Water and Nutrient Budget Analysis

Diamond Lake, Bayfield County, WI

WBIC: 2897100

2022-2023

Project supported by *Diamond Lakers, Inc*. and

Data and analysis provided by:

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Analysis Summary

During the growing seasons (May through September) of 2022 and 2023, in-lake concentrations of total phosphorus, chlorophyll-a, and Secchi depth were monitored to build a water and nutrient budget model for Diamond Lake, Bayfield County, Wisconsin. The inflow of two potential tributaries (18-mile Creek and an inlet from a wetland on the east shore) was monitored along with total phosphorus concentrations. The outflow volume from Diamond Lake was monitored. The lake stage and all precipitation events were recorded weekly (using a USGS gauge installed in Diamond Lake). The observed data from 2022 and 2023 was used to build the model representing the average precipitation growing season, matching the historical averages for total phosphorus, chlorophyll-a, and Secchi depth.

The watershed of Diamond Lake was updated using the Wisconsin DNR GIS database provided by the Wisconsin DNR. The direct-drained land cover was updated using aerial photos from 2020 to account for human development near the lake.

The water-budget model estimates a total water load of 2.3 hm^3 per growing season, with the sources by percent being 30% by direct precipitation onto the lake, 24% from net groundwater inflow, 24% from 18-mile Creek, 13% from the East wetland, and 13% from the direct-drained sub-watershed.

The phosphorus model estimates a total load of 73.3 kg, with the sources by percent being 28.7% from the direct-drained sub-watershed, 23.0% from atmospheric deposition, 16.6% from the 18-mile Creek sub-watershed, 11.3% from the East wetland sub-watershed, 10.9% from septic systems, and 9.5% from net groundwater inflow.

A load analysis resulted in predicted concentrations for total phosphorus, chlorophyll-a concentrations, and Secchi depth responding to changes in phosphorus loading from the direct-drained sub-watershed and septic systems since human activity can affect these two source changes. By reducing the direct-drained sub-watershed by 20%, the predicted total phosphorus concentrations would be reduced from 12.3 µg/L to 11.8 µg/L, a predicted chlorophyll-a concentration from 2.7 µg/L to 2.6 µg/L, and a predicted Secchi depth from 4.0 meters to 4.1 meters. A 20% increase in the direct-drained sub-watershed phosphorus loading is expected to increase the total phosphorus concentration from 12.3 µg/L to 12.7 µg/L, a chlorophyll-a concentration increases from 2.7 µg/L to 2.8 µg/L, and a Secchi depth decreased from 4.0 meters to 3.8 meters. Reducing the septic system loading by 20% was predicted to reduce in-lake phosphorus concentration from 12.3 to 12.1. This 20% reduction is also predicted to lower in-lake chlorophyll-a concentration from 2.7 to 2.6 and increase Secchi depth from 4.0 meters to 4.1 meters. A 20% increase in septic system loading predicted increases from 12.3 to 12.5 for in-lake phosphorus, 2.7 to 2.8 for chlorophyll-a, and a decrease from 4.0 meters to 3.9 meters for Secchi Depth.

It was recommended that a more in-depth evaluation of septic systems present and the population using them is warranted. Furthermore, implementing best management practices (BMP) within the near-shore development could reduce phosphorus concentration or offset future increased loading due to development near Diamond Lake. Finally, a partnership with Crystal Lake property owners is recommended leading to monitoring of Crystal Lake if this relationship is not in place.

Introduction

Diamond Lake is a 322-acre lake located in southern Bayfield County, Wisconsin. It has a mean depth of 33 feet and a maximum depth of 83. It has two inlets, one of which is perennial, known as Eighteen Mile (18-mile) Creek. The other is the outflow from a large wetland on the lake's eastern shore. The lake has moderate development, and the most significant land cover is forested, with much of the riparian zone in a natural state. The trophic status is oligotrophic on the DNR lake list, with clear water and low nutrient concentrations. Figure 1 graphs the trophic state in Diamond Lake since 2000.[1]

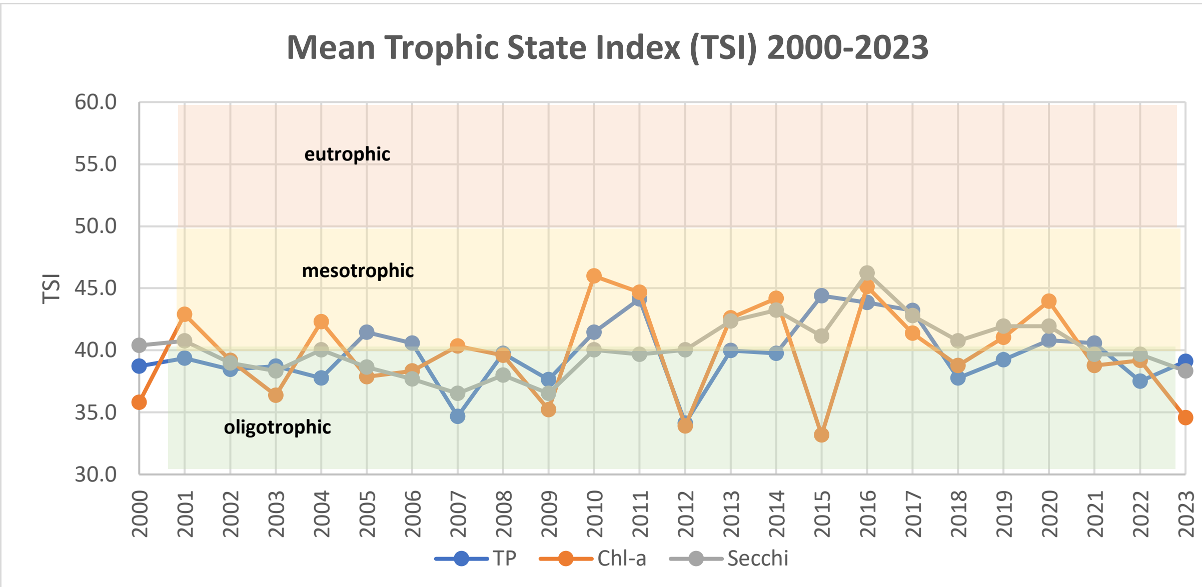


Figure 1: Trophic state index (TSI) graph with total phosphorus (blue triangles), chlorophyll-a (green squares), and Secchi depth (black circles). The mean TSI is determined by the WI DNR using late summer data for total phosphorus (June 1-September 15) and chlorophyll-a (July 15-Sept. 15). The Secchi depths are from June through September (assumed). These data dates are from the Wisconsin Consolidated Assessment and Listing Methodology (WISCALM).

The Diamond Lake Association (Diamond Lakers Inc.) is concerned about changes in water quality that have occurred or may occur in the future. A baseline nutrient and water budget analysis was proposed to address these concerns. A surface water grant was secured to conduct these analyses.

An analysis was conducted in 2022 and extended to 2023 due to drought conditions (precipitation 66.5% in 2022 and 81.8% in 2023 of growing season average). The study involved extensive data collection of monthly water samples at the deep hole in Diamond Lake (see Figure 2 for location) and the two inlets. Flow was measured in the outlet, the two inlets, and the Crystal Lake outflow in 2022 (it flowed for a very short time due to drought conditions). Since Crystal Lake flows into the wetland that 18-Mile Creek drains, any Crystal Lake outflow was measured in both years, including the Crystal Lake outflow (when it occurred). The lake stage was recorded weekly, and the precipitation amounts were collected by volunteers at the lake throughout the growing season. The lake stage was recorded weekly, and the precipitation amounts were collected by volunteers at the lake throughout the growing season.

[1] This data set is data from the Wisconsin DNR (2000-2023) collected and reported by Diamond Lake volunteers.

Dissolved oxygen and temperature profiles were conducted from May through September. Figure 2 shows that Diamond Lake has a large area of over 30 feet. Temperature profiles allowed for evaluating the degree and duration of stratification. Dissolved oxygen profiles allowed for evaluating anoxia below the thermocline and near sediment, which can lead to internal loading.

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

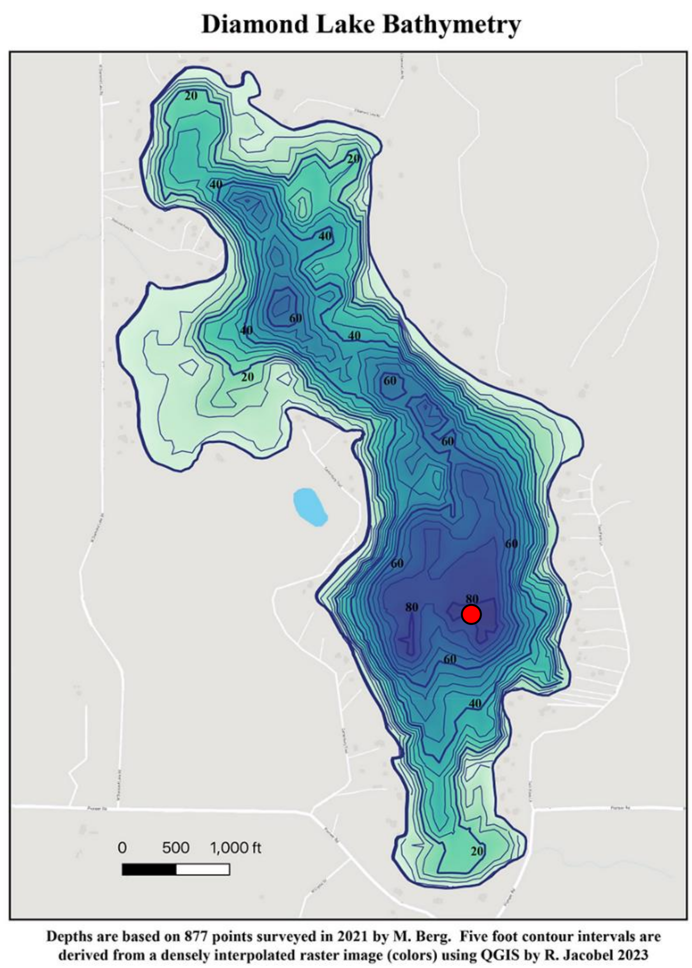


Figure 2: Bathymetry map of Diamond Lake. The red dot is the approximate location of the in-lake sample collections.

Methods

The procedures for determining the nutrient and water budget for Diamond Lake depended on numerous data collections and calculations. The methods are separated into the critical data components that calculate load amounts.

Inlet inflow and Diamond Lake outflow

There are two inlets into Diamond Lake. One has an intermittent flow that drains a large wetland on the eastern shore of Diamond Lake. This inlet is unnamed and is referred to as East Wetland inlet. The other inlet is the 18-mile Creek, a perennial stream that enters Diamond Lake in the most southern bay. Crystal Lake drains into the wetland connected to the inlet stream within the Diamond Lake watershed. Therefore, measurements of the 18-mile Creek contain water drained from Crystal Lake. During the two-year data monitoring, Crystal Lake outflow only occurred for a short time.

Flow measurements had to be completed to determine the contributions of water and phosphorus into Diamond Lake from the 18-mile Creek and East Wetland inlet and the outflow (loss) of water and phosphorus out of Diamond Lake. Pressure transducers were installed to measure the daily flow in the inlets and the outlet. These transducers measure the depth every 15-30 minutes of every day from May 1 until Sept. 30. On at least six occasions, the flow of each stream was measured by determining the cross-section area of water within the stream (culverts when possible) by measuring the depth 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 (ft^3/sec or cfs). These flow values are then graphed with the stage (depth) value and flow to create a flow curve. The trendline is implemented into the graph to get a function (model) allowing flow calculation during each stage logged in the transducer. The function used is the one that will give the highest correlation factor (R^2). Options range from linear, exponential, or polynomial. See the appendix for the flow curves established from the inlets and the outlet. The total flow is determined from the mean daily flows from the stage and the flow curve function.

The total phosphorus was analyzed in water samples from each inlet from May through September. The mean phosphorus concentration and daily flow were used to calculate the total phosphorus load into Diamond Lake via each inlet. The mean epilimnion phosphorus concentration was used to quantify the total phosphorus outflow from Diamond Lake during the monitoring period.

Water Budget

The water budget was determined by using the following expression:

$\Delta S = \sum \text{inflows} - \sum \text{outflows}$

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

Inflows include direct precipitation onto the lake, the total inlet flows, runoff from the watershed surrounding the lake, and groundwater.

Outflows include the outflow from Diamond Lake, evaporation from the lake surface, and groundwater outflow.

Direct precipitation is a measured value based on total precipitation onto the known lake surface area of the lake and the measured precipitation amounts (recorded by volunteers at Diamond Lake). The flow calculations from the inlets are also measured values. The runoff was estimated based on the outflow response to precipitation events. Also, runoff coefficients were referenced for various land covers.

The inflow from the two inlets was determined using a flow curve and measuring the stage at 15 to 30-minute intervals within the stream.

The outflow was calculated using measured flow values. The water loss due to evaporation was estimated using values from literature from a lake in northern Wisconsin (Lenters, 2005).

Since groundwater inflow and outflow could not be measured, the net groundwater inflow was estimated using the volume difference between the inflows and outflows. The higher groundwater inflows are assumed to offset groundwater outflows, leading to a positive net water inflow into Diamond Lake. The value is the net contribution of groundwater to Diamond Lake. Any groundwater inflow from the inlets is accounted for in the measured values.

The water budget was determined for the growing season only (May-September). The water inflow from snowmelt was somewhat accounted for through changes in the lake stage and the inlets in May. The monitoring did not occur for the entire year, so annual estimates were not determined. Most precipitation in a year occurs during the growing season, and the lake's productivity is of interest during the growing season months.

Phosphorus Budget

The total nitrogen to total phosphorus ratio was determined to be 48:1. If this ratio exceeds 15:1, the lake is considered phosphorus-limited (Shaw et al., 2004). The 48:1 determines that Diamond Lake is phosphorus-limited and is the nutrient of focus for this analysis.

The phosphorus budget was determined using a mass balance approach, where the phosphorus inputs equal the phosphorus outputs. Inputs include atmospheric deposition (wet and dry), Eighteen Mile Creek and East Wetland tributary, runoff from the surrounding watershed, and groundwater flux. Outputs include outflow via the outlet of Diamond Lake, settling of the phosphorus from the water column, and biological uptake (absorbed by organisms such as algae). Retention of phosphorus is determined using the settling rate, biological uptake, and outflow.

Another input that can contribute to phosphorus in the epilimnion where algae can grow is internal loading, which results from the sediment release of phosphorus. If a lake remains strongly stratified, this phosphorus cannot reach the upper layers of the lake and is, therefore, unavailable for production. If the lake mixes during the growing season due to deterioration of the stratification, the phosphorus can reach the upper layer and be available for production. Temperature and dissolved oxygen profiles were collected semi-monthly in 2022 and monthly in 2023 to determine the degree of stratification and if the near sediment became anoxic. This can help determine if internal loading may have occurred. No phosphorus data was collected near the bottom (hypolimnion).

The in-lake phosphorus concentration was determined semi-monthly in 2002 and monthly in 2023. The total phosphorus samples were collected in the upper 2-meter portion of the lake.

Atmospheric deposition

Phosphorus can be loaded into the lake from the atmosphere by wet deposition (rainwater containing phosphorus) and dry residue (dust, pollen, and other particles containing phosphorus). An extensive study of lake nutrients in a northwest Wisconsin lake led to data that can extrapolate atmospheric deposition (Roberts and Rose, 2009). It was determined that the rainwater averaged a phosphorus concentration of 17 µg/L in the summer and 12 µg/L in the winter, with an average of 16 µg/L (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 since conifer pollen can contribute a large amount of phosphorus into the lake (Banks et al). Diamond Lake has an extensive conifer composition. Agriculture has little impact on lakes such as Diamond Lake, as minimal land cover is agriculture-related. The dry deposition for confer-containing watersheds is highest in the spring/summer and minimal in winter. The dry deposition coefficients are in lbs./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 the lake area and number of days.

Inlet tributaries

The phosphorus loading into Diamond Lake from the two inlets was determined by multiplying the measured volume of water from each inlet by the mean phosphorus concentration. The groundwater load was determined by multiplying the estimated volume of net groundwater input by 12 µg/L, a concentration used by similar northern Wisconsin Lakes (10 µg/L to 15 µg/L).

Runoff from direct-drainage watershed

The most up-to-date land cover was used to estimate the runoff load. Aerial photos were used to update developed land cover, including impervious surfaces. 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 and runoff coefficients published for Wisconsin Lakes were utilized and adjusted to match the in-lake concentration of phosphorus. Forested land cover has the lowest export coefficient, while residential and agriculture have much higher coefficients (Diamond Lake is dominated by forested land cover). Since export coefficients are based on average conditions each year (precipitation and runoff), these coefficients were adjusted for actual precipitation amounts and lake outflow response to storm events. The following coefficients were utilized[2]:

Land Cover	Low P (lb./mi^2/yr.)	Med P	High P	Runoff coefficient
Forest	29	54	103	0.26
Wetland	22	56	85	0.08
Near-lake development	171	286	457	0.11

Table 1: Export coefficients estimate land cover runoff and nutrient loading.

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

It is essential to understand that 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 the surrounding land, the intensity of storm events, the type of soil, and soil moisture. The estimates are based on runoff coefficients adjusted for the lake's response during precipitation events and soil type. However, a runoff coefficient can differ depending on the rain even 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 the runoff is higher in intensity and the slope grade is greater, this estimate allows for a valid comparison to other phosphorus sources. The model created is broad, based on the entire watershed. Other models would need to be used to analyze specific watershed portions.

Septic systems

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

Total septic load = E_s * (number of capita years0 * (1-S_R),[3]

Where E_s is the phosphorus export coefficient (0.55 kg/capita/year used), the number of capita years is the number of people using the septic system annually (adjusted for growing season). S_R is the soil retention factor (0.85 was used in this study). To determine the capita years, the number of residential buildings was multiplied by 2.43 (since we do not know the exact number of each resident). The estimation uses the estimates suggested by another septic model[4] when the population is unknown.

This estimate is a rough calculation; more detailed data would be needed to estimate the septic load better. This would include the actual number of people using the systems, the age of the systems, and the type of systems. Also, the water table is relatively shallow around Diamond Lake, and the soil type may be coarser, which would reduce the S_R. The loading could be higher than estimated based on these factors or lower if fewer people use it or the types or ages lead to lower loading (e.g., holding tanks).

In-lake Phosphorus Concentration and Areal Load

The biological uptake was not explicitly determined but is likely reflected in the sedimentation rate of phosphorus in the model. The phosphorus sedimentation from the water column was based on the Canfield and Bachman lakes model (Canfield and Bachman, 1981). The 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 the most effective models 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:

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

Where,

[3] Equation from Wisconsin Lakes Modeling Suite (WILMS), (Panuska, 2003)
[4] STEPL model suite

L is the areal phosphorus loading rate in mg/m3,

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

t is the residence time of the water in the lake.

A model is built to predict the nutrient budget of a lake based on the in-lake data. This model can then be used to predict changes in the nutrient loading. The model uses growing season means (GSM) from May through September.

Internal Loading

The bottom sediment can release phosphorus when lakes become anoxic (dissolved oxygen below 1 mg/L). 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 the water are stable, leading to limited to no mixing of the water column. This traps the phosphorus in the bottom layers and is unavailable in the upper layer (epilimnion), where light is not limited, and algae production can occur. For purposes of this study, the internal load is zero even if the sediment releases phosphate but cannot reach the upper layer (entrainment) due to stratification.

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

An index known as the Osgood Index (Osgood, 1988) can predict the likelihood of a lake mixing and potentially leading to internal loading. This equation to predict lake mixing potential is calculated using the following equation:

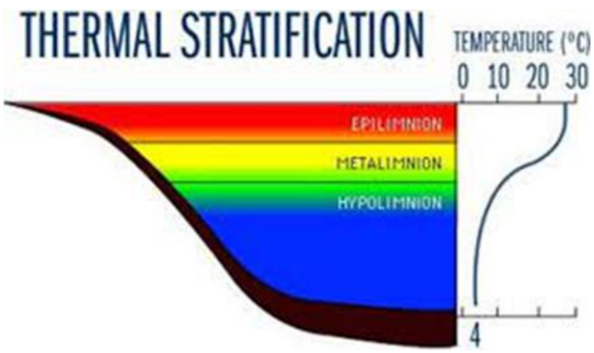
$$\textbf{Osgood Index} = \frac{\text{mean depth (meters)}}{\text{Lake surface area } (\text{km}^2)^{0.5}}$$

The Osgood Index for Diamond Lake is **8.82**, which is considered high (1-5 is considered low and indicates a high probability of mixing during summer). This value for Diamond Lake suggests that Diamond Lake is unlikely to mix and transport bottom water into the upper layer, which reduces the probability of internal loading during the growing season.

Intense internal loading is not a factor if the sediment remains oxic. Dissolved oxygen and temperature profiles are collected to determine if the near bottom becomes anoxic and if the lake remains stratified throughout the summer. Most stratified lakes in northern Wisconsin are dimictic, which means they will mix in the spring and fall. If the lake becomes anoxic but does not mix until fall, it will be too late in the growing season to produce algae. The spring mixing can flux some phosphorus into the upper layer but is typically less intense than in the fall.

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 depletion of oxygen in the water near the bottom. 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.

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 using the Canfield and Bachman model for natural lakes. The model was calibrated to match the predicted values with the in-lake values to make predictions for changes in loading.

Data used for model outputs:

The model used to determine the nutrient (phosphorus) budget uses growing season mean (GSM) data. The growing season is typically recognized as May through September. The GSM data for 2022 and 2023 was used to build the model to determine phosphorus contributions. The model was adjusted using typical precipitation amounts, and the predicted values were compared to historical averages. This model output was compared to available historical data from June through September 2000-2023.

For management/planning purposes, the Wisconsin DNR uses Wisconsin Consolidated Assessment and Listing Methodology (WisCALM) data for target concentrations/evaluation. The WisCALM dates differ somewhat from the typical GSM. The WisCALM data dates are as follows:

- Total Phosphorus = June 1 through September 15.
- Chlorophyll-a = July 15 through September
- There are no date criteria for Secchi depth, so we used June 1 through September 15.

The WisCALM data dates are used to determine if a lake is above any parameter thresholds established for various types of lakes or the list impaired waters. This is not over concern in Diamond Lake at this time.

Results

Watershed

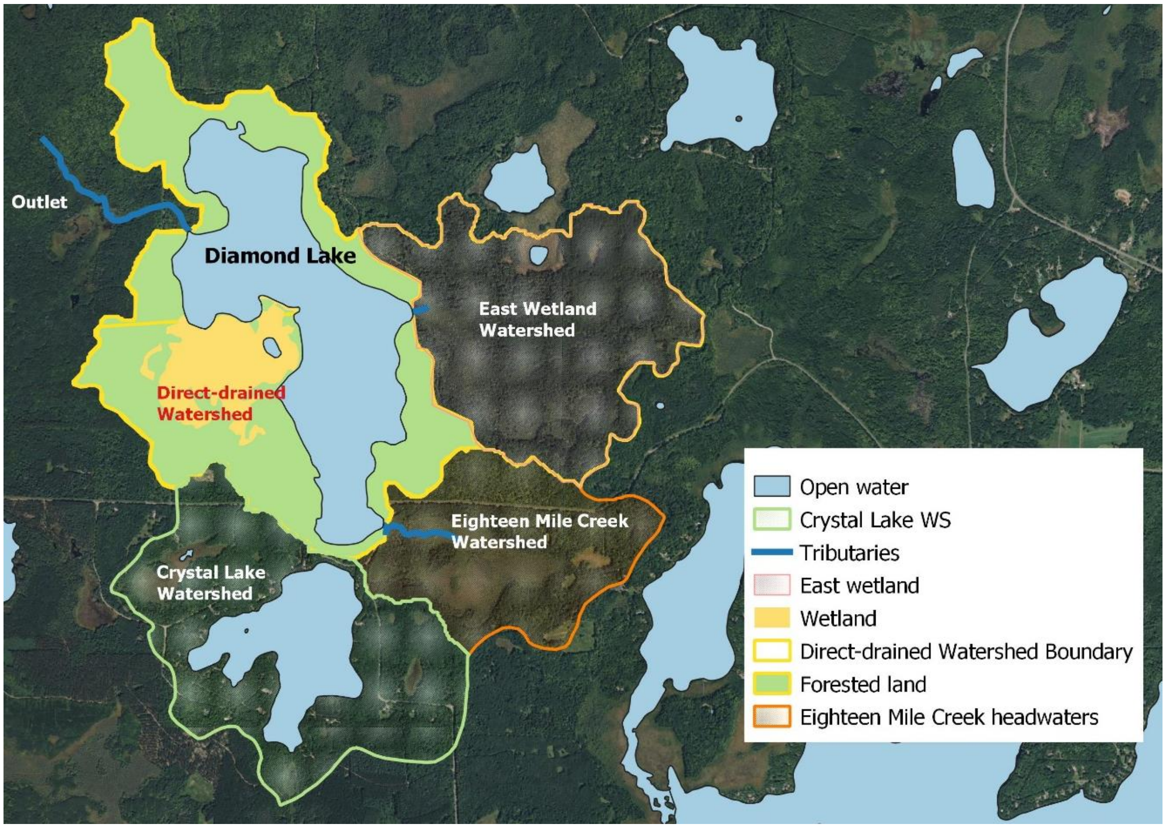


Figure 3: Diamond Lake watershed with land cover in the direct-drained watershed.

The watershed boundary was obtained from the Wisconsin DNR GIS database. The border utilized is for the direct-drained portion only (with no internally drained areas). The available land cover was not precise (from Wiscland 2.0), so 2020 digital aerial photos were used to designate land cover. The near-shore development was delineated based on location relative to the shore with large amounts of impervious surface (roofs, roads, driveways, sidewalks, etc.), which will likely increase runoff compared to forested. These areas have not had ground-truthing conducted.

Two inlets are being monitored and, therefore, separated from the watershed to eliminate the use of export coefficients to estimate water and nutrient loading. These were designated as the 18-Mile Creek Sub-watershed and East Wetland Sub-watershed.

Sub-watershed	Area (acres)	% Of the total area draining into Diamond Lake
Direct drained	859.6	31.0%
East Wetland	605.1	21.8%
Eighteen-mile Creek (18-Mile)	284	10.2%
Diamond Lake	322.4	11.6%
Crystal Lake (flows into Eighteen Mile Creek)	704	25.4%
Total	*2775.1*	*100%*

Table 2: Sub-watersheds of Diamond Lake with area.

The land cover for the 18-mile Creek sub-watershed is listed as 59% forested, 24% wetland, 11% barren, and 7% urban (from PRESTO). The East Wetland is nearly 100% wetland. The land cover breakdown for the Direct-drained sub-watershed is listed in Table 3.

Direct-drained sub-watershed land cover	Area (acres)	% Of total direct-drained land cover
Forested	754.15	87.74%
Open water (not including Diamond Lake)	1.71	0.2%
Wetland	81.14	9.43%
Near-shore developed	22.6	2.63%
Total	*859.6*	*100%*

Table 3: Land cover breakdown of the direct-drained watershed of Diamond Lake.

Water Budget

The water budget estimated for Diamond Lake is based on the 2022 data. The melted winter snowpack is only partially accounted for in this budget and is based on May through Sept precipitation data. The 18-mile creek and East wetland inlet tributaries amounts are from monitored data. The precipitation data is from field data collected at the lake from July through Sept, but the May and June 2022 data is from nearby Cable, WI. The groundwater inflow represented the net (inflow-outflow) and was estimated based on a balanced budget. Evaporation is calculated (estimated) using data from a 10-year study on a northern Wisconsin lake (Lenters et al., 2005). The average precipitation is based on estimated amounts for all sources, which can have errors since the monitored values in 2022 and 2023 were during drought conditions.

The following values summarize the water budget:

Source (values in hm^3)	GS-2022 (66.5% of avg precipitation)	GS-2023 (81.8% of avg precipitation)	GS-100% Avg Precip (estimated)
Precipitation (direct)	0.49	0.61	0.75
18-mile creek inlet (includes Crystal Lake)	0.46	0.5	0.53
East wetland inlet	0.14*	0.27	0.33
Runoff-direct drained watershed	0.06	0.1	0.12
Groundwater (net)	0.55	0.58	0.59
Total inflow	1.7	2.06	2.32

*This value could be a significant error due to a lack of flow data as it stopped flowing early in the season.

Table 4: Water budget by sources in 2022 and 2023 (monitored) and average precipitation growing season (estimated).

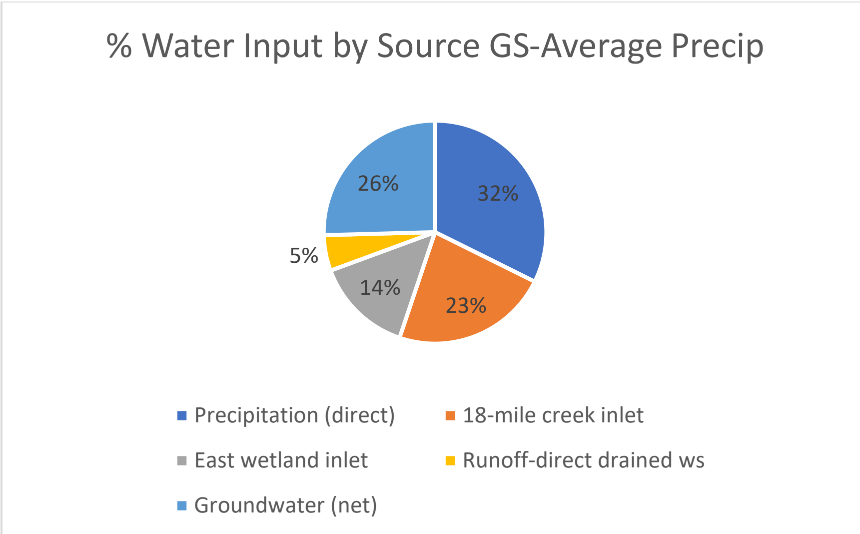


Figure 4: Graph showing the percent water budget by source during average precipitation growing season.

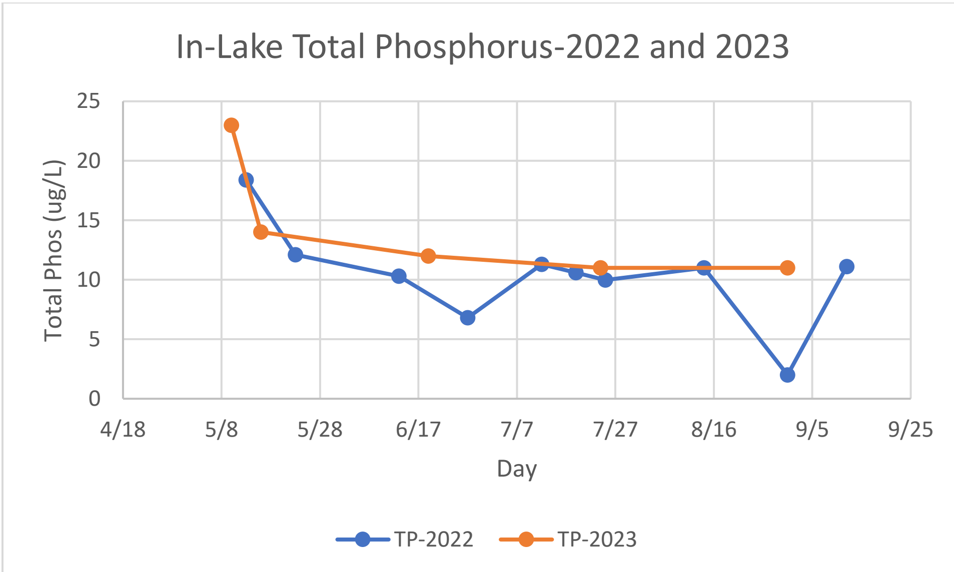
Crystal Lake outflow was measured in 2022 and flowed briefly during the early part of the growing season. During early to mid-May, the Crystal Lake outflow was equal to about 20% of the 18-mile Creek flow. Crystal Lake flow during average precipitation is likely longer during the growing season, which would increase the 18-mile Creek flow since the Crystal Lake outflow enters the wetland that feeds 18-mile Creek. The Crystal Lake flow ceased once the 18-mile Creek flow was about 2.0 cfs or less. Crystal Lake flow was not monitored in 2023 but was observed in June and July to have stopped flowing again.

Phosphorus Budget

The limiting nutrient in Diamond Lake is phosphorus. The TN: TP ratio in May was 48:1. If the TN: TP is >15:1, then the lake is considered phosphorus-limited.

The phosphorus budget was determined using the in-lake concentrations and water loading during the growing season (represented by "GS") (May- September). A mass balance approach was utilized; the input of phosphorus is equal to the output of phosphorus. Inputs include the various sources of phosphorus, while the outputs include the reservoir outflow, sedimentation of the phosphorus (binds to particles and sinks), and biological uptake.

The in-lake phosphorus concentration was low during much of the growing seasons in 2022 and 2023. The highest phosphorus concentration occurred in early May in both years, likely due to snow melt flowing into the lake. 2023 reflects a more intense snowmelt from a significant snowpack in 2023. However, in both years, the phosphorus concentration quickly declined, showing rapid sedimentation rates for phosphorus. Figure 5 shows the in-lake phosphorus concentrations in Diamond Lake from May through September in 2022 and 2023.



	TP-2022	TP-2023
5/10		23
5/13	18.4	
5/16		14
5/23	12.1	
6/13	10.3	
6/19		12
6/27	6.8	
7/12	11.3	
7/19	10.6	
7/24		11
7/25	9.99	
8/14	11	
8/31	2	11
9/12	11.1	

Figure 5: In-lake phosphorus data (near surface) for Diamond Lake 2022-2023 growing seasons.

An empirical model (Canfield-Bachman, which has shown to be an excellent model for northern Wisconsin lakes) for natural lakes was used to determine the most probable total load based on the in-lake concentrations observed in the lake. The model will predict a total phosphorus concentration based on the estimated load. To model the nutrient loading data, input is based on monitored or estimated inputs. In the case of 18-mile Creek and the East wetland, water flow and phosphorus concentrations were monitored. These inputs are based on actual data and should have a smaller error. However, atmospheric loading, watershed runoff loading, septic system loading, and groundwater loading were estimated using data from other studies that allow for predictions.

The phosphorus concentration in Crystal Lake is likely low but is unknown. Also, the water from Crystal Lake flows into the 18-mile Creek wetland, so its flow is probably slowed before entering Diamond Lake. More data on Crystal Lake's phosphorus concentration may be beneficial. Still, it is predicted that this concentration is typically less or nearly equal to the observed phosphorus concentration in 18-mile Creek, meaning Crystal Lake is not likely a significant source of phosphorus in Diamond Lake.

The following data (Table 5) summarizes the model loading predictions and shows how those predictions compare to the observed data. The phosphorus budget percent by source is shown in Figure 6.

Phosphorus Budget (May-Sept)	2022-kg/GS	2023-kg/GS	Avg GS kg/GS	Avg GS % of total loads
18-mile creek (monitored) (includes any flow from Crystal Lake)	7.4	10.9	12.2	16.6%
East wetland (monitored)	4.3	6.5	8.3	11.3%
Direct drained-watershed (estimated)	10.2	16.0	21.0	28.7%
groundwater net (estimated)	6.6	7	7	9.5%
Septic systems (estimated)	8.0	8.0	8.0	10.9%
Atmospheric deposition (estimated)	13.7	16.4	16.9	23.0%
Total Load	50.1	64.8	73.4	100%

Table 5: Phosphorus budget for Diamond Lake growing season 2022, 2023 and an average precipitation growing season.

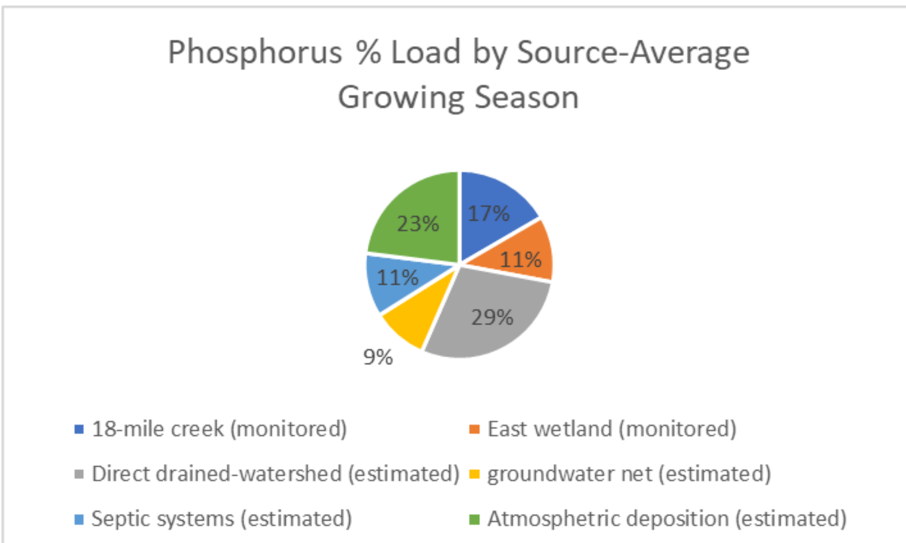


Figure 6: Phosphorus budget % by source in an average precipitation growing season.

The model predicts (see Table 6) an in-lake total phosphorus concentration of 10.7 µg/L (most likely within a reported range of 7.4-12.2). The observed concentration in 2022 was 10.4 µg/L, so the model fits. The drought conditions and reduced water load may cause the difference. Regardless, the Canfield-Bachman equation is a good model for Diamond Lake.

Data was continued into 2023 due to the severe drought conditions of 2022. Unfortunately, 2023 was also a drought year. There was higher precipitation during the growing season, mainly during September, and substantial spring snowmelt runoff. The 2023 model predicted a GSM of 11.6 µg/L. The observed value was 12.0 µg/L, so the model fits the in-lake data but somewhat underestimates. There was less in-lake data collected in 2023.

Since both growing seasons of data collection were drought conditions, the model was used to estimate the phosphorus budget during an average precipitation growing season. The uncalibrated model predicts an in-lake concentration of 12.0 µg/L. The long-term growing season phosphorus concentration is 12.3 µg/L. This shows that the Canfield and Bachman Lake model fits for an average growing season in Diamond Lake. The model requires calibration to fit the mean observed concentration to conduct a load analysis, which is discussed in the load analysis section of this report.

Parameter	2022 predicted/2022 observed	2023 predicted/2023 observed	Average predicted/historical mean (uncalibrated)	Predicted range to fit model
Total Phos (µg/L)	10.7/10.4	11.6/12.0	12.0/12.3	9.0-16.4

Table 6: Predicted and observed total phosphorus concentrations from the model and model fit range.

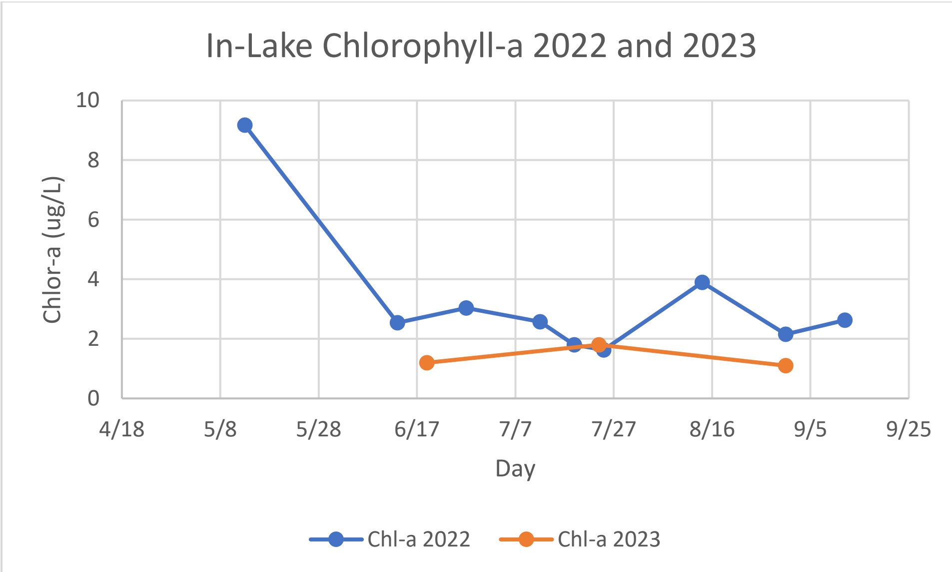
The most significant contributor to Diamond Lake's phosphorus (see Figure 6) is the direct-drained watershed at 29%. This is followed by atmospheric deposition (wet and dry) at 23% and 18-mile creek at 17%. Within the direct-drained watershed, it is estimated (using export coefficients) that the near-shore developed portion of this watershed accounts for approximately ***4.2 to 6.8 kg*** of phosphorus during an average growing season. This is about 20-32% of the total direct-drained watershed estimated loads of 21 kg.

Chlorophyll-a and Secchi Depth Predictions

Two other models that allow for the prediction of chlorophyll-a concentration and Secchi depth were implemented. Chlorophyll-a represents the amount of algae growth in the lake. Chlorophyll-a is one of the photosynthetic pigments synthesized by algae suspended in the water column. The higher the chlorophyll-a concentration, the more algae growth.

The chlorophyll-a model (Bachman-Jones) uses the total phosphorus concentrations to predict the resulting chlorophyll-a concentration. The total phosphorus trophic state index was used for Secchi depth predictions. The chart below shows that the chlorophyll-a model prediction is very close to the observed in-lake concentration in 2022 and the average year. In 2023, the chlorophyll-a concentration was much lower than the model predicted, even though the total phosphorus was higher than predicted. However, this value does fall within the standard error of the model.

Secchi depth represents the water clarity. Typically, the higher the chlorophyll-a concentration (more algae growth), the lower the Secchi depth. The Secchi depth prediction is less precise than the observed data from 2022 and 2023 but an exact match for an average year. These models did need calibrating for the prediction with phosphorus load analysis (later section).



Day	Chl-a-2022	Chl-a 2023
5/13	9.17	
6/13	2.54	
6/19		1.2
6/27	3.03	
7/12	2.57	
7/19	1.8	
7/24		1.8
7/25	1.63	
8/14	3.9	
8/31	2.15	1.1
9/12	2.63	

Figure 7: Graph showing in-lake chlorophyll-a concentrations during the 2022 and 2023 growing seasons.

As the data shows, the chlorophyll-a concentration was highest in May 2022. This corresponds with the highest phosphorus concentration. This may be due to spring snowmelt runoff that increased the nutrients in Diamond Lake. The 2023 chlorophyll-a concentration was lower than in 2022, which is somewhat unexpected since the phosphorus concentration mean was higher in 2023 than in 2022. This difference could be due to a higher water residence time in 2022, leading to more biological uptake of phosphorus and, thus, more algae production. In both years, the mean chlorophyll-a concentration after June is low, so it is of no concern.

Model estimates:

Parameter	**2022 predicted/2022 observed**	**2023 predicted/2023 observed**	**Average predicted/historical mean** (uncalibrated)	**Predicted range to fit model**
Chlorophyll-a (µg/L)[5]	2.6/2.5	2.9/1.4	3.0/2.7	1.7-4.3
Secchi Depth (meters)	4.5/4.1	4.1/5.9	4.0/4.0	2.9-5.4

Table 7: Model predicted (no calibration) chlorophyll-a and Secchi depth values and in-lake, observed values and model fit ranges.

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

Trophic State Index

The trophic state index (TSI) is a value that is calculated using total phosphorus, chlorophyll-a, and Secchi depth (Carlson, 1977). The lower the index value, the less productive the lake. Lower phosphorus will limit algae growth (lowering chlorophyll-a concentration), leading to higher water clarity (Secchi depth). This study utilized values from the growing season for water quality trophic state evaluation. The Wisconsin DNR uses total phosphorus concentration from June to September and chlorophyll-a concentration from July to September to evaluate impaired waters. Since Diamond Lake has excellent water quality, using the WisCALM dates is unnecessary. See Table 8 for the results.

Parameter (May-Sept) 2022	**Mean concentration/value**	**TSI**	**Trophic state**
Total phosphorus (µg/L)	10.1	37.5	Oligotrophic
Chlorophyll-a (µg/L)	2.5	39.4	Oligotrophic
Secchi depth (meters)	4.1	39.7	Oligotrophic

Parameter (May-Sept) 2023 (less data)	**Mean concentration/value**	**TSI**	**Trophic state**
Total phosphorus (µg/L)	12.0	40.0	Oligotrophic/mesotrophic cutoff
Chlorophyll-a (µg/L)	1.4	33.9	Oligotrophic
Secchi depth (meters)	5.9	34.4	Oligotrophic

Parameter (May-Sept) 2000-2023 Average	**Mean concentration/value**	**TSI**	**Trophic state**
Total phosphorus (µg/L)	12.3	40.3	Mesotrophic (at cutoff)
Chlorophyll-a (µg/L)	2.7	40.3	Mesotrophic (at cutoff)
Secchi depth (meters)	4.0	40.0	Mesotrophic (at cutoff)

Table 8: Mean values for total phosphorus, chlorophyll-a, and Secchi depth. Note that a TSI of 30-39.$^{+}$ is oligotrophic, and 40-49.$^{+}$ is mesotrophic.

As the table above shows, in 2022 and 2023, the trophic state for all three parameters is oligotrophic. This may be an aberration from a typical year since 2022 and 2023 were droughts, resulting in limited runoff, which reduced the phosphorus load. For the 2000-2023 historical average, all three parameters give a TSI of 40, which is barely mesotrophic, just over the oligotrophic threshold.

Internal Loading

In lakes with oxygen levels falling below 1 mg/L (anoxic) near the sediment, phosphorus may be released. If the lake remains stratified, that phosphorus will be trapped in the bottom and will only make it to the surface during turnover in the fall, which is often too late to grow algae. If stratification degrades during the summer, allowing for some mixing, phosphorus will be available for algae growth. This is referred to as internal loading.

Diamond Lake did stratify strongly during the growing season, and there was no evidence of mixing. Also, the lake was anoxic near the sediment for only a short period. Also, there were no near-surface phosphorus spikes that precipitation events could not account for. Therefore, there appears to be no internal loading in Diamond Lake in 2022 or 2023. Likely, internal loading is not a factor in the nutrient loading into Diamond Lake in average years.

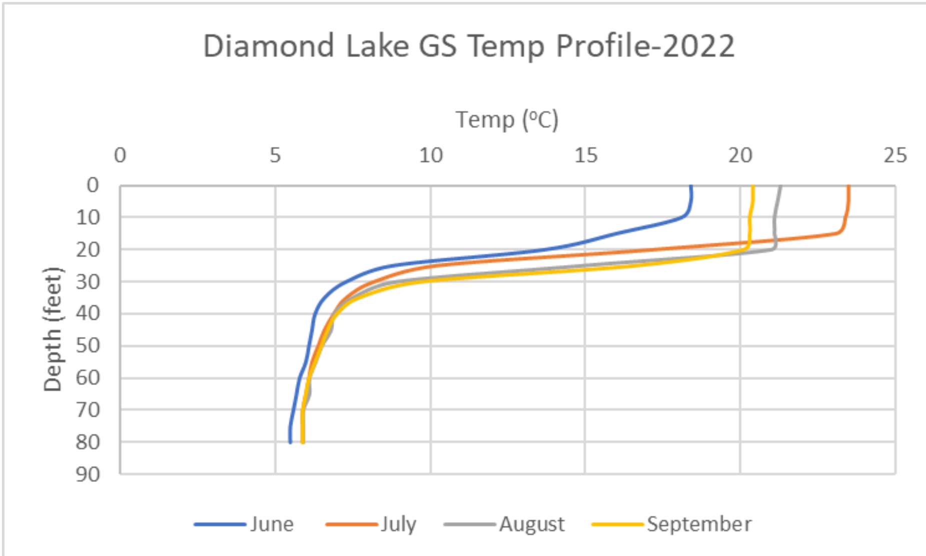


Figure 8: Temperature profile graph of Diamond Lake deep hole during the 2022 growing season.

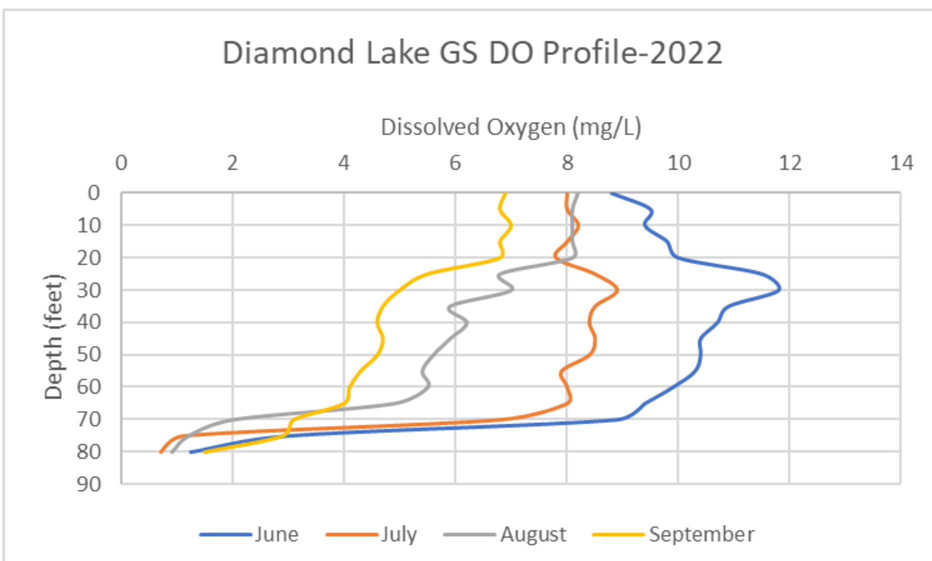


Figure 9: Dissolved oxygen profile graph of Diamond Lake deep hole during the 2022 growing season.

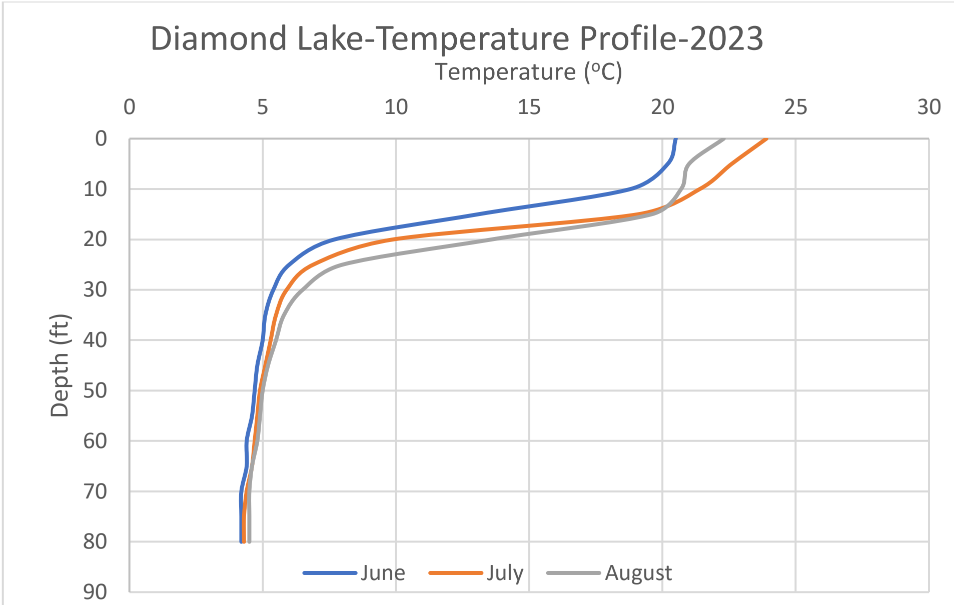


Figure 10: Temperature profile graph Diamond Lake deep hole during the 2023 growing season.

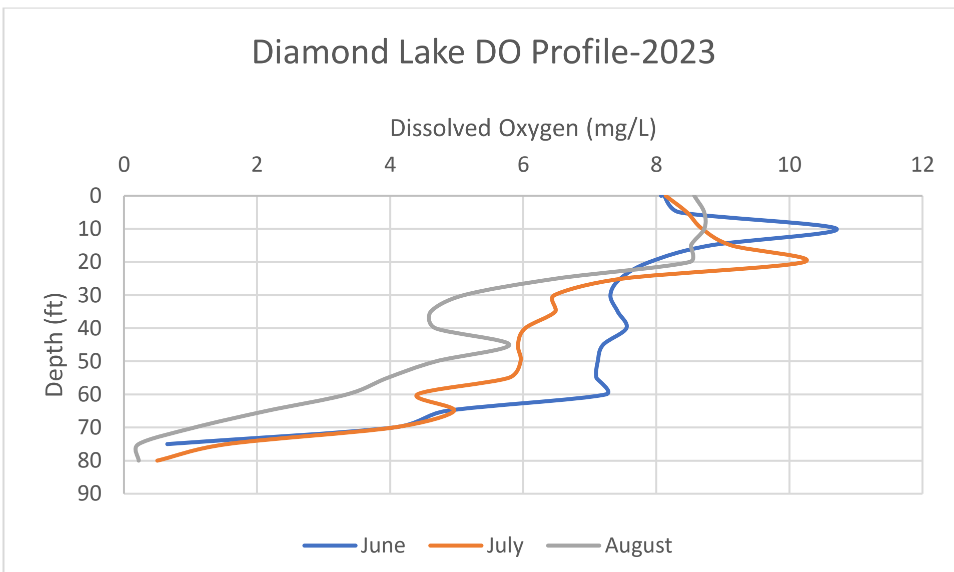


Figure 11: Dissolved oxygen profile graph Diamond Lake deep hole during the 2023 growing season.

Discussion of Results

Water and nutrient budget estimates

The data analysis for Diamond Lake 2022 and 2023 shows high water quality, with total phosphorus, chlorophyll-a, and Secchi depth data indicating an oligotrophic lake. This suggests the limited runoff during drought likely resulted in limited phosphorus loading into Diamond Lake. The 10-year average of total phosphorus during the growing season is 12.3 µg/L (historic data from 2000-2023), so 2022 was well below this concentration and 2023 slightly below this average.

The water budget shows that direct precipitation onto the lake was the most significant contributor of water, followed by groundwater (net) inflow and the 18-mile Creek. 18-mile Creek is a cold-water tributary with low phosphorus concentration, likely due to groundwater being the creek's primary water source. The water budget was determined during two drought years in succession. This could lead to errors in these estimates.

The phosphorus budget analysis showed that the direct-drained watershed was the highest phosphorus contributor, followed by atmospheric deposition and the 18-mile Creek. The Direct-drained watershed had the lowest contribution of water into Diamond Lake, but due to the likely runoff concentration, the total load was higher than the 18-mile Creek total load.

In both 2022 and 2023, the highest phosphorus concentration occurred in May. This indicates that the runoff from the watershed impacts the lake's phosphorus concentration. In 2023, the spring snow melt was intense due to the significant snowpack and a fast warm-up. The phosphorus concentration was the highest of any sample period in both years. However, the phosphorus concentration quickly decreased two weeks later, showing rapid phosphorus sedimentation.

Since 18-Mile Creek and the East Wetland Inlet were monitored for flow and phosphorus concentration, their load calculations are more accurate than if estimated using other methods. The other sources, such as the direct-drained watershed, atmospheric load, and septic load, are estimates based on other research and using assumptions; the error is potentially higher. However, the model fits the historic lake concentrations well, so this model can be used to make valid management decisions.

Nutrient Load Increase/Reduction Analysis

The lake nutrient model was calibrated to make the average year match the historical averages (the model was very close and needed little calibration). A load analysis was performed, which adjusted the model loading estimates by 20% intervals (increases and reductions). Since the only sources that can be mitigated are near-shore development and septic systems, the load analysis separates changes in each load.

The graphs show the predicted results for changing the loading from the direct-drained watershed and septic system for total phosphorus. The charts summarize predicted results for total phosphorus, chlorophyll-a, and Secchi Depth.

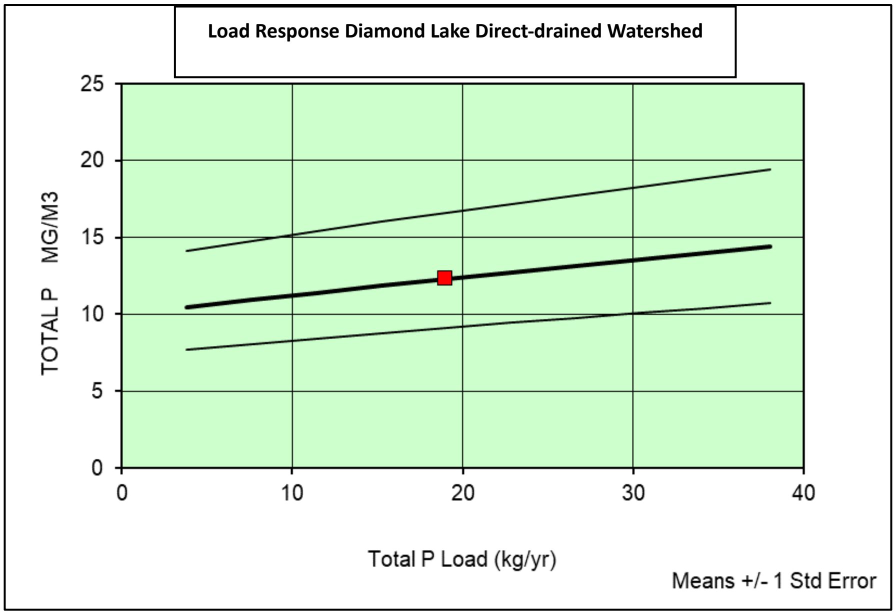


Figure 12: Graph showing the changes in total phosphorus concentration with changes in the direct-drained sub-watershed loading.

Fraction of Direct-drained load	Direct-drained TP load	Predicted TP Concentration	Predicted Chl-a Concentration	Predicted Secchi Depth
0.40	8	10.8	2.3	4.5
0.60	12	11.3	2.4	4.3
0.80	16	11.8	2.6	4.1
1.00	20	12.3	2.7	4.0
1.20	24	12.7	2.8	3.8
1.40	26.6	13.1	3.0	3.7
1.60	10.4	13.5	3.1	3.6

Table 9: Predicted phosphorus and chlorophyll-a concentrations and Secchi depth with changes in the direct-drained sub-watershed phosphorus loading in an average precipitation growing season.

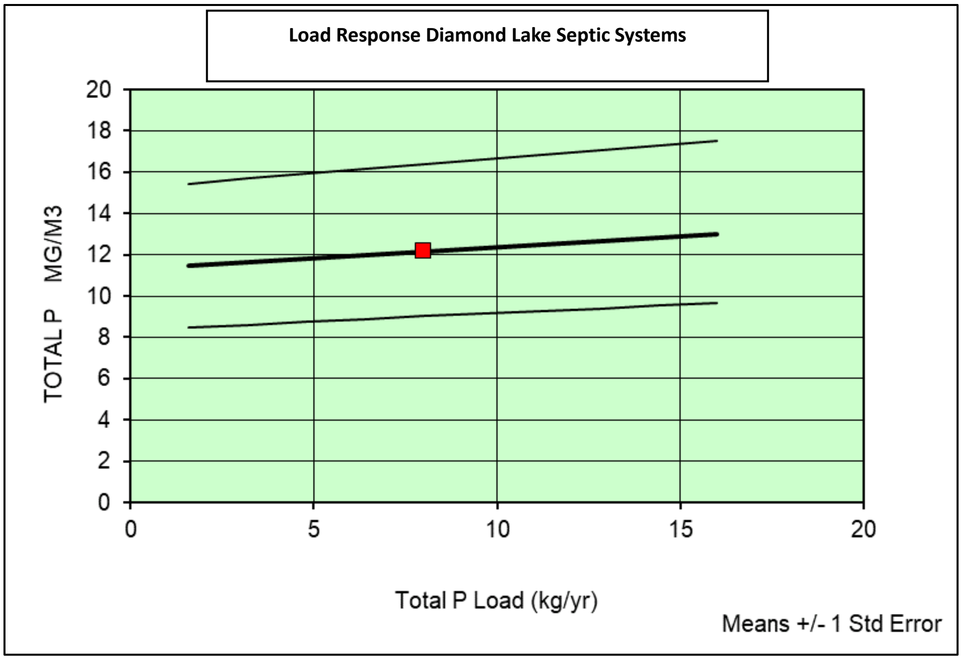


Figure 13: Graph showing the changes in total phosphorus concentration with changes in the direct-drained sub-watershed loading.

Fraction of Septic load (0.2 intervals)	Septic Total Phos Load	Predicted TP Concentration	Predicted Chl-a Concentration	Predicted Secchi Depth
0.40	3.2	11.7	2.5	4.2
0.60	4.8	11.0	2.6	4.1
0.80	6.4	12.1	2.6	4.1
1.00	8.0	12.3	2.7	4.0
1.20	9.6	12.5	2.8	3.9
1.40	11.2	12.7	2.8	3.9
1.60	12.8	12.8	2.9	3.8

Table 10: Predicted phosphorus and chlorophyll-a concentrations and Secchi depth with changes in the direct-drained sub-watershed phosphorus loading in an average precipitation growing season.

The load analysis data shows that reducing or increasing the load from the direct-drained watershed (Table 9) in 20% intervals impacts the predicted in-lake phosphorus, chlorophyll-a concentrations, and Secchi Depth most. Decreasing the direct-drained watershed loading by 20% indicates an in-lake phosphorus concentration reduction from 12.3 µg/L to 11.8 µg/L. The chlorophyll-a concentration Is also predicted to decrease from 2.7 µg/L to 2.6 µg/L, and the Secchi depth increases from 4.0 meters to 4.1 meters. An increase in 20% loading indicates similar increases in those values. Therefore, since Diamond Lake's water quality is excellent, increased loading would lead to degradation in water quality.

Changing the septic loading (Table 10) by 20% intervals predicts more minor changes but is predicted to change in-lake values. However, the load analysis does indicate that changes in septic loading can change in-lake concentrations of phosphorus and chlorophyll-a. Therefore, it may warrant evaluating present septic systems and ensuring the best functioning systems are utilized in future cabins or homes.

Historic Trends

The Wisconsin DNR Lakes website analyzes historical trends from all data collected in Diamond Lake. The trends for total phosphorus, chlorophyll-a, and Secchi Depth are graphs. A scatter plot graph includes trend lines that model the trends. The trends are also analyzed for statistical significance. Figures 14-16 show scatter-plot charts with trend lines.

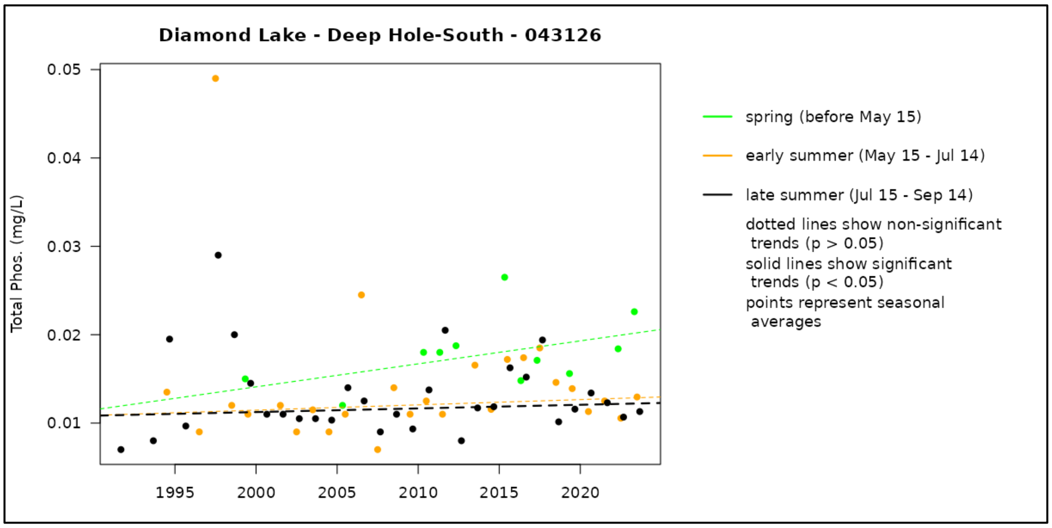


Figure 14: Historical total phosphorus trends in Diamond Lake. Dotted lines indicate that the trend model (line) is not statistically significant, while solids lines are statistically significant.

The total phosphorus trends show an increase in spring total phosphorus concentrations. Still, the trend line is insignificant, indicating that the data does not allow the conclusion that the increase is valid. This may be due to a lack of consistent spring data. The early and late summer show no real change or trend, and the lines are also not statistically significant.

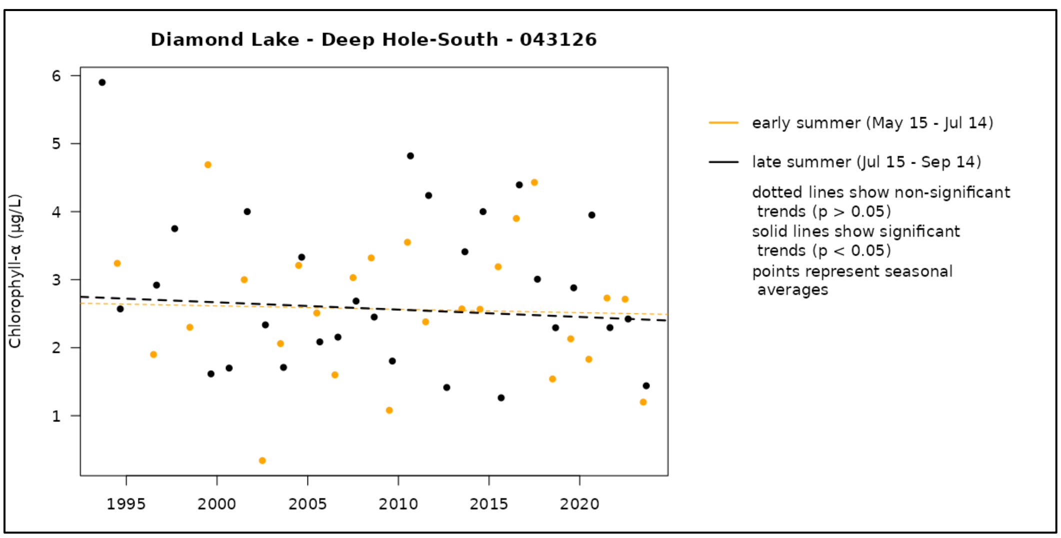


Figure 15: Historical chlorophyll-a trends in Diamond Lake. Dotted lines indicate that the trend model (line) is not statistically significant, while solids lines are statistically significant.

The chlorophyll-a concentration trends show a decrease in early and late summer concentrations. This data contradicts the total phosphorus trend, but the chlorophyll-a is not statistically significant like the phosphorus trend.

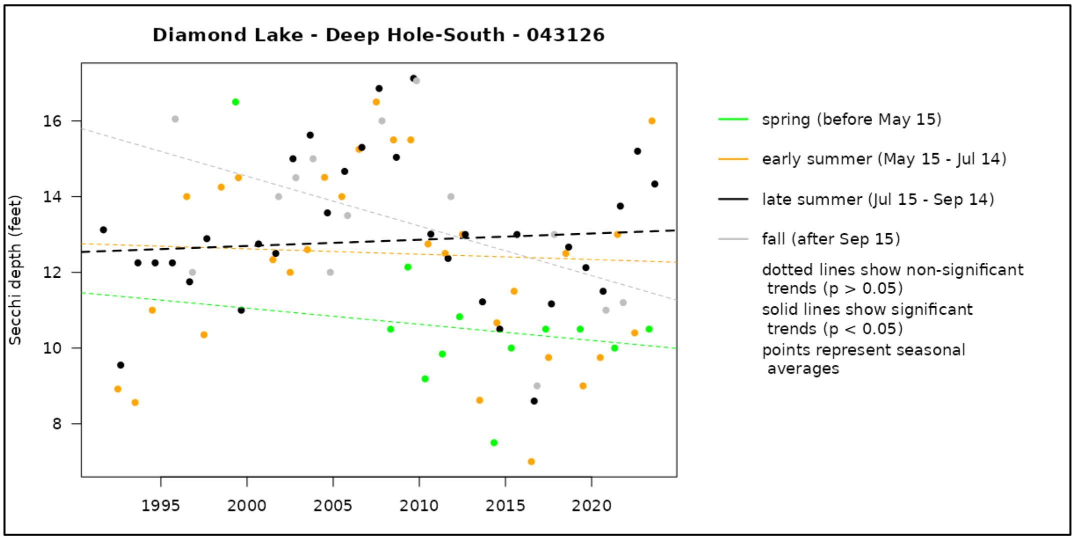


Figure 16: Historical Secchi depth trends in Diamond Lake. Dotted lines indicate that the trend model (line) is not statistically significant, while solids lines are statistically significant.

The historical Secchi depth data and trends are quite variable. The spring and fall data show that Secchi depth has decreased (less clarity). Late summer Secchi depth is trending slightly higher, and the early summer stays the same. As with the other parameters, none of the trend lines are statistically significant and are, therefore, not a valid model for predicting any trends occurring.

Recommendations

The water quality in Diamond Lake was found to be excellent in 2022 and 2023 during this analysis. The historical water quality is also excellent, although slightly more productive than in 2022-23. This slight difference is likely due to the 2022-23 growing seasons being in drought conditions, leading to limited runoff. The nutrient and water budget do indicate some sources that may have mitigation efforts that could be successful. Since the water quality is good, no significant concerns or mitigation needs exist. However, future changes around Diamond Lake could increase runoff and nutrient loading. For this reason, management practices for phosphorus mitigation should be explored to protect Diamond Lake in the future.

Two areas (supported by the load analysis) could be mitigated for phosphorus. One is in the septic systems around Diamond Lake. The estimate for septic systems is based upon some broad assumptions, such as the actual population using septic systems, the age of the systems, and the type of systems (standard, mound, or holding tanks). If there are older or failing systems, the loading could be higher. If the systems are primarily new or holding tanks and the population using septic systems during the growing season is far different than assumed, the loading could be less. A more in-depth analysis of the septic systems around Diamond Lake may be warranted. This could involve reviewing septic permits and Bayfield County inspections and surveying residents. The load analysis shows a limited response to septic load reductions or increases, but it can be mitigated if systems are not functioning well.

The other load source that is a higher priority due to the load analysis results is the direct-drained watershed, namely the development near the lake. This watershed's predominant land cover is forest, the lowest land cover contributor to phosphorus loading. However, a small percentage of the land cover within the direct-drained watershed is near-shore development. Lack of natural vegetation and impervious surfaces will increase runoff, leading to higher nutrient loads. Best management practices such as infiltration devices and shoreline restorations could reduce runoff and phosphorus loading from this land cover type. Even if implemented practices have limited impact, they could offset future development impact. Any land cover changed to developed in the future could have load increases, leading to degraded water quality. Therefore, future development should include best management practices to reduce impact. Many resources are available to determine practices that would help reduce loading around Diamond Lake.

Due to the drought conditions during data collection, the actual impact of Crystal Lake on the water budget and nutrient budget was difficult to quantify for an average growing season. The nutrient loading from Crystal Lake is likely small. However, it is not known for sure. Crystal Lake has minimal development and a small watershed, but it is much shallower than Diamond Lake, making it more susceptible to added nutrients. Partnering with Crystal Lake property owners and establishing a monitoring plan to verify the nutrients leaving Crystal Lake may be beneficial. This would also be in the best interest of the Crystal Lake property owners. If changes in human activity occur around Crystal Lake, it could adversely affect the water quality of Crystal Lake and, potentially, Diamond Lake.

There is concern over the effect of climate change on lakes. This concern is over changes in the intensity of storms. The predicted trend is for more intense rain events to occur. This can lead to more runoff and, therefore, more nutrients in the lake. Sedimentation from increased erosion could increase as well. More sediment accumulation can lead to increased nutrients and lake habitat changes. Increased runoff, coupled with warmer spring and fall seasons, could affect the stratification of the lakes, resulting in increased internal loading. This could lead to more algae production in the upper layer of the lake. Management practices could help reduce changes that could occur from climate change. If precipitation comes in more intense events, runoff could be mitigated through infiltration enhancement and natural shorelines restored where development has occurred.

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Wisconsin Dept of Natural Resources. Pollutant Load Estimation Tool (PRESTO): http://dnr.wi.gov/topic/surfacewater/restorationviewer/

Appendix-Data Sets

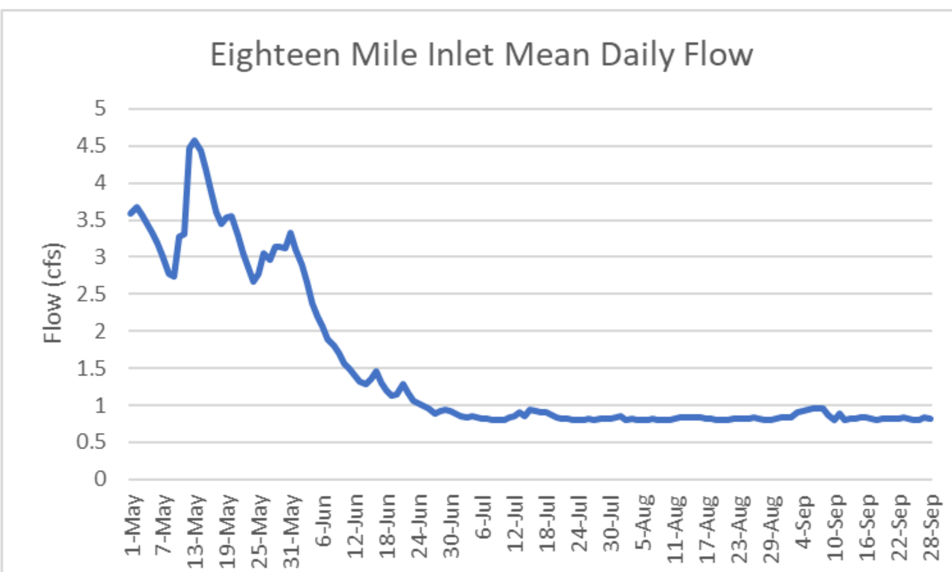
2022 Data:

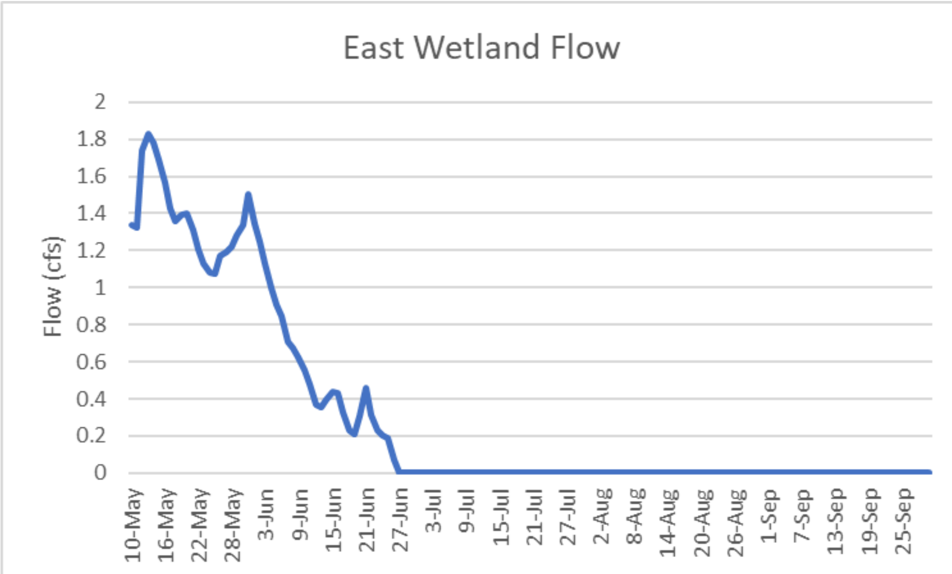
In-lake (deep hole integrated sample for TP and Chl-a)

Date	TP	Chl-a	TN	Secchi
5/13/2022	18.4	9.17	485	
5/23/2022	12.1			3.7
6/13/2022	10.3	2.54		2.7
6/27/2022	6.8	3.03		3.4
7/12/2022	11.3	2.57		3.4
7/19/2022	10.6	1.8		4.6
7/25/2022	9.99	1.63		4.3
8/14/2022	11	3.9		4.6
8/31/2022	2	2.15		4.6
9/12/2022	11.1	2.63		4.9

18-mile	TP
5/10/2022	12.6
6/13/2022	10.1
7/12/2022	19.8
8/12/2022	20.2
9/12/2022	17.5

E wetland	TP	
5/10/2022	22.5	
6/13/2022	28.2	
7/12/2022	46.5	
8/12/2022	59.3	not flowin
9/12/2022	32.4	not flowin




East Wetland Flow
Flow (cfs)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10-May
16-May
22-May
28-May
3-Jun
9-Jun
15-Jun
21-Jun
27-Jun
3-Jul
9-Jul
15-Jul
21-Jul
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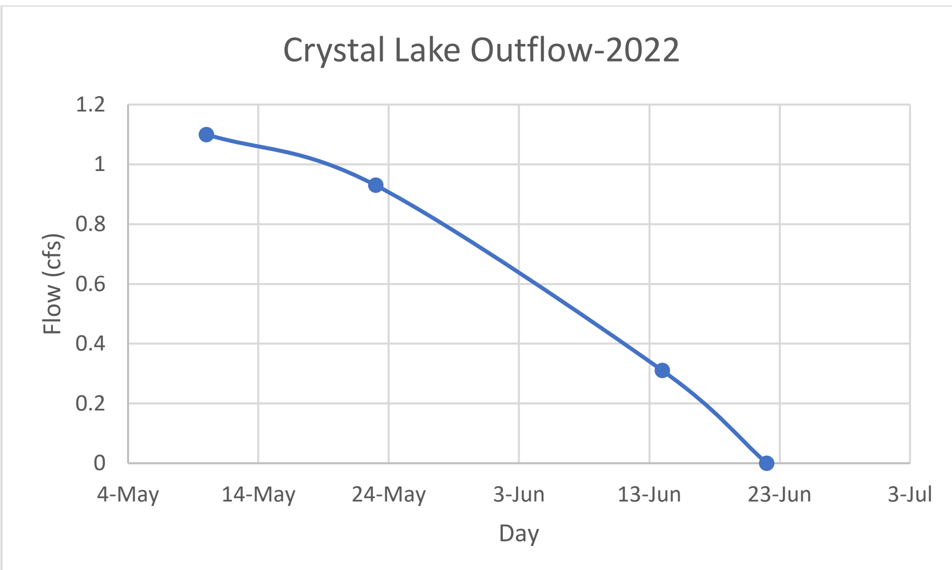
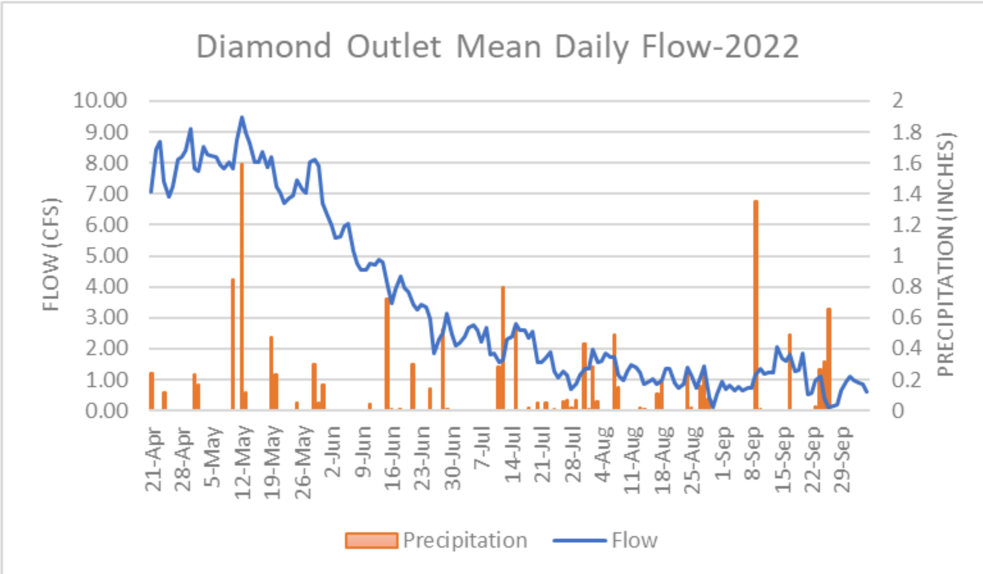
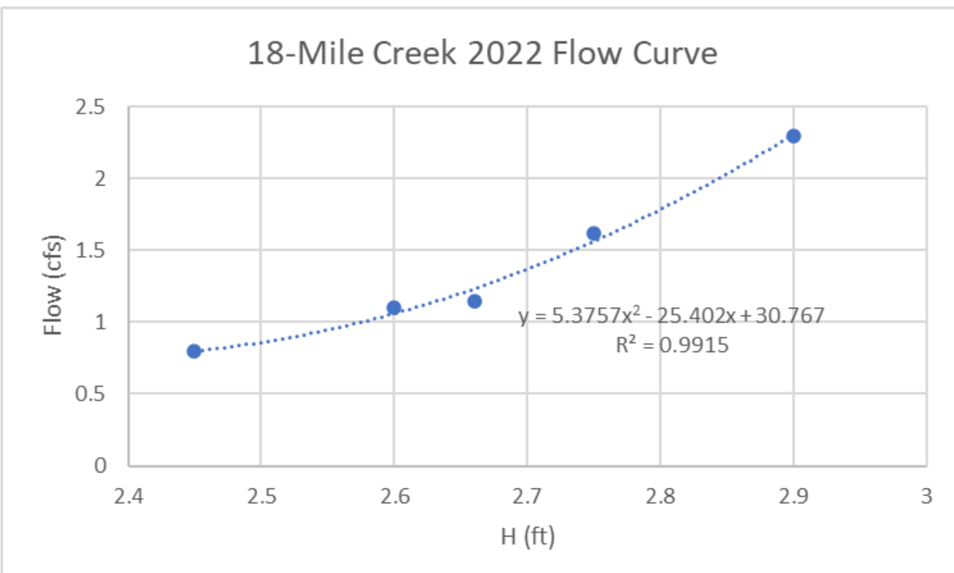
2-Aug
8-Aug
14-Aug
20-Aug
26-Aug
1-Sep
7-Sep
13-Sep
19-Sep
25-Sep

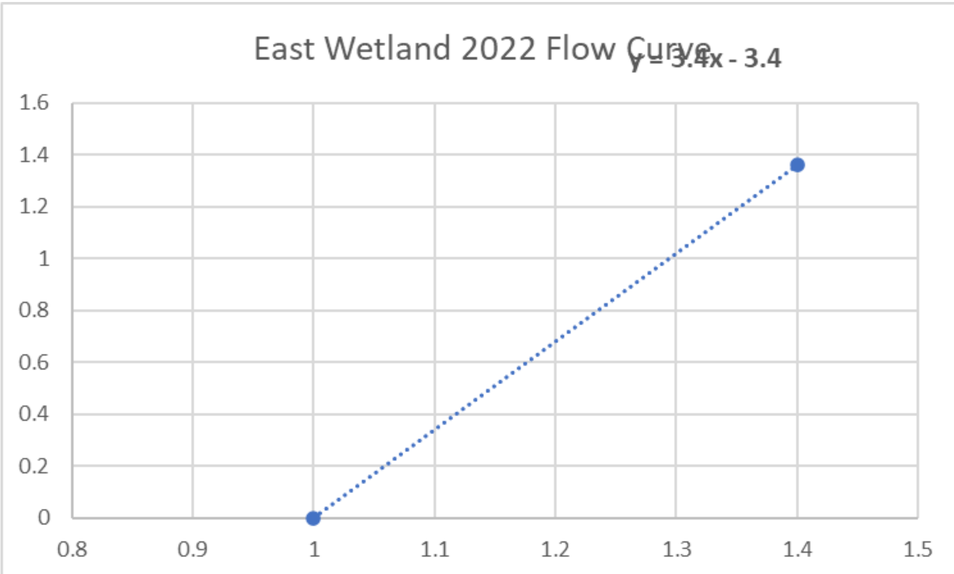

Crystal Lake Outflow-2022
Flow (cfs)
1.2
1
0.8
0.6
0.4
0.2
0
4-May
14-May
24-May
3-Jun
13-Jun
23-Jun
3-Jul
Day

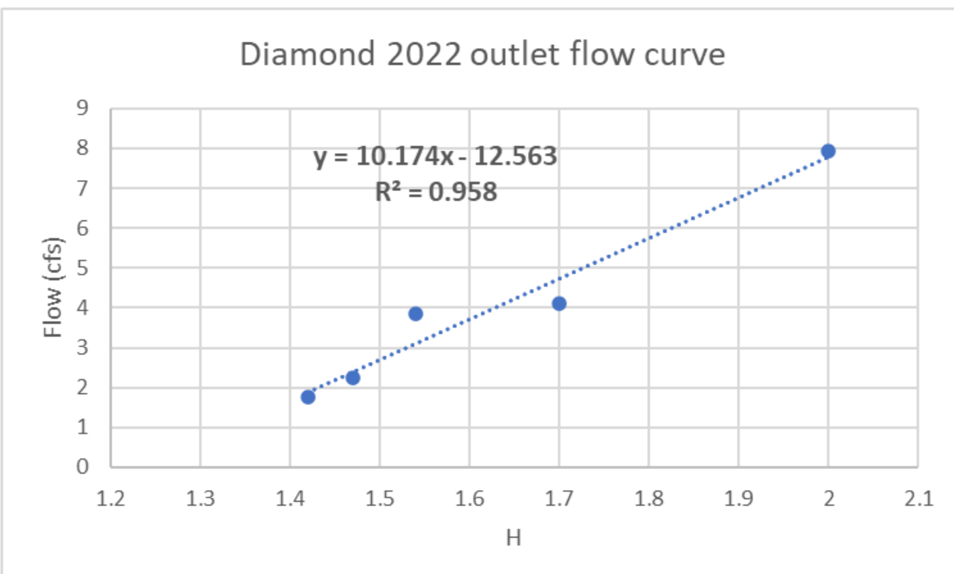


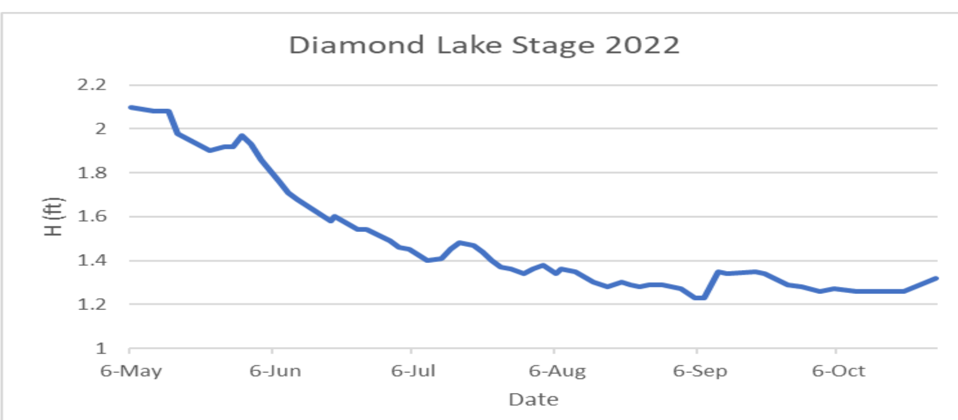
Diamond Outlet Mean Daily Flow-2022
FLOW (CFS)
PRECIPITATION (INCHES)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
21-Apr
28-Apr
5-May
12-May
19-May
26-May
2-Jun
9-Jun
16-Jun
23-Jun
30-Jun
7-Jul
14-Jul
21-Jul
28-Jul
4-Aug
11-Aug
18-Aug
25-Aug
1-Sep
8-Sep
15-Sep
22-Sep
29-Sep
Precipitation
Flow



18-Mile Creek 2022 Flow Curve
Flow (cfs)
2.5
2
1.5
1
0.5
0
2.4
2.5
2.6
2.7
2.8
2.9
3
H (ft)
y = 5.3757x² - 25.402x + 30.767
R² = 0.9915


East Wetland 2022 Flow Curve
y = 3.4x - 3.4
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5


Diamond 2022 outlet flow curve
y = 10.174x - 12.563
R² = 0.958
Flow (cfs)
9
8
7
6
5
4
3
2
1
0
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
H

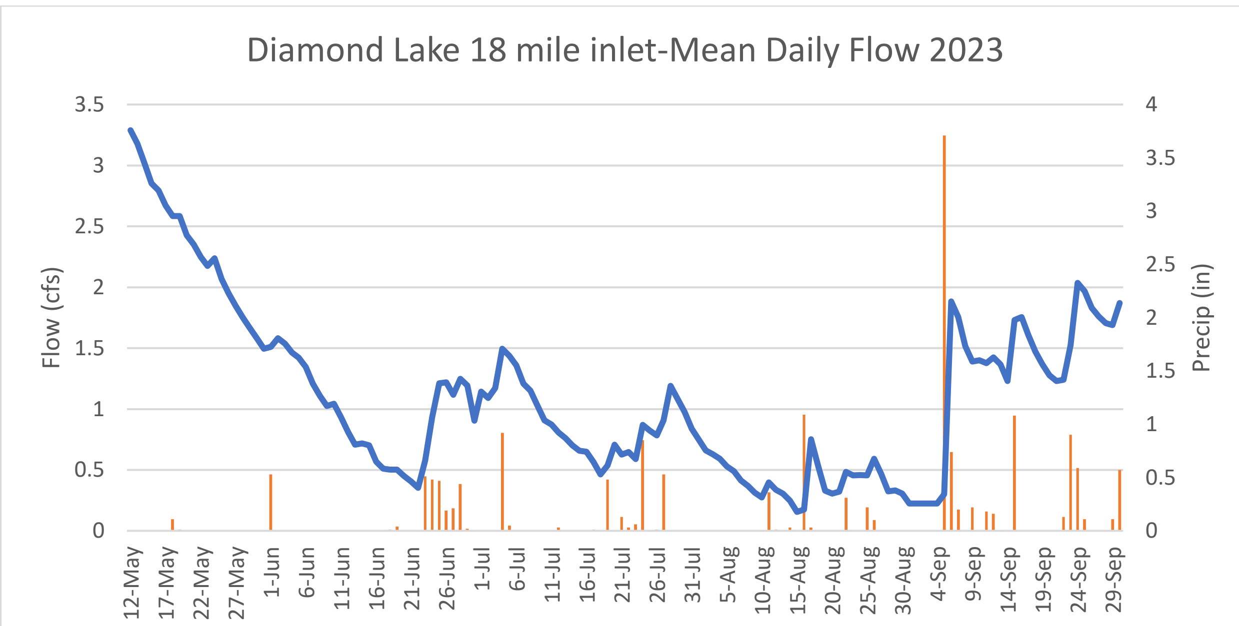

Diamond Lake Stage 2022
H (ft)
2.2
2
1.8
1.6
1.4
1.2
1
6-May
6-Jun
6-Jul
6-Aug
6-Sep
6-Oct
Date

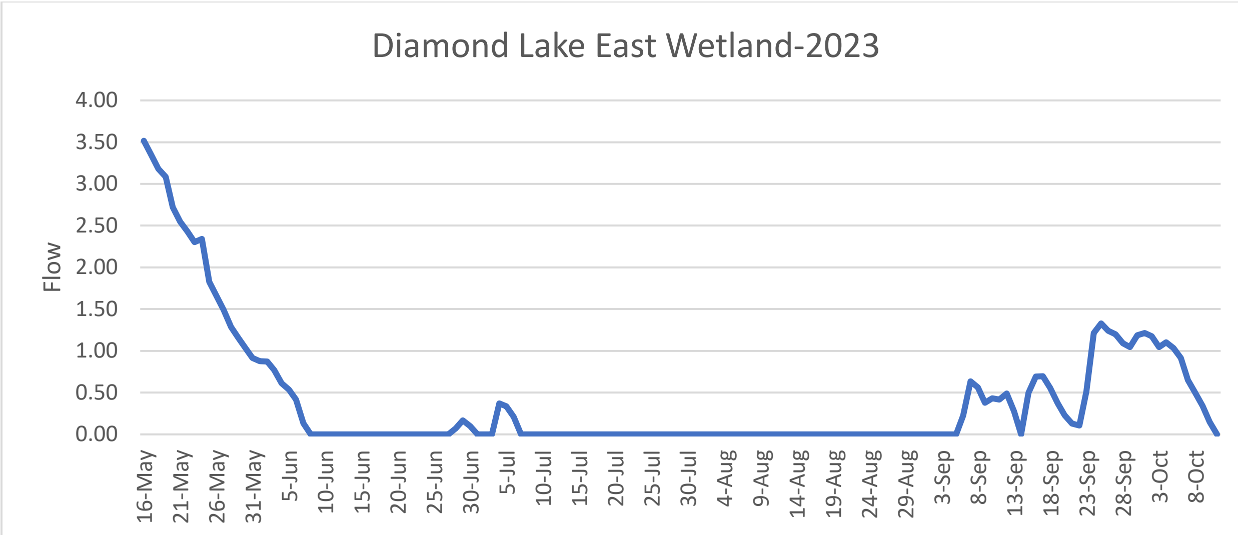
2023 Data:

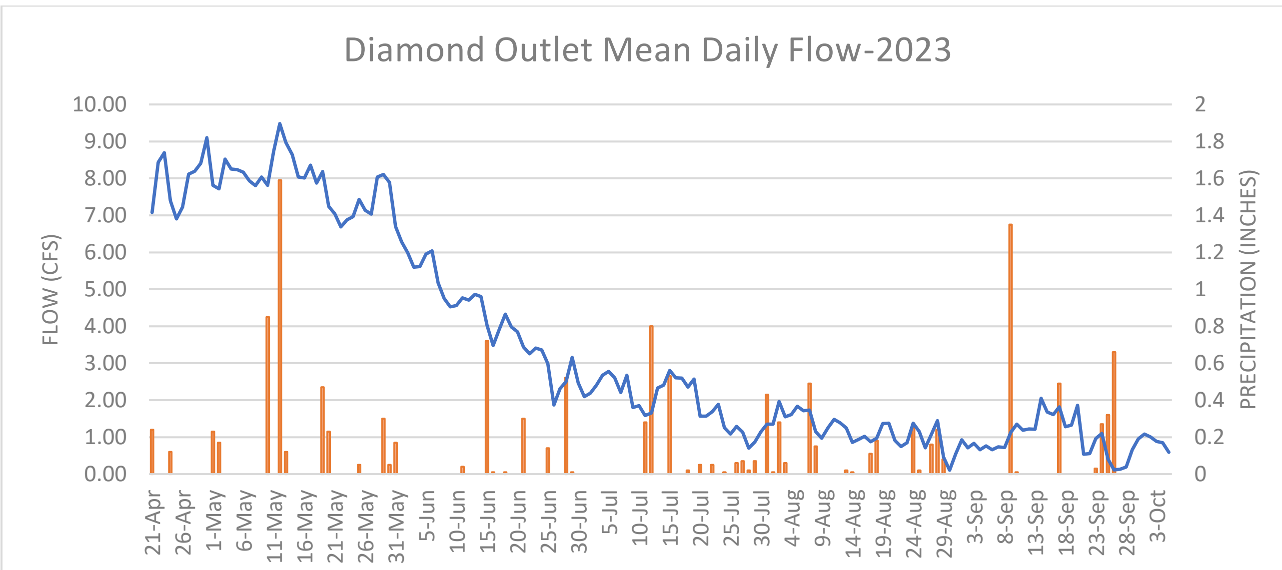
Date In-lake deep hole	TP ug/L	CHl-a	Secchi (ft)
5/10/2023	23		10.5
5/16/2023	14		
6/19/2023	12	1.2	16
7/24/2023	11	1.8	14
8/30/2023	11	1.1	19

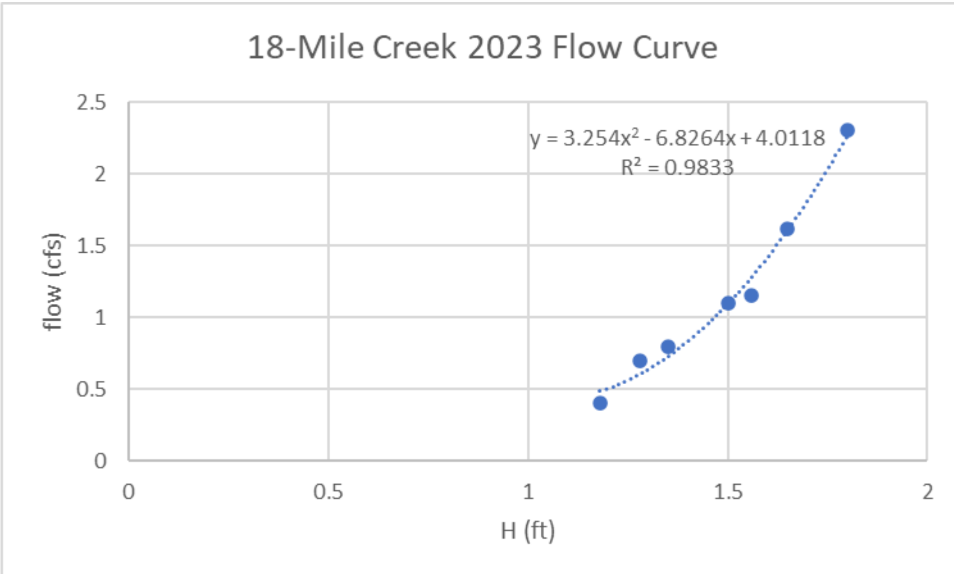
18-Mile Date	TP
5/24/2023	14.2
6/19/2023	24.9
7/24/2023	26.5
8/30/2023	21.3

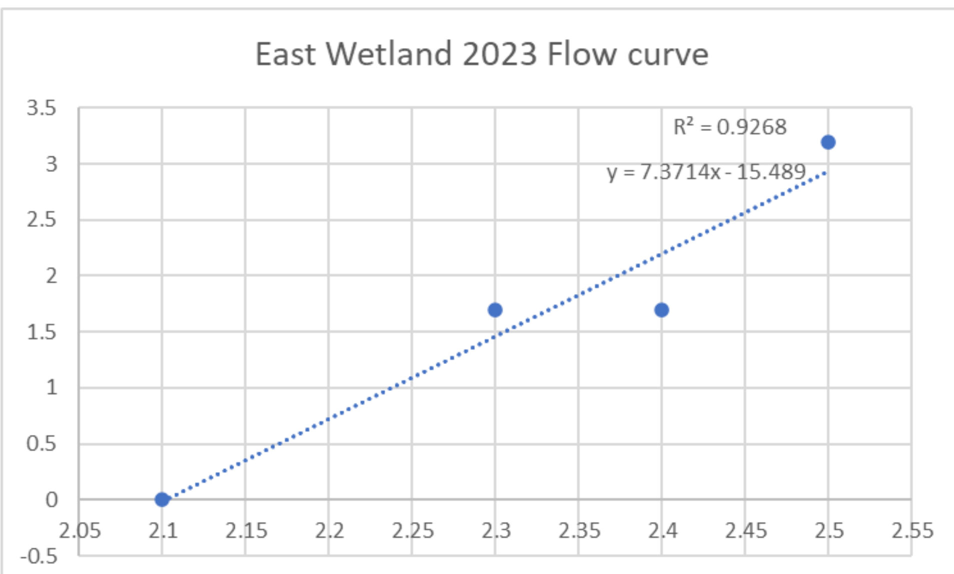
East Wetland Date	TP		
5/24/2023	30.1		
6/19/2023	20.4		
7/24/2023	20.6	not flowing	
8/30/2023	25.9	not flowing	

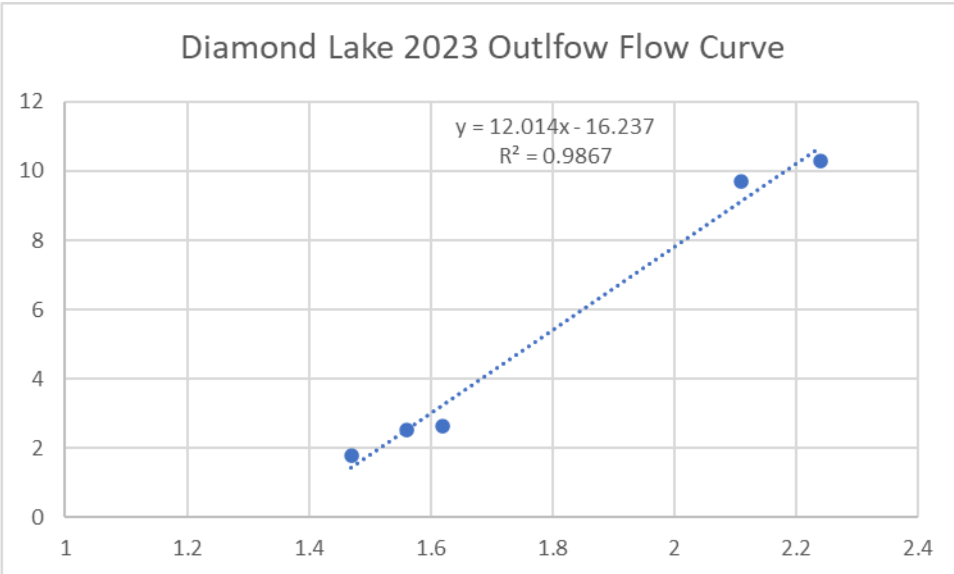


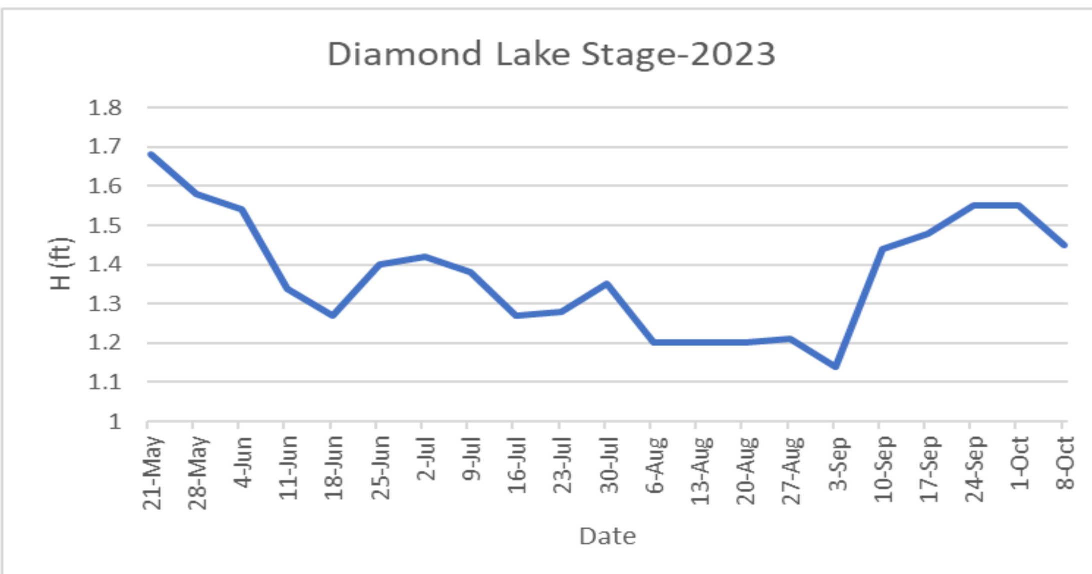

Diamond Lake East Wetland-2023
Flow
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
16-May
21-May
26-May
31-May
5-Jun
10-Jun
15-Jun
20-Jun
25-Jun
30-Jun
5-Jul
10-Jul
15-Jul
20-Jul
25-Jul
30-Jul
4-Aug
9-Aug
14-Aug
19-Aug
24-Aug
29-Aug
3-Sep
8-Sep
13-Sep
18-Sep
23-Sep
28-Sep
3-Oct
8-Oct


Diamond Outlet Mean Daily Flow-2023
FLOW (CFS)
PRECIPITATION (INCHES)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
21-Apr
26-Apr
1-May
6-May
11-May
16-May
21-May
26-May
31-May
5-Jun
10-Jun
15-Jun
20-Jun
25-Jun
30-Jun
5-Jul
10-Jul
15-Jul
20-Jul
25-Jul
30-Jul
4-Aug
9-Aug
14-Aug
19-Aug
24-Aug
29-Aug
3-Sep
8-Sep
13-Sep
18-Sep
23-Sep
28-Sep
3-Oct


18-Mile Creek 2023 Flow Curve
y = 3.254x² - 6.8264x + 4.0118
R² = 0.9833
flow (cfs)
H (ft)
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2


East Wetland 2023 Flow curve
R² = 0.9268
y = 7.3714x - 15.489
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
2.05
2.1
2.15
2.2
2.25
2.3
2.35
2.4
2.45
2.5
2.55


Diamond Lake 2023 Outlfow Flow Curve
y = 12.014x - 16.237
R² = 0.9867
12
10
8
6
4
2
0
1
1.2
1.4
1.6
1.8
2
2.2
2.4


Diamond Lake Stage-2023
H (ft)
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
21-May
28-May
4-Jun
11-Jun
18-Jun
25-Jun
2-Jul
9-Jul
16-Jul
23-Jul
30-Jul
6-Aug
13-Aug
20-Aug
27-Aug
3-Sep
10-Sep
17-Sep
24-Sep
1-Oct
8-Oct
Date

Model Information/Data

2022 Growing Season

Overall Water & Nutrient Balances 2022 Growing Season										
Overall Water Balance										
				Area	Flow	Variance		Runoff		
Trb	Type	Seg	Name	km^2	hm^3/yr	(hm3/yr)^2		m/yr		
1	1	1	18-mile creek (measured)		0.5	0.00E+00				
2	1	1	E wetland (measured)		0.1	0.00E+00				
3	1	1	Direct drained-forest (estimated)		0.1	0.00E+00				
4	1	1	groundwater (net input) (estimated)		0.6	0.00E+00				
5	4	1	Outflow (measured)		1.4	0.00E+00				
6	1	1	Septic systems (estimated)		0.0	0.00E+00				
PRECIPITATION			(measured)	1.4	0.5	0.00E+00		0.37		
TRIBUTARY INFLOW					1.2	0.00E+00				
***TOTAL INFLOW				1.4	1.7	0.00E+00		1.25		
GAUGED OUTFLOW					1.4	0.00E+00				
ADVECTIVE OUTFLOW				1.4	0.0	0.00E+00		0.02		
***TOTAL OUTFLOW				1.4	1.4	0.00E+00		1.04		
***EVAPORATION					0.6	0.00E+00				
***STORAGE INCREASE					-0.3	0.00E+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	1	1	18-mile creek	7.4	14.7%	0.00E+00		0.00	16.0	
2	1	1	E wetland	4.3	8.5%	0.00E+00		0.00	30.4	
3	1	1	Direct drained-forest	10.2	20.3%	0.00E+00		0.00	170.0	

4	1	1	groundwater	6.6	13.2%	0.00E+00		0.00	12.0	
5	4	1	outflow	15.0		1.60E+01		0.27	10.7	
6	1	1	Septics	8.0	16.0%	0.00E+00		0.00	8000.0	
PRECIPITATION				13.7	27.3%	4.69E+01	100.0%	0.50	27.3	10.0
TRIBUTARY INFLOW				36.4	72.7%	0.00E+00		0.00	30.1	
***TOTAL INFLOW				50.1	100.0%	4.69E+01	100.0%	0.14	29.3	36.6
GAUGED OUTFLOW				15.0	29.8%	1.60E+01		0.27	10.7	
ADVECTIVE OUTFLOW				0.3	0.5%	4.99E-03		0.27	10.7	0.2
***TOTAL OUTFLOW				15.2	30.3%	1.66E+01		0.27	10.7	11.1
***STORAGE INCREASE				-3.5		0.00E+00		0.00	10.1	
***RETENTION				38.4	76.6%	4.71E+01		0.18		
	Overflow Rate (m/yr)			0.8		Nutrient Resid. Time (yrs)			2.9356	
	Hydraulic Resid. Time (yrs)			12.7351		Turnover Ratio			0.3	
	Reservoir Conc (mg/m3)			11		Retention Coef.			0.766	

2023 Growing Season

Overall Water & Nutrient Balances 2023 Growing season										
Overall Water Balance										
				Area	Flow	Variance		Runoff		
Trb	**Type**	Seg	Name	km²	hm³/yr	(hm3/yr)²		m/yr		
1	1	1	18-mile creek		0.5	0.00E+00				
2	1	1	E wetland		0.3	0.00E+00				
3	1	1	Direct drained-forest		0.1	0.00E+00				
4	1	1	groundwater		0.6	0.00E+00				
5	4	1	outflow		1.7	0.00E+00				
6	1	1	Septics		0.0	0.00E+00				
PRECIPITATION				1.4	0.6	0.00E+00		0.45		
TRIBUTARY INFLOW					1.4	0.00E+00				
***TOTAL INFLOW				1.4	2.0	0.00E+00		1.49		
GAUGED OUTFLOW					1.7	0.00E+00				
ADVECTIVE OUTFLOW				1.4	0.0	0.00E+00		0.02		
***TOTAL OUTFLOW				1.4	1.8	0.00E+00		1.29		
***EVAPORATION					0.6	0.00E+00				
***STORAGE INCREASE					-0.4	0.00E+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/m³**	**kg/km²/yr**
1	1	1	18-mile creek	10.9	16.8%	0.00E+00		0.00	21.7	
2	1	1	E wetland	6.5	10.1%	0.00E+00		0.00	24.3	
3	1	1	Direct drained-forest	16.0	24.7%	0.00E+00		0.00	200.0	
4	1	1	groundwater	7.0	10.7%	0.00E+00		0.00	12.0	

5	4	1	outflow	20.2		2.74E+01		0.26	11.6	
6	1	1	Septics	8.0	12.3%	0.00E+00		0.00	8000.0	
PRECIPITATION				16.4	25.4%	6.76E+01	100.0%	0.50	26.7	12.0
TRIBUTARY INFLOW				48.4	74.6%	0.00E+00		0.00	33.8	
***TOTAL INFLOW				64.8	100.0%	6.76E+01	100.0%	0.13	31.7	47.3
GAUGED OUTFLOW				20.2	31.2%	2.74E+01		0.26	11.6	
ADVECTIVE OUTFLOW				0.4	0.6%	1.02E-02		0.26	11.6	0.3
***TOTAL OUTFLOW				20.6	31.8%	2.85E+01		0.26	11.6	15.0
***STORAGE INCREASE				-3.6		0.00E+00		0.00	10.1	
***RETENTION				47.8	73.7%	7.07E+01		0.18		
	Overflow Rate (m/yr)			1.0		Nutrient Resid. Time (yrs)			2.4715	
	Hydraulic Resid. Time (yrs)			9.7243		Turnover Ratio			0.4	
	Reservoir Conc (mg/m3)			12		Retention Coef.			0.737	

Average precipitation year growing season

Overall Water & Nutrient Balances-Average growing season										
Overall Water Balance										
				Area	Flow	Variance		Runoff		
Trb	Type	Seg	Name	km²	hm³/yr	(hm3/yr)²		m/yr		
1	1	1	18-mile creek		0.5	0.00E+00				
2	1	1	E wetland		0.3	0.00E+00				
3	1	1	Direct drained-forest		0.1	0.00E+00				
4	1	1	groundwater		0.6	0.00E+00				
5	4	1	outflow		1.7	0.00E+00				
6	1	1	Septics		0.0	0.00E+00				
PRECIPITATION				1.4	0.8	0.00E+00		0.55		
TRIBUTARY INFLOW					1.5	0.00E+00				
***TOTAL INFLOW				1.4	2.3	0.00E+00		1.67		
GAUGED OUTFLOW					1.7	0.00E+00				
ADVECTIVE OUTFLOW				1.4	0.0	0.00E+00				
***TOTAL OUTFLOW				1.4	1.7	0.00E+00		1.21		
***EVAPORATION					0.6	0.00E+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/m³	kg/km²/yr
1	1	1	18-mile creek	12.2	16.6%	0.00E+00		0.00	23.0	
2	1	1	E wetland	8.3	11.3%	0.00E+00		0.00	25.0	
3	1	1	Direct drained-forest	21.0	28.7%	0.00E+00		0.00	210.0	
4	1	1	groundwater	7.0	9.5%	0.00E+00		0.00	12.0	
5	4	1	outflow	20.4		4.99E+01		0.35	12.0	

6	1	1	Septics	8.0	10.9%	0.00E+00		0.00	8000.0	
PRECIPITATION				16.9	23.0%	7.10E+01	100.0%	0.50	22.4	12.3
TRIBUTARY INFLOW				56.4	77.0%	0.00E+00		0.00	36.6	
***TOTAL INFLOW				73.3	100.0%	7.10E+01	100.0%	0.12	31.9	53.5
GAUGED OUTFLOW				20.4	27.8%	4.99E+01		0.35	12.0	
ADVECTIVE OUTFLOW				-0.4		2.20E-02		0.35	12.0	
***TOTAL OUTFLOW				19.9	27.2%	4.79E+01		0.35	12.0	14.6
***RETENTION				53.3	72.8%	9.57E+01		0.18		
	Overflow Rate (m/yr)			1.2		Nutrient Resid. Time (yrs)			2.2547	
	Hydraulic Resid. Time (yrs)			8.2811		Turnover Ratio			0.4	
	Reservoir Conc (mg/m3)			12		Retention Coef.			0.728	

Load Analysis outputs

File:	E:\EIS\My Documents\Consult\Diamond Lake\Diamond Average GS								
Load / Response									
Tributary:	**03 Direct drained-forest**								
Segment:	01 Diamond Lake								
Variable:	TOTAL P MG/M3								
Scale	Flow	Load	Conc	TOTAL P MG/M3					
Factor	hm3/yr	kg/yr	mg/m³	Mean	CV	Low	High		
Base:	0.1	20.0	200.0	12.3	0.35	9.0	16.4		
0.20	0.1	4.0	40.0	10.4	0.35	7.6	14.0		
0.40	0.1	8.0	80.0	10.9	0.35	8.0	14.6		
0.60	0.1	12.0	120.0	11.4	0.35	8.3	15.2		
0.80	0.1	16.0	160.0	11.8	0.35	8.7	15.8		
1.00	0.1	20.0	200.0	12.3	0.35	9.0	16.4		
1.20	0.1	24.0	240.0	12.7	0.35	9.3	16.9		
1.40	0.1	28.0	280.0	13.1	0.35	9.7	17.5		
1.60	0.1	32.0	320.0	13.5	0.35	10.0	18.1		
1.80	0.1	36.0	360.0	13.9	0.35	10.3	18.6		
2.00	0.1	40.0	400.0	14.3	0.34	10.6	19.1		

File:	E:\EIS\My Documents\Consult\Diamond Lake\Diamond Average GS								
Load / Response									
Tributary:	**06 Septic systems**								
Segment:	01 Diamond Lake								
Variable:	TOTAL P MG/M3								
Scale	Flow	Load	Conc	TOTAL P MG/M3					
Factor	hm3/yr	kg/yr	mg/m³	Mean	CV	Low	High		
Base:	0.0	8.0	8000.0	12.3	0.35	9.0	16.4		
0.20	0.0	1.6	1600.0	11.5	0.35	8.5	15.4		
0.40	0.0	3.2	3200.0	11.7	0.35	8.6	15.7		
0.60	0.0	4.8	4800.0	11.9	0.35	8.7	15.9		
0.80	0.0	6.4	6400.0	12.1	0.35	8.9	16.2		
1.00	0.0	8.0	8000.0	12.3	0.35	9.0	16.4		
1.20	0.0	9.6	9600.0	12.4	0.35	9.1	16.6		
1.40	0.0	11.2	11200.0	12.6	0.35	9.3	16.8		
1.60	0.0	12.8	12800.0	12.8	0.35	9.4	17.1		
1.80	0.0	14.4	14400.0	12.9	0.35	9.5	17.3		
2.00	0.0	16.0	16000.0	13.1	0.35	9.7	17.5		