# Nutrient Budget Analysis

# Deer Lake, Polk County, Wisconsin

2025

DEER LAKE CONSERVANCY

Sponsored by: Deer Lake Conservancy and Wisconsin Dept. of Natural Resources

Data collected and analyzed by: Ecological Integrity Service, LLC

## Analysis Summary

Tributary monitoring data collected from 2022–2025, combined with in-lake measurements of total phosphorus (TP), chlorophyll-a, and Secchi depth, were used to develop a comprehensive phosphorus budget for Deer Lake. Phosphorus loading and in-lake response were evaluated using the Canfield–Bachman natural lakes model. Chlorophyll-a concentrations were modeled using the Jones–Bachman formulation, and Secchi depth was evaluated using the chlorophyll-a/turbidity relationship within the U.S. Army Corps of Engineers Bathtub framework. All models showed good agreement with observed in-lake conditions.

Model results indicate that the direct-drained sub-watershed is the largest source of phosphorus to Deer Lake, contributing approximately 23% of the annual load under average precipitation conditions. Atmospheric deposition is the second-largest contributor. Hypolimnetic phosphorus concentrations measured in June and September indicate substantial sediment phosphorus release in 2022 and a smaller release in 2023. However, modeling results suggest that only a small fraction of sediment-released phosphorus (approximately 23 kg in 2022) mixed into the epilimnion. In most years, Deer Lake remains stratified during the growing season, limiting the availability of sediment-derived phosphorus for algal production.

The model demonstrates the effectiveness of previously implemented watershed management practices. Without these practices, predicted growing-season mean total phosphorus concentrations would approach 30 µg/L, compared to the current 10-year average of approximately 18 µg/L.

Load-reduction scenarios indicate that a 20% reduction in phosphorus loading from the direct-drained sub-watershed would reduce growing-season mean total phosphorus from 18.1 to 17.6 µg/L, decrease chlorophyll-a from 4.6 to 4.4 µg/L, and increase Secchi depth from 15.1 to 15.4 feet. A 20% reduction across all tributary sources combined would further improve water quality, reducing total phosphorus to 16.3 µg/L, chlorophyll-a to 4.0 µg/L, and increasing Secchi depth to approximately 16.4 feet. Loading increases from such things as increased development, or changes in the types of development would lead to increased phosphorus loading and lake quality degradation.

## Introduction

Deer Lake is a 786-acre lake located in Polk County, Wisconsin, with a maximum depth of 46 feet and a mean depth of 26 feet. The Wisconsin Department of Natural Resources classifies Deer Lake as mesotrophic. The lake's watershed encompasses approximately 5,893 acres, most of which lies north of the lake. Shoreline development is extensive, with few undeveloped parcels remaining. Numerous residential properties with large lawns extend directly to the shoreline. The lake has no perennial inlet streams and drains through an outlet located on the east end.

The Deer Lake Conservancy has implemented numerous best management practices (BMPs) throughout the watershed over the past several years. Previous studies indicate that these practices have significantly reduced phosphorus loading from targeted sub-watersheds. This analysis integrates recent tributary monitoring data with in-lake measurements to provide an updated phosphorus budget and identify priority sources for future management.

Zebra mussels are present in Deer Lake and may influence nutrient cycling through filter feeding on phytoplankton. Although these effects were not explicitly modeled, they may partially explain observed relationships between total phosphorus, chlorophyll-a, and Secchi depth.

<u>Watershed Updates</u>

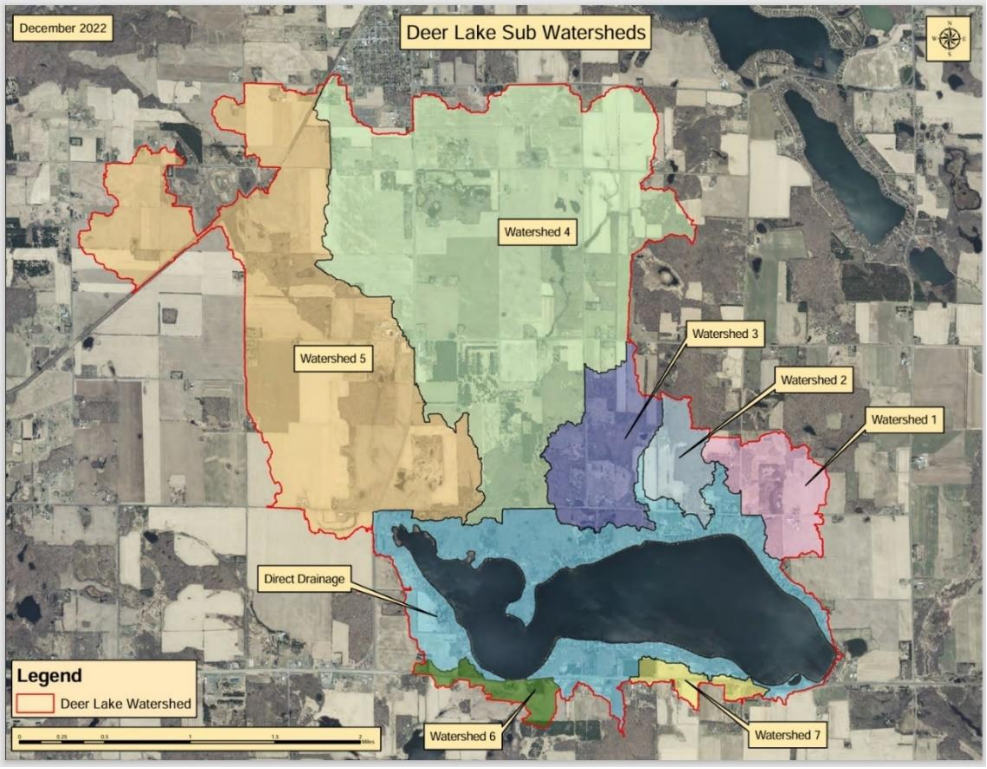



**Figure 1: Map showing the Deer Lake watershed divided into sub-watersheds. This map was created using LiDAR elevation data and a flow analysis.**

Polk County Land and Water Conservation Department updated the watershed boundaries in 2022. The whole watershed was divided into sub-watersheds based on flow patterns. Each sub-watershed draining tributary was monitored for flow and nutrients from 2022-2025. The direct-drained watershed is the area adjacent to Deer Lake that flows directly into the lake.

Polk County also updated the land use (aka land cover) in 2022. Figure 2 shows the land cover in the Deer Lake watershed. Table 1 summarizes the land cover type by area (acres). Land cover type is important to identify since different land cover types give rise to varying runoff amounts and nutrient concentrations. Land cover types such as row crop agriculture and high-density residential have the highest runoff coefficients and nutrient concentrations in that runoff. Forested and wetland areas have the lowest. The map shows there is a large amount of row crop land cover within the watershed, which can lead to large nutrient loads.

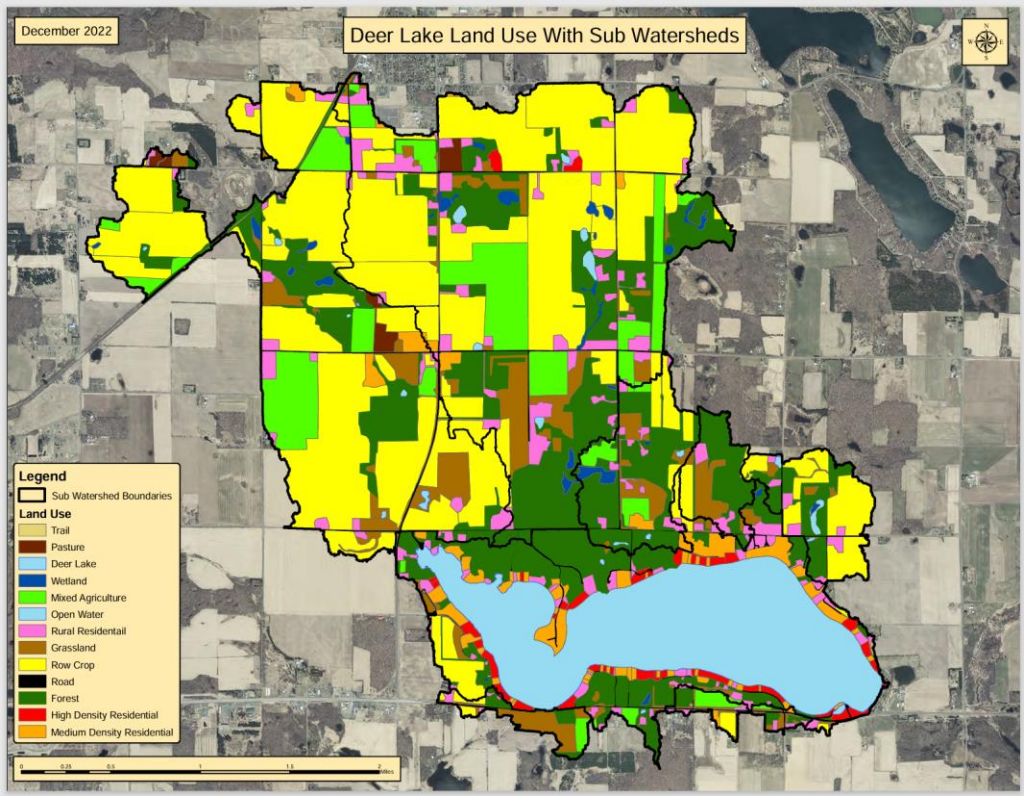



**Figure 2: This map shows the land use (land cover) of the watershed for Deer Lake.**

| Land Use (Land cover) | Acres |
|---|---|
| Row Crop | 2146.7 |
| Forest | 1280.8 |
| Mixed Ag | 470.9 |
| Grassland | 387.3 |
| Rural Residential | 335.0 |
| Medium-density residential | 168.5 |
| Road | 84.7 |
| High-density residential | 76.2 |
| Wetland | 55.3 |
| Pasture | 33.2 |
| Open Water | 29.3 |
| Trail | 3.9 |
| **Total** | **5071.8** |

**Table 1: Land use (land cover) type areas for the Deer Lake watershed.**

Polk County, through LiDAR and flow analysis, identified internally drained areas within each sub-watershed. Internally drained areas are portions of the watershed that will not contribute runoff into Deer Lake during storm events that are less than about 4.3 inches in 24 hours (10-year event). These areas are important to delineate to make predicted runoff amounts more valid. Without this knowledge, external loading from the watershed can be overestimated. Both sub-watersheds 4 and 5 have extensive internally drained areas, much of which contains row crop land cover type. This can help explain why these watersheds may contribute less than would otherwise be predicted.

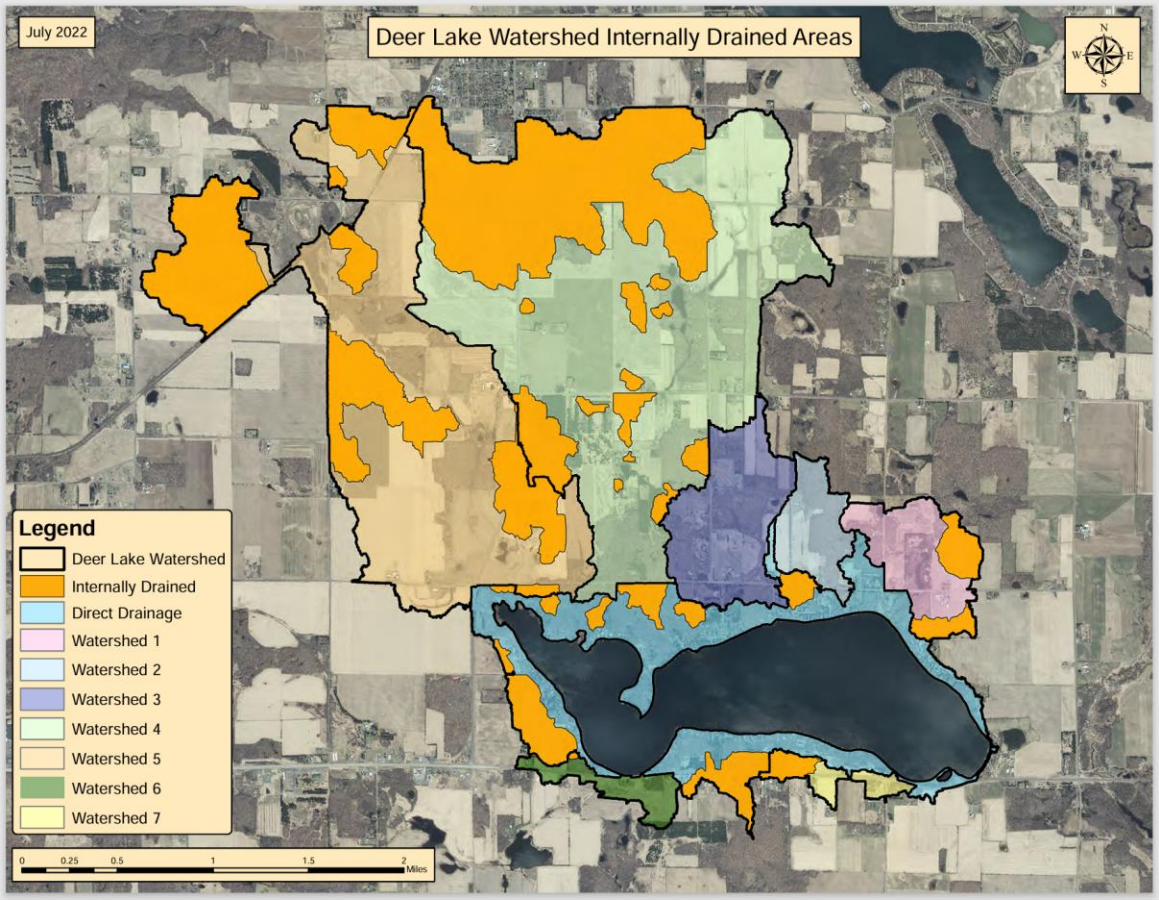



**Figure 3: This map shows the internally drained areas within each sub-watershed. These areas do not contribute runoff into the lake during most rain events.**

| Sub Watershed | Internally Drained Acres |
|---|---|
| Direct Drainage | 178 |
| Sub 1 | 59 |
| Sub 2 | 0 |
| Sub 3 | 0 |
| Sub 4 | 767 |
| Sub 5 | 542 |
| Sub 6 | 1.6 |
| Sub 7 | 21 |
| **Total** | **1568.6** |

**Table 2: A list of internally drained areas within each sub-watershed.**

Since sub-watersheds 1-7 were all field monitored, the only sub-watershed where export coefficients were used to estimate runoff and nutrient loading was the direct-drained sub-watershed. This sub-watershed is approximately 41% forested; however, there are large areas of high-density residential

development (17%) and medium-density residential development (22%) adjacent to the lake, which can increase runoff and nutrient loading (see Table 3 and Figure 4).

| **Direct-drained Sub Watershed Land Use** | |
|---|---|
| **Land Use** | **Acres** |
| Forest | 201.2 |
| Medium-Density Residential | 108.1 |
| Rural residential | 65.4 |
| High-Density Residential | 66.9 |
| Row Crop | 12.1 |
| Grassland | 13.4 |
| Road | 16.7 |
| Mixed Ag | 3.3 |
| Wetland | 0.9 |
| Open Water | 0.8 |
| **Total** | **488.6** |

**Table 3: Land use (cover) type areas for the direct-drained watershed.**

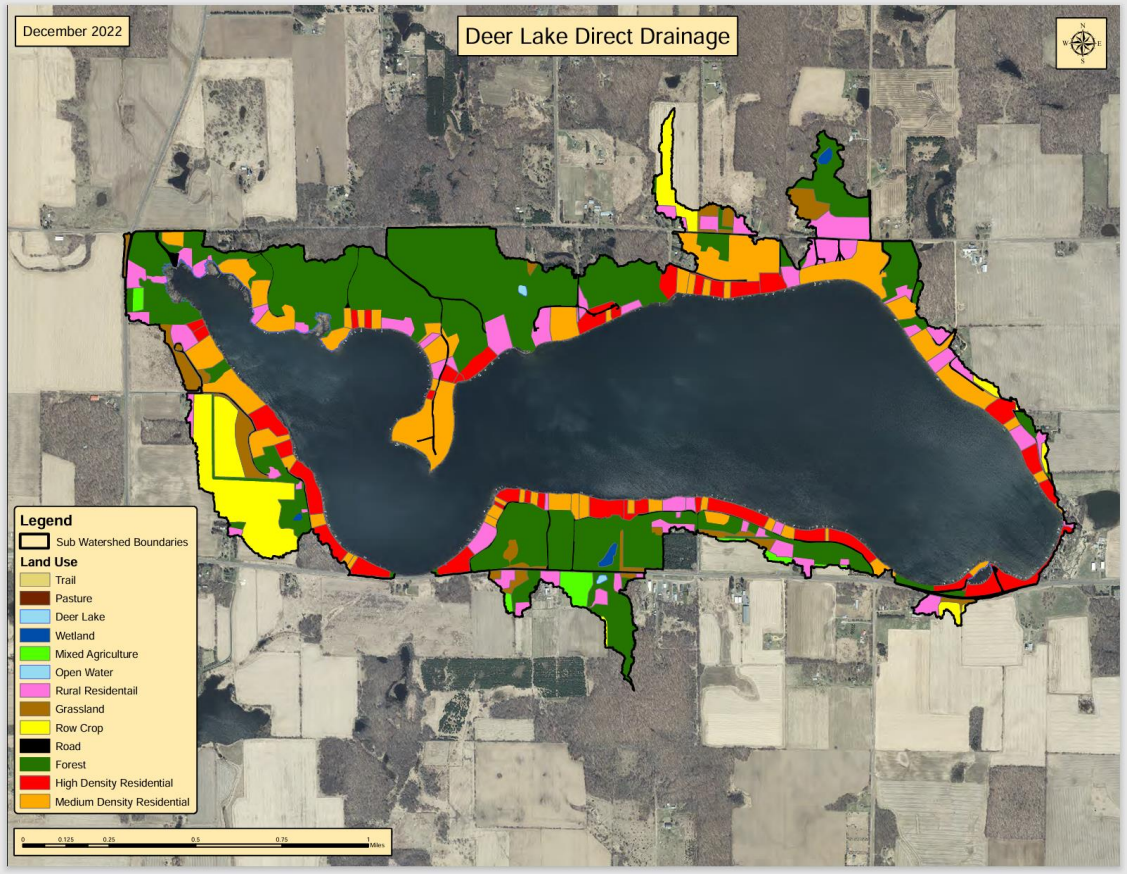



**Figure 4: Map of the land use (land cover) in the direct-drained sub-watershed. Note the large amount of high and medium-density residential land cover (red and orange).**

From 2007 through 2024, technical assistance addressing runoff control was provided to owners of 157 Deer Lake parcels (50% of lake parcels). This is an average of 11 properties visited per year (some are repeat visits). In total, projects such as rain gardens, rock infiltration, and native plantings have been installed on 66 lake properties. Many of these properties had multiple best management practices installed.

Historical data/trends

The graph below shows the trophic state data of the lake going back to the 1990s. Trophic state is determined by a trophic state index (TSI) value. A TSI of 30-40 is defined as oligotrophic, which is the lowest amount of productivity (growth) in a lake. 40-50 is defined as mesotrophic, which is moderate productivity. Eutrophic is a TSI of 50 and above, which is the most productive. It is desired to have a low TSI (oligotrophic). Most data points show Deer Lake is classified as a mesotrophic lake (medium amount of productivity). The Secchi depth has had numerous years since 2010 with TSI values in the oligotrophic state.

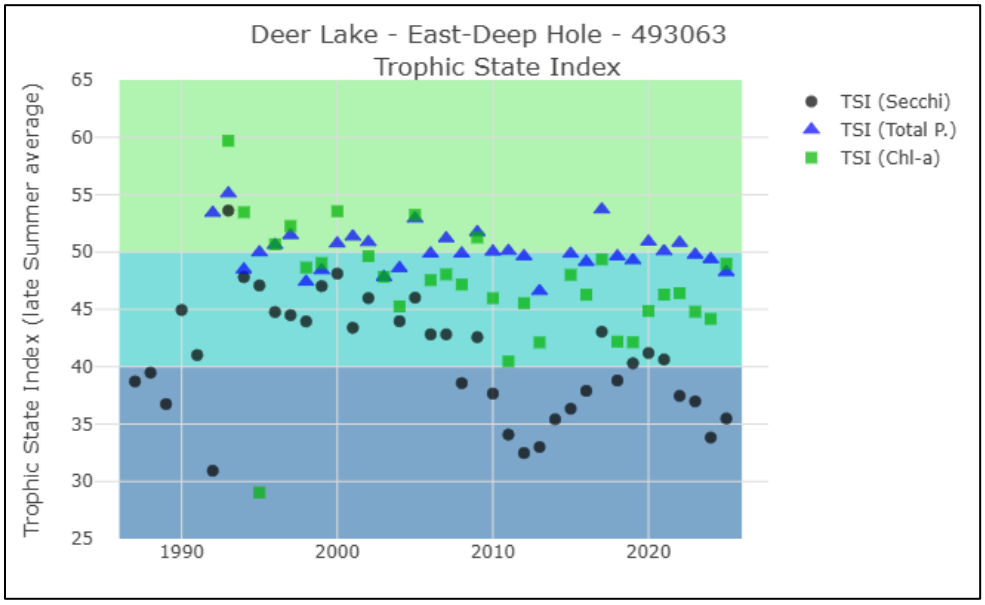



**Figure 5: TSI graph for total phosphorus, chlorophyll, and Secchi depth. Note most values in the "mesotrophic" state.**

There has been a robust data set of water quality parameters collected over several years. The graphs below show the trends (if any) for total phosphorus, chlorophyll a (a measure of algae growth), and Secchi depth (water clarity).

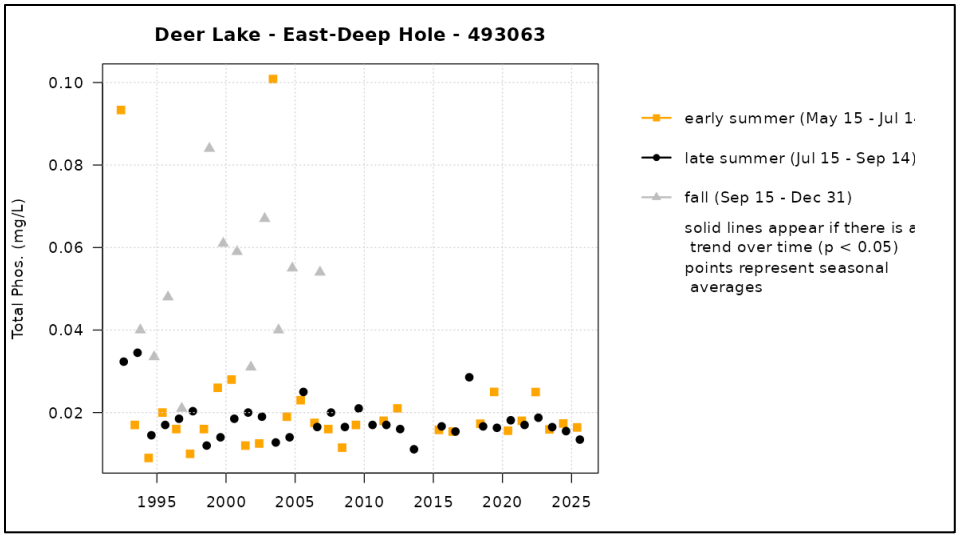



**Figure 6: This graph shows the total phosphorus trends. There is no statistically significant trend.**

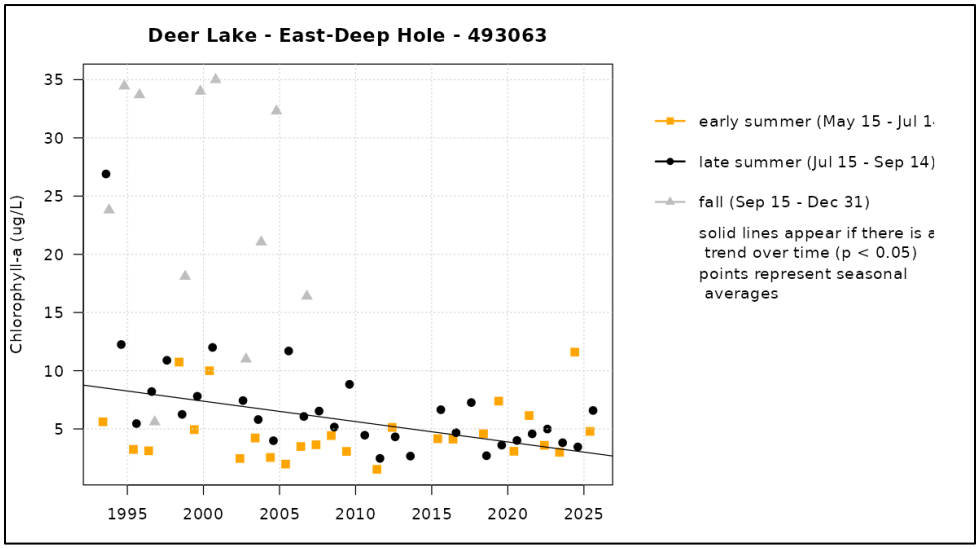



**Figure 7: Deer Lake chlorophyll concentration trend graph. This graph shows that there has been a statistically significant decrease during the late summer period (July 15-Sept. 14). This shows that Deer Lake water quality has been improving.**

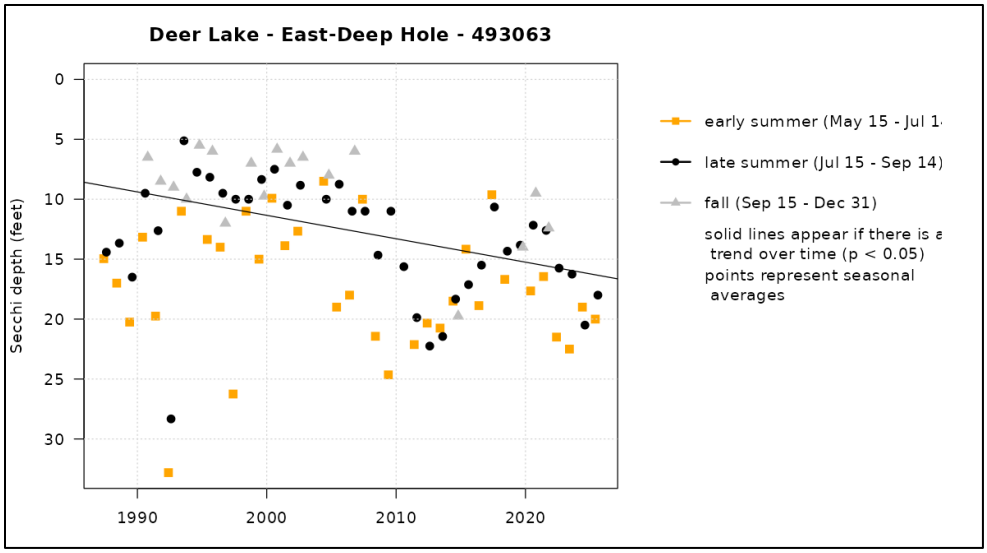



**Figure 8: Graph showing the Secchi depth trend in Deer Lake. The graph shows that there has been a statistically significant increase in Secchi depth in late summer (July 15-Sept 14). This represents improved water clarity in Deer Lake in late summer over time.**

Past data indicate that the late-summer chlorophyll a concentration is decreasing (statistically significant trend) and the late-summer Secchi depth is trend is increasing (statistically significant trend). This shows the water is getting clearer in the late summer/early fall, when the water quality is typically the worst in most Wisconsin lakes. There is no trend for the total phosphorus, which drives the chlorophyll and Secchi depth. However, the total phosphorus concentrations remain low each year, so it is not a concern at this time.

There have been four past analyses of nutrient loading into Deer Lake. In 1992 and 1994, it was estimated that 1393 pounds (1992) and 2511 pounds (1994) were loaded into Deer Lake from various sources. Another study (2003) was conducted to analyze past data (1996 and 2000). That analysis estimated a loading of 5199 pounds in 1996 and 2573 pounds in 2000. The reduction was attributed to management practices implemented in the watershed. A management plan/analysis was created in 2004 (Osgood, 2024). In that plan, the previous estimates were adjusted to predict a phosphorus load of 3392 pounds/year into Deer Lake. That analysis also estimated an internal load of 1833 lbs. The internal load was reported based on sediment release and did not indicate if a portion or all available phosphorus was mixed into the epilimnion, which would be available for algae growth.

## Methods

In 2022, the Polk County Land and Water Conservation Department updated the Deer Lake watershed boundaries using GIS-based flow analysis. The watershed was divided into eight sub-watersheds, and internally drained areas were identified. Seven sub-watersheds drain to Deer Lake through intermittent tributaries and were monitored for flow and nutrient loading over a four-year period (2022–2025). The only sub-watershed for which export coefficients were required was the direct-drained sub-watershed, which drains directly to the lake shoreline.

A water budget was developed using measured precipitation, tributary inflows from the seven monitored sub-watersheds, and lake outflow to establish a water mass balance. Lake evaporation was estimated using pan evaporation data. The water balance was defined by the equation:

$$\Delta S = (P + Qin + Gin) - (E + Qout + Gout)$$

where ΔS is the change in lake storage, P is precipitation on the lake surface, Q is surface inflow and outflow, G is groundwater inflow and outflow, and E is evaporation. Net groundwater input was estimated using winter outflow measurements, when evapotranspiration is negligible and watershed runoff is absent. During these periods, lake outflow provides a reasonable estimate of net groundwater contribution. Winter water samples were also collected to characterize groundwater nutrient concentrations.

The phosphorus budget was developed using measured tributary loading data from monitored sub-watersheds (Appendix B). Export coefficients based on land cover were used to estimate phosphorus loading from the direct-drained sub-watershed. Atmospheric phosphorus deposition was estimated using precipitation data and literature-derived coefficients for wet and dry deposition, calculated as follows:

Wet deposition (kg) = (Lake area, $km^2$) × (16 $mg/m^3$) × (Total precipitation in m)

Dry deposition (kg) = (Lake area, $km^2$) × (4.8 $mg/m^2$)

Phosphorus loading from private septic systems was estimated based on the number of year-round and seasonal residents using septic systems. Septic loading was calculated using the equation:

$$L = (0.5 \text{ kg P capita}^{-1} \text{ yr}^{-1}) \times (\text{capita-years}) \times (1 - P)$$

where P represents the soil phosphorus retention rate. A retention rate of 0.9 was assumed, resulting in 10% of septic phosphorus reaching the lake. Capita-years were estimated assuming three residents per household, with seasonal residences occupied for 0.42 years and full-time residences occupied year-round.

A lake nutrient model was constructed using monthly (April–September) integrated epilimnion (0–6 ft) water samples analyzed for total phosphorus, orthophosphate, and chlorophyll-a. Temperature and dissolved oxygen profiles were collected monthly, along with Secchi depth measurements at the deep hole. In-lake data were collected in 2022 and 2023. Because both years were characterized by drought conditions, tributary monitoring continued through 2024 and 2025. Wisconsin CLMN in-lake monitoring data were used to represent lake conditions in 2024 and 2025.

The Canfield–Bachman natural lakes model was selected to evaluate phosphorus dynamics in Deer Lake. This model estimates in-lake total phosphorus concentrations based on phosphorus loading, lake morphometry, and flushing rate and is appropriate for northern Wisconsin lakes.

The model equation is:

$P = L / [z (1 + \sqrt{p})]$

where P is the predicted total phosphorus concentration (µg/L), L is the areal phosphorus load, z is mean lake depth, and p is the lake flushing rate. The model was implemented using the empirical lake modeling software Bathtub (U.S. Army Corps of Engineers).

Models developed for 2022 and 2023 were calibrated to represent an average precipitation year and adjusted to match 10-year average values for total phosphorus, chlorophyll-a, and Secchi depth. The calibrated model was then used to conduct load-reduction analyses by incrementally adjusting phosphorus inputs from individual sources. Model outputs were used to evaluate changes in predicted total phosphorus concentration, chlorophyll-a concentration, and Secchi depth, allowing identification of phosphorus sources with the greatest potential influence on lake water quality.

## Results

Data from tributary monitoring conducted between 2022 and 2025, in combination with in-lake water quality data (total phosphorus, chlorophyll-a, and Secchi depth) and measured outflow from Deer Lake, were used to develop the phosphorus budget model for 2022, 2023, and an average year.

Water budget

The mean water budget for Deer Lake was evaluated for 2022–2025. Precipitation falling directly onto the lake was the dominant water source, followed by net groundwater inflow. Table 4 summarizes the relative contributions of water sources for 2022–2023 and for an average precipitation year, while Figure 9 illustrates the predicted distribution of water sources for an average year.

| **Source** | **% of total-2022-23** | **% of total-Avg year** |
|---|---|---|
| WS1 | 1.23% | 1.72% |
| WS2 | 0.13% | 0.05% |
| WS3 | 1.28% | 0.65% |
| WS4 | 3.84% | 1.72% |
| WS5 | 0.01% | 0.22% |
| WS6 | 0.15% | 0.10% |
| WS7 | 0.08% | 0.01% |
| Direct-drained | 8.25% | 9.94% |
| Groundwater-net | 24.65% | 25.97% |
| Precipitation | 60.38% | 59.60% |

**Table 4: Water budget sources by % into Deer Lake. WS1-WS7 inputs were from field monitoring data.**

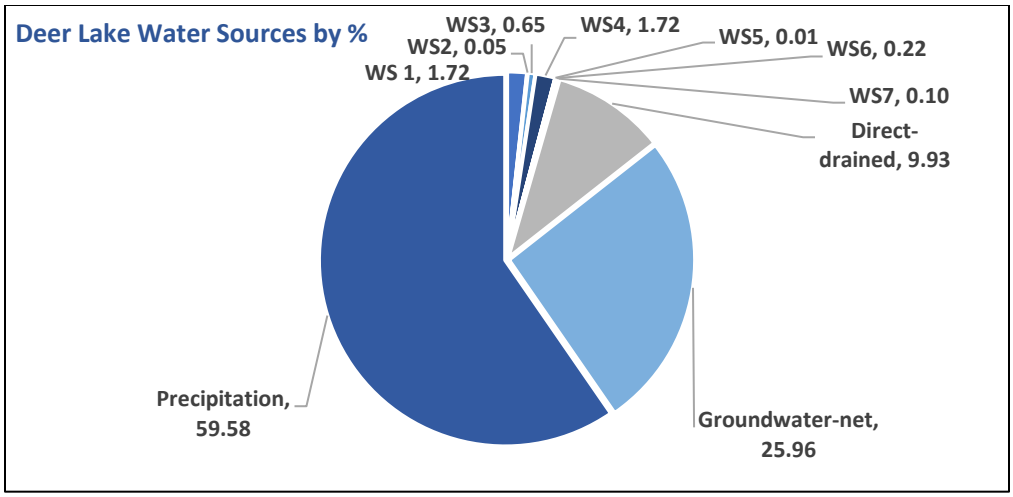



**Figure 9: A pie graph that shows the water budget sources by % of the total.**

Direct precipitation accounted for approximately 59.6% of total water inputs, followed by net groundwater inflow at approximately 26%. Watershed-derived inputs, including tributaries and direct drainage, accounted for approximately 14.4% of total inflow. Groundwater values represent net flow; some groundwater outflow via the water table was not directly measured.

In-Lake Nutrient Monitoring

Growing-season (May–September) mean concentrations of total phosphorus, chlorophyll-a, and Secchi depth were calculated for each monitoring year. Mean total phosphorus concentrations were 17.2 µg/L in 2022 and 16.5 µg/L in 2023, while mean chlorophyll-a concentrations were 4.05 and 3.28 µg/L, respectively. Mean Secchi depth increased from 17.1 feet in 2022 to 19.8 feet in 2023 (Table 5).

| Year | Mean total phosphorus (ug/L) | Mean chlorophyll a (ug/L) | Mean Secchi depth (ft) |
|---|---|---|---|
| 2022 | 17.2 | 4.05 | 17.1 |
| 2023 | 16.5 | 3.28 | 19.8 |

**Table 5: Mean total phosphorus, chlorophyll, and Secchi depth from in-lake monitoring.**

| Year | Mean total phosphorus TSI | Mean chlorophyll a TSI | Mean Secchi depth TSI |
|---|---|---|---|
| 2022 | 50.4 | 44.2 | 35.8 |
| 2023 | 49.8 | 42.6 | 33.6 |

**Table 6: Mean TSI values for each parameter from in-lake monitoring data.**

Trophic State Index (TSI) values indicate that total phosphorus conditions were in the upper mesotrophic range during both years, while chlorophyll-a remained mesotrophic and Secchi depth indicated oligotrophic conditions (Table 6). Lower TSI values than chlorophyll and total phosphorus can indicate substantial zooplankton foraging on algae. This removal of algae can increase the Secchi depth while the phosphorus TSI is higher. If the zooplankton select smaller celled algae, the water clarity could increase with less change in chlorophyll concentration. Consistent with North American Lake Management Society guidance, chlorophyll-a TSI provides the most reliable indicator of trophic condition, which remains mesotrophic for Deer Lake. Elevated Secchi depth values can be partially influenced by zebra

mussels, however a phytoplankton study completed in 2022-23 showed no evidence that this is occurring on Deer Lake. The chlorophyll concentrations have not consistently decreased since zebra mussels have been discovered. They could become a factor if the population increases in the future.

**DO/Temperature Profiles**

Temperature and dissolved oxygen profiles were used to assess thermal stratification and anoxic conditions. Stratification limits vertical mixing and can isolate sediment-released phosphorus within the hypolimnion. If stratification weakens, internal phosphorus can mix into surface waters and stimulate algal growth.

Profiles from 2022 indicate partial degradation of stratification in mid-summer, while 2023 exhibited strong and persistent stratification throughout the growing season (Figures 10 and 11). Dissolved oxygen profiles show the onset of hypolimnetic anoxia in June 2022 and July 2023 (Figures 12 and 13). The morphometric index for Deer Lake is 4.4, indicating a moderate potential for mixing during the growing season.

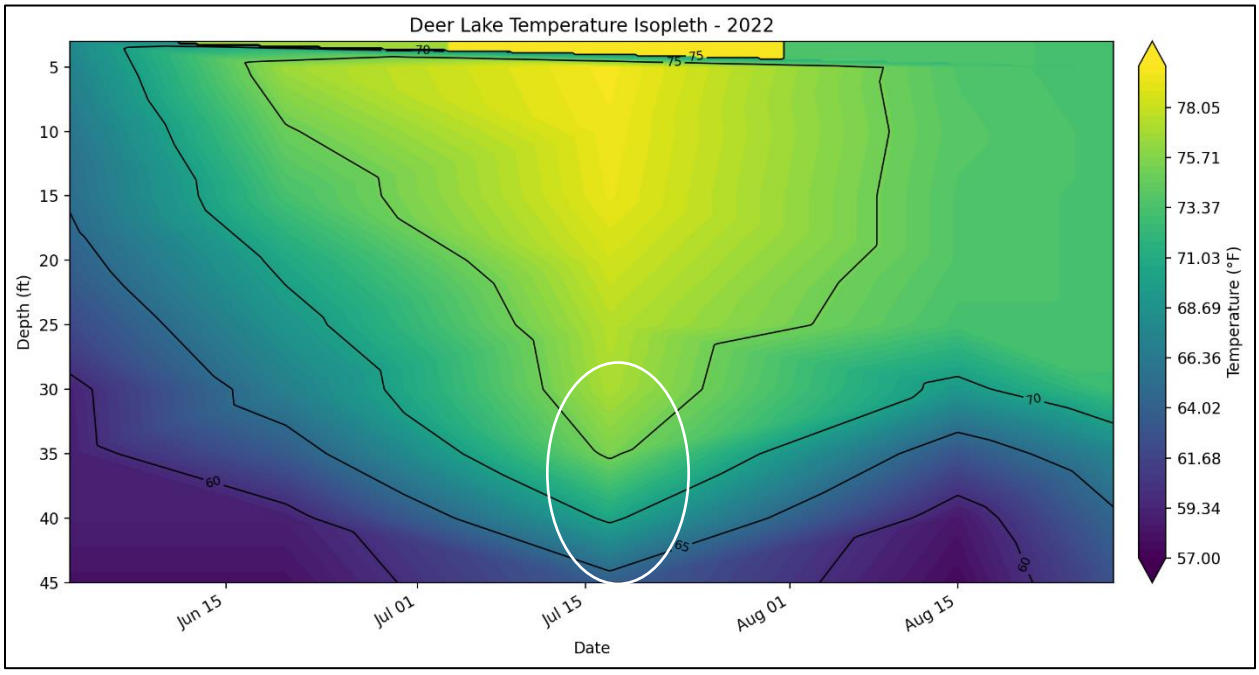



**Figure 10: Temperature profile isopleth graph for the 2022 growing season. Note the stratification degradation in mid-July (circled on graph).**

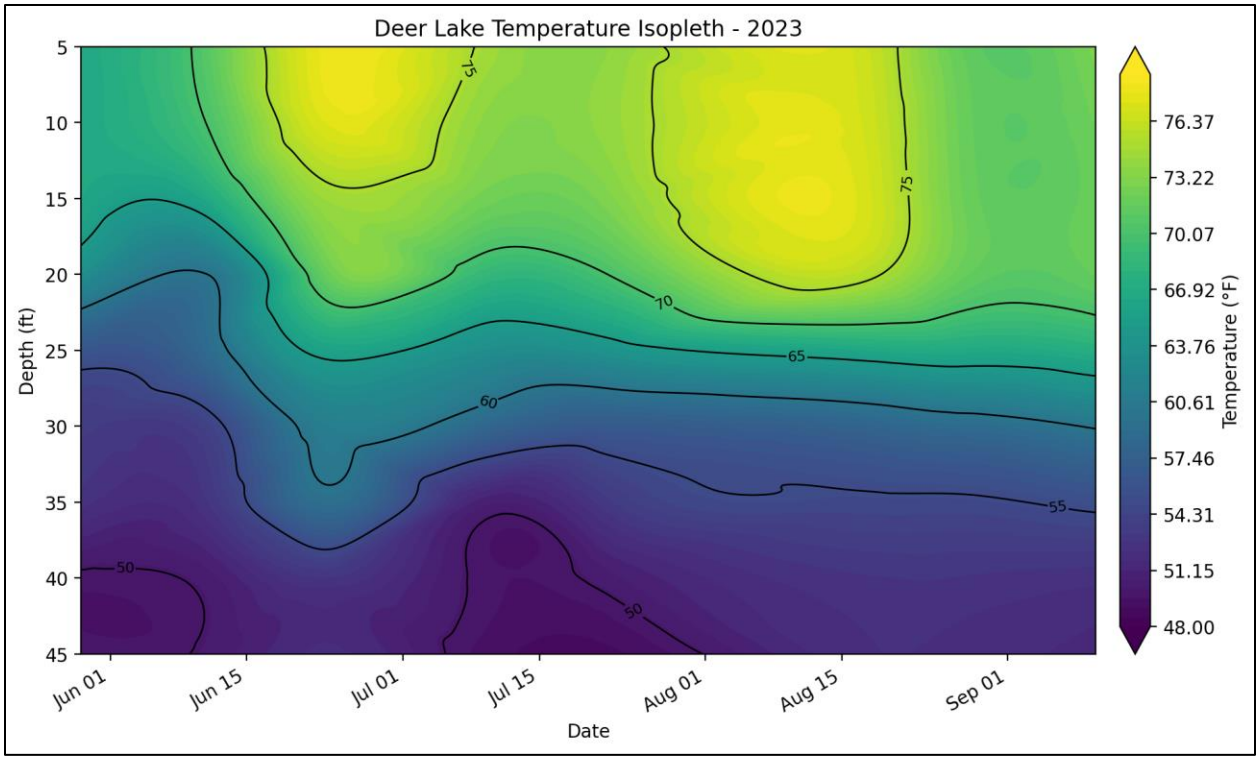



**Figure 11: Temperature profile isopleth graph for the 2023 growing season. Not the strong stratification throughout the growing season.**

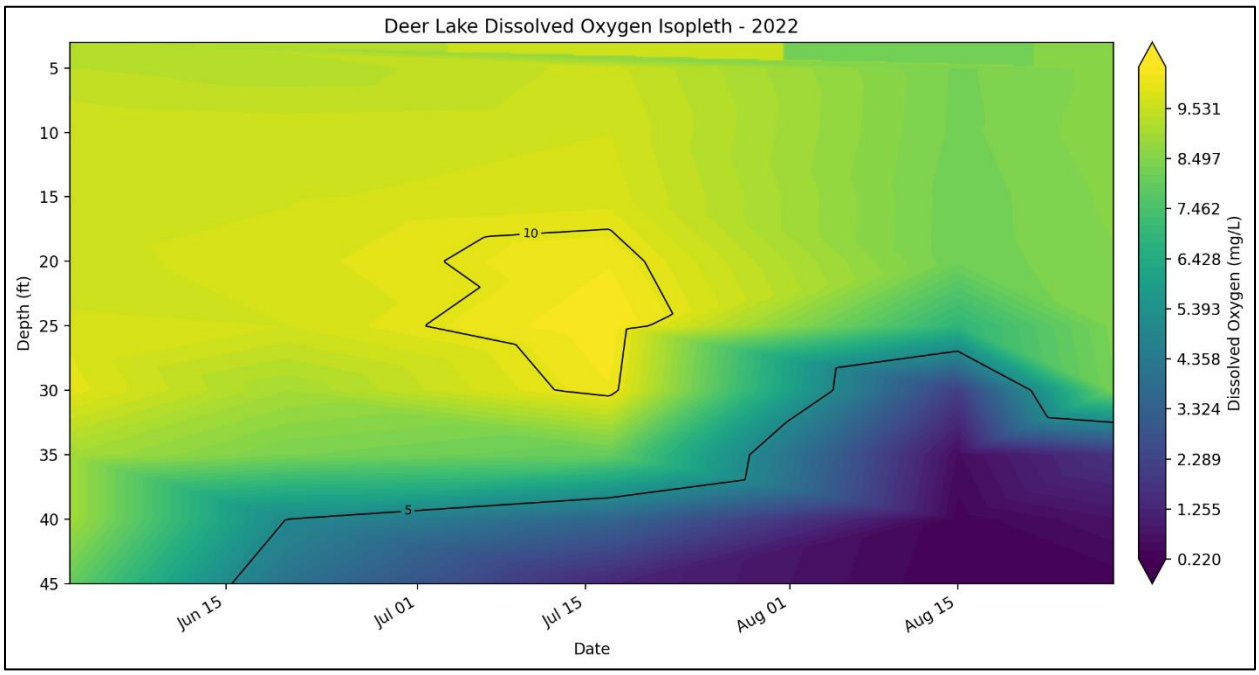



**Figure 12: Dissolved oxygen profile isopleth graph for the 2022 growing season. Note anoxic conditions in June.**

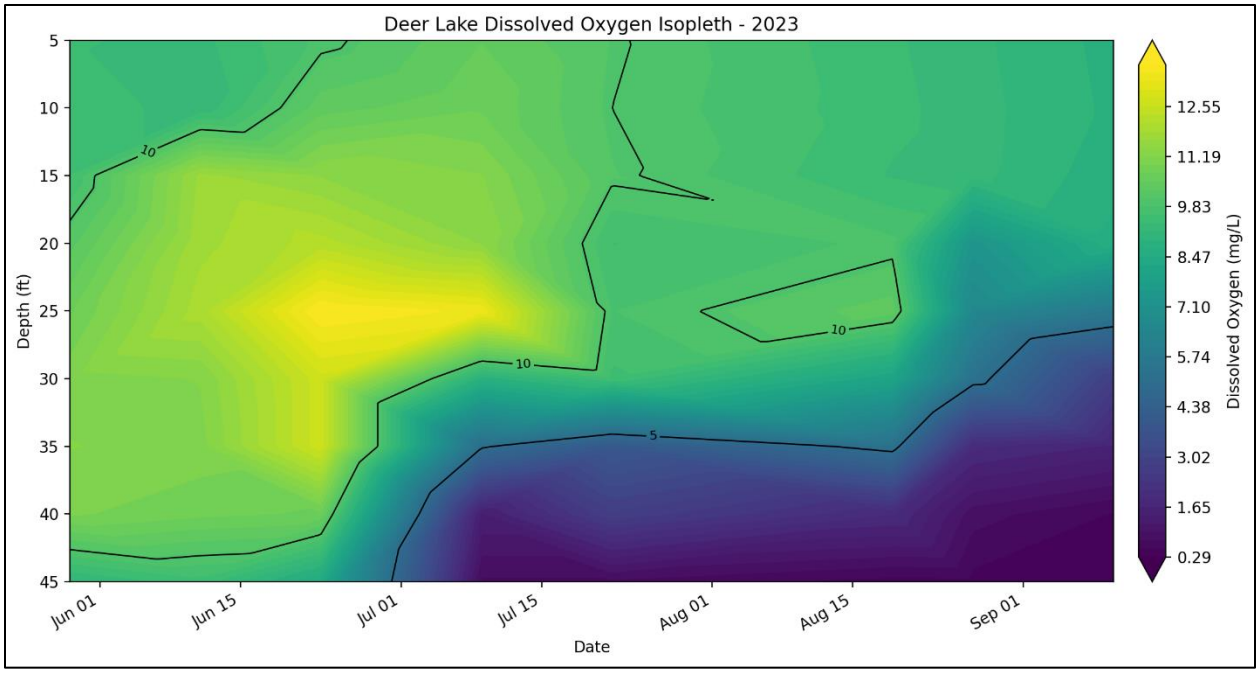



**Figure 13: Dissolved oxygen profile isopleth graph for the 2023 growing season. Note anoxic conditions in July.**

Sediment release/internal loading

| Year | Hypolimnion TP-June (ug/L) | Hypolimnion TP-Sept (ug/L) |
|---|---|---|
| 2022 | 20.1 | 605 |
| 2023 | 23.0 | 254 |

**Table 7: Total phosphorus concentration in the hypolimnion (near bottom) to show accumulation from sediment release.**

Hypolimnetic phosphorus concentrations increased substantially during the growing season, indicating sediment phosphorus release. In 2022, hypolimnetic total phosphorus increased from 20.1 µg/L in June to 605 µg/L in September, while in 2023 concentrations increased from 23.0 to 254 µg/L (Table 7). Reduced accumulation in 2023 is consistent with later onset of anoxia and stronger thermal stratification.

Previous studies estimated sediment phosphorus release rates as high as 6.4 mg P $m^{-2}$ $day^{-1}$, which would yield substantially higher seasonal loads than observed. However, in-lake monitoring data do not support extensive mixing of sediment-released phosphorus into the epilimnion during most years. Model results and profile data indicate that internal loading was minor and episodic, with an estimated 23 kg contributing to surface waters in 2022 and negligible contribution in 2023.

Phosphorus Budget

In-lake data were integrated into the Canfield–Bachman model, which demonstrated good agreement with observed total phosphorus concentrations. Predicted growing season mean concentrations were within one standard error of observed values for both 2022 and 2023 (Table 8). Phosphorus loading estimates were based on monitored tributary data, export coefficients for the direct-drained sub-watershed, and additional sources including atmospheric deposition, groundwater, and septic systems (Table 9).

| Year | Predicted total phosphorus concentration (growing season mean) | Observed total phosphorus concentration (growing season mean) | Model fit within one standard error? |
|---|---|---|---|
| 2022 | 16.7 ug/L | 17.2 ug/L | Yes |
| 2023 | 21.8 ug/L | 16.5 ug/L | Yes |

**Table 8: Model-predicted phosphorus concentrations and observed means.**

Because 2022 and 2023 were drought years, tributary monitoring continued through 2024 and 2025 to better represent average precipitation conditions. These data were used to construct an average-year model, with adjusted direct-drainage and atmospheric deposition inputs.

| Source | 2022 phosphorus loading (kg/gs)* | 2023 phosphorus loading (kg/yr) | % of total-2023 |
|---|---|---|---|
| WS-1 | 8.7 | 30.4 | 9.2 |
| WS-2 | 0.5 | 3.6 | 1.1 |
| WS-3 | 5.5 | 62.6 | 18.9 |
| WS-4 | 10.4 | 76.5 | 23.3 |
| WS-5 | 0.1 | 0.6 | 0.2 |
| WS-6 | 4.2 | 4.3 | 1.3 |
| WS-7 | 0.2 | 3.4 | 1.0 |
| Direct-drained WS | 46.0 | 58.7 | 17.9 |
| Atmospheric deposition (wet and dry) | 41.3 | 57.9 | 17.6 |
| Groundwater | 5.5 | 12.1 | 3.7 |
| Septic systems | 14.3 | 19.0 | 5.8 |
| Internal load | 23.2 | 0 | 0 |
| Total load | 160.0 | 328.6 | 100 |

*Only growing season data were available from tributary flows and loading.

**Table 9: Phosphorus budget for Deer Lake from model estimates in 2022 and 2023.**

For an average precipitation year, total phosphorus loading to Deer Lake is estimated at approximately 279 kg (Table 10). The direct-drained sub-watershed is the largest single source, contributing 23% of the total load, followed by atmospheric deposition at 22.8%. Among monitored tributaries, WS4 contributes the highest overall load, largely reflecting its watershed size. WS4 has the second lowest load per acre. WS1 has the highest load per acre, followed by WS3.

| Source: Avg Precipitation Year | Kg of phosphorus/year | % of total load | Kg/acre |
|---|---|---|---|
| WS-1 | 33.6 | 12.0 | 0.22 |
| WS-2 | 3.6 | 1.3 | 0.03 |
| WS-3 | 33.8 | 12.1 | 0.11 |
| WS-4 | 39.0 | 14.0 | 0.03 |
| WS-5 | 0.6 | 0.6 | 0.001 |
| WS-6 | 6.0 | 2.2 | 0.08 |
| WS-7 | 2.9 | 1.1 | 0.08 |
| Direct-drained WS | 64.0 | 23.0 | 0.13 |
| Groundwater | 12.6 | 4.5 | |
| Septic systems | 19.0 | 6.8 | |
| Atmospheric deposition (wet and dry) | 63.6 | 22.8 | 0.08 |
| Total load | 278.7 | 100 | |
| Loading rate (kg/km$^2$/year) | 87.7 | | |

**Table 10: Phosphorus budget estimates from model for an average precipitation year.**

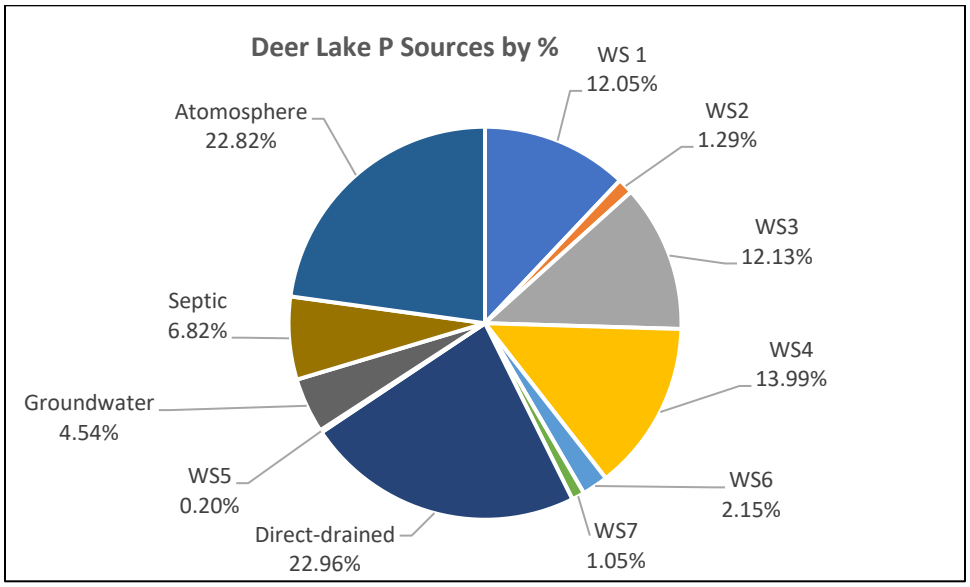



**Figure 14: Pie graph showing the phosphorus sources for an average year in Deer Lake by %.**

### Chlorophyll and Secchi Depth

Bathtub model components were used to evaluate chlorophyll-a concentration and Secchi depth. The Jones–Bachman model was applied for chlorophyll-a, and the chlorophyll-a/turbidity model was used for Secchi depth. Models were calibrated to match multi-year average observed values.

**Loading Analysis**

The model was calibrated to represent multi-year average conditions, assuming internal loading is negligible in most years. Load-reduction scenarios were evaluated by adjusting phosphorus inputs from major sources.

| Deer Lake Multi-year means | Total phosphorus | Chlorophyll | Secchi depth |
|---|---|---|---|
| **Monitored average for last 10 years** | 18 ug/L | 4.5 ug/L | 15 feet |
| **Uncalibrated model predictions** | 18.9 ug/L | 5.9 ug/L | 14.4 feet |
| **Calibrated model predictions** | 18.1 ug/L | 4.6 ug/L | 15 feet |

**Table 11: Model estimates for phosphorus concentration, chlorophyll concentration, and Secchi depth. The calibrated model demonstrates the base concentrations from model before loading is changed.**

Direct-drained watershed

Reducing phosphorus loading from the direct-drained sub-watershed by 20% resulted in a predicted decrease of 0.5 µg/L in total phosphorus, a 0.2 µg/L reduction in chlorophyll-a, and a 0.3-foot increase in Secchi depth (Table 12).

Increases in phosphorus loading from the direct-drained watershed show significant increases in total phosphorus and chlorophyll, with a degradation in Secchi depth.

| Scale factor | Predicted TP | Predicted Chl-a | Predicted Secchi depth |
|---|---|---|---|
| 0.20 | 16.0 | 3.8 | 16.8 |
| 0.40 | 16.5 | 4.0 | 16.4 |
| 0.60 | 17.1 | 4.2 | 15.7 |
| 0.80 | 17.6 | 4.4 | 15.4 |
| 1.00 | 18.1 | 4.6 | 15.1 |
| 1.20 | 18.6 | 4.8 | 14.8 |
| 1.40 | 19.1 | 5.0 | 14.4 |
| 1.60 | 19.6 | 5.2 | 14.1 |
| 1.80 | 20.1 | 5.4 | 13.8 |

**Table 12: Model predictions for total phosphorus (TP), chlorophyll (Chl-a) and Secchi Depth with loading changes in the direct-drained watershed. The scale factor shows the fraction of the base load (0.8 = 20% reduction).**

All tributary sources

A 20% reduction across all tributary sources (approximately 43 kg) resulted in larger predicted improvements, including a 1.8 µg/L reduction in total phosphorus, a 0.6 µg/L reduction in chlorophyll-a, and a 0.7-foot increase in Secchi depth (Table 13). Conversely, increases in phosphorus loading from watershed sources were predicted to result in degraded lake water quality. Changes such as increasing

the number of buildings or other impervious surfaces, would result in higher phosphorus into Deer Lake, leading to more algae and less water clarity.

| Scale factors for all tributary loading | P loading-kg/yr | Predicted TP | Predicted Chl-a | Predicted Secchi |
|---|---|---|---|---|
| 0.20 | 43 | 9.9 | 1.9 | 27.0 |
| 0.40 | 86 | 12.3 | 2.6 | 16.4 |
| 0.60 | 129 | 14.4 | 3.3 | 18.0 |
| 0.80 | 172 | 16.3 | 4.0 | 16.4 |
| 1.00 | 215 | 18.1 | 4.6 | 15.1 |
| 1.20 | 258 | 19.8 | 5.3 | 14.1 |
| 1.40 | 301 | 21.4 | 5.9 | 13.1 |
| 1.60 | 344 | 22.9 | 6.5 | 12.1 |
| 1.80 | 387 | 24.3 | 7.1 | 11.5 |

**Table 13: Model predictions for total phosphorus, chlorophyll, and Secchi depth with changes in all tributary loading.**

## Discussion

The nutrient analysis for Deer Lake indicates that the Canfield–Bachman natural lakes model provides a good fit to observed conditions. Predicted total phosphorus concentrations based on measured phosphorus inputs were within the standard error of observed in-lake concentrations. For 2022, the model slightly underpredicted total phosphorus; however, when approximately 23 kg of internal phosphorus loading was included, predicted concentrations closely matched observed values. An increase in total phosphorus from July to August 2022 (14 µg/L to 18 µg/L) occurred during a period of minimal precipitation and runoff. Coupled with temperature and dissolved oxygen profile data, this pattern supports the estimated contribution from internal loading during that year.

In 2023, the model overpredicted total phosphorus concentrations (21.8 µg/L) relative to observed in-lake measurements. This discrepancy is likely attributable to elevated spring runoff associated with rapid snowmelt rather than growing-season precipitation. Although 2023 was characterized by drought conditions during the growing season, a large snowpack melted over a brief 2–3-day period during winter 2022–23, resulting in substantial runoff over frozen ground. Tributary flow data confirm that several sub-watersheds delivered higher phosphorus loads in 2023 than in an average precipitation year, despite below-average annual precipitation.

Model results for an average precipitation year indicate that the direct-drained sub-watershed is the largest source of phosphorus to Deer Lake. Phosphorus loading from this area was estimated using runoff and export coefficients, which resulted in higher runoff volumes than most monitored tributaries but lower phosphorus concentrations. This approach is considered appropriate given the sub-watershed's proximity to the lake, extensive residential development, high proportions of impervious surfaces, and steep nearshore slopes that promote rapid runoff. Atmospheric deposition represents the second-largest phosphorus source and is largely unmanageable.

Among the monitored tributaries, WS4 contributes the highest overall phosphorus load, followed by WS1 and WS3. WS4 is the largest sub-watershed by area and already contains multiple management practices, resulting in lower loading than would otherwise be expected (it is second lowest per acre). Runoff reduction practices are currently being installed in WS3 (2025–26) and are anticipated to reduce future loading. WS1 presents greater management challenges, as the lower pond contributes higher phosphorus loads than the upper pond, and opportunities for improving lower-pond performance are limited. Long-term trend analyses show significant improvements in chlorophyll-a concentrations and Secchi depth, likely reflecting the cumulative benefits of watershed management practices implemented across multiple sub-watersheds.

Figure 15 illustrates the monitored phosphorus loads from each sub-watershed and compares them to predicted loads based solely on export coefficients. When the model was run using export coefficients for all sub-watersheds instead of measured data, predicted lake conditions were substantially degraded, with total phosphorus increasing to 30 µg/L, chlorophyll-a to 10 µg/L, and Secchi depth decreasing to 9.2 feet. These values represent significantly poorer water quality than the current 10-year averages of 18 µg/L for total phosphorus, 4.5 µg/L for chlorophyll-a, and 15.1 feet for Secchi depth. The 10-year average of 18 ug/L is 60% of the predicted 30 ug/L concentration in Deer Lake. Tributary contributions were monitored at a total load of 121.7 kg (not including direct-drained), while the predicted load from the sub-watersheds (using export coefficients) is 560.3 kg. Therefore, the monitored loading from the sub-watershed (not direct-drained) is 21.7% or a reduction of 78.3%. If the direct drainage area is added at a constant value, the total watershed reduction in phosphorus loading from installation of conservation practices is equivalent to 70%. While there have been many practices installed in the direct drainage area, construction of new large homes and lawns may have offset these loading reductions.

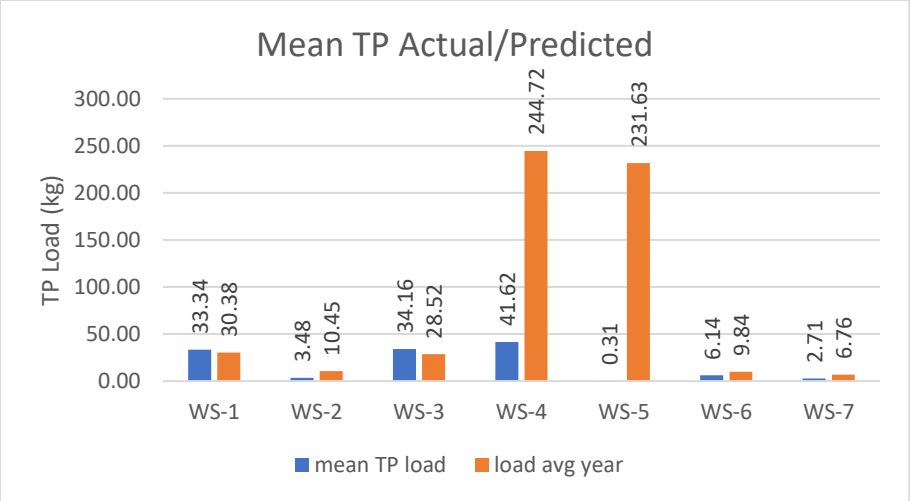



**Figure 15: This graph shows the monitored phosphorus load from each sub-watershed and the predicted loading if export coefficients are used.**

Hypolimnetic phosphorus data indicate substantial sediment phosphorus release in 2022 and a more moderate release in 2023, consistent with previous sediment studies in Deer Lake. Temperature and

dissolved oxygen profiles from 2022 suggest partial weakening of stratification, allowing a small amount of sediment-released phosphorus to mix into the epilimnion. This pattern was not observed in 2023, when stratification remained strong. Given long-term monitoring data, sediment phosphorus release appears to be an infrequent contributor to epilimnion phosphorus during the growing season, as Deer Lake typically remains stratified and retains released phosphorus in the hypolimnion.

Load-reduction scenarios demonstrate that changes in phosphorus loading from the direct-drained sub-watershed would result in measurable changes in lake water quality. A 20% reduction in phosphorus loading from this area is predicted to decrease total phosphorus by 0.5 µg/L, reduce chlorophyll-a by 0.2 µg/L, and increase Secchi depth by 0.3 feet. Additional analyses evaluating combined reductions across tributary sources indicate that a cumulative 20% reduction (approximately 43 kg) would reduce total phosphorus by 1.8 µg/L, decrease chlorophyll-a by 0.6 µg/L, and increase Secchi depth by 0.7 feet. Conversely, increases in phosphorus loading from the direct-drained or tributary sub-watersheds would result in degraded lake conditions. This is an important point as if present development increases or changes (increasing buildings and other impervious surfaces in present developed areas), lake degradation is expected.

Empirical models such as the one used in this study are subject to uncertainty. Phosphorus loading estimates based on export coefficients, flow measurements, and evaporation data all introduce potential error. While tributary monitoring provides more reliable estimates than export coefficients alone, uncertainties remain due to instrumentation limitations and flow-rating curve development. Evaporation estimates based on pan data also introduce uncertainty. Despite these limitations, this analysis benefits from a substantially larger and more robust dataset than previous studies. Model predictions closely match observed in-lake conditions for 2022 and 2023 as well as the 10-year average, indicating that the results provide a reliable and practical framework for managing phosphorus inputs and protecting water quality in Deer Lake.

### Recommendations

The direct-drained sub-watershed represents the highest priority for future phosphorus reduction efforts since it is estimated to be the largest contributor of nutrients and can be managed. This area contains extensive residential development with impervious surfaces and manicured lawns that increase runoff and nutrient delivery. Numerous management practices have previously been implemented that reduce nutrient loading; however, these could have been offset by added development. Management practices that promote infiltration and reduce runoff—such as shoreline buffers, rain gardens, infiltration practices, reduced fertilizer use, and conversion of turf to native vegetation—should be emphasized in areas that have not installed practices. These should be considered for present developed areas as well as future development.

Additional mitigation opportunities should be evaluated in other contributing sub-watersheds, particularly WS-1 and WS-3. Continued long-term monitoring is recommended to track watershed loading trends and in-lake response and to support adaptive management of Deer Lake.

## References


Banks, Hugh H. and James E Nighswander. Relative Contribution of Hemlock Pollen to the Phosphorus Loading of the Clear Lake Ecosystem Near Minden, Ontario. Proceedings: Symposium of Sustainable Management of Hemlock Ecosystems in Eastern North America.

Canfield, Daniel and Roger W. Bachman. Prediction of Total Phosphorus Concentrations, Chlorophyll a, and Secchi Depths in Natural and Artificial Lakes. 1981. Canadian Journal of Fisheries and Aquatic Sciences 38(4):414-423.

Carlson, R. E. 1977. A Trophic State Index for Lakes. Limnology and Oceanography. Vol. 22 p. 361-369

Hunt, Randall J, Steven R. Greb, and David J. Gracyk. Evaluating the Effects of Near Shore Development in Wisconsin Lakes. USGS.

Jones, John & Bachmann, R.W. (1976). Prediction of Phosphorus and Chlorophyll Levels in Lakes. Journal of the Water Pollution Control Federation. 48. 2176-2182.

Lenters, John D., Timothy K. Kratz, and Carl J. Bowser. 2005. Effect of Climate Variability on Lake Evaporation: Results from a Long-term Energy Budget Study of Sparkling Lake Northern Wisconsin (USA). 308:168-195.

Mattson, Mark D., and Russell A. Isaac. 1999 Calibration of Phosphorus Export Coefficients for Total Maximum Daily Loads of Massachusetts Lakes. Lake and Reservoir Management. 15(3): 209-219.

Nurnberg, Gertrud K. 1998. Prediction of annual and seasonal phosphorus concentrations in stratified and polymictic lakes. Limnology and Oceanography. 43(7). 1544-1552.

Nurnberg, Gertrud K. 2004. Quantified Hypoxia and Anoxia in Lakes and Reservoirs. The Scientific World Journal (2004) 4, 42–54.

Osgood, Richard A. 1988. Lake mixing and internal phosphorus dynamics. Arch. Hydrobiologia. 113(4). 629-638.

Osgood Consulting. 2004. Lake and Watershed Analysis Deer Lake Management Plan.

Panuska, John C. and Jeff C. Kreider. 2003. Wisconsin Lakes Modeling Suite. Wisconsin Department of Natural Resources.

Panuska, John C. and Richard A. Lillie. 1995. Phosphorus Loadings from Wisconsin Watersheds: Recommended Phosphorus Export Coefficients for Agriculture and Forested Watersheds. Bureau of Research-Wisconsin Department of Natural Resources.

Robertson, Dale M., William T. Rose, and Paul E. Juckem. 2009. Water Quality and Hydrology of Whitefish (Bardon) Lake, Douglas County Wisconsin with Special Emphasis on Responses of an Oligotrophic Seepage Lake to Changes in Phosphorus Loading and Water Level. Scientific Investigations Report 2009-5089. US Geological Survey.

Rose, William J. 1989. Water and Phosphorus Budgets and Trophic State, Balsam Lake, Northwestern Wisconsin, 1987-1989. US Geological Society.

Schieffer, Steve. Summary of Baseline Phytoplankton Composition in Deer Lake, Polk County, WI 2022-23.

Sondergaard, Martin. Jensen, Jens Peder. and Erik Jeppesen. 2003. Role of sediment and internal loading of phosphorus in shallow lakes. Hydrobiologia. 506-509: 135-145

Sorenson, Colton. Deer Lake Land Use and Flow Accumulation Mapping. Polk County Land and Water Conservation Dept. 2022.

Taube, Clarence M. 2000. Ch. 12: Three Methods for Computing the Volume of a Lake. Manual of Fisheries Survey Methods II.

Walker, William W. Jr. Ph.D. 2004. BathTub (version 6.1): Simplified Techniques for Eutrophication Assessment and Prediction. USAE Waterways Experiment Solutions.

Watras, Carl, Ken A. Morrison, and J.L. Rubsam. 2016. Effect of DOC on Evaporation from Small Wisconsin Lakes. Journal of Hydrology. 540:162-165.

***Appendix A: Data used for the analysis***

In-lake analysis data:

| TP (ug/L) | May | June | July | August | Sept | Mean | | |
|---|---|---|---|---|---|---|---|---|
| 2022 | 17 | 14 | 18 | 19 | 18 | 17.2 | | |
| 2023 | 18 | 15.5 | 15 | 20 | 14 | 16.5 | | |
| Chl-a (ug/L) | May | June | July | August | Sept | Mean ga | July-Sept mean | |
| 2022 | 1.5 | 2.1 | 5.9 | 6.05 | 4.7 | 4.05 | 5.55 | |
| 2023 | 0.9 | 2 | 5 | 4.5 | 4 | 3.28 | 4.5 | |
| Secchi depth (ft) | May | June | July | August | Sept | Mean (ft) | mean (m) | |
| 2022 | | 21.5 | 14 | 16 | 17 | 17.125 | 5.22 | |
| 2023 | 27 | 24 | 15 | 17 | 16 | 19.8 | 6.04 | |

Profile data:

| Date | Depth (ft) | Temperature (°F) | Date | Depth (ft) | Temp (°F) |
|---|---|---|---|---|---|
| 06/02/2022 | 3 | 67.8 | 05/29/2023 | 5 | 66.5 |
| 06/02/2022 | 6 | 66.9 | 05/29/2023 | 10 | 66.5 |
| 06/02/2022 | 9 | 66.2 | 05/29/2023 | 15 | 66.4 |
| 06/02/2022 | 12 | 65.5 | 05/29/2023 | 20 | 63.2 |
| 06/02/2022 | 15 | 65.3 | 05/29/2023 | 25 | 56.2 |
| 06/02/2022 | 18 | 64.6 | 05/29/2023 | 30 | 53.4 |
| 06/02/2022 | 21 | 63.7 | 05/29/2023 | 35 | 52.4 |
| 06/02/2022 | 24 | 62.4 | 05/29/2023 | 40 | 49.8 |
| 06/02/2022 | 27 | 61.2 | 05/29/2023 | 45 | 49.8 |
| 06/02/2022 | 30 | 59.2 | 06/11/2023 | 5 | 71 |
| 06/02/2022 | 35 | 59 | 06/11/2023 | 10 | 70.1 |
| 06/02/2022 | 40 | 59 | 06/11/2023 | 15 | 66.7 |
| 06/02/2022 | 45 | 58 | 06/11/2023 | 20 | 60 |
| 06/20/2022 | 5 | 76.7 | 06/11/2023 | 25 | 58.7 |
| 06/20/2022 | 10 | 74.8 | 06/11/2023 | 30 | 54.1 |
| 06/20/2022 | 15 | 73.2 | 06/11/2023 | 35 | 52.7 |
| 06/20/2022 | 20 | 70.7 | 06/11/2023 | 40 | 50.4 |
| 06/20/2022 | 25 | 68.9 | 06/11/2023 | 45 | 50.2 |
| 06/20/2022 | 30 | 66.9 | 06/23/2023 | 5 | 78.1 |
| 06/20/2022 | 35 | 63.5 | 06/23/2023 | 10 | 77.4 |
| 06/20/2022 | 40 | 59 | 06/23/2023 | 15 | 74.3 |
| 06/20/2022 | 45 | 58 | 06/23/2023 | 20 | 71.7 |
| 07/17/2022 | 5 | 79.8 | 06/23/2023 | 25 | 65.7 |
| 07/17/2022 | 10 | 79.5 | 06/23/2023 | 30 | 61.1 |
| 07/17/2022 | 15 | 79.3 | 06/23/2023 | 35 | 59.2 |

| Date | Depth (ft) | Temperature (°F) | Date | Depth (ft) | Temp (°F) |
|---|---|---|---|---|---|
| 07/17/2022 | 20 | 78.4 | 06/23/2023 | 40 | 52.7 |
| 07/17/2022 | 25 | 77.5 | 06/23/2023 | 45 | 51.8 |
| 07/17/2022 | 30 | 77.1 | 07/09/2023 | 5 | 74.8 |
| 07/17/2022 | 35 | 75.4 | 07/09/2023 | 10 | 73.7 |
| 07/17/2022 | 40 | 70.5 | 07/09/2023 | 15 | 72.5 |
| 07/17/2022 | 45 | 63.8 | 07/09/2023 | 20 | 68.7 |
| 08/15/2022 | 5 | 73.7 | 07/09/2023 | 25 | 63.2 |
| 08/15/2022 | 10 | 73.9 | 07/09/2023 | 30 | 58.4 |
| 08/15/2022 | 15 | 73.7 | 07/09/2023 | 35 | 50.9 |
| 08/15/2022 | 20 | 73.7 | 07/09/2023 | 40 | 49.8 |
| 08/15/2022 | 25 | 73.2 | 07/09/2023 | 45 | 49.4 |
| 08/15/2022 | 30 | 69.2 | 07/22/2023 | 5 | 73.7 |
| 08/15/2022 | 35 | 62.9 | 07/22/2023 | 10 | 74 |
| 08/15/2022 | 40 | 58.4 | 07/22/2023 | 15 | 73 |
| 08/15/2022 | 45 | 57.5 | 07/22/2023 | 20 | 70 |
| 08/28/2022 | 5 | 73 | 07/22/2023 | 25 | 63.8 |
| 08/28/2022 | 10 | 73.2 | 07/22/2023 | 30 | 56.7 |
| 08/28/2022 | 15 | 73.2 | 07/22/2023 | 35 | 53.1 |
| 08/28/2022 | 20 | 73.2 | 07/22/2023 | 40 | 50.4 |
| 08/28/2022 | 25 | 73.2 | 07/22/2023 | 45 | 48.9 |
| 08/28/2022 | 30 | 72.9 | 08/19/2023 | 5 | 75.9 |
| 08/28/2022 | 35 | 67.4 | 08/19/2023 | 10 | 76.2 |
| 08/28/2022 | 40 | 64.5 | 08/19/2023 | 15 | 76.5 |
| 08/28/2022 | 45 | 62.7 | 08/19/2023 | 20 | 75 |
| | | | 08/19/2023 | 25 | 66.5 |
| | | | 08/19/2023 | 30 | 58.1 |
| | | | 08/19/2023 | 35 | 54.7 |
| | | | 08/19/2023 | 40 | 52.7 |
| | | | 08/19/2023 | 45 | 52.2 |
| | | | 08/27/2023 | 5 | 71.7 |
| | | | 08/27/2023 | 10 | 72.1 |
| | | | 08/27/2023 | 15 | 72.3 |
| | | | 08/27/2023 | 20 | 71.9 |
| | | | 08/27/2023 | 25 | 66.7 |
| | | | 08/27/2023 | 30 | 58.8 |
| | | | 08/27/2023 | 35 | 54.7 |
| | | | 08/27/2023 | 40 | 52.7 |
| | | | 08/27/2023 | 45 | 52 |
| | | | 09/10/2023 | 5 | 72.9 |
| | | | 09/10/2023 | 10 | 72.2 |
| | | | 09/10/2023 | 15 | 71.9 |

| Date | Depth (ft) | Temperature (°F) | Date | Depth (ft) | Temp (°F) |
|---|---|---|---|---|---|
| | | | 09/10/2023 | 20 | 71.7 |
| | | | 09/10/2023 | 25 | 67.4 |
| | | | 09/10/2023 | 30 | 60.2 |
| | | | 09/10/2023 | 35 | 55.5 |
| | | | 09/10/2023 | 40 | 52.4 |
| | | | 09/10/2023 | 45 | 51.5 |

| Date | Depth | Dissolved Oxygen (mg/L) |
|---|---|---|
| 06/02/2022 | 3 | 9.2 |
| 06/02/2022 | 6 | 9.44 |
| 06/02/2022 | 9 | 9.62 |
| 06/02/2022 | 12 | 9.68 |
| 06/02/2022 | 15 | 9.67 |
| 06/02/2022 | 18 | 9.64 |
| 06/02/2022 | 21 | 9.62 |
| 06/02/2022 | 24 | 9.71 |
| 06/02/2022 | 27 | 9.87 |
| 06/02/2022 | 30 | 9.97 |
| 06/02/2022 | 35 | 9.00 |
| 06/02/2022 | 40 | 9.00 |
| 06/02/2022 | 45 | 8.00 |
| 06/20/2022 | 5 | 9.23 |
| 06/20/2022 | 10 | 9.65 |
| 06/20/2022 | 15 | 9.68 |
| 06/20/2022 | 20 | 9.81 |
| 06/20/2022 | 25 | 9.7 |
| 06/20/2022 | 30 | 9.02 |
| 06/20/2022 | 35 | 8.34 |
| 06/20/2022 | 40 | 5.00 |
| 06/20/2022 | 45 | 4.00 |
| 07/17/2022 | 5 | 9.6 |
| 07/17/2022 | 10 | 9.7 |
| 07/17/2022 | 15 | 9.8 |
| 07/17/2022 | 20 | 10.2 |
| 07/17/2022 | 25 | 10.4 |
| 07/17/2022 | 30 | 10.2 |
| 07/17/2022 | 35 | 8 |
| 07/17/2022 | 40 | 3.5 |
| 07/17/2022 | 45 | 1.3 |
| 08/15/2022 | 5 | 8.29 |
| 08/15/2022 | 10 | 8.27 |

| | | |
|---|---|---|
| 08/15/2022 | 15 | 8.21 |
| 08/15/2022 | 20 | 8.2 |
| 08/15/2022 | 25 | 6.87 |
| 08/15/2022 | 30 | 2.1 |
| 08/15/2022 | 35 | .54 |
| 08/15/2022 | 40 | .29 |
| 08/15/2022 | 45 | .22 |
| 08/28/2022 | 5 | 8.57 |
| 08/28/2022 | 10 | 8.62 |
| 08/28/2022 | 15 | 8.54 |
| 08/28/2022 | 20 | 8.48 |
| 08/28/2022 | 25 | 8.4 |
| 08/28/2022 | 30 | 8.27 |
| 08/28/2022 | 35 | 1.71 |
| 08/28/2022 | 40 | .72 |
| 08/28/2022 | 45 | .27 |

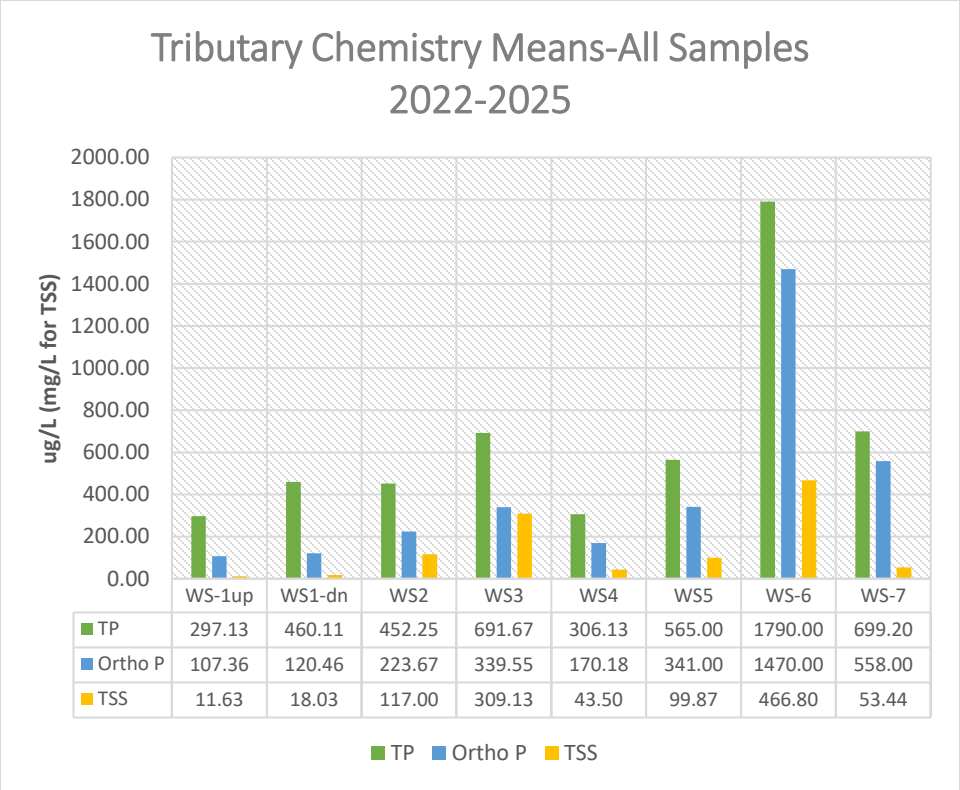
| Date | Depth (ft) | Dissolved Oxygen (mg/L) |
|---|---|---|
| 05/29/2023 | 5 | 9.4 |
| 05/29/2023 | 10 | 9.6 |
| 05/29/2023 | 15 | 9.6 |
| 05/29/2023 | 20 | 10.2 |
| 05/29/2023 | 25 | 10.7 |
| 05/29/2023 | 30 | 11.1 |
| 05/29/2023 | 35 | 11.2 |
| 05/29/2023 | 40 | 11 |
| 05/29/2023 | 45 | 9.1 |
| 06/11/2023 | 5 | 9.3 |
| 06/11/2023 | 10 | 9.2 |
| 06/11/2023 | 15 | 11.7 |
| 06/11/2023 | 20 | 11.8 |
| 06/11/2023 | 25 | 12 |
| 06/11/2023 | 30 | 11.2 |
| 06/11/2023 | 35 | 11.1 |
| 06/11/2023 | 40 | 10.8 |
| 06/11/2023 | 45 | 9.5 |
| 06/23/2023 | 5 | 9.9 |
| 06/23/2023 | 10 | 10.4 |
| 06/23/2023 | 15 | 11.4 |
| 06/23/2023 | 20 | 12.2 |
| 06/23/2023 | 25 | 13.7 |
| 06/23/2023 | 30 | 12.7 |
| 06/23/2023 | 35 | 12.7 |

| | | |
|---|---|---|
| 06/23/2023 | 40 | 10.7 |
| 06/23/2023 | 45 | 8.4 |
| 07/09/2023 | 5 | 10.5 |
| 07/09/2023 | 10 | 10.7 |
| 07/09/2023 | 15 | 11.2 |
| 07/09/2023 | 20 | 11.4 |
| 07/09/2023 | 25 | 13.4 |
| 07/09/2023 | 30 | 8.8 |
| 07/09/2023 | 35 | 5.1 |
| 07/09/2023 | 40 | 1.4 |
| 07/09/2023 | 45 | .7 |
| 07/22/2023 | 5 | 10.04 |
| 07/22/2023 | 10 | 10 |
| 07/22/2023 | 15 | 10.07 |
| 07/22/2023 | 20 | 9.59 |
| 07/22/2023 | 25 | 9.82 |
| 07/22/2023 | 30 | 9.54 |
| 07/22/2023 | 35 | 4 |
| 07/22/2023 | 40 | 2.74 |
| 07/22/2023 | 45 | .7 |
| 08/19/2023 | 5 | 9.41 |
| 08/19/2023 | 10 | 9.45 |
| 08/19/2023 | 15 | 9.35 |
| 08/19/2023 | 20 | 9.88 |
| 08/19/2023 | 25 | 10.4 |
| 08/19/2023 | 30 | 8.05 |
| 08/19/2023 | 35 | 5.27 |
| 08/19/2023 | 40 | 1.91 |
| 08/19/2023 | 45 | .42 |
| 08/27/2023 | 5 | 929 |
| 08/27/2023 | 10 | 9.23 |
| 08/27/2023 | 15 | 9.22 |
| 08/27/2023 | 20 | 7.24 |
| 08/27/2023 | 25 | 6.56 |
| 08/27/2023 | 30 | 5.31 |
| 08/27/2023 | 35 | 1.93 |
| 08/27/2023 | 40 | .85 |
| 08/27/2023 | 45 | .44 |
| 09/10/2023 | 5 | 8.84 |
| 09/10/2023 | 10 | 8.87 |
| 09/10/2023 | 15 | 8.77 |
| 09/10/2023 | 20 | 8.62 |
| 09/10/2023 | 25 | 522 |
| 09/10/2023 | 30 | 2.74 |

| | | |
|---|---|---|
| 09/10/2023 | 35 | 1.61 |
| 09/10/2023 | 40 | .5 |
| 09/10/2023 | 45 | .29 |

| **Land Cover coefficients** | **Low P (lb./mi2/yr)** | **Med P (lb./mi2/yr)** | **High P (lb./mi2/yr)** | **runoff coefficient** | **mg/m3 low** | **mg/m3 med** | **mg/m 3 hi** |
|---|---|---|---|---|---|---|---|
| Rural Residential | 29 | 57 | 143 | **0.15** | **41** | **80** | **202** |
| Medium Density Urban | 171 | 286 | 457 | **0.26** | **139** | **233** | **372** |
| High Density Urban | 571 | 856 | 1142 | **0.5** | **241** | **362** | **483** |
| Pasture/Grass | 57 | 171 | 286 | **0.25** | **48** | **145** | **242** |
| Row Crop Agriculture | 286 | 571 | 1713 | **0.25** | **242** | **483** | **1449** |
| Forest | 29 | 54 | 103 | **0.1** | **61** | **114** | **218** |
| Wetland | 22 | 56 | 85 | **0.08** | **58** | **148** | **225** |

| Sub-WS runoff volumes | **2022*($hm^3$)** | **2023($hm^3$)** | **2024#($hm^3$)** | **2025($hm^3$)** | **Avg. monitoring period($hm^3$)** | **Predicted from avg year ($hm^3$)** |
|---|---|---|---|---|---|---|
| WS-1 | 0.019 | 0.066 | 0.084 | 0.0675 | 0.073 | 0.11 |
| WS-2 | 0.001 | 0.008 | 0.0096 | 0.0055 | 0.008 | 0.06 |
| WS-3 | 0.008 | 0.09 | 0.0283 | 0.03 | 0.049 | 0.16 |
| WS-4 | 0.034 | 0.25 | 0.093 | 0.065 | 0.136 | 0.87 |
| WS-5 | 0.00017 | 0.001 | 0.00015 | 0.00045 | 0.001 | 0.71 |
| WS-6 | 0.006 | 0.0041 | 0.0045 | 0.0083 | 0.006 | 0.05 |
| WS-7 | 0.0003 | 0.0048 | 0.003 | 0.0038 | 0.004 | 0.03 |
| | | | | | | |
| | **April 4-Oct 1* | | **2023-2025 (Oct 1-Sept 30)** | | | |
| | *#No spring melt observed* | | | | | |




Precipitation data:

| 2021-22 | 2021-22 | | 2022-23 | 2022-23 | | 2023-24 | 2023-24 | | 2024-25 | 2024-25 |
|---|---|---|---|---|---|---|---|---|---|---|
| Oct | 1.69 | | Oct | 0.18 | | Oct | 4.27 | | Oct | 1.07 |
| Nov | 0.91 | | Nov | 1.65 | | Nov | 0.03 | | Nov | 2.57 |
| Dec | 1.28 | | Dec | 2.15 | | Dec | 2.32 | | Dec | 1.3 |
| Jan | 0.28 | | Jan | 1.93 | | Jan | 0.12 | | Jan | 0.3 |
| Feb | 0.44 | | Feb | 2.01 | | Feb | 0.47 | | Feb | 0.74 |
| March | 2.14 | | March | 2.22 | | March | 2.16 | | March | 2.15 |
| April | 2.45 | | April | 5.37 | | April | 4.41 | | April | 2.02 |
| May | 3.15 | | May | 1.63 | | May | 6.08 | | May | 2.75 |
| June | 2.62 | | June | 0.73 | | June | 8.73 | | June | 6.62 |
| July | 1.6 | | July | 3.85 | | July | 3.85 | | July | 5.49 |
| August | 7.62 | | August | 1.38 | | August | 5.89 | | August | 2.53 |
| Sept | 0.85 | | Sept | 4.79 | | Sept | 0.69 | | Sept | 2.2 |
| Total yr (in) | 25.03 | | | 27.89 | | | 39.02 | | | 29.74 |
| Total April-Sept (in) | 18.29 | | | 17.75 | | | 29.65 | | | 21.61 |
| meters/yr | 0.64 | | | 0.71 | | | 0.99 | | | 0.76 |
| meters/gs | 0.46 | | | 0.45 | | | 0.75 | | | 0.55 |

Sub-watershed tributary loading from tributary analysis.

| 2022* | TP load | Ortho load | Sediment load | 2023 | TP load | Ortho load | Sediment load | 2024 | TP load | Ortho load | Sediment load | 2025 | TP load | Ortho load | Sediment load |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WS-1 | 8.74 | 2.28 | 342 | | 30.36 | 7.92 | 1188 | | 38.6 | 10.1 | 1512 | | 31.05 | 8.1 | 1215 |
| WS-2 | 0.452 | 0.22 | 117 | | 3.62 | 1.79 | 936 | | 4.34 | 2.15 | 1123 | | 2.49 | 1.23 | 644 |
| WS-3 | 5.53 | 2.71 | 2472 | | 62.19 | 30.51 | 27810 | | 19.55 | 9.59 | 8745 | | 20.73 | 10.17 | 9270 |
| WS-4 | 10.4 | 5.78 | 1496 | | 76.5 | 42.5 | 11000 | | 28.46 | 15.81 | 4092 | | 19.89 | 11.05 | 2860 |
| WS-5 | 0.1 | 0.06 | 17 | | 0.565 | 0.34 | 100 | | 0.1 | 0.05 | 15 | | 0.25 | 0.15 | 45 |
| WS-6 | 4.36 | 3.56 | 1868 | | 4.47 | 3.65 | 43.5 | | 4.9 | 4 | 47.7 | | 9.04 | 7.39 | 3876 |
| WS-7 | 0.21 | 0.17 | 15.9 | | 3.36 | 2.67 | 254.4 | | 2.1 | 1.67 | 159 | | 2.66 | 2.12 | 201 |

| **Overall Water Balance** | | | | | | **Averaging Period =** | **1.00** | **years** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **Area** | **Flow** | **Variance** | **CV** | **Runoff** | | |
| **Trib** | **Type** | **Seg** | **Name** | **km²** | **hm³/yr** | **(hm3/yr)²** | **-** | **m/yr** | | |
| 1 | 1 | 1 | WS 1 | | 0.073 | 0.00E+00 | 0.00 | | | |
| 2 | 1 | 1 | WS2 | | 0.008 | 0.00E+00 | 0.00 | | | |
| 3 | 1 | 1 | WS3 | | 0.049 | 0.00E+00 | 0.00 | | | |
| 4 | 1 | 1 | Rock Creek | | 0.130 | 0.00E+00 | 0.00 | | | |
| 5 | 1 | 1 | Flagstad | | 0.006 | 0.00E+00 | 0.00 | | | |
| 6 | 1 | 1 | HWY 8 | | 0.004 | 0.00E+00 | 0.00 | | | |
| 7 | 1 | 1 | Direct-drained | | 0.400 | 0.00E+00 | 0.00 | | | |
| 8 | 1 | 1 | WS5-Sediment pond | | 0.001 | 0.00E+00 | 0.00 | | | |
| 9 | 1 | 1 | Groundwater-net | | 1.150 | 0.00E+00 | 0.00 | | | |
| 10 | 1 | 1 | Septic | | 0.000 | 0.00E+00 | 0.00 | | | |
| PRECIPITATION | | | | 3.2 | 2.639 | 0.00E+00 | 0.00 | 0.83 | | |
| TRIBUTARY INFLOW | | | | | 1.821 | 0.00E+00 | 0.00 | | | |
| ***TOTAL INFLOW | | | | 3.2 | 4.461 | 0.00E+00 | 0.00 | 1.40 | | |
| ADVECTIVE OUTFLOW | | | | 3.2 | 2.489 | 0.00E+00 | 0.00 | 0.78 | | |
| ***TOTAL OUTFLOW | | | | 3.2 | 2.489 | 0.00E+00 | 0.00 | 0.78 | | |
| ***EVAPORATION | | | | | 1.972 | 0.00E+00 | 0.00 | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| **Overall Mass Balance Based Upon** | | | | **Predicted** | | **Outflow & Reservoir Concentrations** | | | | |
| **Component:** | | | | **TOTAL P** | | | | | | |
| | | | | **Load** | | **Load Variance** | | | **Conc** | **Export** |
| **Trib** | **Type** | **Seg** | **Name** | **kg/yr** | **%Total** | **(kg/yr)²** | **%Total** | **CV** | **mg/m³** | **kg/km²/yr** |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | WS 1 | 33.6 | 12.05% | 0.00E+00 | | 0.00 | 460.0 | |
| 2 | 1 | 1 | WS2 | 3.6 | 1.29% | 0.00E+00 | | 0.00 | 450.0 | |
| 3 | 1 | 1 | WS3 | 33.8 | 12.13% | 0.00E+00 | | 0.00 | 690.0 | |
| 4 | 1 | 1 | WS4 | 39.0 | 13.99% | 0.00E+00 | | 0.00 | 300.0 | |
| 5 | 1 | 1 | WS6 | 6.0 | 2.15% | 0.00E+00 | | 0.00 | 1000.0 | |
| 6 | 1 | 1 | WS7 | 2.9 | 1.05% | 0.00E+00 | | 0.00 | 699.0 | |
| 7 | 1 | 1 | Direct-drained | 64.0 | 22.96% | 0.00E+00 | | 0.00 | 160.0 | |
| 8 | 1 | 1 | WS5 | 0.6 | 0.20% | 0.00E+00 | | 0.00 | 565.0 | |
| 9 | 1 | 1 | Groundwater | 12.6 | 4.54% | 0.00E+00 | | 0.00 | 11.0 | |
| 10 | 1 | 1 | Septic | 19.0 | 6.82% | 0.00E+00 | | 0.00 | ######## | |
| PRECIPITATION | | | Atmosphere | 63.6 | 22.82% | 1.01E+03 | 100.0% | 0.50 | 24.1 | 20.0 |
| TRIBUTARY INFLOW | | | | 215.1 | 77.2% | 0.00E+00 | | 0.00 | 118.1 | |
| ***TOTAL INFLOW | | | | 278.7 | 100.0% | 1.01E+03 | 100.0% | 0.11 | 62.5 | 87.7 |
| ADVECTIVE OUTFLOW | | | | 45.1 | 16.2% | 2.85E+02 | | 0.37 | 18.1 | 14.2 |
| ***TOTAL OUTFLOW | | | | 45.1 | 16.2% | 2.85E+02 | | 0.37 | 18.1 | 14.2 |
| ***RETENTION | | | | 233.6 | 83.8% | 1.10E+03 | | 0.14 | | |
| | | | | | | | | | | |
| | Overflow Rate (m/yr) | | | 0.8 | | Nutrient Resid. Time (yrs) | | | 1.6395 | |
| | Hydraulic Resid. Time (yrs) | | | 10.1311 | | Turnover Ratio | | | 0.6 | |
| | Reservoir Conc (mg/m3) | | | 18 | | Retention Coef. | | | 0.838 | |

| Predicted & Observed Values Ranked Against CE Model Development Dataset | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Segment:** | **1** | **Deer Lake** | | | | |
| | **Predicted Values--->** | | | **Observed Values--->** | | |
| **Variable** | **Mean** | **CV** | **Rank** | **Mean** | **CV** | **Rank** |
| TOTAL P MG/M3 | 18.1 | 0.37 | 14.0% | 18.0 | | 11.8% |
| CHL-A MG/M3 | 4.6 | 0.60 | 17.8% | 4.5 | | 29.5% |
| SECCHI M | 4.6 | 0.37 | 97.2% | 4.6 | | |
| ORGANIC N MG/M3 | 268.3 | 0.27 | 13.2% | | | |
| TP-ORTHO-P MG/M3 | 6.0 | 0.84 | 4.5% | | | |
| HOD-V MG/M3-DAY | 73.7 | 0.34 | 47.6% | | | |
| MOD-V MG/M3-DAY | 61.7 | 0.40 | 44.6% | | | |
| ANTILOG PC-1 | 30.7 | 0.90 | 5.6% | | | |
| ANTILOG PC-2 | 12.5 | 0.15 | 89.7% | | | |
| TURBIDITY 1/M | 0.1 | | 1.1% | 0.1 | | 1.1% |
| ZMIX * TURBIDITY | 0.6 | | 1.3% | 0.6 | | 1.3% |
| ZMIX / SECCHI | 1.5 | 0.37 | 2.5% | | | |
| CHL-A * SECCHI | 21.3 | 0.27 | 85.0% | | | |
| CHL-A / TOTAL P | 0.3 | 0.31 | 66.0% | 0.4 | | 84.7% |
| FREQ(CHL-a>10) % | 6.0 | 1.90 | 17.8% | 14.0 | | 29.5% |
| FREQ(CHL-a>20) % | 0.4 | 2.79 | 17.8% | 1.4 | | 29.5% |
| FREQ(CHL-a>30) % | 0.0 | 3.33 | 17.8% | 0.2 | | 29.5% |
| FREQ(CHL-a>40) % | 0.0 | 3.71 | 17.8% | 0.0 | | 29.5% |
| FREQ(CHL-a>50) % | 0.0 | 4.01 | 17.8% | 0.0 | | 29.5% |
| FREQ(CHL-a>60) % | 0.0 | 4.25 | 17.8% | 0.0 | | 29.5% |
| CARLSON TSI-P | 45.9 | 0.12 | 14.0% | 44.6 | | 11.8% |
| CARLSON TSI-CHLA | 45.6 | 0.13 | 17.8% | 48.5 | | 29.5% |
| CARLSON TSI-SEC | 38.0 | 0.14 | 2.8% | | | |