutrient Resid. Time (yrs)			1.7593		
	Hydraulic Resid. Time (yrs)			6.0050		Turnover Ratio			0.6		
	Reservoir Conc (mg/m3)			14		Retention Coef.			0.707		

Segment:	**1**	**Grindstone Lake**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	13.7	0.33	8.2%	13.7		8.2%
CHL-A MG/M3	2.2	0.54	3.0%	2.4		3.8%
SECCHI M	5.9	0.35	98.7%	5.8		98.7%
HOD-V MG/M3-DAY	59.5	0.31	36.5%			
MOD-V MG/M3-DAY	47.0	0.38	30.2%			
ANTILOG PC-1	12.2	0.79	1.1%	13.3		1.3%
ANTILOG PC-2	9.2	0.20	75.2%	9.6		77.9%
ZMIX / SECCHI	1.2	0.34	0.9%	1.2		0.9%
CHL-A * SECCHI	13.0	0.32	63.3%	13.9		67.0%
CHL-A / TOTAL P	0.2	0.30	38.2%	0.2		43.0%
FREQ(CHL-a>10) %	0.3	2.59	3.0%	0.5		3.8%