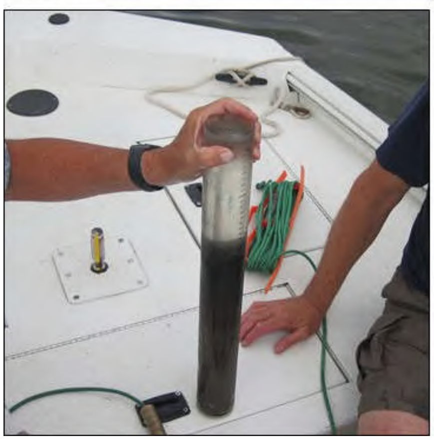
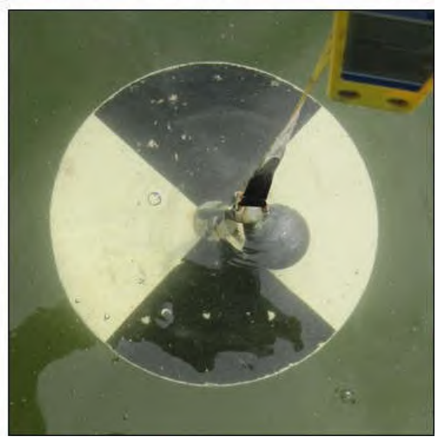
Bullhead Lake

Manitowoc County, Wisconsin

Alum Feasibility Study – Final Report

January 2020



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1.0 INTRODUCTION

Bullhead Lake is an approximate 73-acre, eutrophic, deep headwater drainage lake with a maximum depth of 38 feet and a mean depth of 14 feet. The lake's watershed encompasses approximately 301 acres, yielding a small watershed to lake area ratio of 3:1. Watershed composition includes 96 acres of agricultural row crops (32%), 73 acres of the lake's surface (24%), 44 acres of forested wetlands (15%), 40 acres of low density urban land use (13%), 37 acres of upland forests (12%), 7 acres of non-forested wetlands (2%), and 4 acres of ruderal grasslands (2%). Approximately 31% of the lake's shoreline contains a moderate to high degree of human development with little to no natural habitat, while the remaining 69% contains minimal to no development and has intact natural habitat.

In 2018, the Bullhead Lake Advancement Association, Inc. (BLAA) completed a comprehensive management planning project for Bullhead Lake utilizing funding from a Wisconsin Department of Natural Resources (WDNR) Large-scale Planning Grant. Analysis of available phosphorus data indicated that phosphorus concentrations from 1988-2008 were relatively stable and on average were considered *good* for Wisconsin's deep headwater drainage lakes. However, a trend of increasing phosphorus and chlorophyll-*a* concentrations began in 2009, and concentrations increased markedly in 2017, exceeding the threshold for *poor condition*.

Studies completed as part of the lake management plan development indicated that the hypolimnion is anoxic with elevated phosphorus concentrations for much of the summer stratified period, and the anoxic water volume within the lake had been increasing over the past decade. This suggested that the internal loading of phosphorus from anoxic sediments was occurring and potentially increasing, and it was hypothesized that this process was resulting in the increased phosphorus and algal levels observed over the last few years.

Alum treatments have been completed in Bullhead Lake in the past, one in 1978 and another in 1988 in order to reduce internal loading. However, the benefits of these treatment only persisted for a few years, likely due to insufficient alum dose rates in combination with high rates of external phosphorus loading. In an effort to quantify the internal loading of phosphorus in Bullhead Lake, its impact on water quality, and the feasibility and cost of completing an alum treatment, the BLAA was awarded a WDNR Lake Protection Grant in February of 2019 to carry-out more detailed studies and analyses. The specific project objectives were as follows:

1) Update trends analysis for Bullhead Lake water quality with data collected through 2019.
2) Quantify the flux of phosphorus being released into the hypolimnion from lake sediments during summer stratification and its impact on Bullhead Lake's water quality.
3) Estimate the current external phosphorus load to Bullhead Lake from the watershed and inventory/model best management practices (BMPs) that have been implemented on Dallmann Farms managed lands and other lands within the watershed.
4) Determine the alum dose required to significantly reduce the internal loading of phosphorus in Bullhead Lake based on the standard of a 90% reduction.
5) If appropriate, estimate the cost of completing an alum treatment on Bullhead Lake utilizing the determined dosage.

2.0 METHODS

2.1 Update Trends Analysis for Bullhead Lake Water Quality

To obtain the most recent water quality data from Bullhead Lake and to continue examining ongoing trends of water quality degradation, near-surface total phosphorus concentrations were collected by the BLAA Citizen Lake Monitoring Network (CLMN) on three occasions during the summer in 2018, and by both Onterra staff and BLAA volunteers on ten occasions from April through October 2019. Similarly, chlorophyll-*a* concentrations were measured on three occasions in 2018 and six occasions between June and September in 2019, and Secchi disk transparency was measured on four occasions in 2018 and nine occasions between May and October 2019.

2.2 Sediment Phosphorus Flux

To determine the mass of phosphorus flux from Bullhead Lake bottom sediments to the overlying water, phosphorus concentration profiles were collected from May through November 2019 at the lake's deep hole sampling location (Map 1). Samples were collected from seven sampling depths ranging from three feet below the surface to one foot above bottom sediments. Concentrations from the hypolimnion are of most significance, so most samples were collected from this layer. These results were used to determine the mass of phosphorus that is being internally loaded to the water column from anoxic sediments during summer stratification.

2.3 Determine Influence of Internal Phosphorus Loading on Bullhead Lake's Water Quality

To determine the significance of internal phosphorus loading on Bullhead Lake's water quality, an estimate of the current external load of phosphorus to Bullhead Lake from the watershed was also determined. To estimate external loading from the watershed, the Environmental Protection Agency's Spreadsheet Tool for Estimating Pollutant Loads (STEPL) was utilized. This model estimates phosphorus and other pollutant runoff (nitrogen, sediments, etc.) from cropland, pastureland, urban lands, and upland forests within a watershed. The model utilizes the universal soil loss equations with county-specific (Manitowoc County) coefficients and local precipitation data (from Chilton, WI) to estimate the phosphorus loads originating from these land cover types.

The STEPL model also allows for the input of BMPs that have been implemented within the watershed to estimate reductions in phosphors loading. Nick Dallmann, who manages a portion of the croplands within the Bullhead Lake watershed, was consulted so that the BMPs implemented on these croplands could be incorporated into the model. Information on tillage and crop rotation on the other croplands within the watershed were obtained from Manitowoc County and incorporated into the model. Estimates of external phosphorus loading from atmospheric deposition and riparian septic systems were obtained from Wisconsin Lakes Modeling Suite (WiLMS), the watershed modeling software utilized during the lake management planning development. Once estimates for internal and external loads of phosphorus were determined, WiLMS was utilized to determine how in-lake phosphorus concentrations were influenced by the internal loading of phosphorus and what water quality improvements could be expected if 90% of the internal load was reduced through an alum treatment.

2.4 Determine Correct Alum Dosage & Feasibility of Alum Treatment

Six sediment cores were extracted from Bullhead Lake, sectioned, and provided to Mr. William James at UW-Stout for phosphorus fractionization analysis. Specifically, two of the cores were sectioned at 0-6 cm/1cm; 6-12 cm/2cm. The remaining four cores were sectioned from 5cm from the top and each analyzed as a composite sample. In total, 22 sediment sections were analyzed.

The UW-Stout analyses provided the concentrations of different phosphorus containing molecules (mg/g) in each of 22 sections. Loose-P and Fe-P are the molecules of most interest and together are considered Redox-P because these forms of phosphorus are most readily released from the sediment during anoxic conditions. Using these data, calculations were made to determine the amount of aluminum required to bind 90% and 75% of the Redox-P within the sediment. These calculations were made for the upper 5cm and 10cm of sediment.

3.0 RESULTS

3.1 Bullhead Lake Water Quality Trends Analysis Update

Summer near-surface total phosphorus data from Bullhead Lake are available from 1991 and annually from 1993 to 2019 (Figure 1). Average summer total phosphorus concentrations ranged from 21 µg/L in 1997 to 100 µg/L in 2019. The weighted summer average total phosphorus concentration is 36 µg/L, and falls into the *fair* category for Wisconsin's deep headwater drainage lakes. Bullhead Lake's phosphorus concentrations are approximately two times higher than the median values for deep headwater drainage lakes in the state and are higher than the median values of all lake types within the Southeast Wisconsin Till Plains Ecoregion (SWTP) ecoregion.

Prior to 2009, the average summer phosphorus concentration in Bullhead Lake was 27 µg/L, falling within the *good* category for Wisconsin's deep headwater drainage lakes. Since 2009, concentrations have been increasing, and 2019 saw the highest concentrations measured on record for Bullhead Lake. The average summer total phosphorus concentration from 2009-2019 was 48 µg/L, falling in the *fair* condition.

Summer chlorophyll-*a* concentration data are available annually from 1993 to 2019 (Figure 2). Average summer chlorophyll-*a* concentrations ranged from 2 µg/L in 2006 to 96 µg/L in 2019. It should be noted that only one summer chlorophyll-*a* sample was collected in 2006 and it may not be representative of the 2006 summer average chlorophyll-*a* concentration. The weighted summer chlorophyll-*a* concentration is 16 µg/L and falls into the *fair* category for chlorophyll-*a* concentrations in Wisconsin's deep headwater drainage lakes. Bullhead Lake's chlorophyll-*a* concentrations are approximately three times higher than the median values for deep headwater drainage lakes in the state and for all lake types within the SWTP ecoregion.

Algal levels are considered to reach nuisance conditions when chlorophyll-*a* concentrations exceed 20 µg/L. Prior to 2010, this level was only exceeded 3 times out of 65 samples. Starting in 2010 this value has been exceeded multiple times, including an exceptionally high chlorophyll-*a* concentration of 133 µg/L occurring on June 26, 2019. While no samples have been analyzed for blue green algal toxins, the World Health Organization considers chlorophyll-*a* levels exceeding 50 µg/L to pose a high risk for adverse health effects.

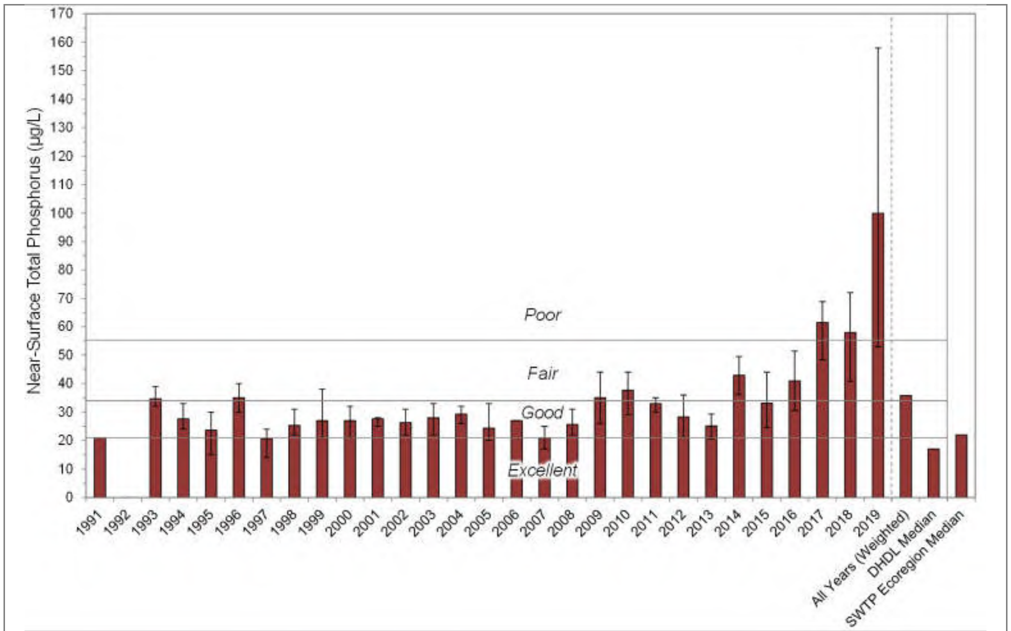

Figure 1. Summer near-surface total phosphorus concentrations from Bullhead Lake, and median concentrations from WI deep headwater drainage lakes and SWTP regional lakes. Mean values calculated with summer month surface sample data. Error bars represent maximum and minimum concentrations. Water Quality Index values adapted from WDNR PUB WT-913.

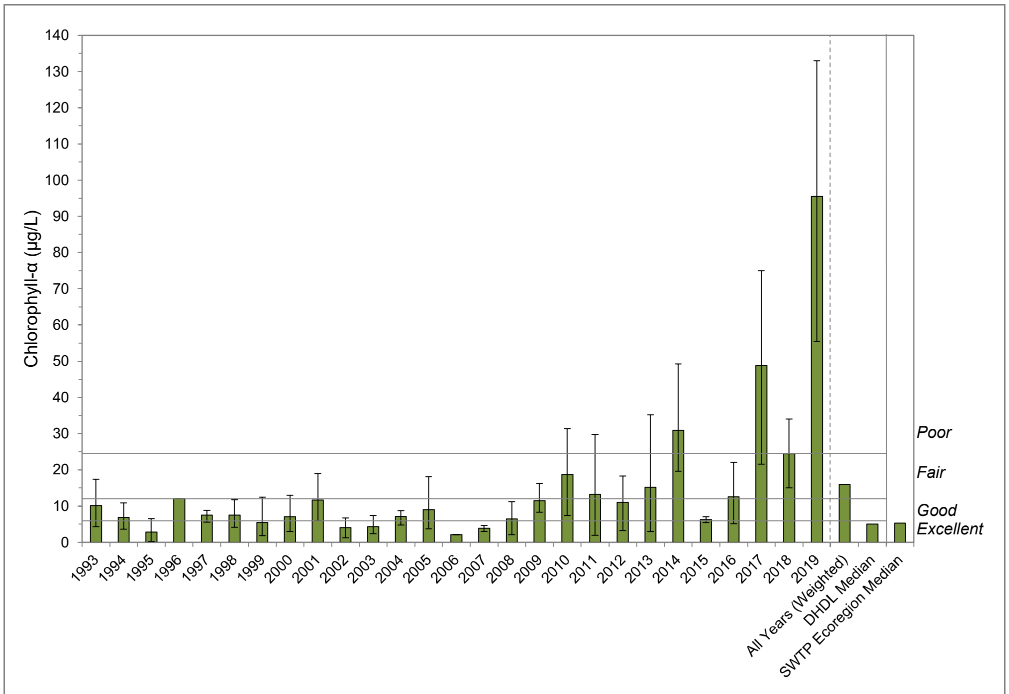

Figure 2. Summer chlorophyll-α concentrations from Bullhead Lake, and median concentrations from WI deep headwater drainage lakes and SWTP regional lakes. Mean values calculated with summer month surface sample data. Error bars represent maximum and minimum concentrations. Water Quality Index values adapted from WDNR PUB WT-913.

The 2017 average summer chlorophyll-*a* concentration was over four times higher than the lake's long-term weighted average, with an average concentration of 49 µg/L. In 2019, even higher concentrations occurred, with a summer mean concentration of 95.5 µg/L. In most of Wisconsin's lakes, chlorophyll-*a* concentrations are highly correlated with total phosphorus concentrations. As expected, chlorophyll-*a* concentrations in Bullhead Lake are highly correlated with phosphorus (Figure 3). As phosphorus concentrations increase, chlorophyll-*a*, or free-floating algae, increase.

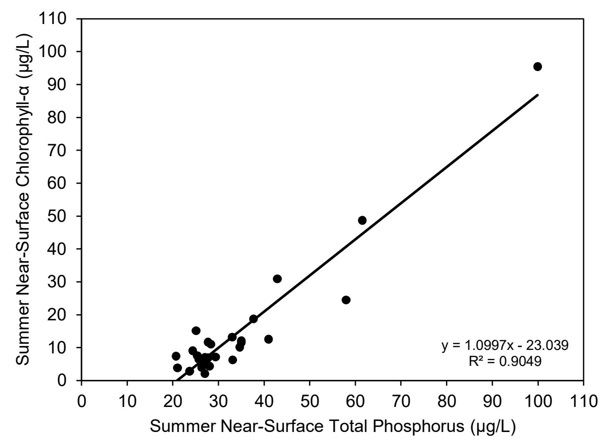

Figure 3. Bullhead Lake 1993-2019 summer total phosphorus concentrations plotted against summer chlorophyll-α concentrations. Chlorophyll concentrations reach the established 20 µg/L nuisance threshold when phosphorus concentrations are around 39 µg/L.

In July 2017 during vegetation surveys, Onterra staff noted an algal bloom and surface-matted filamentous algae in Bullhead Lake (Photograph 1). The occurrence of filamentous algae mats in near-shore areas has been reported by residents to be problem for the last few years. Chlorophyll-*a* measurements discussed previously do not directly measure these algae, although it is likely some fragments are broken off from the algal mats and could be collected in the water samples. These filamentous algal mats typically grow initially on the lake bottom or on aquatic plants where they are able to extract nutrients from the sediments and the water. As these algal mats grow, gases such as oxygen and carbon dioxide are trapped within the mats and they float to the lake surface. These mats frequently become entangled in floating vegetation and along the shoreline, and their presence is most often an indicator of excessive nutrient input from the watershed.

Photograph 1. Planktonic algal bloom (left) and surface-matting filamentous *Cladophora* spp. (right) in Bullhead Lake in 2017. Photo credit Onterra.

These mats have grown to nuisance levels in Bullhead Lake, and the BLAA regularly collects and removes them from the lake with a mechanical harvester. In 2019, the algal mat coverage was much less and it was not necessary to mechanically remove it. It is likely that planktonic algal levels, which were very high in early summer, reduced the light penetration to the sediments so that the algal mats did not grow on the sediments to the extent that occurred in earlier years.

Summer Secchi disk transparency data are available from Bullhead Lake annually from 1986 to 2005 and from 2007 to 2019 (Figure 4). Average summer Secchi disk depth ranged from 11.6 feet in 1990 to 2.9 feet in 2019. The weighted summer average Secchi disk depth is 8.6 feet, which falls into the *excellent* category for Secchi disk depth in Wisconsin's deep headwater drainage lakes. The weighted average summer Secchi disk depth is less than the median values for deep headwater drainage lakes in Wisconsin but exceeds the median values for all lake types within the SWTP ecoregion.

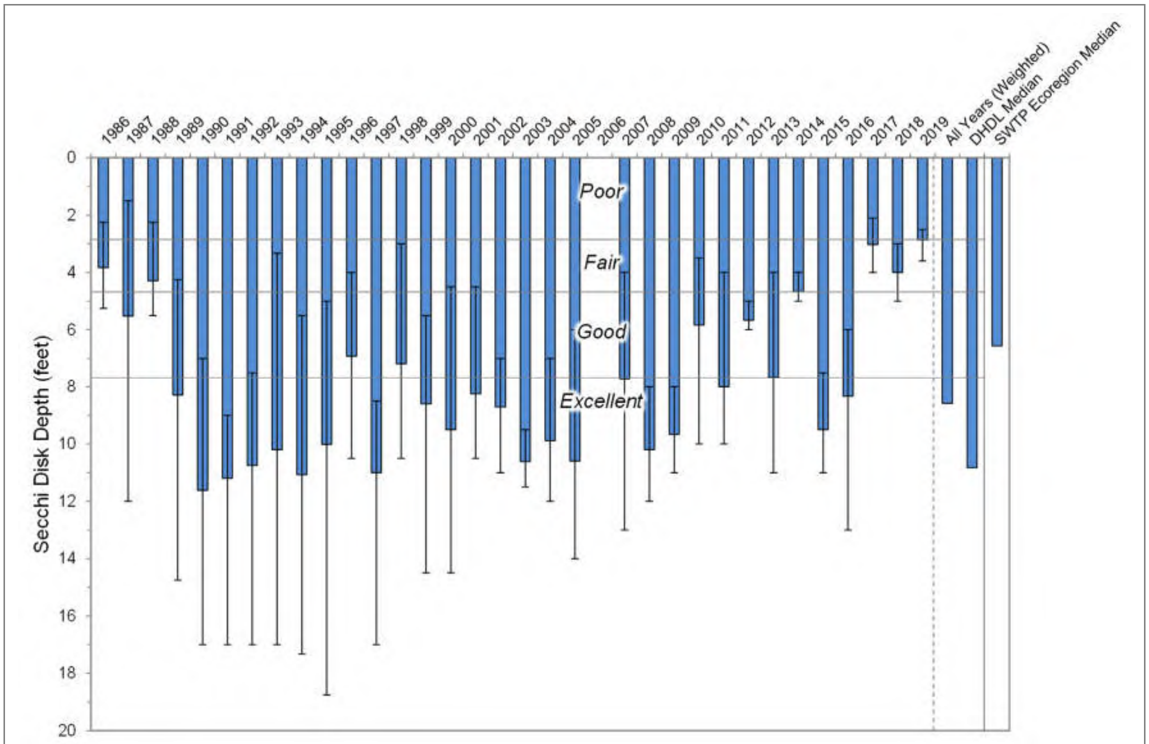

Figure 4. Summer Secchi disk depths from Bullhead Lake, and median concentrations from WI deep headwater drainage lakes and SWTP regional lakes. Mean values calculated with summer month data. Error bars represent maximum and minimum values. Water Quality Index values adapted from WDNR PUB WT-913.

However, given the increase in chlorophyll-*a* concentrations around 2009-2010, water clarity in Bullhead Lake has been declining. The years 2017-2019 saw the lowest water transparency on record, falling into the *fair* and *poor condition* categories. The average summer Secchi disk depth from 2010-2019 was 5.7 feet, approximately 3.0 feet lower when compared to average measurements prior to 2010. Secchi disk depth, or water clarity in Bullhead Lake is primarily regulated by the planktonic algal abundance. Figure 5 illustrates the relationship between Secchi disk depth and chlorophyll-*a* concentrations in Bullhead Lake using data from 1993-2019.

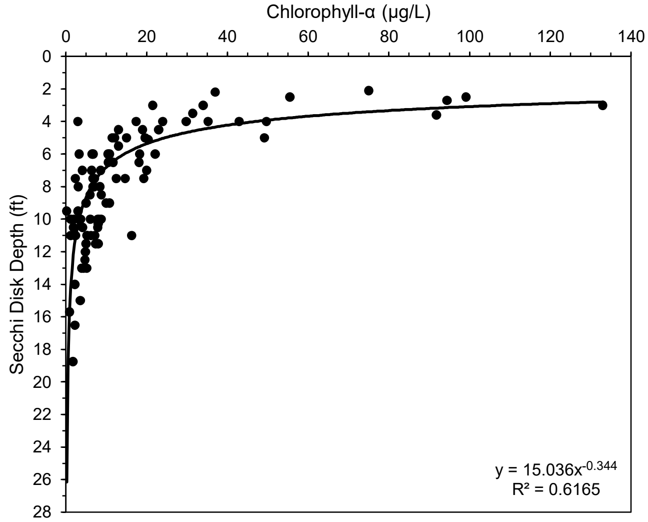

Figure 5. Bullhead Lake 1993-2019 chlorophyll-α concentrations plotted against Secchi disk depths.

3.2 Sediment Phosphorus Flux

The previous discussion indicated that from 2017-2019, Bullhead Lake has seen the worst water quality since record keeping began in the late 1980s. The purpose of the present study was to determine if the internal nutrient loading was an important source of phosphorus and the primary factor causing water quality degradation in Bullhead Lake. This was done by collecting detailed phosphorus profiles during the summer and using sediment cores from the lake to estimate sediment phosphorus release rates. Onterra staff collected phosphorus, oxygen, and temperature profiles five times from May 30 to September 30, 2019.

By the end of May, Bullhead Lake was strongly stratified and oxygen was not present below 25 feet (Figure 6). By June 19, the depth of anoxia had moved up to less than 20 feet. Oxygen levels in the upper waters were in excess of 10 mg/L, which was over 150% saturation. These high oxygen levels were the result of high rates of photosynthesis from a large algal bloom that was occurring (chlorophyll-*a* concentration of 133 μg/L). By the end of July, oxygen was only present down to approximately 5 feet, meaning much of the lake volume was devoid of oxygen. Stratification with an anoxic hypolimnion continued until at least September 30.

In order to estimate how much phosphorus was released from the sediments during summer stratification, especially when the bottom waters were anoxic, Onterra staff collected phosphorus profiles. The phosphorus concentrations in the deeper waters were consistently higher than the concentrations in the surface waters (Figure 7). Phosphorus levels steadily increased in the hypolimnion throughout the stratified period. This indicates that phosphorus was being released from the bottom sediments. Using the phosphorus profile data, it was estimated that the mass of phosphorus in Bullhead Lake between the end of May and the end of September increased by 127 kg or 280 pounds.

While the estimated annual internal load of 280 pounds is significant, most of this phosphorus remains within bottom waters during summer where it is unavailable to algae at the surface.

During fall mixing in October, this phosphorus is then circulated throughout the water column. However, algal production at this time is lower given the cooler water temperatures. It is difficult to estimate how much of the phosphorus released during stratification and mixed throughout the water column in fall carries over into the following summer.

Historical spring and fall data from Bullhead Lake indicate that on average, approximately 50 pounds of phosphorus are released during summer stratification. Spring concentrations are almost always lower than those in fall, suggesting that most of the internally-loaded phosphorus settles back to bottom sediments over the course of the winter. This indicates that most of the phosphorus internally loaded during summer and mixed to surface waters in the fall is not available for agal production the following year. However, this analysis is complicated by the fact that there are likely higher external inputs of phosphorus during spring and fall with snowmelt and higher precipitation. These events would contribute phosphorus and result in higher concentrations in the lake during spring and early summer.

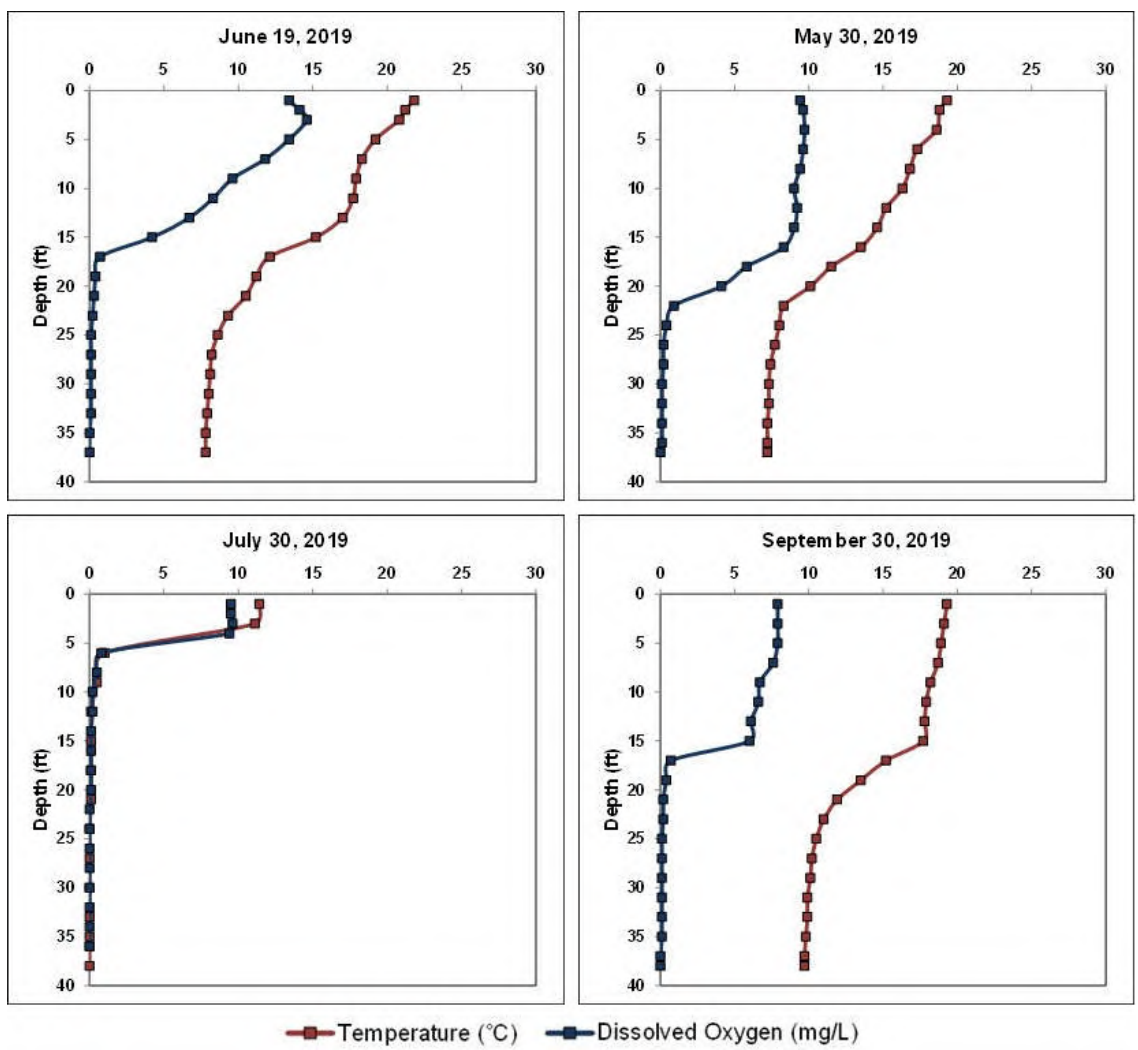

Figure 6. Bullhead Lake 2019 dissolved oxygen and temperature profiles.

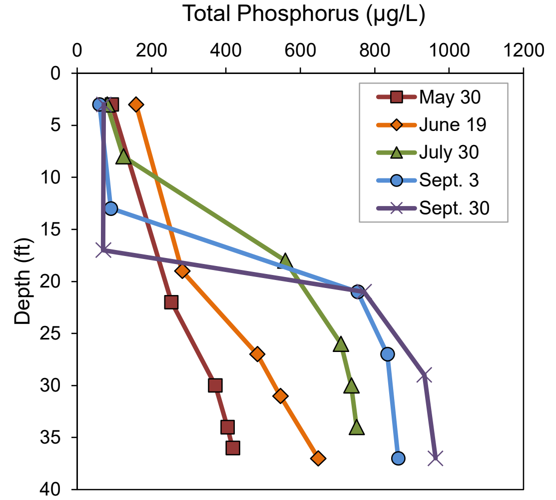

Figure 7. Bullhead Lake total phosphorus profiles collected in 2019. Phosphorus in bottom waters increases over the course of the summer, indicating internal phosphorus loading.

3.3 External Phosphorus Loading

The *Bullhead Lake Comprehensive Management Plan* (Onterra 2018) estimated that on average 129 pounds of phosphorus are loaded to Bullhead Lake from its watershed on an annual basis. This estimate was based upon the Wisconsin Lake Modeling Suite (WiLMS). WiLMS uses phosphorus runoff coefficients for different landuse types to estimate the external load to the lake. For example, row crops are assumed to deliver phosphorus at a rate of 1.00 kg/ha/year, while grasslands have a runoff coefficient of 0.30 kg/ha/yr. WiLMS also calculates the lake's flushing rate and residence time using county-specific average precipitation/evaporation values. The model also includes predictive models which use the external load and lake's flushing rate, average depth, and other morphometric characteristics to estimate the growing season mean phosphorus concentration. If there is a significant amount of internal loading, the model will underestimate the predicted growing season mean phosphorus concentration.

The WiLMS model performed reasonably well for the mean phosphorus concentration measured in Bullhead Lake until 2017. For 2017, WiLMS underestimated the growing season mean phosphorus concentration, resulting in the hypothesis that internal loading had become a larger portion of the annual phosphorus in the lake. However, as discussed previously, it appears that most of the phosphorus internally loaded into bottom waters during the summer is not available for algal production. Additionally, near-surface phosphorus concentrations in Bullhead Lake from 2017-2019 were increasing in early summer when the lake was already stratified, an indication that phosphorus at the surface was originating from another source and not from bottom waters.

Annual precipitation in the Bullhead Lake region has increased in recent years (Figure 8). Precipitation data from Chilton, WI were used in this analysis as data obtained from a station in Brillion, WI (closer to Bullhead) were less complete. Precipitation in 2017, 2018, and 2019 was the highest on record, consecutively, for the area (Chilton NWS ID 471568). In fact, annual precipitation has been consistently above average since 2009. Precipitation data were compared

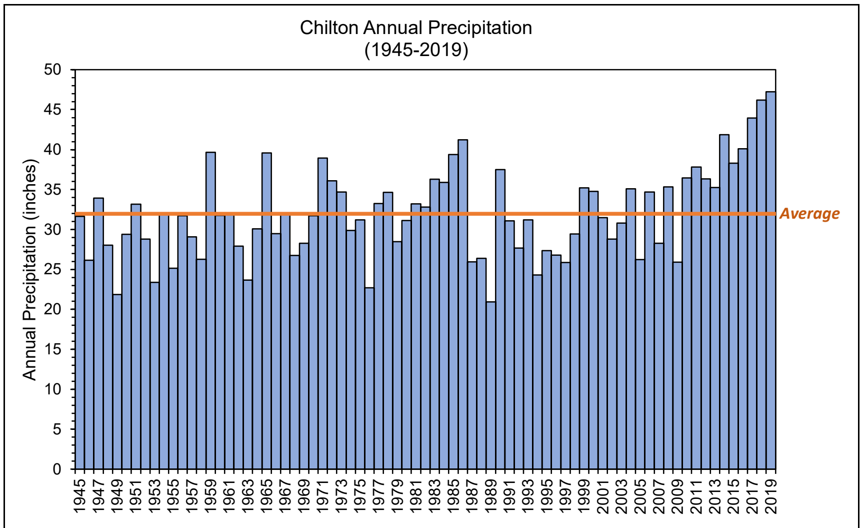

Figure 8. Annual precipitation recorded at Chilton for the period 1945-2019. The mean annual precipitation for this period was 32.0 inches.

against water quality data from Bullhead Lake to see if a relationship existed between annual precipitation and phosphorus concentrations. Annual precipitation and summer mean phosphorus concentration in Bullhead Lake are highly correlated with one another (Figure 9). The correlation coefficient (R^2) was 0.53 which is highly significant. The years with the highest precipitation (2014, 2016-19) also had the highest mean summer phosphorus concentrations, indicating that the external loading of phosphorus had the most influence over surface water quality in Bullhead Lake during these years.

In the 2018 *Bullhead Lake Comprehensive Management Plan* it was concluded that the increased phosphorus concentrations measured in 2017 were the result of a higher rate of internal nutrient loading. However, with additional data collected in 2018 and 2019, it became more apparent that this initial conclusion was incorrect and the elevated phosphorus concentrations were largely the result of above-normal precipitation. If the internal loading of phosphorus was a significant source of near-surface phosphorus in Bullhead Lake, the relationship between annual precipitation and phosphorus would be expected to be significantly weaker.

Even though 2019 saw the highest annual precipitation on record, phosphorus concentrations were still significantly higher than predicted based on precipitation (Figure 9). To gain a more accurate understanding of how the watershed and precipitation affect external phosphorus loading to Bullhead Lake, the model Spreadsheet Tool for Estimating Pollutant Load (STEPL) was utilized. The Bullhead Lake watershed was subdivided into six subwatersheds (Figure 10), and phosphorus loading from each subwatershed was estimated. Best management practices that have been implemented in croplands within the watershed were also input into the model to estimate levels of phosphorus reduction. The BMPs included no-till conservation farming, grassed

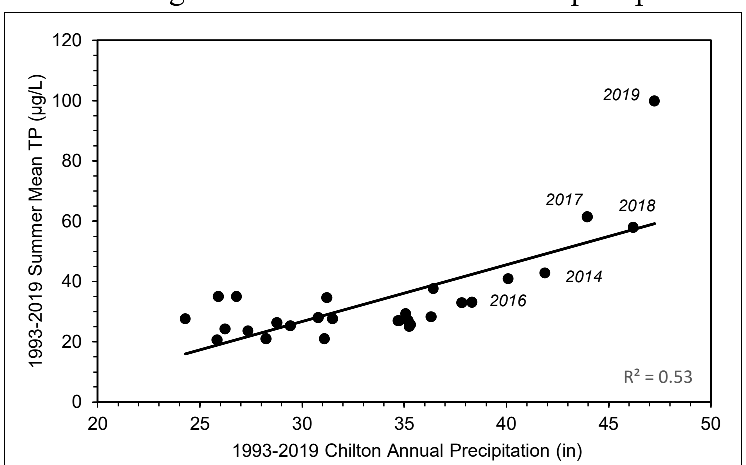

Figure 9. Annual precipitation vs summer mean phosphorus concentrations in Bullhead Lake for the years 1993-2019. The years with the highest precipitation also had the highest phosphorus levels.

waterways, and a sedimentation basin. Average annual manure application on croplands was also input into the model.

Most of the agricultural fields in the Bullhead watershed have some BMPs incorporated into the farming practices. In SW1 no till farming is done and there is an approximate 170-foot wide grassed waterway. In SW3, SW4, and SW5 there is no till farming, and SW4 also contains a sedimentation basin. The model indicates that these BMPs reduce external phosphorus loading by about 44%.

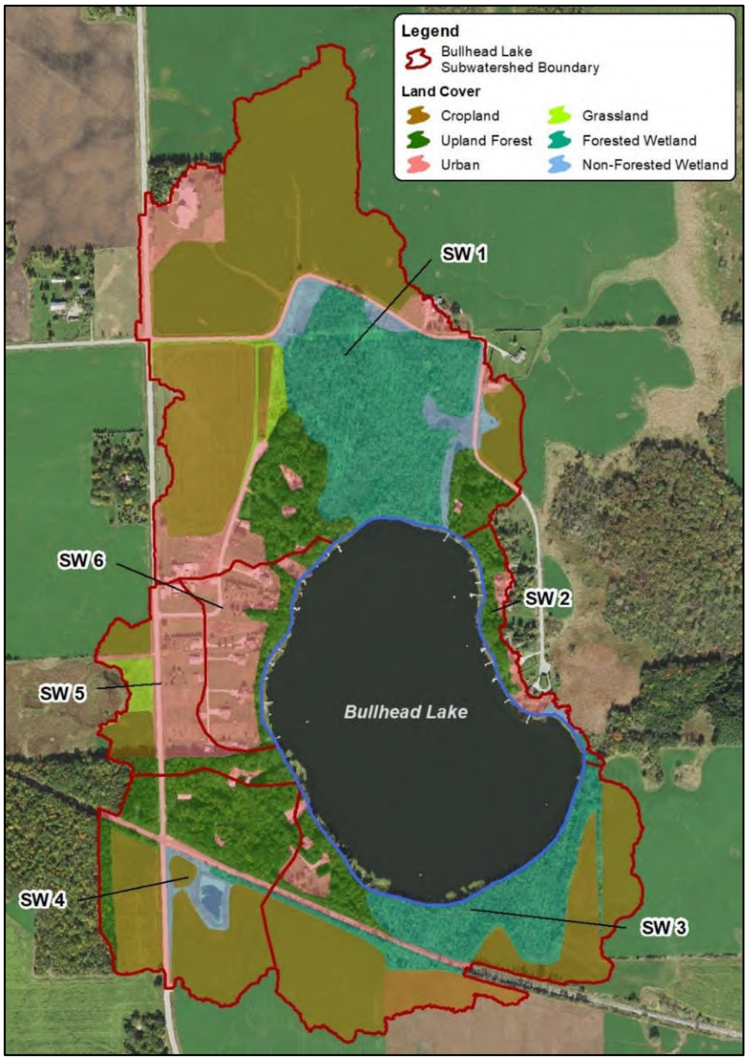

Figure 10. Bullhead Lake watershed with six subwatersheds used in the STEPL modelling.

The STEPL model indicates that with the current BMPs in place within the Bullhead Lake watershed, a total of 182 pounds of phosphorus are externally loaded to Bullhead Lake on an annual basis (Table 1). Subwatersheds 1 and 3 together account for 71% of the annual phosphorus load. Based on an external load of 182 pounds, WiLMS estimates that the growing season mean (GSM) concentration in Bullhead Lake is predicted to be 51 µg/L. This is higher than the measured GSM concentration from 1988-2016 of 36 µg/L, and lower than the measured GSM concentration from 2017-2018 of 65 µg/L.

Since the STEPL model was designed to estimate how watersheds contribute pollutant loads to a waterbody, it does not consider impact from wetlands. Bullhead Lake has 48 acres of mainly forested wetlands within its watershed – approximately 31 acres adjacent to the northern shore, and 17 acres adjacent to the southern shore (Figure 10). These wetlands intercept runoff from adjacent croplands before it enters Bullhead Lake. Forested wetlands are known to retain and sequester phosphorus over time, acting as buffers between uplands and adjacent aquatic systems (Reddy et al. 1999). Retention of phosphorus occurs by both biotic and abiotic processes, including uptake by vegetation and microorganisms, sedimentation, and absorption by sediments/soils (Reddy et al. 1999).

The retention efficiency is highly variable and the efficiency was not specifically determined for the wetlands in the Bullhead Lake watershed. Although the STEPL model is reported to overestimate phosphorus and nitrogen contribution from fields (Nejadhashemi et al. 2011), it appears that in most years these wetland complexes are highly efficient at sequestering the phosphorus delivered to them via runoff from adjacent croplands. Without the wetlands, the STEPL model predicts the growing season phosphorus concentration to be about 51 µg/L, which is considerably higher than the long-term means of 36 µg/L and 27 µg/L during normal rainfall years.

When these wetlands are incorporated into the STEPL model, it is estimated that they sequester approximately 42% of phosphorus being loaded to them, reducing the total annual estimated phosphorus load to Bullhead Lake to around 100 pounds. This estimated phosphorus retention rate for the wetlands of 1.5 pounds/acre/year falls within measured values for temperate forested wetlands (Reddy et al. 1999). An external load of 100 pounds to Bullhead Lake results in a predicted GSM concentration of 36 µg/L, which aligns with the measured GSM from 1998-2016.

Table 1. Estimated external phosphorus loading to Bullhead Lake from STEPL modeling. Current BMPs are estimated to reduce external phosphorus loading by 40%.

		No Wetlands		With Wetlands	
External Phosphorus Source	Acres	No BMPs Annual P Load (lbs/year)	Current BMPs Annual P Load (lbs/year)	No BMPs Annual P Load (lbs/year)	Current BMPs Annual P Load (lbs/year)
Subwatershed 1	113.8	142	72	94	24
Subwatershed 2	4.9	1	1	1	1
Subwatershed 3	46.3	72	48	49	25
Subwatershed 4	32.6	36	12	32	8
Subwatershed 5	16.4	16	13	16	13
Subwatershed 6	13.0	8	8	8	8
Atmospheric Deposition to Lake Surface	73.2	20	20	20	20
Septic Loading	N/A	7	7	7	7
Total External Load		302	182	227	106

The significant increase in phosphorus concentrations from 2017-2019 are believed to be due to the higher precipitation causing these wetlands to flood, significantly reducing their capacity to retain phosphorus. Under flooded conditions, the surface of Bullhead Lake and the water within the adjacent forested wetlands are one and the same. Not only is previously stored phosphorus likely being released from sediments under flooded conditions in these wetlands, but increased runoff from adjacent uplands can readily flow through them and into Bullhead Lake. In other words, under flooded conditions, these wetlands largely lose their capacity to retain phosphorus from entering Bullhead Lake. When the retention capacity of these wetlands is removed from the STEPL model and the precipitation totals from 2017-2019 are used, the predicted GSM concentration in Bullhead Lake is 59 µg/L – more closely aligned with measured GSM in 2017 and 2018 of 65 µg/L.

As mentioned earlier, phosphorus concentrations in 2019 were significantly higher with a GSM concentration of 100 µg/L. It is estimated that 570 pounds of phosphorus had to be loaded to Bullhead Lake in 2019 to achieve this concentration, approximately 150% more when compared to 2017 and 2018. Phosphorus concentrations in April of 2019 were already elevated at near 80 µg/L, the highest spring concentration measured to date within the dataset. It is not apparent if the initial high concentrations in spring were the result of higher precipitation, carry over from a higher rate of internal loading from the previous summer, or a combination of both. Near-surface phosphorus concentrations continued to increase into June following four precipitation events averaging nearly one inch each. Aerial photographs taken by Onterra indicate these precipitation events occurred before any significant vegetation was growing in the croplands and the adjacent forested wetlands were also flooded. These conditions likely resulted in significant runoff and phosphorus loading to Bullhead Lake.

The importance of the wetlands at Bullhead Lake is illustrated by nearby Round and Long lakes. Like Bullhead Lake, Round Lake is a deep headwater drainage with a large portion of its watershed comprised of croplands. It also has a similar watershed to lake ratio as Bullhead Lake. One significant difference is that Round Lake only has one acre of wetlands within its watershed. The summer mean phosphorus concentration in Round Lake from 2012-2017 was 102 µg/L, which is considerably higher than in Bullhead Lake at 39 µg/L during the same time period. However, when the retention capacity of the wetlands in Bullhead Lake's watershed are lost, phosphorus concentrations in Bullhead Lake are more similar to those in Round.

Long-term data from Round Lake is limited, but Long Lake which is downstream of Round Lake has a longer dataset. Like Bullhead Lake, the summer mean phosphorus concentration in Long Lake is positively related to annual precipitation (Figure 11). Even though Long Lake is larger than Bullhead Lake, it has higher phosphorus concentrations because of the higher phosphorus loads from its watershed. With the loss of phosphorus retention in the flooded wetlands around Bullhead Lake, phosphorus concentrations in 2019 in Bullhead Lake were similar to those in Long Lake.

As discussed previously, summer mean phosphorus concentrations in Bullhead Lake since 2010 have generally been higher than the long-term average. This is also the period when precipitation has been higher than normal. While the mean summer phosphorus concentration the last three years was 78 µg/L, prior to 2010, when precipitation was near normal, the mean summer phosphorus concentration was about 27 µg/L. It can be expected that with more normal precipitation this concentration will return. This reduction in phosphorus would also result in less algal growth including filamentous algae. The reduction in filamentous algal growth may be delayed as they can obtain nutrients from the sediments prior to their floating to the surface.

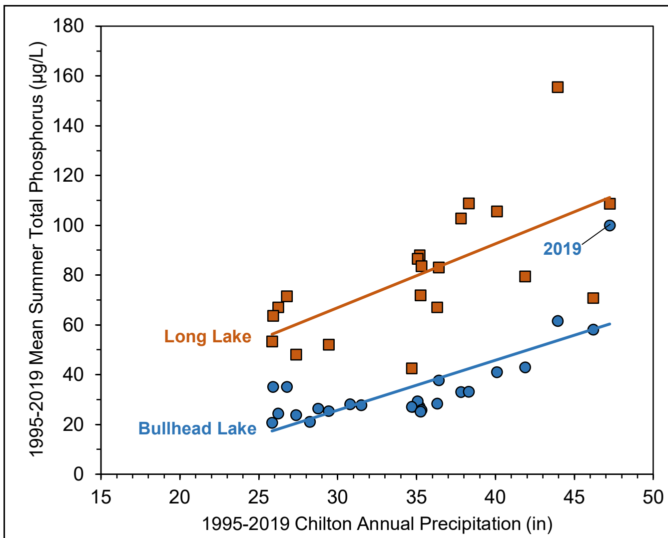

Figure 11. Annual precipitation vs summer mean phosphorus concentrations in Bullhead and Long lakes for the period 1995-2019. The years with the highest precipitation also had the highest phosphorus levels.

3.4 Alum Treatment Feasibility & Dosage

A proven technique to substantially reduce internal loading from sediment phosphorus release during anoxic conditions is the application of aluminum sulfate (alum) to a lake. Alum is applied to the near surface waters of the lake. It quickly settles to the bottom of the lake where it acts as a barrier to phosphorus being released from the sediments. While on the sediments, the aluminum binds with sediment phosphorus to prevent it from entering the water column even when the bottom waters are anoxic. Iron-bound phosphorus in the sediments dissolves when there is no oxygen and the iron and phosphorus move from the sediments into the over lying water. Alum is effective because it binds with the phosphorus and the aluminum-phosphorus bond is not sensitive to oxygen concentrations. In other words, the phosphorus bound with the aluminum remains in the sediments even in the absence of oxygen.

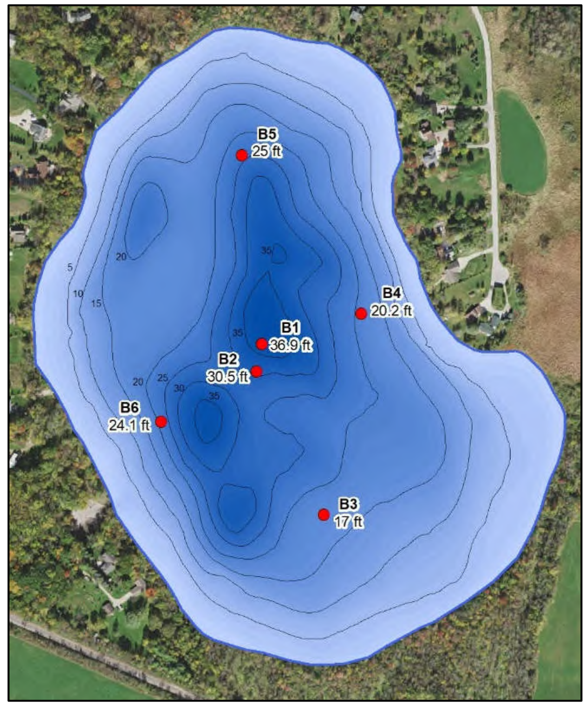

Figure 12. Locations of six sediment cores (red circles) collected from Bullhead Lake in 2019 that underwent phosphorus fractionation and release testing.

Eventually all of the phosphorus binding sites are saturated and the alum layer no longer prevents internal loading. The longevity of the alum is dependent upon how much alum is added as well as how much sediment and phosphorus enters the lake from the watershed. The material from the watershed both buries the alum layer and provides phosphorus which saturate the aluminum binding sites.

On July 30, 2019, Onterra staff collected sediment cores from six locations in Bullhead Lake (Figure 12). At the two sites in the deepest area of the lake, the top 12 cm were collected and sectioned into 2 cm intervals. At the other four sites, the top 5 cm were composited. The samples were sent to the Mr. William James at the UW-Stout for determination of various chemical concentrations including the amount of phosphorus available to be released into the overlying water when the deep waters are devoid of oxygen. The form of phosphorus that is available for release into the overlying water is primarily phosphorus bound with iron and is known as redox phosphorus. By knowing how much available phosphorus is present in the upper sediments, a more accurate alum application rate can be determined.

Table 2. Application rate of aluminum (alum) at each site to achieve a reduction in phosphorus release of 90%.

Core Site	Al Dosage (g/m^2)
1	95.7
2	119.8
3	53.0
4	65.0
5	93.0
6	70.9

Based upon the amount of available sediment phosphorus at each site, an appropriate application rate was determined. This application rate is expected to reduce the release of 90% of the available sediment phosphorus. Table 2 shows the aluminum application rate at each site to reduce 90% of the redox phosphorus. The application rate determined at each site was projected to various areas in the lake below 10 feet. The mean application rate for the lake deeper than 10 feet is 71.2 grams Al per square meter. Often following an alum treatment, there is a significant increase in the growth of filamentous algae because of the increased water clarity. In East Alaska Lake, alum was applied in the 5 to 10-foot depth range at a rate of 40 g/m^2 which greatly reduced the growth of filamentous algae.

Alum treatments have been completed in a large number of lakes in the USA and Europe. Treatments have been completed for a number of years so that it is possible to estimate the expected longevity of a treatment if a significant amount of phosphorus delivered from the watershed has been reduced. Huser et al. (2016) examined 114 lakes with alum treatments and developed a model to estimate an alum treatment longevity based upon the application rate, watershed to lake ratio, and the lake's morphometry (Osgood Index). Based upon the model, it is estimated an alum treatment in Bullhead Lake would be effective for 30-40 years if watershed sources are minimized and no new large phosphorus sources develop.

While alum treatments can be very effective in reducing phosphorus concentrations, their effectiveness is limited if internal loading is not a large part of the annual phosphorus load. One example in Wisconsin is Snake Lake in the City of Woodruff in the northern part of the state. While the alum treatment greatly reduced the sediment release of phosphorus, storm sewers continued to discharge into the lake resulting in frequent algal blooms in the lake. Another example is Delavan Lake in southeastern Wisconsin. The treatment was effective for two years but when a high precipitation period occurred in 1993, the alum layer was buried because considerable sediment and phosphorus entered the lake from Jackson Creek. For an alum treatment in Bullhead Lake to have long term success, it is important that external loading be significantly reduced. Although at the present time it appears that significant phosphorus from internal loading is not available for algal growth following fall and spring turnover, with a reduction in external loading, the importance of internal loading may become more obvious.

While the phosphorus profiles and sediment cores indicate that the internal loading of phosphorus occurs in Bullhead Lake during stratification and the onset of hypolimnetic anoxia, it is not readily apparent that this phosphorus is readily available for algal production during the growing season. While this phosphorus is mobilized to the surface during fall turnover, lower phosphorus concentrations in spring suggest the majority of this phosphorus settles back to the sediment. The relationship between water quality and annual precipitation, especially from 2017-2019, are highly indicative that external phosphorus loading from the watershed plays a more significant role currently in Bullhead Lake's water quality when compared to internal loading.

4.0 CONCLUSIONS & DISCUSSION

The primary objectives of this study were to quantify the internal loading of phosphorus in Bullhead Lake, determine its impact on the lake's water quality, and determine the feasibility and dosage of a potential alum treatment. This study revealed that approximately 280 pounds of phosphorus were released into anoxic bottom waters during the 2019 growing season. While this represents a significant portion of Bullhead Lake's annual phosphorus budget, it is not believed that this phosphorus is available for use by algae at the surface.

Phosphorus profiles collected in 2019 indicate that bottom-released phosphorus remains within bottom waters over the course of the summer and is only mobilized to the surface in October during fall turnover. While a portion of this phosphorus may remain in surface waters and become available to algae the following spring, lower phosphorus concentrations in spring suggest most of this phosphorus settles back to the sediment. In conclusion, while the internal loading of phosphorus in Bullhead Lake is significant, its impact on growing season water quality does not appear to be substantial at the present time.

This study did reveal that external phosphorus loading from the watershed does play a more significant role in Bullhead Lake's water quality than previously thought, especially when precipitation is high. The analyses presented earlier show that near-surface summer phosphorus concentrations in Bullhead Lake are positively correlated with annual precipitation. The years 2017-2019 saw the highest annual precipitation on record for the area and phosphorus concentrations in Bullhead Lake were also the highest measured on record. The increasing trend in phosphorus concentrations since 2010 correspond to an increasing trend in annual precipitation. More advanced watershed modeling using STEPL showed that the BMPs currently in place within the watershed reduce external phosphorus loading from croplands by 40%. The modeling also indicated that the forested wetlands adjacent to Bullhead Lake are highly important for the lake's water quality. In most years, modeling suggests that these wetlands intercept and retain approximately 40% of the phosphorus from adjacent croplands, preventing this phosphorus from entering Bullhead Lake.

However, under high precipitation conditions in 2017-2019, these wetlands were inundated and the surface of Bullhead Lake extended into these wetlands. Under these conditions, runoff from croplands was likely able to flow directly through the wetlands and into the lake. It's also likely that previously deposited phosphorus was released from sediments within these wetlands when flooded. This study revealed that more mitigation within the watershed is needed to reduce phosphorus runoff, especially in high precipitation years.

While completing an alum treatment would reduce internal phosphorus loading, significant water quality improvements in Bullhead Lake would not be realized given the significant external loading that has occurred over the past few years. It is believed that an alum treatment in Bullhead Lake is not appropriate at this time and that the BLAA's primary focus should be on further reduction of external phosphorus loading. The subsequent list contains recommended actions that the BLAA can take to continue making improvements within the Bullhead Lake watershed.

Monitoring

- To increase understanding of water quality dynamics and trends in Bullhead Lake, the BLAA should continue their monitoring of Bullhead Lake's water quality. The BLAA currently monitors the lake's water quality annually through the WDNR's Citizens Lake Monitoring Network (CLMN) Program, collecting phosphorus and Secchi disk data in spring, June, July, and August, and chlorophyll data in June, July, and August.

  The BLAA should also consider expanding this monitoring to include the collection of phosphorus samples during fall turnover. Ideally, the spring sample should be collected approximately two weeks after ice-out (typically April), while fall turnover in Bullhead Lake occurs in October. Temperature and dissolved oxygen profiles should also be collected during each sampling event. This information will be useful when precipitation returns to near normal levels in an effort to determine if an alum treatment would be applicable in the future.

- As discussed, the forested wetlands adjacent to Bullhead Lake are believed to be highly significant in terms of intercepting and retaining phosphorus. However, when these wetlands become flooded, they lose their capacity to retain phosphorus. In an effort to understand when these wetlands flood and the duration of flooding, the BLAA should consider enrolling in the WDNR's Water Level Monitoring Program. This involves weekly volunteer monitoring of water levels by reporting the water level from a staff gauge installed in the lake. Volunteers would also indicate if standing water was present in the wetlands. This would allow resource managers to determine the lake level at which the wetlands become flooded and the duration of flooding. This may also help determine if the implementation of some type of water level control would be appropriate for Bullhead Lake in the future.

- Bullhead Lake has experienced significant filamentous algal growth in most of the recent years. These algae can obtain phosphorus from the sediments where they often begin growth in the summer. The literature indicates that this type of algae can be phosphorus-limited, but nitrogen limitation is also common. It should be determined what is the limiting nutrient for the algae in Bullhead Lake. While reducing phosphorus input to the lake will undoubtedly reduce overall algal growth, if the filamentous algae are found to be nitrogen limited, other management strategies may be appropriate. If the BLAA is interested in completing this analysis, they should work with resource managers to determine the most appropriate methodology.

Nutrient Reduction Techniques

Considerable effort has and is being made in the agricultural part of the watershed to reduce nutrient input into the lake. These efforts should continue even though the nutrient reduction efforts may not be immediately noticeable in the lake. As was evident in 2019 when the wetlands became flooded, the wetlands around the lake play a very important part in reducing the external phosphorus load to the lake. Like lakes, wetlands can become degraded if they receive excessive amounts of nutrients. By employing BMPs in the agricultural fields, the reduction in nutrient loading will extend the nutrient retention efficiency of the wetlands.

- In subwatershed 4 (Figure 10 and 13), croplands drain into a sedimentation basin before draining underneath the railroad tracks and into Bullhead Lake. While these sedimentation basins are designed to intercept and retain nutrients and sediments flowing into them, their functionality can be lost over time as they begin to fill in with sediment. This sedimentation basin should be assessed to determine its efficiency and if excavation or other mitigation techniques are necessary to improve its efficiency.

- Examination of detailed elevation data suggests that runoff from portions of subwatershed 6 and subwatershed 4 (Figure 10 and 13) may be channelized and thus nutrients are not being retained within the wetlands. It should be determined if flow pattern can be modified so that runoff is more diffuse and be made to flow through the wetlands.

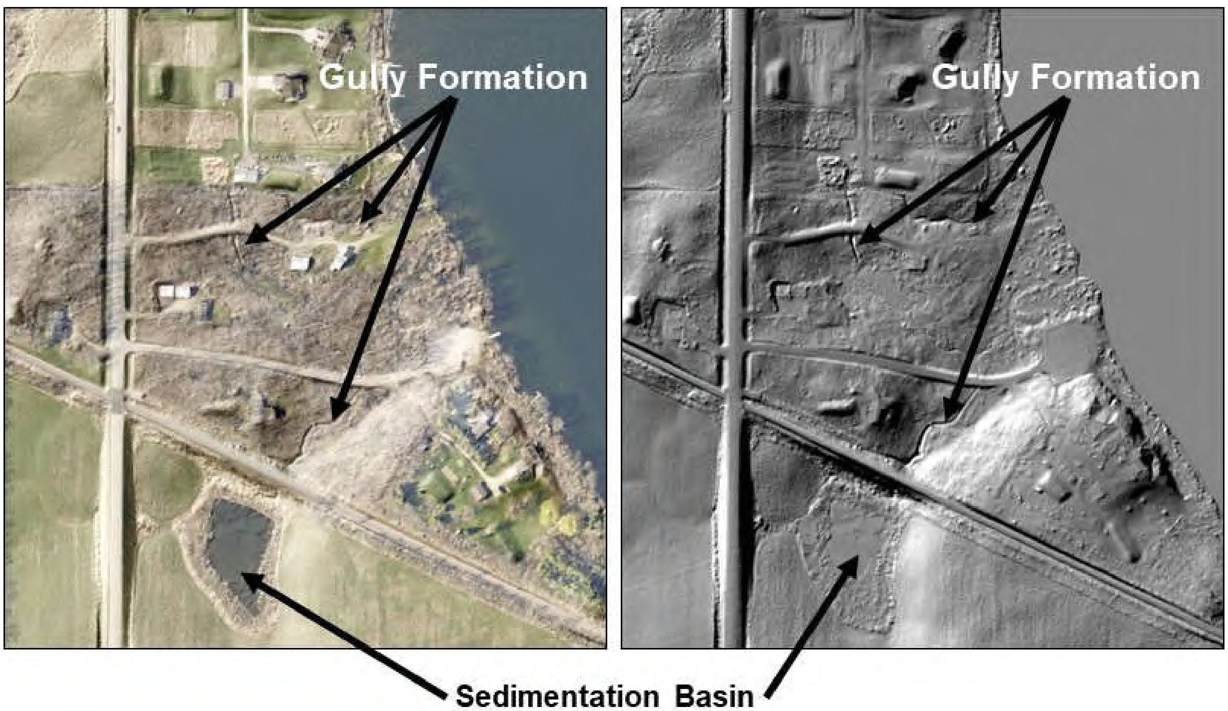

Figure 13. Sedimentation basin and gully formation areas that may allow nutrients to directly drain into the lake without flowing through the wetlands. LIDAR hillshade data obtained from Manitowoc County.

- There are a number of shoreland homes around Bullhead Lake. While the amount of nutrients contributed per unit area is less than agricultural practices, in Bullhead Lake, most of the agricultural land drains into the wetlands which sequester a large amount of the phosphorus. This sequestration does not occur with the shoreland properties; meaning they contribute a significant nutrient load. Studies have shown that buffer vegetation at the lakeshore can significantly reduce nutrient runoff into the lake. Even though phosphorus is usually no longer included in synthetic fertilizer, nitrogen is an important component. Studies have shown that filamentous algae, can be nitrogen limited. If this is the case, over use of lawn fertilizer could be causing significant algal growth in the lake. Even though phosphate fertilizer is not used on lakeshore lawns, grass clippings and leaves contain a significant amount of phosphorus.

The studies completed in 2017 on Bullhead Lake found that approximately 30% of the shoreline was highly developed, containing little to no natural habitat. Restoration of these shorelines would likely reduce runoff from upland yards, homes, and driveways, decreasing nutrient inputs to Bullhead Lake. The BLAA should work with riparian property owners to pursue Healthy Lake Initiative Grants to restore developed shorelands and/or implement BMPs on their property (e.g., rain gardens) to reduce runoff and improve natural habitat.

The WDNR's Healthy Lakes Initiative Grants allow partial cost coverage for native plantings in transition areas. This reimbursable grant program is intended for relatively straightforward and simple projects. More advanced projects that require advanced engineering design may seek alternative funding opportunities, potentially through the county and the WDNR Lake Protection Grant Program. For a larger project that may include a number of properties, it may be more appropriate to seek funding through a WDNR Lake Protection Grant. While more funding can be provided through a Lake Protection Grant and there are no limits to where that funding is utilized (e.g. technical, installation, etc.); however, the grant does require that the restored shorelines remain undeveloped in perpetuity.

- The cropland in the southwest portion of subwatershed 1 (Figure 10 and 14) contains a series of subsurface drain tiles with an outfall on the east side of the field. This outfall delivers water to a ditch along Neumeyer Ln, which then flows down into the forested wetland complex on the north side of the lake. Research has shown that these drain tiles can be a significant source of phosphorus and other nutrients, and greatly accelerate runoff (Kovacic et al. 2000).

  While buffer strips are often planted along waterways within croplands to slow runoff, buffer strips are not effective when drain tiles are present as water is not allowed to pass through the buffer strips. The BLAA should work with Dave Hintz who owns/manages this cropland to determine if there are any strategies that can be taken to reduce nutrient runoff. Strategies may include removal of the drain tile system and installation of waterway buffer strips. If possible, a retention basin could be installed at the drain tile outfall to allow nutrients and sediment to settle out before flowing down into Bullhead Lake. The BLAA could also work with Mr. Hintz to see if acquisition of this cropland by the BLAA is a possibility. The WDNR offers grants for land acquisition where the state would fund 75% of the cost to purchase. Once purchased, the BLAA could work to restore this property from cropland to native grassland. The long roots of native grassland plants would help to stabilize soils and reduce runoff.

- Harvesting of filamentous algae should continue as long as there are large algal mats present. Removing the algae removes phosphorus from the lake. An estimate should be made of the amount of material that is removed from the lake. Determining the phosphorus content of algae will allow an estimation of phosphorus removal. This may be important in the future if an alum treatment is considered. The removal of the phosphorus will reduce the amount of phosphorus that can contribute to the internal load.

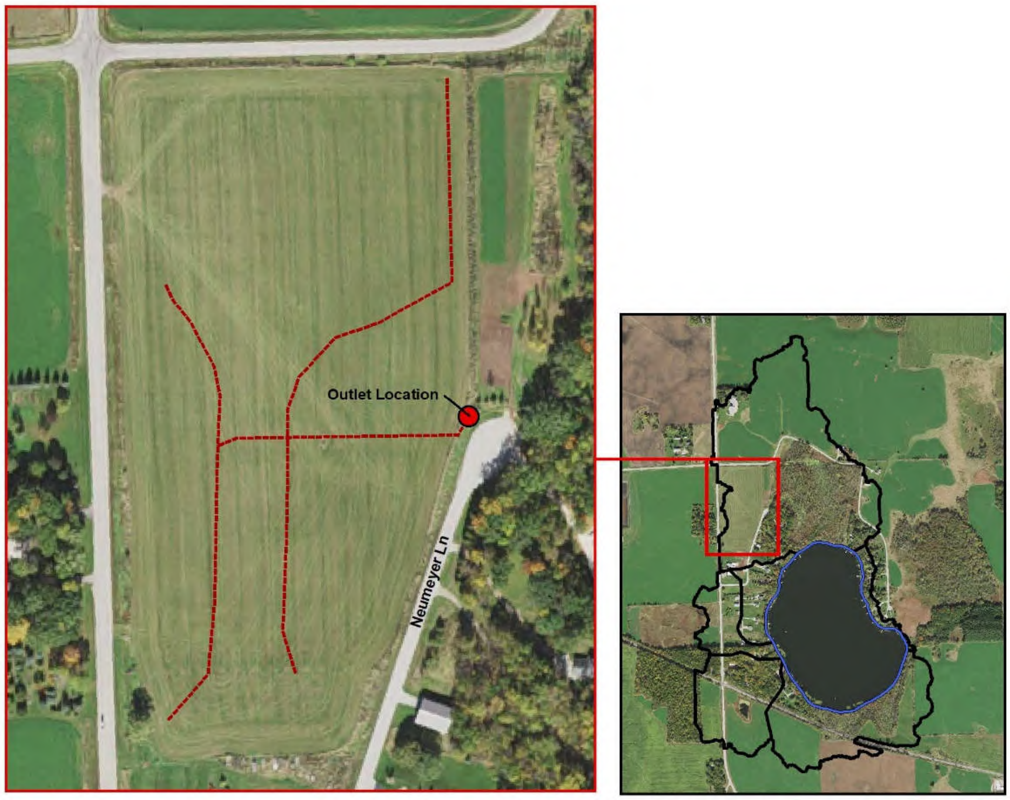

Figure 14. Approximate location of agricultural drain tiles (red dashed line) and outlet on cropland in Bullhead Lake watershed.

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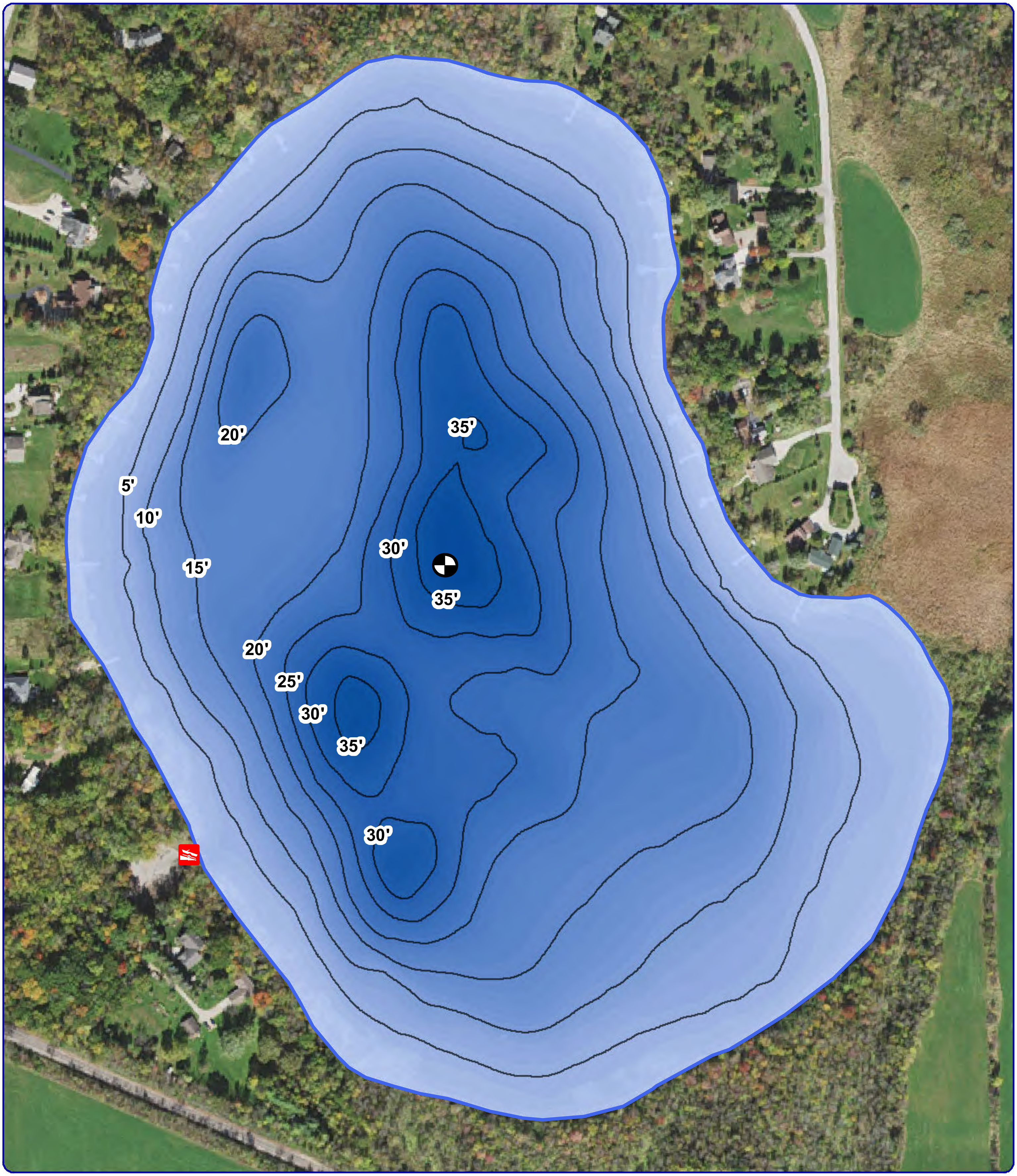

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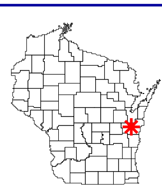
Sources:
Hydro: Modified by Onterra
Bathymetry: Onterra 2017
Aerial Photography: NAIP 2017
Map Date: January 23, 2020 BTB


Project Location in Wisconsin

Legend
- Deep Hole Sampling Location
- Public Boat Landing

Map 1
Bullhead Lake
Manitowoc County, Wisconsin
Project Location