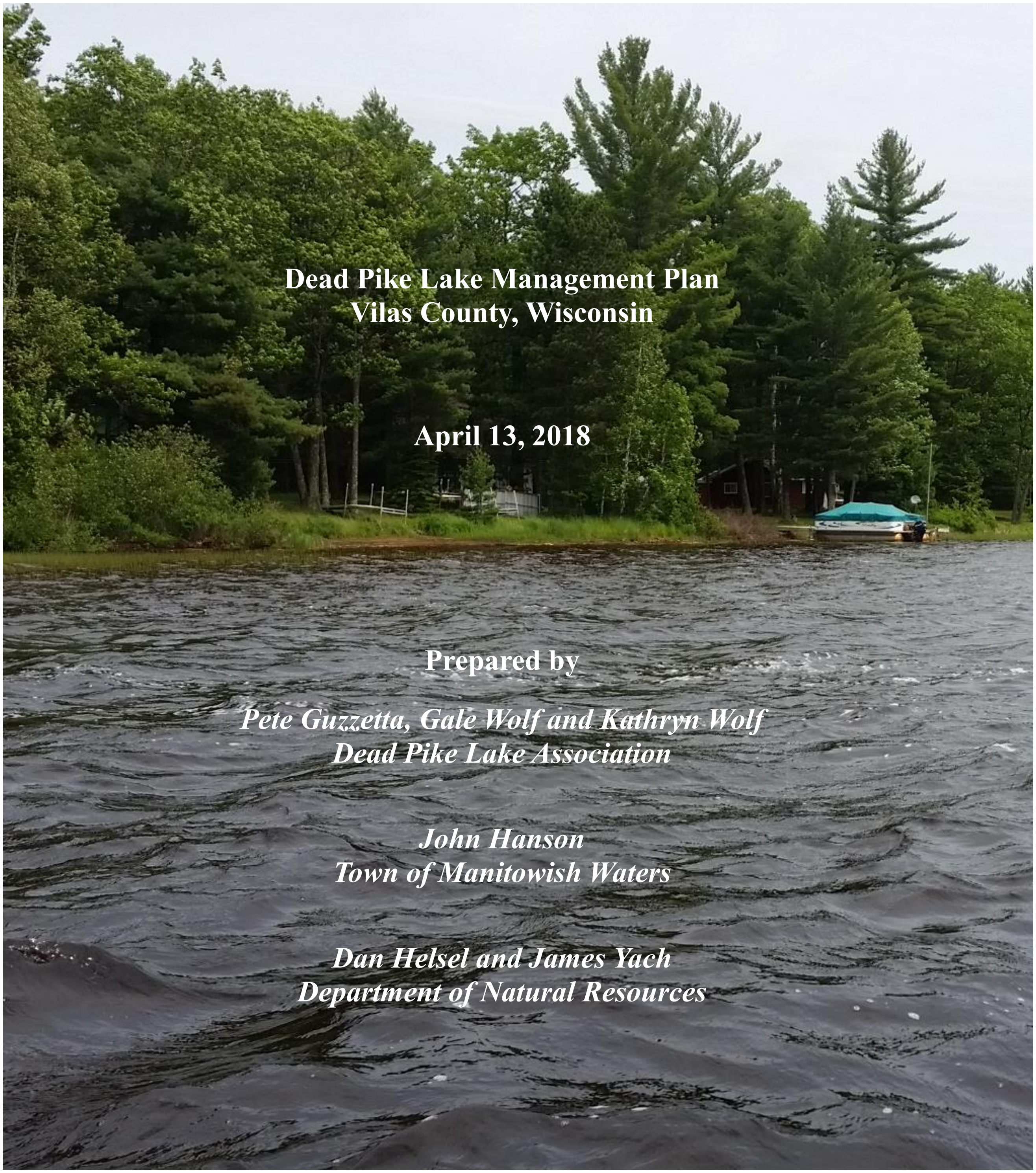

Dead Pike Lake Management Plan
Vilas County, Wisconsin

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1 Executive Summary

The Dead Pike Lake management plan was developed through a partnership with the Dead Pike Lake Association (DPLA), the Town of Manitowish Waters (Town) and the Wisconsin Department of Natural Resources (WDNR). The plan sets water quality goals for removing the lake from the State list of impaired waters for phosphorus, and reducing iron and manganese loading to reduce harmful environmental conditions and improve lake recreational uses.

Dead Pike Lake (DPL) and the upstream, state-owned Powell Marsh State Wildlife Area (PMSWA) are closely connected by surface and groundwater flows and are part of the ecosystem. Over the years, multiple partnerships have formed to address water quality issues of elevated phosphorus and iron at DPL and Powell Marsh. When the Natural Resources Board approved the PMSWA master plan in December 2016, they directed the WDNR to work with the DPLA to develop a lake management plan to address water quality concerns. A work group comprised of the DPLA, Town and WDNR representatives, working closely with professionals from Applied Ecological Services, prepared this lake management plan which focuses on the reduction of phosphorus and iron to meet State Water Quality standards and reduce environmental and aesthetic impairments.

Dead Pike Lake, located on the western border of Vilas County, is a 297-acre soft water lake with a maximum depth of 80 feet. DPL is used by anglers, hunters, wildlife viewers, and recreational boaters. DPL has one public boat landing with parking for up to five cars and trailers as well as parking on Powell Road. DPL is largely undeveloped with about 60% of the shore line owned by the State along with about 20 residential parcels. The total watershed area of the lake is approximately 3,400 acres. The Powell Marsh State Wildlife Area is the primary surface water contributor encompassing a drainage area of approximately 2,000 acres for the lake. The PMSWA provides extensive public access with multiple access points and is used for wildlife viewing, hunting, trapping, hiking and biking.

1.1 Dead Pike Lake Water Quality Goals

The Dead Pike Lake management plan recognizes the multiple lake and watershed goals including maintenance of the ecological integrity of the lake and marsh watershed. The primary water quality concerns at Dead Pike Lake include the risk to the 2-story fisheries caused by elevated phosphorus and the environmental and recreational impairments caused by excess iron and manganese. Lake management goals for Dead Pike Lake follow a conventional, quantitative approach for total phosphorus where a reduction in loading results in a correlated reduction of in-lake concentration. Iron management goals have been developed based upon the STELLA model results and the estimated reductions that can be achieved through the proposed management actions.

Dead Pike Lake was added to the 2016, State 303(d) impaired water list because both the long-term geometric mean (16.6 μg/L) and the lower boundary of the 90% confidence interval (15.2 μg/L) exceeded the 2-story lake phosphorus standard of 15 μg/L for the Recreation use and Fish and Aquatic Life use. The total phosphorus water quality goal for Dead Pike Lake is conservatively set to have the long-term geometric mean equal to, or less than 15 μg/L, the State water quality criteria for a 2-story fisheries lake.

Well-developed and peer reviewed lake response models that predict reductions in-lake iron (Fe) concentrations or iron floc densities in response to load reduction are not available. The STELLA model provides a coarse estimate of the relationship between Fe loading and in-lake concentrations but not for iron floc accumulations. Accordingly, percent load reductions are based primarily upon what reductions in Fe loading can be achieved through the management actions. The iron water quality goal for Dead Pike is to reduce the 3.5 mg/L Fe inflow concentration to 1.49 mg/L or less with an estimated reduction in the inflow load of ~4,300 Fe kg/yr. A complementary water quality goal is to reduce the Fe groundwater load by 74%, to reduce the iron floc/iron bacteria densities in the lake and along the nearshore areas of the lake.

1.2 Recommended Management Actions

The sources, transport and environmental effects of excess phosphorus, iron and manganese in Dead Pike Lake and Powell Marsh State Wildlife Area are complex. The management actions recommended in this section are based upon a water quality conceptual framework described in Chapter 0 and have been deemed most likely to reduce the levels of phosphorus and iron/manganese in Dead Pike Lake.

The sources of iron and phosphorus come from both groundwater and surface water inputs, with groundwater being the largest contributor of iron (86% to 92%) and total phosphorus (66%). The high concentration of iron in the groundwater is not related to man-made pollution, and although the amount of iron entering Dead Pike Lake from groundwater is affected by changes in the water budget (e.g. drought, lake elevation, etc.), the groundwater portion of the iron load is a naturally occurring condition. Similarly, the relatively high phosphorus concentrations in the groundwater are associated with watersheds dominated by wetlands (Robertson D. , 2018) and the groundwater portion of the phosphorus load is also a naturally occurring condition.

The smaller proportion of iron and phosphorus entering Dead Pike Lake from Powell Marsh has been increased by the construction of the ditches and impoundments in the 1950s. Average iron and phosphorus concentrations discharged from Powell Marsh are about two times greater than the concentrations discharged from the unditched watershed of Deerfoot Marsh to the north.

The recommended management actions described in this section include:

- Raise the bottom of the Dead Pike outlet stream channel by ½ to 1 foot;
- Create a wetland biofilter system in the Powell Marsh ditches nearest to the lake, thereby reducing the inflowing phosphorus and iron by 50% to 70%;
- Construct a clean water diversion from Stepping Stone impoundment if necessary to maintain lake surface water elevations;
- Apply lime to the lake after implementation of the phosphorus and iron source reductions.

Given the complexity of the water quality issues at DPL and PMSWA, implementation follows the principals of adaptive management with staged implementation combined with evaluation monitoring and progressive management. The recommended management actions are also planned with an overall goal of reversibility. That is, implement the initial management action, monitor the results toward obtaining the water quality goal and if the goal is not achieved, implement more progressive management actions. And if none of the management action components are effective, reverse the action and restore to pre-management conditions.

1.3 Implementation Plan

The completion of the Dead Pike Lake Management Plan and modifications to the Powell Marsh State Wildlife Area sets the foundation for implementation of in-lake and watershed management actions to address water quality concerns. The Town of Manitowish Waters and the Dead Pike Lake Association, in partnership with the WDNR, have received a lake planning grant to take the next step of developing conceptual plans and refining cost estimates for the recommended lake management actions, including 1) establishing a minimum lake level, 2) an in-channel/wetland treatment system, 3) a clean water diversion and 4) a lime treatment. The information generated by the lake grant will provide the information necessary to pursue funding for final engineering and implementation. For local, state and federal regulatory permits that require a lower level of review (e.g. general permits), the conceptual plans will be used as part of permit applications. For more rigorously reviewed permits (e.g. individual permits), permit applications will have to include final engineering plans. The lake planning grant work will start in February 2018 and be completed by December 2018.

2 Recommended Lake Management Actions

2.1 Lake Management Plan Foundation

Dead Pike Lake is in Vilas County in Northern Wisconsin (Figure 2) and is directly downstream from the Powell Marsh State Wildlife Area. Dead Pike Lake and Powell Marsh State Wildlife Area are closely connected by surface and groundwater flows and both water bodies are important resources within the Town of Manitowish Waters (Town) and the State. The Wisconsin Department of Natural Resources (WDNR) earliest documented contact about water quality concerns at Dead Pike lake was in 1976. Since that time, lake residents and the Town have continued to voice water quality concerns to the WDNR.

The Wisconsin Natural Resources Board approved the PMSWA master plan in December 2016 and through an amendment, directed the WDNR to work with the Dead Pike Lake Association (DPLA) to develop a lake management plan to address water quality issues. Since January 2017, the WDNR has been working in partnership with DPLA and the Town to develop a lake management plan specifically focused on management actions to address these water quality concerns.

The lake management plan work group includes: John Hanson (Town), Pete Guzzetta, Gale Wolf and Kathryn Wolf (DPLA), Dan Helsel, Michele Woodford and James Yach (WDNR). The work group met monthly with ongoing e-mail and conference call communications supplementing the face to face contact. This team also included regular input from Applied Ecological Services (AES), an environmental consulting firm working for the Town with funding from the WDNR. AES assembled a team of environmental engineers, ecologists and eco-toxicologists and provided extensive data interpretation, eco-system modeling and field surveys along with two workshops with stakeholders to discuss scientific findings and present lake management alternatives.

This lake management relies heavily on previous technical reports (Krohelski, 2002), (Kreitlow, 2007), (Barr, 2011), technical memos (Garrison, 2012), (Garrison, 2013), (Helmuth, 2017), (Ludwig J. , 2017) and incorporates the recent water quality and modeling work by Applied Ecological Services (Apfelbaum, 2018).

2.2 Summary of Water Quality Goals

The Dead Pike Lake management plan recognizes the multiple lake and watershed goals including maintenance of the ecological integrity of the lake and watershed. To be successful, the long-term management of the causes and impacts of Dead Pike Lake water quality concerns must be correctly defined and quantified. This begins with developing a clear understanding of factors affecting water quality in the lake and watershed ecosystem. A sound water quality database has been developed encompassing the critical elements of the lake's hydrology, morphometry, water chemistry, biota, pollutant load and trophic state. The lake management plan has evolved from analysis and interpretation of this comprehensive data set and provides for the distinct goals of improving lake water quality and achieving ecological and recreational goals in the watershed.

Photo 1. Iron accumulation along shoreline of Dead Pike Lake (2017)

The primary water quality concerns at Dead Pike Lake include the risk to the 2-story fisheries caused by elevated phosphorus concentration (eutrophication) and the environmental and recreational impairments caused by excess iron and manganese. Lake management goals for Dead Pike Lake follow a conventional, quantitative approach for total phosphorus where a reduction in loading results in a correlated reduction of in-lake concentration (Table 1). Water quality goals for total phosphorus, chlorophyll-a and water clarity (Secchi disk) use data from the prescribed assessment periods in WisCALM (2017b). Due to the stained waters of Dead Pike Lake and Powell Marsh, established relationships between total phosphorus and chlorophyll-a and water clarity are different from many clear, unstained lakes.

Conventional assessment and predictive models are not available for iron concentrations and iron floc formation; however, AES used the STELLA (ISEE, 2008) modeling framework to develop site specific relationships between iron load and in-lake iron concentrations (Apfelbaum, 2018). Iron management goals have been developed based upon the STELLA model results and the estimated reductions that can be achieved through the proposed management actions. Because of the unpredictability associated with iron and iron floc response to management actions, adaptive management will be an important component of lake management implementation.

Table 1. Water Quality Goals for Dead Pike Lake

Water Quality Parameter	Existing Condition	In-lake Goal	Reduction Goal
Phosphorus Concentration **TSI**	17 µg/L 44	15 µg/L < 47	12% concentration reduction Meets goal
Chlorophyll -a **TSI**	4 µg/L 39	< 10 µg/L < 47	Meets goal
Secchi Disk **TSI**	6.88 feet 49	8.40 feet < 47	24% increase in clarity
Phosphorus Annual Load (GFlow model)	206 kg/yr	173 kg/yr	16% load reduction
Iron Floc Accumulation (Total Iron Load from STELLA model)	53,222 kg/yr	26,611 kg/yr	50% load reduction
Iron Concentration (Annual average)	1.2 mg/L	1.00 mg/L	20% concentration reduction
Iron – Inflow Concentration (Annual average)	3.52 mg/L	1.49 mg/L	58% concentration reduction
Iron Floc Formation (Viewing bucket rating)	TBD	TBD	50% reduction

Total Phosphorus

The total phosphorus water quality goal for Dead Pike Lake is to be equal or less than 15 µg/L, the State water quality standard for a 2-story fisheries lake (WDNR, 2017b). The Dead Pike Lake total phosphorus general assessment for trophic status index (TSI) is rated as good with a TSI of 44 and meets the State goal of 47. Dead Pike Lake was added to the 2016, 303d impaired water list because both the long-term geometric mean (16.6 µg/L) and the lower boundary of the 90% confidence interval (15.2 µg/L) exceeded the 2-story total phosphorus standard of 15 µg/L for the Recreation use and Fish and Aquatic Life use. With the addition of 2017 data, the 2018 assessments showed continued impairment.

The water quality goal applied a conservative approach using the long-term upper 90% CI of 17 µg/L as the initial in-lake phosphorus concentration. Accordingly, the goal for the in-lake total phosphorus is a 12% reduction in the 90% CI value of 17 µg/L to 15 µg/L. Achieving 15 µg/L in-lake total phosphorus requires a 16% reduction in annual phosphorus loading from watershed and groundwater sources discussed in Chapter 0.

Iron and Manganese

Elevated iron (Fe) concentrations in Dead Pike Lake cause excessive iron floc and iron bacteria formation resulting in aesthetic impairments, potential toxicity and habitat degradation in shallow bays and nearshore areas of the lake. Manganese (Mn) may also contribute to potential in-lake toxicity issues and since Mn chemistry is very similar to Fe chemistry, the goal reductions for iron are expected to also achieve comparable reductions in Mn.

Well-developed and peer reviewed lake response models that predict reductions for in-lake Fe concentrations or iron floc densities in response to load reduction are not available. The STELLA model provides a site-specific estimate of the relationship between Fe loading and in-lake concentrations but not for iron floc densities (Apfelbaum, 2018). Accordingly, percent load reductions are based primarily upon what reductions in Fe loading can be achieved through the management actions. Wetland complexes are used to effectively remove iron and are a common management action for Fe and Mn associated with metal mining runoff. Successful wetland treatment technologies have reduced iron concentrations from 30 mg/L and greater down to concentrations to 1.0 mg/L and in most cases below 0.5 mg/L (Batty, 2005).

Water quality goals for iron include reducing in-lake concentrations and the visible formation of iron floc/iron bacteria along the near shore of the lake. Achieving in-lake iron concentrations goal requires reductions in both the iron load discharged from PMSWA and the iron groundwater load. The Fe water quality goal for Dead Pike is to reduce the 3.5 mg/L Fe inflow concentration to 1.5 mg/L assessed to be background conditions from the un-ditched marsh watershed of Deerfoot Marsh Creek that drains into Dead Pike Lake on the north. The surface water inflow reduction equates to an estimated reduction in the inflow load of 4,300 Fe kg/yr. The Fe groundwater load reduction goal of 41% to 72% (18,500 kg/yr to 33,800 kg/yr) is based upon projected Fe loading reductions from incremental increases in minimum lake levels.

Chlorophyll-a

The data review for the 2016 impaired water listing showed Dead Pike Lake currently meeting the state standard for chlorophyll-a (Chl-a) of 10 μg/L with an average of 4 μg/L and an upper 90 CI of 4 μg/L. In 2017, the Chl-a averaged 2.35 μg/L with a range between 1.52 μg/L and 3.8 μg/L. Management actions implemented to achieve phosphorus or iron water quality goals could possibly affect in-lake chlorophyll concentrations. Although there is not a reduction goal for chlorophyll now, the water quality goal for chlorophyll is to maintain concentrations equal to or less than 4 μg/L.

Secchi Disk

The summer average Secchi disk water clarity goal for Dead Pike Lake is 8.4 ft based upon a Trophic Status Index of 47, which is a 24% increase in the average water clarity from 2017 readings. Because Dead Pike Lake is heavily stained by organic matter combined with iron, improvements in water clarity associated with reductions in phosphorus or chlorophyll concentrations are expected to be minor. The reduction in substances that color the water such as organic matter (dissolved organic carbon, DOC), iron and manganese is expected to improve water clarity but it is difficult to predict. In the presence of organic carbon, iron is associated with decreasing the water clarity (Maloney, 2005) while cations like calcium and magnesium increase water clarity (Carpenter, 2017). During drought conditions in Northern Wisconsin in 2005 – 2010, Dead Pike Lake Secchi disk averaged 12.2 feet, likely reflecting a reduction in dissolved organic carbon and iron inputs from surface water and groundwater. Drought conditions result in reductions of both in surface water and ground water inputs, such that all inputs are reduced. Since the stained color of Dead Pike Lake is a result of the DOC and iron, the lower inputs of dissolved organic carbon that transports the iron from the marsh (see Chapter 10) into Dead Pike Lake likely caused the increased water clarity (Carpenter, 2017). Secchi disk measurements are expected to approach drought condition water clarities of 12 feet when water quality goals for phosphorus and especially iron are achieved.

Trophic Status Indices (TSI)

The general assessment Trophic Status Indices (TSI) water quality goal for Dead Pike Lake is equal to or less than a TSI of 47 equating to water quality rating of *good* (WDNR, 2017b). The TSI threshold of 47 is based upon diatom community information from reference lake sediment cores. Since adequate sediment core data from two-story lakes is not available, the 75th percentile value for deep seepage lakes was used for the threshold between excellent and good condition. The total phosphorus and chlorophyll-a general Trophic State Indices are less than 47 and meet the WisCALM goal. Using the last five years of data (2013-2017), the Secchi disk TSI is 49 and exceeds the threshold. The general assessment TSI water quality goal for Dead Pike Lake is to maintain a TSI of 47 or less which is equal to a Secchi disk measurement of 8.40 feet.

2.3 Management Actions

The sources, transport and environmental effects of excess phosphorus, iron and manganese in Dead Pike Lake (DPL) and Powell Marsh State Wildlife Area (PMSWA) are complex. The management actions recommended in this section are based upon water quality conceptual framework described in Chapter 0 and have been deemed most likely to reduce the levels of phosphorus and iron/manganese in Dead Pike Lake.

The recommended management actions described in this section include:

- Reduce the groundwater inflow of iron and phosphorus by establishing a higher minimum lake elevation by raising the bottom of the Dead Pike outlet stream channel by ½ foot to 1 foot;
- Treat phosphorus and iron flowing from Powell Marsh by creating a wetland biofilter in the Powell Marsh ditches nearest to the lake;
- Construct a clean water diversion from Stepping Stone impoundment used to maintain a minimum lake surface water elevation when necessary;
- Precipitate and sequester iron and phosphorus below the thermocline by applying lime to the lake after reducing the surface water and groundwater loads.

Given the complexity of the water quality issues at DPL and PMSWA, implementation follows the principals of adaptive management with staged implementation combined with evaluation monitoring and progressive management. The recommended management actions are also planned with an overall goal of reversibility. That is, implement the initial management action, monitor the results toward obtaining the water quality goal and if the goal is not achieved, implement the second more progressive management action. And if none of the management action components are effective, reverse the action and restore to pre-management conditions.

Raising the bottom of the outlet stream by one foot and treating 70% of the inflowing iron and phosphorus from Powell Marsh are predicted to reduce the Dead Pike lake iron load by 72% and the phosphorus load by 65% (Figure 1). Raising the bottom of the outlet stream by ½ foot and treating 50% of the inflowing iron and phosphorus from Powell Marsh are predicted to reduce the iron and phosphorus loads by 41% and 39%, respectively.

Either of these combined management actions are predicted to meet the 16% load reduction water quality goals for phosphorus and the in-lake average iron concentration goal of 1.49 mg/L. Without a direct relationship between iron loading and iron floc accumulation in Dead Pike Lake, it's unclear whether a 41% or a 72% reduction in the groundwater iron load will reduce iron floc in the lake basin by the 50% goal.

Local, State and Federal authorization will be required for all the proposed management actions and will be pursued following the development of the conceptual plans and, when needed, fully engineered plans. Some management actions are aligned with existing general permits such as ditch plugs as a wetland restoration activity, while other management actions will require engineering plan development and submittal. The adaptive management approach of step by step implementation of the least costly and intensive management action with active monitoring, also provides an opportunity for a comparable approach to permitting.

Preliminary cost estimates (Table 2) are provided as a starting point and will be further refined with the preparation of conceptual design plans in 2018. The collection of site specific information and conceptual plan development for the recommended lake management actions will be completed with funding a large-scale lake management plan grant awarded to the Town of Manitowish Waters.

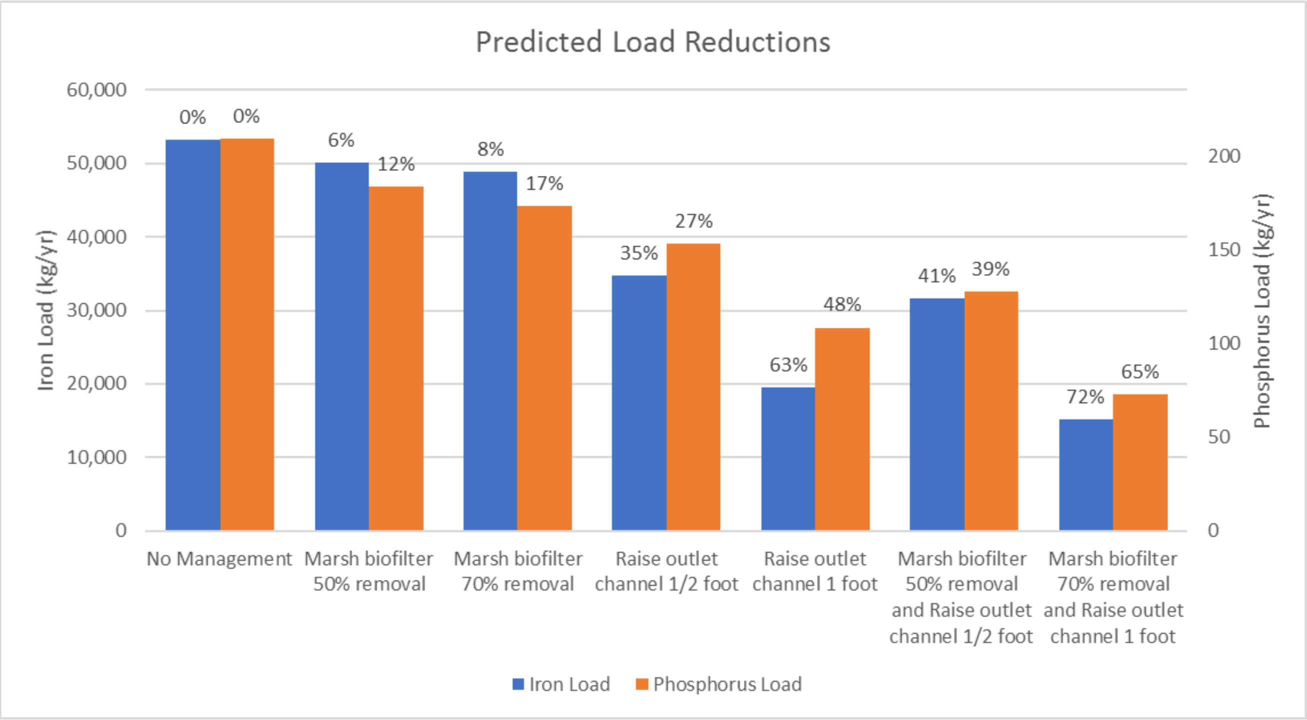


Figure 1. Predicted Iron and Phosphorus Reductions

Establishing a Minimum Dead Pike Lake Elevation

Applied Ecological Services (Apfelbaum, 2018) estimates 45,600 kg/year of iron is delivered into Dead Pike Lake via groundwater discharge with iron concentrations about eight times greater than surface water concentrations – ~30 mg/L compared to ~3.5 mg/L. Maintaining a constant higher water level in DPL increases the hydraulic pressure on groundwater inflow and reduces the groundwater load. The normal lake water elevation fluctuates between 1595.31 and 1596.31 fasl (feet above sea level). Increasing the minimum lake elevation increases the hydraulic head on the groundwater and reduces the seasonal influx of iron and other constituents into the lake from groundwater. The GFlow model was used to evaluate the change in water budget with a 0.25-foot increase in the lake level (Helmuth, 2017) and showed a 5% reduction in groundwater inflow. GFlow model errors were not acceptable at higher lake level simulations.

Photo 2. Dead Pike outlet location of raising the bottom stream elevation.

The STELLA model was also used to model reductions in groundwater inflow as a result of raising the bottom stream elevation. Raising the elevation of the outlet channel by 1 foot, from 1594.4 to 1595.4 was modeled to increase lake levels to a range from 1596.11 to 1597.05 fasl and reduce groundwater inflow by 74% (from 1.96 cfs to 0.51 cfs). The differences in the water budget formulation between the GFlow and STELLA model results are discussed further in Chapter 4.

The predicted reduction in groundwater inflow from STELLA reduces the influx of iron rich groundwater into the lake by 63% and reduces phosphorus groundwater loading by 48% (Figure 1). Raising the elevation of the outlet channel by ½ foot, from 1594.4 to 1595.9 was modeled to increase lake levels to a range from 1595.78 to 1596.79 fasl and reduces groundwater inflow by

40% (from 1.96 cfs to 1.17 cfs). This reduction in groundwater inflow reduces the influx of iron rich groundwater into the lake by 35% and reduces phosphorus groundwater loading by 27% (Figure 1).

Establishing the minimum lake elevation can be accomplished by construction of a structure that raises the bottom elevation of the outlet stream channel. An important design consideration of this structure, which may simplify permitting, is to not raise the lake elevation above the established ordinary high-water mark (OHWM). The regulatory OHWM was designated at six locations on the lake basin proper (Jefferson, 2017) that averaged 1597.35 fasl; although the lake outlet and lake inlet cove had slightly lower OHWMs of 1596.0 and 1596.6, respectively.

Initial plans are to install a temporary, reversible structure that raises the bottom stream elevation and widens the river channel to maintain the discharge capacity of the outlet. The temporary structure would remain in place for 2-4 years while evaluation monitoring was conducted. After two years, the structure would either be re-constructed as a permanent structure or removed depending on effectiveness of reducing in-lake phosphorus and iron concentrations and iron floc formation. The preliminary estimates for design and construction of a structure to maintain a minimum lake elevation is $200,000 - $300,000.

Phosphorus and Iron Treatment System in Powell Marsh

Approximately 6,200 kg of iron and 51 kg of phosphorus are delivered to Dead Pike Lake from the Powell Marsh State Wildlife Area annually. The construction of a wetland biofilter system could reduce iron and phosphorus loads from PMSWA by 50% to 70%. Introducing wetland biofilters into backfilled ditch systems of PMSWA would reduce the amount of phosphorus through biological uptake and precipitation and reduce the amount of iron and manganese through precipitation and some biological uptake. The proposed wetland biofilters within the ditches are a modification of the proposed ditch plugs in the PMSWA master plan (WDNR, 2016a). The wetland biofilters would be combined with underlying limestone backfill that would seal the bottom of the ditches, disconnecting the surface-to-groundwater interaction. The sealing serves to reduce the inflow of iron and manganese rich groundwater entering the ditches (Helmuth, 2017). The wetland biofilters are estimated to remove between 3,100 and 4,300 kg/yr of iron and between 25 and 36 kg/yr of phosphorus.

Photo 3. Powell Marsh North-South ditch flowing from the Main Pool Impoundment and proposed location for sealing and biofiltration

Preliminary design plans backfill approximately the lower two-thirds of each ditch with limestone screenings, or limestone rock, topped with a filter fabric followed by installation of soil that is subsequently planted with biofilter wetland vegetation. Staged implementation begins with construction of the biofilters and backfilled limestone within the existing east-west and north-south ditches connected to the PMSWA Main Pool. If after evaluation monitoring, sufficient phosphorus, iron and manganese removal is not achieved, the channels will be modified to increase the flow path length and increased residence time. If sufficient iron and phosphorus removal is still not achieved, a larger wetland treatment system with a series of treatment ponds and a final polishing wetland biofilter will be designed and constructed. Preliminary sizing of the wetland complex ranges from 1,500 feet of in-channel bio-filters to 25-40 acres with 2 feet of excavation, added soil amendments and a possible outlet control structure. The estimated costs for the in-channel wetland treatment system to construction of a larger treatment wetland complex is $300,000 to $700,000.

Lime Application

Dead Pike Lake is a relatively soft-water ecosystem with a modest amount of dissolved ionizing substances but with a low conductivity due to the low amounts of calcium, magnesium and other alkalizing substances. Dissolved ions in lakes tend to follow their position in the periodic table and their valence state. Monovalent atoms with low atomic weights are less prone to react to form complex heavy molecules than heavier polyvalent atoms. It is the deficiencies of the alkalizing cations of calcium and magnesium that allow the heavier iron and manganese to remain soluble and with increased potential toxicity (Ludwig J. , 2017). With the small concentrations of alkalizing cations, iron and manganese remain soluble or in complexes with dissolved organic matter.

Probably the single most beneficial chemical/environmental change that could be imposed on the Dead Pike Lake ecosystem is to increase the concentrations of these key alkalizing cations (Ludwig J. , 2017). Raising the pH of Dead Pike Lake will promote the formation of heavier complexed molecules and increase the efficiency of iron and phosphorus settling. With the low conductivity and alkalinity of DPL, a relatively small addition of dissolved bivalent cations (calcium and magnesium) would result in a relatively rapid increase in pH. The anions (CO_3^{-2} + HCO_3^{-}) will complex with the iron floc to generate much larger molecules than the floc that is now present, settling faster and falling through the thermocline into the bottom sediments. Increasing the amount of the alkalizing cations like calcium and magnesium will result in less soluble iron and manganese and increase the precipitation of these heavy metals. These anions also will help complex the dissolved organics and improve water clarity and reduce iron and phosphorus transport.

Even with load reductions, up to three lake volume flushing (i.e. 6 years) could be needed to fully purge the lake basin of the elevated iron and phosphorus. The one-time application of lime will quicken the lake's response to load reductions by precipitating the iron and phosphorus and dissolved organic carbon. The lime treatment is not designed to be a long-term control mechanism for iron and phosphorus. As the reduced levels of iron, phosphorus and dissolved organic carbon (i.e. humic acids) flow into Dead Pike Lake through surface water and groundwater, the lake will slowly return toward historic pH levels.

Based upon the DPL lake volume, rough estimates for the addition of about 200 metric tons of well-agitated calcitic lime (80% $CaCO_3$, 20% $MgCO_3$) will increase Ca levels to about 10 mg/L and Mg to about 1.4 mg/L with a pH shift of about 0.6 – 0.8 units upwards. Estimated costs for the application of limestone to DPL were converted from 1982 costs provided by Menz (1983) with a 20% contingency. The application of lime to Dead Pike Lake estimated cost range is between $15,000 and $30,000.

Clean Water Diversion

Monitoring has documented lower iron and phosphorus concentration in the PMSWA Stepping Stone impoundment, although the impoundment also has a lower pH which, combined with the water chemistry, is thought to cause some potential toxicity issues detected through WET testing. Nonetheless, if the flow from PMSWA main ditch is reduced due to the construction of the wetland treatment system in the ditches, the Stepping Stone impoundment would be a suitable source of water for a clean water diversion with placement of limestone or similar materials to adjust the pH and reduce toxicity. To maintain a suitable water level in Stepping Stone impoundment to avoid impacting the important habitat in the impoundment, additional flow from the Little Trout impoundment or another source may be required. Additional groundwater sampling and flow hydraulics for the diversion channel/pipe is included in the work that will be done through the planning grant awarded to the Town. Preliminary estimates to construct the clean water diversion from Stepping Stone impoundment into Pete's creek is $60,000.

Table 2. Preliminary Cost Estimates

Recommended Management Action	Location	Estimated Cost Range
Establish a minimum lake level	Lake Outlet	$200,000 - $300,000
In-channel/wetland biofilter	Marsh Main Ditch	$300,000 - $700,000
Clean water diversion	Stepping Stone Impoundment	$60,000
Lime treatment	Lake Basin	$15,000 - $30,000
Evaluation monitoring (3 yr total)	Lake and Marsh Sites	$15,000
Total Estimated Cost Range		$590,000 - $1,105,000
From: Applied Ecological Services Report (Apfelbaum, 2018)		

The cost estimates will be further refined based upon the conceptual plans developed in 2018 and the progressive stepwise approach to implementation will be considered. The conceptual plans focus on the lowest cost, easily reversible actions as a starting point. For example, the initial wetland treatment system could be designed for construction within the existing 1,500-foot North-South ditch before treatment is installed in the

1,000-foot East-West ditch. If treatment goals are achieved within the north-south ditch, the costs would likely be substantially less than $300,000. The development of the conceptual plans is planned for late summer, 2018 in partnership with local WDNR resource managers.

Based upon the preliminary estimates, the unit cost of iron control by maintaining a minimum lake elevation is about $9/kg and $100/kg to $160/kg to reduce iron with the wetland biofilter in Powell Marsh. Iron treatment are most commonly used to remove iron from metallic mining discharges and can range widely from $8/kg to over $700/kg (Kirby, 2014)

Because the reduction goals for phosphorus target only 33 kg compared to the iron reduction goal of more than 26,000 kg, and management actions address both iron and phosphorus at the same time, the cost per kg of phosphorus control is high. The unit cost of phosphorus reduction by maintaining a minimum lake elevation is about $3,000/kg compared to between $12,000/kg to $20,000/kg to reduce phosphorus with the wetland biofilter in Powell Marsh. Though the cost of phosphorus treatment increases dramatically as the targeted concentration is reduced, reported costs for constructed wetland treatment is $2,000/kg (Hamill, 2010) while point source phosphorus control is in the range of $660/kg and $20/kg for non-point source phosphorus control (WDNR, 2018c).

2.4 Funding Options

The type of funding sources and amounts of the allocation depend on the eligibility requirements for each specific funding source. In addition, the budgetary needs for implementation of each management action also guides the type of funding source. This management plan has been prepared to meet plan requirements for likely funding options for implementation (Table 3). WDNR surface water grants can fund lake management activities prescribed in an approved lake management plan to a maximum of $200,000 per project (WDNR, 2017a) and require a non-state match. Federal s. 319 Clean Water Act funding can be directly allocated to the project by the State either through a grant or contract for water quality improvements within qualifying Nine-Key Element Watershed Plans. The WDNR may allocate certain types of state funds or pass-through federal monies to the project such as General-Purpose Revenue (GPR) or Sport Fish Restoration (SFR). The state or federal legislature could allocate funding for implementation through a budget resolution or special appropriation bill. Other funding sources could include donations or grants from private foundations and commercial businesses concerned with environmental restoration and protection. Some funding sources like the WDNR surface water grant program will pay for engineering costs and permitting and some funding sources will only fund implementation activities and no engineering or planning costs.

The identification of potential funding sources, including governmental and non-governmental sources and private foundations, will continue into 2018. Applications for implementation funding will be assembled soon after the conceptual plans are available with more precise cost estimates for construction.

Table 3. State and Federal Planning Requirements

Plan Type	Plan Requirements	Potential Funding Sources
WDNR Lake Management Plan	(WDNR, 2017a)- Appendix C	State surface water grant
Nine-Key Element Plan	(WDNR, 2017a)- Appendix D https://www.epa.gov/nps	Federal 319 funding
Environmental Accountability Project	(WDNR, 2012)- EAP Factsheet	Federal clean water act funding

2.5 Evaluation Monitoring

Evaluation monitoring is key to understanding the effectiveness of management actions during and following implementation. Contingent upon available funds, evaluation monitoring will focus on the

- Direct measurements of the key water quality parameters including phosphorus, chlorophyll, water clarity and iron combined with annual water budget data and hypolimnetic oxygen;

- Secondary biological indicators that respond to improvements in water clarity and reductions in iron floc such as aquatic plants, mussels and fisheries.

Water Budget Monitoring

Extensive inflow and outflow stream data was collected in 2017 and provided for the development of reliable rating curves at both locations (i.e. a well-defined flow relationship based upon stream depth). In 2018, a total positioning system (e.g. Gowin TKS) will be used to established local bench marks in feet above sea level at the inlet and outlet stream channels and the lake basin. The local bench marks will provide the means to re-install staff gauges each year during open water conditions. The staff gauges will be manually read and existing rating curves used to translate the water depths into instantaneous flow. The lake basin staff gauge will record changes in lake storage to complete the information needed to calculate a basic annual water budget. Staff gauges will be read on a weekly basis and synchronized with the collection of phosphorus and iron – useful at a basic level to compare concentration loads from year to year. To estimate annual loads, continued installation of the HOBO units will be required.

Water Quality

Total phosphorus and total iron will be collected monthly from the lake inflow during the prescribed assessment period in WisCALM (June through September) and then synchronized with staff gauge readings at the inflow. Using information from 2017 and other historic phosphorus and iron loading data, the annual loads for phosphorus and iron will be calculated using measured open water and estimated ice-covered flows.

Total phosphorus, chlorophyll, Secchi disk and total iron will be collected from the surface of Dead Pike Lake at the deep hole monthly during the assessment period June through September. Sample collection will follow standard volunteer monitoring protocol and be synchronized with collection of the inflow samples and staff gauge readings.

Monitoring the oxygen in the hypolimnetic layer is an important factor for Dead Pike Lake since continuous presence of oxygen at concentration above 6 mg/L in portions of the colder water hypolimnion is necessary to support a 2-story fishery. Temperature and oxygen profiles will be collected at least once during the late summer to monitor the hypolimnetic oxygen concentrations.

Evaluation monitoring will be implemented to assess changes in general surface water quality associated with implementation of specific management actions. For instance, pH, alkalinity, transparency tube and key cations like calcium and magnesium will be monitored monthly in surface waters upstream and downstream of lime application or in-place limestone structures and biofiltration systems.

A pilot iron floc assessment project is proposed for the summer of 2018 and if the methodology is found to be valid, this monitoring will be continued monthly during the summer months. In 2017, the WDNR developed a periphyton assessment tool using density rating grid within a viewing bucket. This methodology should be transferable to a semi-quantifiable assessment tool for iron floc/bacteria accumulations along the near shore of DPL. The evaluation monitoring will follow the pilot viewing bucket assessment protocol for the collection of iron floc/bacteria density rating data developed in 2018.

Secondary Biological Monitoring

Implementation of the management actions are targeted to improve water clarity and reduce iron floc formation which may have a secondary effect on certain in-lake biological components such as aquatic plants, mussels and the fisheries. Evaluation monitoring should continue the point intercept aquatic plant community monitoring on a 5-year cycle. A 2018 lake wide mussel survey is planned and continued monitoring of the mussel community will be on a similar 5-year schedule. Routine fisheries assessment will continue according to standard schedules including spring fyke netting, fall electro-surveys and vertical gill netting for cisco and rainbow smelt.

Evaluation Monitoring Reporting

Evaluation monitoring efforts will likely be implemented by several different groups with different funding sources. Volunteer monitoring will likely continue to be a strong component of the monitoring as well as WDNR core and specially tailored monitoring projects. State and Federal funding and grants may also likely be used to fund evaluation monitoring. Real-time monitoring data will be used as part of the planned adaptive management steps for the project. At a minimum, the suite of data collected (Table 4) will be collectively evaluated every five years or more frequently as part of lake management plan updates.

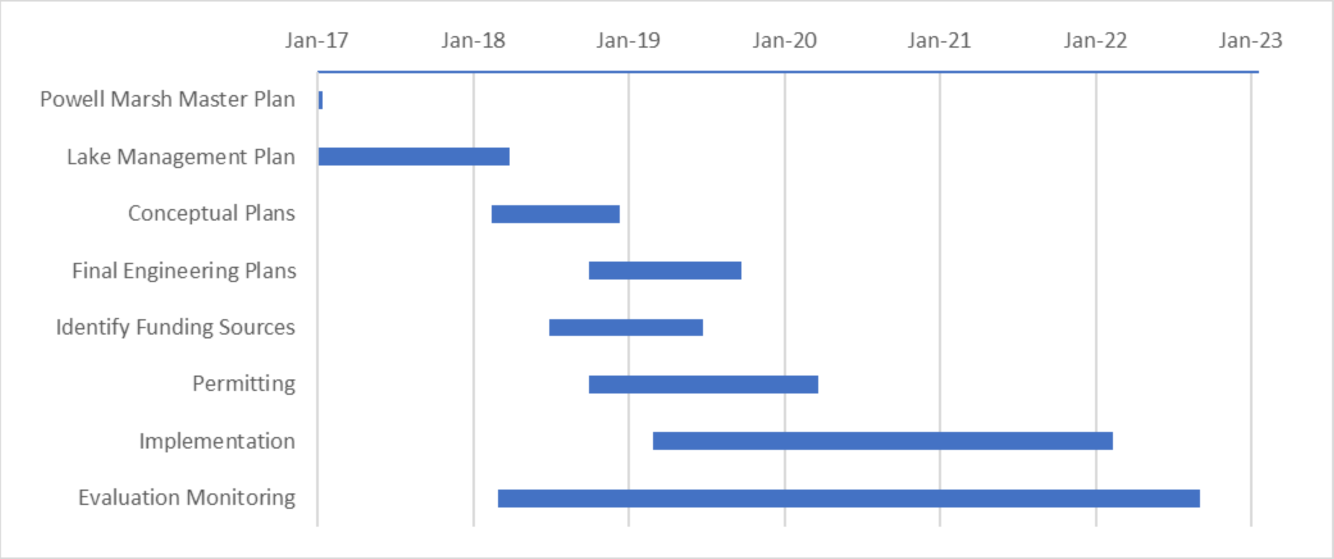
Table 4. Evaluation Monitoring Framework

Component	Parameters	Location	Frequency
Water Budget	Staff gauge readings	Inflow, outflow and lake basin	Weekly
Surface Water	Phosphorus, iron, chlorophyll, Secchi Disk etc.	Inflow and deep hole	Monthly
Biological	Aquatic Plant Mussels Fisheries	Lake basin	Every 5 years

2.6 Implementation Schedule

The completion of the Dead Pike Lake (DPL) Management Plan and modifications to the Powell Marsh State Wildlife Area (PMSWA) sets the foundation for implementation of in-lake and watershed management actions to address water quality concerns (Table 5). The Town of Manitowish Waters and the Dead Pike Lake Association in partnership with the WDNR have already received a lake planning grant to take the next step of developing conceptual plans and refined cost estimates for the recommended lake management actions, including 1) establishing a minimum lake level, 2) in-channel/wetland biofiltration treatment system and 3) a clean water diversion, if needed. The information generated by the lake grant will provide the information necessary to pursue funding for final engineering and implementation. For local, state and federal regulatory permits that require a lower level of review (e.g. general permits), the conceptual plans will be used as part of permit applications. For more rigorously reviewed permits (e.g. individual permits), permit applications will have to include final engineering plans. The lake planning grant work will start in February 2018 and be completed by December 2018.

Table 5. Dead Pike Lake Management Timeline



3 Background - Dead Pike Lake and Powell Marsh

Wisconsin has over 15,000 lakes and most of those lakes (more than 80%) are in northern Wisconsin where the recent glaciation created one of the densest clusters of lakes anywhere in the world (H.S. Garn et al., 2003). Dead Pike Lake was likely created as a kettle outwash or ice block lake as the Wisconsin Valley and Ontonagon Lobes of the Laurentide Ice Sheet receded about 18,000 years ago (WGNHS, 2013; Attig, 1985). The glacial deposits directly adjacent to Dead Pike Lake (Figure 3) commonly have depressions (kettles) that resulted from melting of ice blocks buried during the deposition phase. Dead Pike Lake fits the description by Graczyk (2003) of a protruding debris-rich ice block and would be surrounded by silt and clay layers that creates a more complex lake-groundwater system. The entirety of Powell Marsh was described as post glacial organic sediment 1 meter to 5 meters thick underlain by fluvial, glacial or lacustrine sediment (Attig, 1985). While lakes are abundant in the region, large, open peatlands, like Powell Marsh, are rare across northern Wisconsin (WDNR, 2016)

3.1 Dead Pike Lake

The earliest map of Dead Pike Lake and Powell Marsh from the original government survey in 1860 (Figure 4) shows higher water levels and roughly 30% more surface water. Between the 1860 survey map and the first air photo available in 1937 (Figure 5), the characteristics of the watershed changed substantially. The boundaries of the lake were substantially reduced. In comparison with the outline of its current shoreline, the large lobe shown on the northern portion of the Lake in the original survey was absent, as was the extensive bay at the Lake's northeast corner protruding out toward the complex of Stepping Stone Lakes. In the marsh, water levels were lowered, agricultural activities were put in place (e.g. ditching, filling and cropping) and a railroad line crossed the complex diagonally, southwest to the northeast (Barr, 2011; WDNR, 2016a).

Dead Pike Lake is a stratified, low-land, drainage lake with both surface water inflow and outflow. DPL has the water clarity and nutrient levels of a mesotrophic lake (i.e. medium range of nutrients). The lake also represents a distinct natural community and is classified as a two-story fisheries lake which is defined in WisCALM (WDNR, 2017b) as:

> *Two Story Fishery Lakes – Two-story fishery lakes are often more than 50 feet deep and are always stratified in the summer. They have the potential for an oxygenated hypolimnion during summer stratification and therefore the potential to support coldwater fish species in the hypolimnion. In order to be included in this category, a lake should meet the definition of "stratified" (Lathrop/Lillie equation value >3.8), be greater than five acres, and support a coldwater fishery. Supporting a coldwater fishery may either be demonstrated through documentation of a current or historical native cold-water fishery (e.g., cisco, lake trout), or verification with DNR fisheries biologists that the lake is on a long-term stocking plan for coldwater species, where the individuals have good year-to-year survival.*

The uniqueness of Dead Pike Lake is represented by several factors. Its isolated location within the heavily developed region of the Chain provides a retreat from the congestion and crowded conditions of the Manitowish Chain of Lakes. Its pristine quality remains assured by sparse development and over 60% of its shore land being held by the State of Wisconsin. It boasts a highly diversified aquatic plant community with 50 species, and no invasive species. The lake's heavily forested surroundings are protected by being included within the Northern Highland American Legion State forest as well as its direct connection to the renowned Powell Marsh State Wildlife Area.

3.2 Powell Marsh

The large area that is now Powell Marsh formed during the first 2,000 years post glacial period as the glacial retreated and the permafrost melted resulting in runoff and overland sediment deposition (Carson, personal communication, 2018). The progression of bog maturation or peatland formation is both episodic and spatially complex and includes both terrestrialization and paludification (Ireland, 2013) that started at least 4980 years ago across the Great Lakes region. Classic, undisturbed bog formation would have gradually resulted in filling of the peatland, accumulation of sphagnum moss and ultimately the formation of a raised bog (Ludwig J. F., 1983). The raised bog would have functioned as an aquitard and greatly restricted sub surface groundwater interactions.

In 1955, the Commissioner of Lands (by patent) granted and conveyed to the State of Wisconsin all of Sections 29,30,31,32, and 33 in the Township of Manitowish Waters, County of Vilas (Barr, 2011). This acquisition resulted in the transfer of 3,125 acres which would ultimately become the Powell Marsh State Wildlife Area (PMSWA). PMSWA encompasses 4,850-acre area bounded on three sides by the Northern Highland – American Legion State Forest and by the Lac du Flambeau Indian Reservation to the south.

Sometime prior to 1937 and continually into the mid-1900s, the ditches were constructed to drain the soil for agricultural row cropping. In the 1950s, the Conservation Department expanded the existing dike and impoundment infrastructure to include approximately 14 miles of dikes and access roads and a series of flowages with 14 control structures (Barr, 2011). It encompasses a portion of a 20,000-acre wetland complex mostly owned and managed by the Lac du Flambeau Reservation. About 12,000 acres of the tribally owned lands have leatherleaf bog habitat similar to lands on the State wildlife area. The ditch and impoundment infrastructure on the marsh has been largely unchanged since 1960 except for routine ditch and outlet control structure maintenance (Woodford, 2017) and is primarily an open peatland with several flowages and seepage lakes. The ditching cut through the bog aquitard and increased the interface between groundwater and surface water discharging to Dead Pike Lake. The construction of the impoundments created an additional hydraulic head pressure on the groundwater entering the ditches. This increased connection and seasonally fluctuating hydraulics, increases the discharge of iron, phosphorus and dissolved organic carbon to Dead Pike Lake. This parallels the work by Elder (2000) who found the low dissolved organic carbon yields were attributed to the lack of overland flow and very limited stream channel coverage in the catchment area the peatland adjacent to Allequash Lake.

The Powell Marsh State Wildlife Area master plan was recently updated (WDNR, 2016a) and highlights multi-recreational and resource conservation purposes. Traditional recreational activities include berry picking photography, waterfowl hunting and trapping along with hunting grouse and deer on the upland portions of the property. Walking and biking on the berms are common activities and birders frequenting the marsh have documented over 213 species of birds (Ebird, 2018).

The important habitat values are associated with the semi-permanent water for waterfowl and semi-aquatic furbearers. The expansive open-water marshland and sedge meadows support many species of greatest conservation need (WDNR, 2016a). Notably this includes the yellow rail, LeConte’s sparrow, Nelson’s sharp-tailed sparrow and the black tern. Large, open sedge meadows are preferred habitat for Yellow Rail, LeConte’s Sparrow and Nelson’s Sharp-tailed Sparrow.

4 Watershed and Flow Characteristics

A common quote in lake management is “a lake is a reflection of its watershed.” More specifically, there are several key watershed characteristics that affect a lake’s water quality including size, topography, geology, landuse, and soil fertility. Different land uses in the watershed have the potential to load different types and amounts of pollutant. For example, heavy metals, toxins and nutrients are the main pollutants of concern from urban land uses (Steuer, 1997) compared to concerns of sediment and nutrient pollutants from agricultural land use (Corsi, 1997). Undistributed and natural forests and wetlands generally have the lowest pollutant export rates (Liu, 2009). However, extensive ditches within a lake’s watershed also affect surface water and groundwater flow and those exchanges are spatially and temporally complex (Jones P. a., 2015). Jones (2015) found that groundwater flows toward and into the ditches during periods of little precipitation but when ditch-waters rise, the ditch water flows into the adjacent groundwater – producing an accordion effect of groundwater flowing into and out of the ditches.

Although, compared to lakes in other parts of Wisconsin with watersheds dominated by urban and or agricultural landuse, Dead Pike Lake may appear to have a pristine, natural watershed; in fact, the watershed is highly developed with dikes, ditches and impoundments – all of which affect the water budget and added additional iron and phosphorus loading to the lake.

4.1 Dead Pike Lake Watershed and Water Budget

Dead Pike Lake is located on the western border of Vilas County in North Central Wisconsin. This lake is a medium sized, 297-acre lake with 3.84 miles of shoreline. Dead Pike Lake has a maximum mapped depth of 80 feet and is classified as a two-story, mesotrophic lake. The western, northern and eastern shorelines are relatively shallow while the southern shoreline drops off quickly. There are 24 private residential riparian parcels on the lake with approximately 60% of the shoreline publicly owned by the State.

The watershed delineation for Dead Pike Lake used both the I-THIA (Purdue, 2016) mapping function from the Department’s Surface Water Viewer (WDNR, 2018) and EVAAL mapping function with LiDAR information for Vilas County (Nelson, 2017). The total watershed area of the lake is estimated to be approximately 3,466 acres (Figure 6). Surface water inputs are primarily from by the Powell Marsh to the south either through the main inlet under Powell Road or through Pete’s Creek to the east (Figure 7) with approximately 2,071 acres contributing through these two lake inlets. Intermittent flow from Deerfoot Marsh to the north and from the Stepping Stone chain of lakes to the east also flow into Dead Pike Lake, primarily in the spring and later fall.

The most recent land use information from Wiscland 2.0 (WDNR, 2016b) show the dominant land-uses (Table 6) are wetlands (42%) and forest (46%) and open water (12%). The residential properties on the shores of Dead Pike Lake maintain sufficient forest cover and Wiscland classifies those nearshore areas as forest.

Table 6. Dead Pike Lake Watershed Land Use

Land use	Area(acres)	%
Open Water	424	12%
Emergent/Wet Meadow	1046	30.2%
Lowland Scrub/Shrub	628	18.1%
Forested Wetland	379	10.9%
Mixed Deciduous/Coniferous Forest	362	10.5%
Coniferous Forest	300	8.6%
Broad-leaved Deciduous Forest	300	8.6%
Floating Aquatic Herbaceous Vegetation	14	0.4%
Idle Grassland	12	0.3%
Cranberries	1	0.0%
Total	3466	100%

The development of the Dead Pike Lake water budget followed conventional methods which are based upon the water budget equation:

Change Lake Storage =

(Precipitation + Surface Water in + Groundwater in) – (Evaporation + Surface Water out + Groundwater out)

Net ground-water flow to the lake may be calculated as the residual in the water-budget equation, or determined by using surface water and/or groundwater elevation data nearby the lake to develop a two-dimensional ground-water-flow model, such as GFLOW (Haitjema, 1995) to the area (Garn, 2003). Several previous studies have developed water budgets for Dead Pike lake including the USGS (Krohelski, 2002) and Barr (Barr, 2011). These two studies arrived at much different water budgets for the lake (Table 7).

There are several differences and limitations associated with each of the USGS and the Barr approaches. The USGS used a steady-state groundwater model (GFlow, (Haitjema, 1995)) that reflects long-term averages during baseflow conditions. The USGS used limited number of surface water control

Photo 4. Dead Pike Lake surface water elevations dropped about a foot in 2017.

points for calibrations and focused mainly on groundwater elevations for calibrations. Whereas Barr measured surface water flows and used net groundwater inflow to balance the water budget equation. Barr's actual flow measurements were collected for a period of six months. Garrison reviewed both reports and arrived at a reasonable approach to resolving the differences in the two water budgets (Garrison, 2012) by increasing the Barr surface water flow by 40%. Garrison noted that the water budgets were developed for different years and though not mentioned by Garrison, the PMSWA began discharging a minimum flow of 1.2 cfs into Dead Pike Lake in the summer of 2007. Although USGS and Barr surface water and groundwater budgets were nearly inverse, the average annual flows were fairly close.

In 2017, similar approaches were used to develop water budgets for Dead Pike Lake. Applied Ecological Services (AES) used surface water elevation and flow data collected by WDNR staff to develop a water budget based upon surface waterflows similar to Barr's approach (Apfelbaum, 2018). AES used the dynamic modeling platform STELLA (ISEE, 2008) to construct a transient water budget with a daily time step. Inflows and outflows were measured by the Department using HOBO pressure sensors installed at the inlet (Powell Road) and outlet channel. The HOBO sensors recorded pressures every 15 minutes and were calibrated with an atmospheric pressure sensor at the inlet and converted to a water depth. Flow measurements were collected approximately every two weeks from April through September at the inlet and outlet. AES developed rating curves using the measured flow values and water level data from the HOBO pressure sensors (Figure 8). The equations in the rating curves were used to calculate daily average flows from the HOBO data set. Within the limited range of the measured flows, the rating curves may be over estimating the flows at greater water depths. Precipitation data was downloaded from the Manitowish River weather site and evaporation was estimated (Helmuth, 2017). The AES transient water budget showed a seasonal pattern of the surface water and groundwater contributions. In the spring, when lake levels were higher, the groundwater contribution is non-existent. As the lake level drops through the summer, the groundwater contribution became a larger portion of the water budget (Figure 9).

In addition, WDNR Groundwater Water Use Section staff used surface water elevations collected by the WDNR to develop a steady-state water budget using GFlow similar to USGS's approach (Helmuth, 2017). Water-surface elevations of selected nearby lakes and streams were collected with a Real-Time Kinematic Global Positioning System (RTK-GPS) for calibration of the GFlow model. Surveyed elevations have an accuracy of about 0.1 ft and were calibrated to the Department of Transportation bench mark at the Manitowish Waters airport. Base-flow discharge measurements were also made at stream sites concurrently with the elevation measurements. The 2017 GFlow model differed from the 2002 GFlow model by several factors including utilization of a "lake package" that was not available in 2002 and calibration to the inflow at the inlet, the outflow at Lost Creek and the DPL lake level rather than primarily groundwater elevations. During base flow conditions in late August (i.e. steady-state conditions), the STELLA and the GFlow water budgets were similar using 2017 data (Table 7) recognizing that the GFlow model represents long-term average base flow condition and the STELLA model includes variations in surface flows including higher flow conditions.

Table 7 Summary of Water Budgets for Dead Pike Lake

Water Budget Approach	Surface Water	Groundwater	Annual Inflow Flow
GFlow USGS (Krohelski, 2002)	23%	77%	4.3 cfs
Surface Water Based (Barr, 2011)	85%	15%	3.1 cfs
Hybrid (Garrison, 2012)	67%	33%	4.3 cfs
GFlow (Helmuth, 2017)	43%	57%	3.5 cfs
Surface Water Based (Apfelbaum, 2018)	58%	42%	4.9 cfs

Lake Elevation Factors

There's evidence that historically water levels on Dead Pike Lake were affected by natural beaver dams and possibly man-made barriers installed to hold the water levels higher on the outlet stream, Lost Creek. As recently as the fall of 2018, beavers had constructed a new beaver dam downstream of the lake (John Hanson, pers. comm.) that affected late fall water levels. Presently, the nearest man-made feature on Lost Creek, are two culverts on Pier Lake road about 0.74 stream miles downstream from the lake. In 2002 the WDNR replaced a damaged and sloped upstream 60-inch culvert with two 48-inch culverts, providing a greater flow capacity. WDNR collected structural and surface water elevations with a RTK unit in September 2017. The top of the culverts was at an elevation of approximately 1593.3 feet above sea level (fasl), the bottom of Lost Creek stream bottom elevation at 1589.9 fasl and the elevation of Pier Lake Road (center) was at 1595.59 fasl. The steady state Dead Pike Lake surface water elevation was at 1596.5. AES used a HEC-RAS hydrologic model to estimate the ability of the two new culverts to pass a 100-year flood flow and assess their potential effects on the elevation of the lake. AES estimated, during the 100-year flood flow, Pier Lake Road would be overtopped by approximately 4 inches of water. However, blocking the lower 3 feet of the two 48-inch culverts raised the water level over the road but did not affect the water surface elevation at Dead Pike Lake.

4.2 Powell Marsh Surface Water Flows

The Powell Marsh State Wildlife Area (PMSWA) is located approximately 3 miles south of Manitowish Waters in Vilas County, Wisconsin. The state wildlife area includes about 4,850 acres and is part of a larger, 20,000-acre wetland complex mostly owned by the Lac du Flambeau Reservation. PMSWA extends from Highway 47 on the west, to Powell Road and Manitowish Lake on the north and south to Little Trout Lake. The Marsh is directly adjacent to Dead Pike Lake to the North. PMSWA does not have a predominantly surface water inflow (Figure 10). Historically, a surface water inflow connection with Little Trout Lake to the south may have existed, but this connection has been blocked. In the past, the cranberry operations have pumped water from Little Trout Lake onto their cranberry beds to irrigate and harvest and then discharged water through the ditches into Powell Marsh. However, in 2017, the cranberry operations pumped water obtained from Little Trout Lake back into the lake.

There are three outlets of surface water flow from the marsh. Most of the marsh drains into the Main Pool which flows directly into Dead Pike Lake through the north-south and east-west ditches. Surface water flow from PMSWA can sometimes flow or be diverted toward the southwest into Sugarbush Creek, continuing under Highway 47 and emptying into the Little Bear River. Drainage from a small portion of Powell Marsh on the far west side (about 200 acres) bypasses Dead Pike Lake and discharges directly to Lost Creek after flowing under Powell Road (Figure 7).

In 2007, east-west Ditch (the primary ditch draining the Powell Marsh flowages) was defined as a navigable stream. On navigable streams, a minimum flow through water control structures is required and that flow has been estimated at 1.2 cfs by use of the Base Flow Index and at 0.6 cfs by use of the Area Weighted method (SEH, 2007). Since 2007 a minimum flow of 1.2 cfs has been maintained by water discharge from the Main Pool Impoundment with a slotted control structure. Before this, water management primarily entailed capturing spring runoff to fill the ponds through waterfowl season and late fall drawdowns for vegetation management. Minimum flows in the ditch were not historically maintained (WDNR, 2016a).

5 Surface Water Information/data

Chapter Five presents the surface and groundwater chemistry information collected primarily in 2017 with some historic comparisons for key water quality parameters like total phosphorus, iron and transparency. Water chemistries are presented for the assessment periods defined in Wisconsin Consolidated Assessment and Listing Methodology (WisCALM,WDNR, 2017) for those parameters with listing criteria. Water chemistry data outside the assessment period is presented if useful in management discussion of the water quality.

Water chemistry data is presented for three similar functional groups of monitoring sites including 1) Dead Pike Lake deep hole and outlet, 2) Dead Pike Lake surface water inflow sources and 3) Powell Marsh ditches. The discussion of water chemistry relationships and influences on surface water uses, impairments, environmental impacts and potential toxicity for Dead Pike Lake and Powell Marsh is covered in Chapter 0.

Surface water quality concerns have been documented at Dead Pike Lake since 1976 when State Water Pollution Biologist, Larry Maltbey responded in writing to Mr. Loren Wolf about concerns of discolored water at Dead Pike Lake. Since that time, there has a tremendous amount of information collected for the Dead Pike Lake and Powell Marsh system. Over 20 surface water monitoring stations have been established within the Dead Pike Lake watershed (Figure 11). Monitoring efforts have included surface water and groundwater quality, flow, fisheries, aquatic plants, sediment cores and sedimentation rates. Citizen monitors, Pete and

Nancy Guzzetta, have been monitoring Secchi disc since 1996 and added total phosphorus and chlorophyll monitoring in 2005.

In 2017, the Department's Bureau of Water Quality funded a water quality monitoring project including surface water chemistries, ambient whole effluent toxicity (WET) testing and flows. This project continued and expanded a 2016 water quality monitoring project previously supported. Surface water chemistries and physical parameters were planned for collection every two weeks, April through September from 10 sites including the deep hole and outflow of Dead Pike Lake (DPL); two intermittent stream inflows (Deerfoot Creek and Pete's Creek) and the perennial main inflow ditch (Unnamed Ditch a.k.a. Lake Inflow) (Figure 12). Sample collection and instrument calibration followed standard Department protocol (WDNR, 2015a) . If flow was present at the outlet control structure or in the stream channel, surface water grabs were collected and analyzed for various parameters at the State Lab of Hygiene (Table 8).

Table 8. Surface Water Quality Parameters

Surface Water Parameters			
Total Phosphorus	Total and Soluble Iron	Total and Soluble Manganese	Calcium
Magnesium	Dissolved Organic Carbon	Hardness	pH (field)
Conductivity (field)	Dissolved Oxygen (field)	Transparency Tube (field)	Flow (field)
Temperature (field)	Chlorophyll a and Secchi depth at lake deep hole		

5.1 Dead Pike Lake Secchi and Chlorophyll-a

Secchi Disk

Since Father Angelo Secchi, a 19th century Italian Jesuit priest and Papal scientist invented the Secchi disk, this 20-centimeter diameter black and white disk has been the standard for measuring water clarity in lakes. In Wisconsin, citizen lake volunteers collected Secchi disk measurements from about 800 lakes and in recent years, satellites collect water clarity samples on another 8,000 Wisconsin lakes (ERSC, 2018). Many different factors can directly affect the clarity of water including algae, suspended and dissolved material including organic matter and tannic acids.

Secchi disk measurements have been collected from Dead Pike Lake since 1996 by Pete and Nancy Guzzetta at least four times a summer supplemented by measurements collected by Department staff. Average summer Secchi disk ranged from a low in 2016 of 5.3 feet to a high of 15.9 feet in 2007 (Figure 13). Historic Secchi disk readings measured by Birge in August 1927 and July 1928 were 7.7 feet and 11.5, respectively. Dead Pike Lake Secchi disk readings are decidedly correlated with precipitation (Figure 14). Secchi disk show clearer water during the drought conditions from 2004 to 2009 with an average of 12.0 feet compared to 6.1 feet for the recent normal precipitation years of 2013 to 2017 and in general, water clarity improves throughout the course of the summer season.

Chlorophyll-a

Chlorophyll *a* (Chl-a) is a photosynthetic pigment found in algae and other green plants. Typically sampled from the surface waters at the lake's deep hole, Chl-a is commonly used as a measure of the density of the algal population which affects the water clarity. In Wisconsin, Chl-a greater than about 7–10 µg/L indicate eutrophic conditions and greater than 20–30 µg/L are usually considered to be associated with nuisance algal blooms (Robertson D. W., 2003). WisCALM uses Chl-a for both 1) fish and aquatic life use and 2) recreational use impairment thresholds. The fish and aquatic life threshold for 2-story fisheries lake is less than 10 µg/L. The recreational use impairment threshold for 2-story fisheries lakes is less than 5% occurrence of nuisance algal blooms determined to Chl-a greater than 20 µg/L. The assessment period for Chl-a prescribed in WisCALM is July 15th through Sept 15th with acceptable data within 1 week of each date.

Dead Pike lake has a long term Chl-a average of 3.27 µg/L while the 2017 average was 4.08 µg/L mainly due to a high September 2017 sample (Figure 15) and meets the water quality thresholds specified in WisCALM. Chl-a concentrations are slightly lower than expected given nutrient concentrations likely attributed to the colored water due to organic acids. Whereas Secchi was strongly correlated with precipitation, Chl-a increased during moderately wet conditions but then decreased during periods of high precipitation (Figure 16). Although, these are relatively small changes in concentration, during periods of wet conditions increased organic acids may have resulted in darker water and less Chl-a production

Trophic Status Indices

One method of classifying the water quality or productivity of a lake is by computing water-quality indices such as Trophic State Indices (TSI) (Carlson, 1977) (Lillie, 1993). Oligotrophic lakes (TSIs less than 40) typically have a limited supply of nutrients, clear water, low algal populations, low phosphorus concentrations, and the deepest water in the lake typically contains oxygen throughout the year. Mesotrophic lakes (TSIs between 40 and 50) typically have a moderate supply of nutrients, are prone to moderate algal blooms, and may have occasional oxygen depletions at depth. Eutrophic lakes (TSIs greater than 50) are nutrient rich with correspondingly water-quality problems, such as frequent seasonal algal blooms, oxygen depletion in the deeper areas of the lakes, and poor clarity. Lakes with TSIs greater than 60 are considered hypereutrophic and usually have extensive algal blooms during summer (Robertson D. W., 2003).

WisCALM (WDNR, 2017b) uses TSI for Secchi and Chl-a developed by Carlson (1977) and TSI Chl-a TSI ranged narrowly between 41 and 47 from 2013 to 2016 and indicated *Excellent* to *Good* condition. In 2017 monthly averages were 40 (July), 36 (August) and 50 (September) with an average of 40 (*Excellent*). Although, Secchi disk annual averages span the same range of 38 to 53 as Chl-a TSI, since 2013 the average Secchi disk TSI has been 50 to 53 and on the boarder of fair to poor condition level. For 2013 – 2017, the TSIs for Secchi disk and Chl-a are not well correlated with a R^2 of 0.23.

Although there is developed TSI for total phosphorus (TP), Wisconsin uses actual TP concentrations for water quality assessment purposes. However, the comparison of the three different TSI is useful in evaluating if transparency is affected by factors others than nutrient and algal growth. The average TSI values for Dead Pike Lake consistently show higher (reduced water quality) for Secchi disk compared to Chl-a and TP (Figure 17). The higher TSI for Secchi disk are associated with the stained color of the water associated with greater concentrations of dissolved organic acids made darker by iron concentrations.

Table 9. TSI General Assessment Thresholds (WDNR, 2017b)

Condition Level	Chl-a and Secchi TSI
Excellent	< 43
Good	43 - 47
Fair	48 - 52
Poor	≥ 53

5.2 Total Phosphorus

Maintaining a low algal biomass is critical in 2-story fisheries lakes where excessive algal biomass falling through the water column and subsequent decay can contribute to the oxygen demand in the hypolimnion. Additional oxygen demand in the hypolimnion could potentially cause anoxic conditions and extirpate cold-water species like cisco. Many factors affect the inter-annual variability and long-term changes in the trophic state of lakes. One factor affecting lake productivity is the variability in the amount of nutrients input from its watershed (external loading). The effects of nutrient loading are sufficiently understood that empirical eutrophication models have been developed to predict in-lake total phosphorus (TP) concentrations, chlorophyll-a concentrations, and water clarity (Secchi depth) from lake morphometry and external water and TP loading (Panuska, 2003). Accordingly, the focus of this management plan is phosphorus which should be the nutrient limiting algal growth that would contribute to addition oxygen demand in the hypolimnion.

5.2.1 *Dead Pike Lake Deep Hole and Outlet*

Dead Pike Lake (DPL) is classified as a stratified, two-story fishery lake with a WisCALM established impairment criteria of 15 μg/L total phosphorus (WDNR, 2017b). Dead Pike Lake was added to Wisconsin's 303d impaired waters list on April 1st, 2016 which was approved by the EPA August 29, 2017 (WDNR, 2018b) for total phosphorus (TP). The TP data used for the impairment listing was from the deep hole between 2010 and 2016 and included five years and 11 individual monthly values. The grand mean of the data was 16 µg/L with a lower 90% confidence interval of 14 µg/L and an upper 90% confidence interval of 17µg/L TP.

The allowable date range for TP samples prescribed in WisCALM is June 1st through Sept 15th. The average annual TP (June 1 – Sept 30 data) at the deep hole has ranged between the low and high readings of 10 µg/L in 2003 and 19.0 µg/L in 2016, though only one or two samples were available both of those years (Figure 18). 2017 TP at the deep hole showed relatively higher concentrations in April and May with concentrations slowly decreasing except for a clear peak concentration in late June (Figure 19). Although the average TP in 2017 was below the level of impairment (14.5 µg/L) for June 1 thru September 30, the upper 90% confidence interval was 15.7 µg/L and still exceeded the 15 µg/L impairment thresholds.

Lake Response Modeling

Many different types of lake empirical eutrophication models are used to predict in-lake phosphorus and chlorophyll *a* concentrations and water clarity (Secchi depth) from external phosphorus loading. These models are based on data sets from widely differing loading rates and hydrologic conditions and are most useful in comparing changes in phosphorus loading from pre- to post-management. The Wisconsin Lake Modeling Suite (WiLMS) model is a lake planning tool that is used to predict the in-lake water quality responses to changes in internal and external total phosphorus (TP) loading (Panuska, 2003). In the case of Dead Pike Lake, the lake response models, in combination with the estimated groundwater and surface water iron and phosphorus loads, contribute to selecting effective management actions.

Several different approaches were used to estimate the phosphorus load to Dead Pike Lake (Table 10). Land use data from Wiscland 2.0 was used in WiLMS to predict the annual total phosphorus loading to Dead Pike Lake with a likely annual load of 154 kg/year. Garrison estimated an annual phosphorus load of 220 kg/year which is within the predicted range of WiLMS of 103 to 299 kg/year (Garrison, 2013). The estimated water budget developed in GFlow (Helmuth, 2017) was also used to estimate an annual phosphorus load. The 2017 average TP inflow concentration from Powell Marsh of 0.041 mg/L was used to calculate the surface water load. The estimated value of 0.076 mg/L for TP concentrations in the groundwater was used. The 0.076 mg/L is the average of shallow groundwater samples collected in 2017 from around the circumference of the lake. Two of the shallow groundwater TP samples were significantly greater at 0.348 mg/L and 0.375 mg/L and were not used in calculating the average groundwater TP concentrations because the results seem very high and outside the range of expected values. The groundwater concentration used of 0.076 mg/L is higher than the 0.017 mg/L used by Garrison in 2012, but within the range of groundwater TP measured (~0.131 mg/L) from wetland dominated sub watersheds of Muskellunge Lake, Vilas County at w, (Dale Robertson, pers. comm. 2018). Wet (snow and rainfall) and dry deposition unit areal phosphorus loading was taken from Muskellunge lake study (Robertson D. W., 2003) and were relatively small – 13 kg/yr precipitation and 5 kg/yr dry deposition.

Table 10. Dead Pike Lake Annual Phosphorus Load

Approach	Methodology	Estimated Load kg/yr
WiLMS	Based on watershed land uses and typical P export coefficient	154 most likely 103 to 299 range
Garrison	Based on 2008 P inlet P load developed by Barr assuming this was 90% of the load, with estimated P concentrations of 0.017 mg/L in groundwater and 0.093 mg/L in surface water	220
GFLOW	Based upon the water budget developed in GFlow with estimated P concentrations of 0.076 mg/L in groundwater and 0.041 mg/L in surface water	206

5.2.2 *Lake Surface Water Inflow Sources*

The primary Lake Inflow stream under Powell Road (unnamed ditch) is classified as a warm water sport fish community while the two intermittent streams flowing into Dead Pike Lake (Deerfoot Marsh and Pete's Creeks) would likely be classified as forage fish communities. All three of these streams would have this same total phosphorus water quality standard of 0.075 mg/L (WDNR, 2017b). All the 2017 TP concentrations collected at the lake surface water inflow sources met the state TP water quality standard. The TP of the two intermittent inflow streams, Deerfoot and Pete's creeks, was generally lower than the concentration of the primary lake inflow from Powell Marsh, except for Pete's creek having a high TP concentration in September (Figure 20). Deerfoot Marsh Creek TP ranged between 0.010 mg/L and 0.0299 mg/L with an average of 0.0187. Pete's Creek TP ranged between 0.0135 mg/L and 0.0369 mg/L with an average of 0.0243 mg/L. The lake inflow TP was about twice as high with a range between 0.0264 mg/L and 0.0621 mg/L with an average (0.0406 mg/L) about twice as high as the intermittent streams. The primary lake inflow stream that flows under Powell Road from PMSWA consists mainly of water discharged from the Main Pool with some seasonal flows from Vista Pool entering the East-West ditch.

5.2.3 *Powell Marsh Ditches*

The ditches on the PMSWA would likely be classified as limited forage fish communities and have a total phosphorus water quality standard of 0.075 mg/L ((WDNR, 2017b). Total phosphorus concentrations across the marsh are highest in the upper reaches of the marsh discharging from the Little Trout Impoundment beginning in June (Figure 21). The TP concentrations decrease as surface water flows north toward the lake and are discharged from the Main Pool Impoundment into the North-South ditch (Table 11). The TP discharged from the Main Pool is approximately the same as the TP measured at the lake inflow under Powell Road, while TP discharged from Vista, Goose Pen and Stepping Stone Impoundments is always lower than TP at the main inflow. 2017 average TP ranged from a low of 0.0182 mg/L at Stepping Stone Impoundment to a high of 0.0593 mg/L at Little Trout Impoundment

Table 11. 2017 Total Phosphorus at Powell Marsh Ditches

Location	2017 Average TP (mg/L)	TP Range (mg/L)
Little Trout Impoundment	0.0593	0.0165 – 0.112
Goose Pen Impoundment	0.0195	0.0128 – 0.0255
Stepping Stone Impoundment	0.0182	0.0111 – 0.0294
Main Pool Impoundment	0.0393	0.0216 – 0.0595
Vista Impoundment	0.0276	0.0204 – 0.0375
Lake Inflow	0.0406	0.0264 – 0.0621

5.3 Iron & Manganese

Iron sedimentary rock is wide spread in the general area of Dead Pike Lake, along the western edge of Vilas County and adjacent to Iron County from processes that started 1.9 billion years ago. The level of iron and manganese found in a stream or lake depends on its position in the landscape and watershed characteristics. Since iron and manganese follow nearly the same chemistries, iron is used as representative for both elements in this lake management plan.

The presence and effects of iron in aquatic system varies seasonally based upon the physical, chemical and biological processes. Iron concentration and speciation in water is affected by many factors including redox potential, light, pH, and dissolved organic matter. Mobilization and transport of iron in surface water is largely controlled by organic matter (Vuori, 1995). As summarized by Vuoir (1995), iron has both direct and indirect effects in rivers ecosystems including:

- Direct precipitation on, and binding of iron-hydroxides to external gills and body surfaces of macroinvertebrates and encrustations internally on macroinvertebrate guts,
- Secondary effects of reduced distribution, reproduction and feeding success and behavior avoidance of iron-hydroxide suspensions,

There are no Wisconsin promulgated surface water quality criteria for iron although the U.S. EPA has recommended a quality criterion of 1.0 mg/L for freshwater aquatic life (USEPA, 1988) (USEPA, 2004). Several states have promuglated iron criteria and most are comparable to the recommend EPA criteria of 1.0 mg/L (IDNR, 2005) but some are more restrictive while many states are like Wisconsin and have not adopted water quality criteria for iron or manganese.

Wisconsin has not promulged surface water quality criteria for manganese and the USEPA has not published a recommended freshwater aquatic life criterion. NR 105 Adm. Code. provides for the calculation of secondary acute and chronic values when criteria for a metal, like manganese has not been promulgated. In 2015 and based on updated information, the secondary acute value for manganese was 525 μg/L and the secondary chronic value was 29.2 μg/L (Yang, 2015). At least one state has taken a closer look at both iron and manganese standards and developed recommendations to remove the criteria for both (NCDENR, 2015).

5.3.1 *Dead Pike Lake Deep Hole and Outlet*

Dead Pike Lake iron concentrations at the deep hole ranged narrowly between 1.0 mg/L to 1.5 mg/L with 2017 average of 1.21 mg/L. The lake outlet iron was equal to, or sometimes slightly greater than the deep hole iron with a 2017 average of 1.36 mg/L and a range from 1.12 mg/L to 1.72 mg/L (Figure 22). Dissolved iron showed the same pattern with deep hole dissolved iron ranging from 0.91 mg/L to 1.20 mg/L with an average of 1.04. The lake outlet dissolved iron ranged from 0.91 mg/L to 1.43 mg/L with an average of 1.14 mg/L.

The greatest 2017 deep hole total manganese were in April and November and were 62.5 μg/L and 34.9 μg/L, respectively with an annual average of 19.74 mg/L. Between May and September 2017, the deep hole total manganese ranged narrowly between 8.42 μg/L and 15.3 μg/L. Total manganese at the outlet varied more in comparison to the deep hole with a range from 12.5 μg/L to 62.1 μg/L with an average of 29.70 μg/L. Throughout most of the summer, June through September, the outlet manganese was substantially greater than manganese at the deep hole (Figure 23). Dissolved manganese showed a similar pattern where the deep hole ranged narrowly between 2.91 μg/L and 4.48 μg/L with an average of 3.59 μg/L while the outlet manganese was substantially greater with a range between 6.39 μg/L and 38.00 μg/L and an average of 16.54 μg/L.

5.3.2 *Lake Surface Water Inflow Sources*

The total iron concentrations of the surface water inflows to Dead Pike Lake ranged widely during 2017 (Figure 24). Deerfoot Creek had the lowest iron concentrations in early spring ranging between 0.46 mg/L and 0.69 mg/L which increased to a maximum concentration of 3.72 mg/L in mid-July before the intermittent flow stopped. Deerfoot Creek drains a wetland area that is not ditched or flowed and is represented of iron concentrations discharged from a relatively undisturbed environment with an average iron concentration of 1.49 mg/L.

Pete's Creek also started with relatively low total iron concentrations in early spring ranging between 1.08 mg/L and 1.33 mg/L before increasing in June to above 7 mg/L. Pete's Creek greatest total iron concentration was measured in June at 9.89 mg/L but even in August and September the concentrations were above 5 mg/L. Pete's Creek source water comes from a water course that drains from the PMSWA Stepping Stone impoundment and visible groundwater discharge from wetlands downgradient of the impoundment.

The perennial lake inflow from Powell Marsh had an average total iron concentration of 3.49 mg/L. The lake inflow iron varied seasonally being relatively low in April and May (1.57 mg/L to 2.51 mg/L), with higher values in June and July (4.32 mg/L to 5.36 mg/L) and then falling to 2.01 mg/L in September but increasing in November to 3.26 mg/L. Dissolved iron showed similar patterns at all three sites with lower concentration in early spring and later summer and high concentrations in mid-summer. For example, at the primary lake inflow, dissolved iron was below 1.4 mg/L in April and May; greater than 2.2 mg/L in June and July and then dropping to less than 2.0 mg/L in August and September.

The total manganese concentrations of the surface water inflow showed the same general pattern of lower values during the spring months of April and May; increasing concentrations in June and July with lower concentrations in August and September (Figure 25). Total manganese in Deerfoot Marsh Creek was generally the highest when flow occurred, ranging from 41.2 μg/L to 291.0 μg/L with an average of 138.1 μg/L. Pete's Creek showed slightly higher manganese concentrations than the primary lake inflow with an average of 73.0 μg/L compared to 63.3 μg/L. Dissolved manganese showed similar patterns at all three sites with lower concentration in early spring and later summer and high concentrations in mid-summer. For example, at the primary lake inflow, dissolved manganese was below 21 μg/L in May; greater than 62 μg/L in June and July and then dropping to less than 48 μg/L in August and September

5.3.3 *Powell Marsh Ditches*

Total iron concentrations in the Powell Marsh ditches showed similar seasonal patterns as the other surface water sources to Dead Pike Lake. Concentrations were lower in the spring (April and May), increased in June and July and then dropped off in August and September (Figure 26). Iron concentrations at Powell Road (i.e. primary lake inflow) were consistently greater than other sites on the marsh. Total iron concentrations from the Main Pool matched the concentrations at lake inlet, but were on average 35% lower (ranging from 13% to 56% lower). Total iron at the Little Trout Impoundment were lowest during the early spring and increased in late July and early August to nearly as high as the lake inflow. All total iron concentrations dropped off sharply in August through September. Dissolved iron showed similar patterns at all six sites with lower concentration in early spring and late summer and high concentrations in mid-summer. For example, at the Main Pool Impoundment, dissolved iron was below 1.1 mg/L in April and May; greater than 1.4 mg/L in June and July and then dropping to less than 1.0 mg/L by September.

Total manganese concentrations in the Powell Marsh ditches followed the same pattern as iron with lower concentrations in early spring, increasing through June and July and then dropping off in August (Figure 27). In April and May, the Powell Marsh ditches had similar total manganese concentration ranging between 4.45 μg/L and 25.1 μg/L. Total manganese remained relatively low at Goose Pen and Vista Impoundments through July when discharge from the two impoundments ceased. Total manganese increased dramatically in June and July at the lake inflow under Powell Road with smaller increases observed at Main Pool and Little Trout Impoundments. Although the lake inflow total manganese started to drop off in the first part of August, the total manganese at the Main Pool and Little Trout Impoundments remained high through the first part of August and dropped in mid-August. Dissolved manganese showed similar patterns at all six sites with lower concentration in early spring and late summer and high concentrations in mid-summer. For example, at the Main Pool Impoundment, dissolved manganese was below 13 μg/L in April and May; greater than 31 μg/L from mid-July through mid-August with a maximum of 65.4 μg/L and then dropping to less than 22 μg/L by September.

5.4 Dissolved Organic Carbon

Dissolved organic carbon (DOC) is a measure of the organic molecules that pass through a 0.45 um filter and affect physical, chemical and biological properties of lakes and streams. DOC increases with the proportion of wetlands in the watershed, especially with organic soil wetlands or peatlands present. As summarized by (Gergel, 1999) and (Dillon, 1997), these affects include:

- Solar UV-B protection to aquatic microflora and fauna,
- Depression of primary productivity and decreased lake transparency,
- Influence of acid-base chemistries affecting pH and alkalinity,
- Complexes with many metals and nutrients.

DOC also binds with metal ions like iron, manganese and copper and is important in the control of the chemical speciation, bioavailability and toxicity of metals in water (Breault, 1996). Iron and manganese readily bind with organic compounds due to their affinity for the organic ligands.

DOC was measured every two weeks from April through September and again at fall turnover in November. Samples were collected at discharge points with flow and at the Dead Pike Lake deep hole. Dissolved organic carbon was virtually the same and held consistent at the lake outlet and the deep hole (Figure 28). The lake outlet and the deep hole average DOC was 10.18 mg/L and 10.12 mg/L, respectively. The lake inflow DOC ranged between 14.1 mg/L and 21.2 mg/L with an average of 16.7 mg/L. Pete's Creek, which flowed intermittently, had a similar range of DOC and an average of 17.3 mg/L. DOC in Deerfoot Marsh Creek showed the highest levels of DOC with a maximum of 38.4 mg/L in July before the intermittent stream ceased to flow.

DOC from about 50 Vilas county lakes show a county average DOC of 7.18 mg/L with a range of DOC from lake deep holes from 2.59 mg/L to 16.5 mg/L. The DOC from the deep hole of Dead Pike Lake is higher than the average county DOC and although DOC measurements from stream and ditches in Vilas county is limited, the surface water entering Dead Pike Lake is high in DOC compared to the county lake surface waters.

5.5 Calcium, Magnesium and Hardness

Calcium and magnesium play various structural roles in plant cell membranes, contributes to oxalate accumulation and regulates water transport as well as metabolic processes in aquatic organism. The two bivalent ions are also important in the regulation of pH, water hardness and alkalinity. Water hardness is primarily the amount of calcium and magnesium, and to a lesser extent, iron in the water. Water hardness is measured by adding up the concentrations of calcium (Ca), magnesium (Mg) and converting this value to an equivalent concentration of calcium carbonate ($CaCO_3$) in mg/L of water. Water hardness in most groundwater is naturally occurring from weathering of limestone, sedimentary rock and calcium bearing minerals.

Calcium, magnesium and hardness were fairly stable during the April to November monitoring period at the Dead Pike Lake deep hole and at the outlet (Table 12) and indicate soft water (i.e. 17 to 60 mg/L as $CaCO_3$). Historical measurements of low alkalinity in 1989 (38 mg/L) and 2003 (25 mg/L) at the deep hole also show a low acid neutralizing (buffering) capacity. Cation concentrations in Dead Pike Lake are slightly less than the average for northeastern Wisconsin lakes, as described by Lillie and Mason (1983), with softer water and lower concentrations of most constituents. Lillie and Mason collected data from a random set of 660 Wisconsin lakes, 243 of which were in northern Wisconsin. The average concentrations for the northwestern Wisconsin Lakes were 10 mg/L for calcium, and 5 mg/L for magnesium compared to 8.22 mg/L Ca and 2.05 mg/L Mg, respectively, for Dead Pike Lake.

Table 12. Key Divalent Ions at Dead Pike Lake Deep Hole and Outlet

	Deep Hole (average/range)	**Lake Outlet (average/range)**
Calcium (mg/L)	8.22 7.67 – 9.09	8.08 7.40 – 8.76
Mg (mg/L)	2.05 1.92 – 2.25	2.03 1.84 – 2.29
Hardness (mg/L as $CaCO_3$)	29.29 27.1 – 31.9	28.55 26.1 – 31.1

Calcium and magnesium showed a distinct seasonal pattern in 2017 at the surface water inflows to Dead Pike Lake including the primary lake inflow from PMSWA, Deerfoot Marsh Creek and Pete's Creek. April calcium and magnesium concentrations were low in April and gradually increased throughout the summer (Figure 29). At the lake inflow, calcium and magnesium concentrations increased 3-fold from April through September, from 2.75 mg/L to 9.05 mg/L and 0.85 mg/L to 2.87 mg/L, respectively. The same seasonal pattern was present at the Little Trout Impoundment which had the highest concentration of both calcium and magnesium beginning with April concentrations of 5.21 mg/L and 1.53 mg/L and increasing to August concentrations of 13.9 mg/L and 4.61 mg/L, respectively. Other Powell Marsh ditches with intermittent flow discharges were more stable. For instance, Vista Impoundment discharge varied from a low of 1.09 mg/L Ca to a high of 1.66 mg/L Ca.

5.6 pH

pH is a measure on a logarithmic scale of the water's acidity and affects many chemical and biological processes. Many aquatic organisms prefer specific pH conditions and most survive well in pH ranges between 6.5 and 8.0. Low pH can increase the bioavailability of aquatic toxins like heavy metals such as copper, iron and manganese. Changes in photosynthesis and source water (groundwater verses runoff) can result in pH shifts in a lake or stream. Wisconsin's pH state water impairment threshold for all classes of lakes, rivers and streams is outside the range of 6.0 to 9.0 standard units (s.u.) (WDNR, 2017b). The EPA published the recommended water quality criteria between the range of 6.5 to 9.0 s.u. (USEPA, 1986).

In 2017, pH at Dead Pike Lake deep hole ranged between 7.3 s.u. and 7.91 s.u., while the lake outlet showed a slightly greater range from 7.14 s.u. to 8.01 s.u. In-lake pH readings consistently reflected neutral to slightly basic conditions. The pH of the surface water inflow sources to Dead Pike Lake (i.e. Deerfoot Marsh Creek, Pete's Creek and the Lake Inflow) as well as the pH of the Powell Marsh ditches were consistently below neutral and showed acidic conditions (Figure 30). The lowest average pH values, below 6 s.u., were observed at Deerfoot Marsh Creek, Pete's Creek, Goose Pen Impoundment and Stepping Stone Impoundment. The other Powell Marsh ditch sites all had average pH values above 6 s.u.

5.7 Conductivity

Conductivity is a measure of the ability of water to pass an electrical current and is affected by the presence of inorganic dissolved solids with negative or positive charges. Organic compounds generally do not conduct electrical current very well and do not contribute to conductivity. The warmer the water, the higher the conductivity so conductivity is typically reported as conductivity at 25 degrees Celsius.

Conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows. Streams that run through areas with granite bedrock tend to have lower conductivity because granite is composed of more inert materials compared to streams that run through areas with clay soils tend to have higher conductivity because of the presence of materials that ionize when washed into the water. Ground water inflows can have the same effects depending on the bedrock they flow through (USEPA, 2012).

Overall conductivities found in the Dead Pike Lake and Powell Marsh system were very low to low (Table 13). The two intermittent streams, Deerfoot Marsh and Pete’s creeks had very low conductivities less than about 30 µmhos/cm. Vista, Goose Pen and Stepping Stone impoundments also had very low conductivities less than 20 µmhos/cm. Little Trout Impoundment was the outlier with an average conductivity of 86 µmhos/cm.

Table 13. 2017 Average Conductivity (µmhos/cm) at Surface Water Monitoring Sites

Location	2017 Average Conductivity	Conductivity Range
Little Trout Impoundment	86.00	27.00 – 207.90
Goose Pen Impoundment	15.48	13.70 – 17.40
Stepping Stone Impoundment	11.84	10.00 – 14.00
Main Pool Impoundment	51.09	25.80 – 160.00
Vista Impoundment	12.05	9.90 – 17.10
Deerfoot Marsh Creek	16.25	12.10 – 24.70
Pete’s Creek	17.28	2.20 – 30.70
Lake Inflow	48.32	16.10 – 126.00
Deep Hole	61.67	58.10 – 67.00
Lake Outflow	61.65	57.40 – 67.00

5.8 Stream Transparency

Stream/ditch transparency was measured with a transparency tube capable of recording a maximum water clarity of 120 cm. Different types of suspended and dissolved materials can affect the measured turbidity including suspended and dissolved solids, dissolved organic materials, algae and detritus. Decreases in transparency reduces the amount of light available to plants and animals and may represent an increase in suspended or dissolved solids that can also impact aquatic organism. For instance, decreased transparency can make it difficult for sight-feeding predators, such as bass and pike to feed.

Several sites had transparency tube (TT) measurements consistently equal to, or greater than 120 cm, including Vista Impoundment and the Lake Outflow (Table 14). Little Trout Impoundment also had high water clarity with a range from 105 cm to 120 cm. Pete’s Creek had the lowest recorded water clarity of 26 cm on June 28 and Deerfoot Marsh Creek had the second lowest TT of 45 cm on July 11, 2017.

Table 14. 2017 Transparency Tube Measurements

Location	2017 Average Transparency (cm)	Transparency Range
Little Trout Impoundment	118	105 - 120
Goose Pen Impoundment	95	56 - 120
Stepping Stone Impoundment	108	75 - 120
Main Pool Impoundment	105	81 - 120
Vista Impoundment	120	120
Deerfoot Marsh Creek	95	45 -120
Pete's Creek	79	26 - 120
Lake Inflow	89	55 - 120
Lake Outflow	120	120

6 Groundwater Quality Information

Groundwater inflows (groundwater discharge) to lakes and streams often transport and deliver similar water quality constituents to surface water, but concentrations and quantities can vary temporally and spatially (both vertically and horizontally). Key groundwater constituents at Dead Pike Lake are phosphorus and iron. Previous studies have reported iron and/or phosphorus groundwater concentrations at this site and other areas of northern Wisconsin (Krohelski, 2002, Garrison, 2012, Graczyk et al., 2003, Robertson et al., 2003).

In order to obtain an idea of total iron and phosphorus samples in the shallow groundwater around the lake, a groundwater sampling "sipper" was borrowed from the USGS. The sipper is a 1 inch diameter, 3 foot long hollow teflon probe with a pointed end with slots exending 2 inches above the point. The probe is pushed into the soil 16 cm to 30 cm deep and a perisaltic pump is used to withdraw the interstitial shallow groundwater. Six sample locations were identified around the circumference of the lake. Five of these locations were sampled on August 23, 2017 and the site along the southern lake shoreline was not sampled because of the rocky nature of the nearshore. Recognizing the small number of samples and that groundwater chemistries, especially shallow groundwater, can change seasonally and be affected by groundwater recharge, the sipper results were used to inform the conceptual groundwater flow model and used in context with other available data.

6.1 Iron

The highest and lowest shallow total iron concentrations from around the lake circumference were from 0.39 mg/L along the west-central shore and 89.5 mg/L along the north-central shoreline (Figure 31). The other samples from around the lake ranged between 7.7 mg/L and 27.8 mg/L. Dissolved iron concentrations paralleled the total iron concentrations and ranged between 63% and 88% of the total iron. This range of iron is consistent with values reported by Krohelski et al. (2002) for dissolved iron of 19 mg/L to 68 mg/L.

6.2 Total Phosphorus

Total phosphorus sampled from shallow groundwater around the circumference of Dead Pike Lake was greatest along the northern shoreline with values of 0.348 mg/L and 0.375 mg/L (Figure 32). Total phosphorus from other shoreline sampling points ranged between 0.048 mg/L and 0.111 mg/L. Though the highest total phosphorus values correspond with the highest iron concentrations, total phosphorus concentrations were higher than other values reported by Juckem (2014) and Robertson (2003) which were in the range of 0.013 – 0.131 mg/L.

7 Aquatic Plants

With assistance from Dr. Susan Knight and Carol Warden from UW-Madison's Trout Lake Station, a point intercept aquatic plant survey was completed in July 2017 on Dead Pike Lake. The survey replicated a 2008 survey completed by Dr. Knight and colleagues. A total number of 305 sampling points were visited and a maximum rooting depth of 9.0 feet was established and a total of 41 species were collected at sampling points while another 9 species were visually observed for a total of 50 species. No non-native aquatic plants were found in Dead Pike Lake and plant diversity was relatively high throughout the lake. Many of the low growing aquatic plants (e.g. Chara, slender naiad) in shallow zones in the south bay and northern shorelines were covered with iron floc/iron bacteria deposits – reflecting similar conditions noted in 2008 (Barr, 2011).

Photo 5. Iron floc accumulation on submerged Chara

Some characteristics of the aquatic plant community did change between the 2008 and 2017 surveys (Table 15). Most notable the maximum rooting depth decreased from 16 to 9 feet and the average number of species collected at each sample point decreased from 2.75 to 1.81 species/sampling point. The shift in rooting depth and # of species at each sampling point may be attributed to the change in water clarity during the period of each survey. The average Secchi disk for the period of 2006 to 2008 was 12.5 feet compared to 6.24 feet for the period of 2015 to 2017. Several species showed a higher frequency of occurrence at vegetative sample points during the clearer water phase in 2008 including three pondweed species, northern milfoil and common waterweed. Large purple bladderwort was not observed during the 2008 survey and was the 3rd most common plant found in 2017. There were 8 aquatic plant species recorded in 2008 that were not observed in 2017 and 12 species recorded in 2017 that were not observed in 2008. Most of these species had a frequency of occurrence less than one and their presence or absence simply associated with sampling methodology. Overall, the species richness, diversity index and the floristic quality index changed little and continued to reflect a highly diverse, healthy aquatic plant community with the presence of two species of special concern, small purple bladderwort and Robbin's spike rush.

Table 15. Comparison of 2008 and 2017 Aquatic Plant Survey Metrics

	2008	**2017**
Species Richness	41	41
Maximum Rooting Depth	16 feet (1)	9 feet (1)
Simpson Diversity Index	0.92	0.91
# Species per Sampling Point	2.75	1.81
Frequency of Occurrence	74.62 (2)	83.2
Floristic Quality Index (Nichols, 1999)	47.2	44.68
Five Most Common Species	Chara Variable pondweed Slender naiad Large-leaf pondweed Common waterweed	Chara Variable pondweed Slender naiad Large purple bladderwort Brown-fruited rush

(1) Outlier data points dropped for 22 feet in 2008 and 18 feet in 2017
(2) Calculated with a maximum depth of 22 feet

8 Fisheries

The most recent comprehensive fishery surveys of Dead Pike Lake were conducted in 2015 (Gilbert S. , 2016) and 2005 (WDNR, 2011), both consisted of fyke netting and electrofishing. The 2015 population estimate found 0.6 adult walleyes per acre; a decrease from the 2005 estimate of 1.3 walleyes per acre. Northern pike, largemouth and smallmouth bass were also targeted for sampling and 34, 30 and 39 of each species were recorded, respectively. The average length of the northern pike was reported as poor and only 13% of the largemouth bass and 10% of the small mouth bass were greater than 14 inches. Five adult muskellunge, 3 of them over 40 inches, were incidentally captured during the survey. The survey also targeted panfish and characterized the population as low density that lacks numbers of quality sized fish. Other species were collected at low numbers including golden shiner, grass pickerel, logperch, mottled sculpin, pumpkinseed, rock bass, white sucker and yellow bullhead.

Dead Pike Lake walleye population is sustained through stocking. Though Dead Pike Lake has been stocked with walleyes going back to 1950 (Barr, 2011), the lake has not established a naturally reproducing walleye population and there is no evidence that an abundant walleye fishery ever existed in Dead Pike Lake (Gilbert S. , 2017). From 2002 to 2006 WDNR fisheries biannually stocked an average of 17,470 small fingerling walleyes. From 2008 to 2016 WDNR stocked an average of 3,474 large fingerling walleyes. With the steep rocky shorelines along the southern half of the lake and well oxygenated water column and healthy aquatic plant community, there is ample fisheries habitat present in Dead Pike Lake. A couple of factors have been hypothesized to limit the walleye recruitment in Dead Pike Lake including the presence of iron floc and the impact of exotic rainbow smelt that have been present in the system since 1990 or earlier (Barr, 2011).

Dead Pike Lake has the physical characteristics sufficient to support a two-story fishery. Dead Pike Lake was sampled for coldwater species of fish in 2009 and 2013 with standardized vertical gill net surveys (Lyons, 2015). Two ciscos were collected in 2009 and none were collected in 2013 with 2 nights of netting effort. Ninety-nine rainbow smelt (an invasive fish that has been documented to decrease walleye recruitment) were collected in 2009 and two were reported in 2013. Although standard protocols were used during both sampling events, the nets used in 2009 had finer netting, less visible to fish that likely contributed to a lower catch rate.

In 2015, the East-West ditch below the Vista Impoundment was surveyed by WDNR using a stream shocker. A 30-meter section of the ditch was sampled in 15 minutes. Eight species were collected totaling 83 individuals including brook stickleback, black bullhead, yellow perch, brassy minnow, finescale dace, northern red bellied dace, white sucker and Iowa darter. The sample size and survey length was not sufficient to calculate an index of biological integrity for the ditch.

9 Recreational Uses

At 297 acres in size, Dead Pike Lake encourages small lake activities. Kayaking regularly draws transient participation as well as affording residents the enjoyment of a quiet, pristine paddle. Such activity is enhanced by the lack of mechanized recreation, such as water skiing and the presence of wave runners. This has also encouraged wind surfing and some sail boating with one period during which there were four sail boats moored at separate docks during the summer months.

The main activity is fishing. The lake's fishery appears to be rebounding to historic levels from a past productivity confirmed by experiences from the mid-1900's. An example is the historical account of a Frenchman named Goodreaux living at the southwest corner of the lake who based his livelihood on a livery of 10 fishing boats. Guides from that era also reported that the lake's water was drinkable, a benefit they often took advantage of.

Waterfowl hunting is limited, although large flocks of divers, especially Ring Bills, tend during migration to gather sporadically in the large outlet bay and feed on the ample supply of aquatic vegetation. Geese and mallards routinely nest on the lake but seldom in numbers necessary for hunting. Bird watching, while not a concentrated activity, is often rewarded with multiple sightings, especially loon and shorebirds. Coupled with the occasional presence of swan, sandhill crane and an occasional lakeside turkey, bird watchers might well be defined as a recreational group.

The need for lake ordinances is non-existent at this time. The outboard size used by residents is reasonable and except for an occasional inner tube drag, with a grandchild in tow, there is little mechanized boating. The boat launch, while somewhat difficult to manage, is sufficient and in keeping with the type of watercraft the lake can accommodate, i.e. it is shallow and offers limited parking space. It reflects the character and the quality of the lake and dictates to some extent, the usage it can accept.

10 Water Quality Discussion

Chapter 10 brings together the surface water flow information described in Chapter 4 and the water monitoring data described in Chapter 5 and explains the iron and phosphorus dynamics for the Dead Pike Lake and Powell Marsh State Wildlife Area system. As stated previously, since iron and manganese follow nearly the same chemistries, iron is used as representative for both elements. The important iron and phosphorus dynamics described in this Chapter include:

- Iron and phosphorus enter the lake through both surface water and groundwater flow.
- Iron export from Powell Marsh has been influenced by the construction of the ditches.
- Iron/Iron floc is present at concentrations to have negative environmental impacts

10.1 Phosphorus Sources, Transport and Loading

Phosphorus is delivered into Dead Pike Lake through both groundwater and surface water discharges from Powell Marsh, Pete's Creek and Deerfoot Marsh Creek with smaller amounts from wet and dry deposition.

As discussed in Section 5.2, several methods were used to estimate the proportion of phosphorus delivered from each of these sources (Table 10). The Canfield-Backman natural lake sub-model in WiLMS (Panuska, 2003) best predicted water responses to phosphorus loading for Dead Pike Lake. The back- calculation module in WiLMS (Appendix 2) predicted a 16% reduction in phosphorus load required to meet the water quality goal of 15 µg/L during the growing season. Using the phosphorus load predicted by GFlow of 206 kg/yr, a 16% reduction goal is 173 kg/yr. Assuming no reduction in wet and dry phosphorus deposition, the groundwater and surface water loads both require a 18% reduction to achieve the 173 kg/yr (Table 16).

Table 16. Estimated Phosphorus Loading and Reduction Goals

Phosphorus Source	Existing Load (kg/yr)	Goal Load (kg/yr)	Percent Reduction
Groundwater	136	112	18%
Surface water	51	42	18%
Precipitation	13	13	0%
Dry Deposition	5	5	0%
Total	206	173	16%

With the elevated dissolved organic carbon in the PMSWA ditches, phosphorus transport is facilitated by the dissolved organic carbon and the capacity to bind phosphorus in the presence of ferric iron (Jones R. K., 1988) (Dillon, 1997). Dillon (1997) reported remarkably consistent TP/DOC ratios between 1.4 to 2.0 mg P/g DOC in 20 watersheds in central Ontario. The 2017 TP/DOC ratio in Dead Pike Lake averaged 1.5 mg TP/g DOC compared to 2.38 mg P/g DOC average observed at the inflow to Dead Pike Lake. On average, the DOC coming from Powell Marsh is associated with about 35% more phosphorus than observed in the lake. The reduction in the TP/DOC ratio in the lake may be related to the oxidation of iron and phosphorus complexed with DOC as water is flushed out of the marsh and into the well oxygenated basin with the longer residency time

Management actions for the reduction of phosphorus focus on 1) reducing the water budget component of groundwater inflow, 2) reducing the ability of DOC to transport phosphorus and 3) the removal of phosphorus through biological uptake.

10.2 Iron Sources, Transport and Loading

The interaction of groundwater and surface water and organic matter play an important role in the release and transport of iron (and manganese) into Dead Pike Lake. The glacial till near Dead Pike Lake is laden with iron and manganese (Apfelbaum, 2018). An early ditch network constructed in the PMSWA is visible in the 1937 air photo of the marsh with the ditch network fully developed by the mid-1950s including approximately 9 miles of ditches and roughly 230 acres of open water impoundments (WDNR, 2016a). The extensive series of ditches penetrated the bog's semi-aquitard, increasing the connection between precipitation and groundwater and increased the groundwater and surface water interface within the ditches themselves. AES also confirmed the dike and levee road system of PMSWA contained a substantial component of taconite ore (a low-grade iron ore) that provides another likely source of iron and manganese. The groundwater moving through the subgrade of the road and discharging into the deeply dug ditch side slopes and ditch bottoms are the main sources of iron in PMSWA (Apfelbaum, 2018). Attributing increased iron to the flowages and ditches is consistent with the work by Roesler (2016) that attributed increased iron release from the flowages and ditches at Crex Meadow Wildlife Area in Burnett County, Wisconsin.

Near large wetland complexes like PMSWA, groundwater is typically anoxic and provides a chemically reduced environment. As the groundwater passes through the glacial substrate it picks up iron and manganese and is discharged into oxygenated PMSWA ditches. Iron would normally precipitate out in a matter of minutes in the presence of oxygen. However, dissolved iron binds rapidly to the ligands of dissolved organic matter forming a strong complex that slows the oxidation of the iron (Theis, 1974). The iron and dissolved organic carbon complexes are transported in the flowing water (Dillon, 1997) from the PMSWA ditch network and into Dead Pike Lake. A portion of the groundwater iron is also transformed into an oxyhydroxide floc as it enters the ditch systems and exported via the surface water flows into Dead Pike Lake (Apfelbaum, 2018). In the presence of well oxygenated lake water, the oxidation reaction eventually breaks the DOC ligand bonds and iron Fe^{+2} is converted into the solid and floc forming iron oxyhydroxide and Fe^{+3} (Krabbenhoft, 2018).

As Kreitlow properly suggested (Kreitlow, 2007), soluble iron is precipitated in the Powell Marsh ditches and transported as visible floc into Dead Pike Lake. Kreitlow found the iron concentrations, formation of floc and reduced water clarity was correlated to the residence time in the ditches and a continuous flow improved the aesthetic appearance of the ditch water flowing into Dead Pike Lake. However, even in flowing water, the surface water chemistry results in the formation of soluble iron/DOC complexes that are transported into Dead Pike Lake from Powell Marsh in the absence of visible floc. With a Dead Pike Lake residence time of 1.8 years, the iron is ultimately oxidized and “flocked out” in the lake basin.

The other source and transport of metals into Dead Pike Lake occurs with the discharge of iron and manganese rich groundwater directly into the lake basin. Known groundwater iron concentrations range between 10 mg/L and near 90 mg/L with a typical ambient concentration of 25-30 mg/L. The differences between the AES and Helmuth 2017 water budget for Dead Pike Lake have been described in Section 4.1 and both methods estimate the groundwater discharge into Dead Pike Lake is the major source of iron to the lake (Table 17). Both iron budgets assume that all the soluble iron is readily transported in the anoxic groundwater into Dead Pike Lake where the iron is either oxidized, complexed with dissolved organic carbon or biological utilized.

Table 17. Estimated Iron Loading to Dead Pike Lake

Approach	Methodology	Groundwater (GW) and Surface Water (SW) %	Estimated Load
Garrison	Based on 2008 Fe concentrations of 4 mg/L baseflow and 10 mg/L spring runoff and 25 mg/L Fe in groundwater.	GW – 43% SW – 57 %	41,382 kg/yr
STELLA	Based upon the STELLA water budget and using 2017 bi-weekly measured inflow concentrations and an average groundwater concentration of 30 mg/L.	GW - 86% SW - 14%	53220 kg/yr
GFLOW	Based upon the water budget developed in GFlow using an average of 30 mg/L in groundwater and 3.49 mg/L in surface water	GW – 92% SW – 8%	57,943 kg/yr

10.3 Iron and Iron Floc Environmental and Recreation Impacts

This section evaluates the potential toxicity effects of iron and manganese in Dead Pike Lake and Powell Marsh. The effects of the metals in both the water column and in benthic floc deposits are evaluated based upon Whole Effluent Toxicity (WET) testing and literature reviews.

Assessing the ecological impacts of toxic factors in lake ecosystems is a daunting task owing to the number of variables that influence survival and reproduction of aquatic species. The temporal fluctuations of the variables and differing life cycle of aquatic species add another layer of complication in evaluating toxicity. A list of the more important interacting variables affecting actual toxic conditions in freshwater lakes are found in Table 18. Although this section focuses on the toxicity and recreational impacts of iron and iron floc, manganese is likely another compound with potential toxicity impacts at DPL and PMSWA. Like other portions of the lake management plan, this discussion focuses on iron as the critical metal of concern.

Table 18. Significant Variables and General Effects in Aquatic Toxicology

Variable	General Effect	Factors that Exacerbate Toxic Effects
Dissolved Oxygen	Essential substrate	pH, conductivity, oxygen demand, metals, additive to many toxins.
Conductivity	Measure of all ions	pH, alkalinity, H^+ ion, metals.
Redox Potential	Influences all ions	pH, precipitation, mobilization or use of metals, nutrient anions as O_2 source.
Ammonia	Toxic to many species	Generated under anoxic conditions from nitrate/nitrate or organic N sources.
Sulfates	Non-toxic until reduced	H2S or S released under anoxic conditions.
Alkalinity	Buffers pH changes	Participates in precipitation of metals
Nitrite/nitrate	Limiting nutrient	Plant-available forms of nitrogen
Soluble organics	Sources of biological oxygen demand	Demands O2, can precipitate or buffer pH
Particulate organics	Sources of biological oxygen demand	Demands O2, can precipitate or settle out.
Metal ions	Highly variable	Toxicity will depend on valence, position, and presence or absence of other metals.
From (Ludwig J. , 2017)		

Benthic Iron Floc Toxicity and Recreational Impacts

Vuori (1995) summarized the effects of iron precipitates on survival, reproduction and behavior of aquatic species. The effects include clogging of macroinvertebrate and fish gills, behavioral avoidance by fish, decreasing hatching success, suffocation of fish egg embryos and the alteration of benthic habitats. Addition work cited by Vuori suggest the combined direct and indirect effects of iron and manganese concentrations and blooms of iron bacteria (i.e. *Leptothix ochracea*) reduces diversity and density of lotic invertebrates and diatoms.

Burrowing invertebrates and other species that live in close contact with sediments can have heavy depositions of iron oxides on their outer body surfaces. Exposure to other metals absorbed onto the iron oxides may increase with iron oxides encrustations. Although no testing was available to assess the direct and indirect biological effects of iron floc in Dead Pike Lake, the well-established body of literature supports the conclusion that environmental impacts are present.

The heavy buildup of iron floc along the developed shoreline of Dead Pike Lake also reduces the aesthetic value and likely the market value of the shoreline properties. The ability of the lake residents to comfortably use the lake for swimming and other recreation is also diminished. Many studies across the country have associated lower property values with reduced water quality, specifically water clarity (MDEP, 2016) (Krysel, 2003). Recently Kemp (2016) estimated a 3-foot improvement in water clarity produces a 9-16% increase in the market price of riparian properties.

Water Column Iron and Manganese Toxicity

As mentioned above, the bioavailability of metals (i.e., the amount of metal that is available for uptake by organisms) within surface water is highly dependent on several factors. For example, dissolved organic carbon (DOC) in the water binds with metals like Fe, and cations (such as calcium) compete with metals for uptake by an organism, and both pH and alkalinity affect metal speciation. For metals like copper and iron, bioavailability is greatest in waters with low DOC, low hardness, and low pH and bioavailability generally decreases as any one of the parameters increases. Hardness has been explicitly used in assessing metal bioavailability for some time and more recently the EPA is using or developing biotic ligand models (BLM) to more accurately predict the ambient water chemistry on metal bioavailability (USEPA, 2016). Unfortunately, there are not BLMs developed for iron or manganese to provide a thorough assessment of bioavailability and toxicity based upon the site-specific water chemistries at DPL and PMSWA.

The 2017 whole effluent toxicity (WET) testing results from Dead Pike Lake did not show any significant acute or chronic effects with ambient iron ranging between 1.02 mg/L and 5.28 mg/L and manganese ranging between 8.42 μg/L and 114.0 μg/L. Even with no significant toxicity present, the WET testing should be interpreted with caution, given the relatively insensitive species used and with lab pH and oxygen concentrations held constant according to WET procedures (Ludwig J. , 2017). Although other studies have shown that fathead minnows have some of the lowest species mean chronic values (Cadmus, 2018). Manganese concentrations were well below the secondary acute values but were often found above the secondary chronic values calculated by Yang (2015).

As mentioned previously, a number of states (IDNR, 2005), Canada (Phippen, 2008) and the EPA water quality "red book" (USEPA, 1988) recommend a water quality standard of 1.0 mg/L for iron to protect fish and aquatic life . Cadmus (Cadmus, 2018) recently conducted several chronic laboratory studies and used previously published toxicity data to derive a final chronic iron concentration value of 0.499 mg/L.

On the other hand, North Carolina removed the water quality standard recognizing the ameliorating effects that alkalinity, pH, temperature and ligands have on iron toxicity and observed healthy fish fauna in the presence of 10 mg/L and greater (NCDENR, 2015). Although the specific toxicity mitigation effects of DOC ligand binding with iron and manganese at DPL cannot be explicitly calculated, the literature does provide some general information. Similar results were reported by (Loeffelman) where surface waters with iron between 10 and 15 mg/L and pH above 6 and oxygen above 5 mg/L did not show toxic effects or change species composition within streams (Loeffelman, 1985).

Roesler et al. (2016) studied the environmental impacts of high iron downstream from flowages and ditches at Crex Meadows Wildlife Area in Burnett County, WI and concluded:

- Trout are no longer present in Hay Creek due to increased iron turbidity.
- Fish species in the greatest abundance occurring in streams with high iron appear to be adapted to stream conditions resulting from high iron.
- Macroinvertebrate communities in streams with high iron show indications of poorer quality with fewer mayflies, stoneflies and caddisflies.

The literature review, especially given Cadmus' recent work, is at some level at odds with the WET test results and recent efforts of some states to remove the surface water criteria for iron and manganese. These differences are not surprising given the complexity of iron and manganese chemistry and the fluctuation of environmental conditions that affect their toxicity (i.e. dissolved organic carbon, pH, redox-potential, hardness, etc.). Couple these factors with the wide range of sensitivities among the biota and their different life stages, it's very difficult to make a definitive statement that the surface water column of Dead Pike Lake is toxic to the native species.

Overall, the available data and literature support the conclusion that iron concentrations in Dead Pike Lake and Powell Marsh, have the potential to have toxic effects, especially for benthic organisms like mussels or macroinvertebrates and certain fish life stages that use bottom substrates. The heavy formation of iron floc along the shorelines also reduces the visual aesthetics of the lake and interfere with recreational activities such as swimming.

10.4 Environmental and Recreational Impacts

This section provides an assessment of the direct and secondary impacts of the recommended lake management actions described in Chapter 2. The recommended lake management actions prescribe a relatively small change of ½ to 1 foot in the minimum lake water elevation, construction of a wetland treatment system within the man-made ditches of Powell Marsh and an application of lime to shift the pH upwards by 0.5 to 0.8 s.u. A clean water diversion from Stepping Stone impoundment on Powell Marsh is also recommended if additional surface water is required to maintain a minimum lake elevation.

The recommended management actions are predicted to substantially reduce iron floc accumulation and reduce the phosphorus levels in the lake, leading to reduced iron floc accumulation, improved water clarity and preservation of the 2-story fisheries. Iron floc accumulation are predicted to decrease by 50% and water clarity is expected to increase by 24% or greater.

Establishing a Minimum Dead Pike Lake Elevation

The aquatic plant community is not expected to change in response to a higher minimum lake level and respond favorable as a result of the improved water clarity and reduction in iron floc accumulation. Establishing a minimum lake elevation ½ to 1 foot higher while maintaining the same ability to discharge outflow will only affect the low water level conditions of the lake and the high-water elevations conditions of the lake will remain unchanged. The increase of ½ to 1 foot minimum lake elevation is within the range of historic lake level fluctuations of two feet or more (Figure 33). In a short period of years, the aquatic plants community is expected to normalize around the new minimum lake level. As noted in Chapter 7, even with moderately different lake conditions in 2008 and 2017, the aquatic plant surveys continued to represent a highly diverse and healthy community.

The fisheries community is expected to respond positively to the reduction of iron floc accumulation due to the reduction in potential toxicity effects on sensitive egg and larval life stages, as well as the reduction in potential physio-biological impacts of the iron floc on gills. Similar positive effects on macroinvertebrates and mussels are also expected because of the reduced iron floc accumulation and improved water clarity. Because the proposed elevation change at the outlet stream is small, a ½ to 1 foot, maintaining the existing ability of fish to pass and migrate from Lost Creek into and out of Dead Pike Lake is feasible and will be included in the conceptual design phase of the project.

The STELLA modeling results indicate that by establishing a higher minimum lake level at Dead Pike Lake, the groundwater inflow volume is predicted to be reduced by about 1.45 cfs. This groundwater flow would be diverted toward and discharge into other discharge features including Lost, Little Bear and Sugarbush Creeks; nearby wetlands; and the Manitowish River. Due to proximity, Lost Creek would likely pick up a substantial portion of that discharge and downstream flow may approach rates occurring at existing lake levels. Also, some of the diverted flow may be lost to the atmosphere due to increased evapotranspiration resulting from increased water table levels. Given the ground watershed of thousands of acres and the number of discharge features, increases in discharge into specific streams or wetlands will be likely be small (Helmuth, pers. comm. 2018).

By examination of the surface water and structural elevations on the lake and marsh, raising the minimum lake elevation is not predicted to result in high water over the top of Powell Road and not reduce the ability to dewater Powell Marsh impoundments. The STELLA model predicts raising the outlet stream bottom by 1 foot will result in maximum lake level of 1957.05 fasl or approximately the same elevation of the ordinary high-water mark in the lake's southwest cove and at least 2 inches lower than the OHWM elevations set on the main lake basin (Jefferson, 2017). The top of the 6-foot culvert at Powell Road is at 1599.06 fasl and the center line of Powell Road is at 1601.64 fasl. The Powell Marsh Main Pool Impoundment with an August 2017 surface water elevation of 1602.97, generates the head pressure for flow to Dead Pike Lake in the ditch at 1598.58 fasl. Recognizing the surface water elevations were collected when ~1.2 feet of the upstream Powell Road culvert was plugged with beaver dam residue, the top of the Powell Road culvert is about 2 feet higher than predicted highest lake level and the Main Pool Impoundment is 5.9 feet above the highest predicted lake level, water is not predicted to back up at, and flow over Powell Road.

Recreational and property values at Dead Pike Lake are predicted to improve as a result of raising the bottom of the outlet stream to 1594.9 (1/2 foot) or 1595.4 (1 foot) fasl since this results in a predicted maximum lake level of 1597.05 fasl or just below the average lake basin ordinary high water mark of 1597.35. Boating access from riparian piers and the boat launch will be enhanced by the increased minimum water level. Many property owners have installed shoreline riprap based upon historic water levels at the delineated OHWM. Water levels are expected to better align with the existing installed shore protection and shoreline erosion is not expected to increase. Property values are well documented to respond to improvements in water quality (Kemp, 2016) (Krysel, 2003) and even in lake level management (Kashian, 2015) and accordingly, are expected to increase with improved water clarity, reduced iron floc and increased water levels at Dead Pike Lake.

Phosphorus and Iron Treatment System in Powell Marsh

The lake management plan recommends the construction of a wetland-biofilter treatment system designed to remove between 50% and 70% of the iron and phosphorus load originating in Powell Marsh State Wildlife Area. Portions of the main ditch system downstream from the Main Pool impoundment would be modified to reduce groundwater inflow, shift the pH upwards and biologically remove phosphorus. Anticipated changes to the ditch water quality and habitat include increased iron floc deposition, pH, alkalinity and temperature, and decreases in surface water area.

With the use of aquatic vegetation within the channels, primarily targeting phosphorus uptake, no loss of aquatic vegetation or wetland plant community impacts are expected. Plants used in the design for bio-filtration will be native and compatible with the existing communities of Powell Marsh. Depending on the final design of the treatment systems, regular maintenance of sediment and detritus removal followed by replanting will be more frequent than maintenance under the existing PMSWA area plan.

Depending on how many linear feet of ditches are modified to remove iron and phosphorus, some ditch fisheries habitat will be converted to vegetative open water marsh. The existing fisheries with a fair index of biological integrity in the filled portions of the ditches will likely shift. The increased vegetation density placed to remove iron and phosphorus will result in greater oxygen concentration swings and likely greater anoxic conditions during respiration at night. Low oxygen tolerant fish species will become more common in the ditches where treatment is constructed. While the water column is expected to have less iron and improved water clarity with the biological treatment and small shift in pH, precipitated iron in the ditches is expected to increase which may affect some fish spawning habitat in the ditches.

Lime Application

A small increase in pH in the range of 0.6 to 0.8 to the lake basin and within the Powell Marsh ditches will facilitate iron precipitation and reduce the formation of the iron and dissolved organic carbon complexes. Most of literature available about the environmental impacts of liming is associated with the treatment to neutralize acidic conditions and evaluate substantial pH shifts, compared to the small shift of 0.6 to 0.8 pH units proposed at Dead Pike Lake. Hassler's famous "whole-lake" experimental work to lime Peter Lake initially raised the pH from 5.9 to 7.3 and eventually as high as 8.3; while the reference lake remained in the range of 6.5 +/- (Elser, 1986) . With the 2-unit shift in pH, Elser summarized the important changes to include transparency, dissolved inorganic carbon and alkalinity all increased.

The increased transparency also leads to temporal changes in algal blooms but not changes in density, a more diverse zooplankton community and increased deeper oxygenated zones with the precipitation of the water column humic material. The precipitated iron, manganese and dissolved organic carbon will be transported from the nearshore erosional zone to the deeper accumulation zones. With the oxic hypolimnion of Dead Pike Lake, the bonds between phosphorus and iron hydroxides will remain intact and increases in hypolimnetic phosphorus is not expected.

The distribution and species composition of the aquatic plant community is likely to respond to the reduction of iron floc accumulation and increases in water clarity. The expected shifts are expected to parallel changes observed between the 2008 aquatic plant survey conducted during a clear water phase and the 2017 survey during a lower water clarity phase. Most of aquatic plant species (45) had shifts of less than 5% frequency of occurrence from 2008 to 2017 and the Simpson index of diversity was 0.92 and 0.91 in 2008 and 2017 respectively. The maximum rooting depth of the aquatic plants did increase between 2008 and 2017 and will likely increase in response to the improved water clarity from a lime treatment. The fisheries, macroinvertebrate and mussel communities are expected to respond to the increased water clarity and reduction in iron floc accumulation because of the lime treatment.

Clean Water Diversion

At this time, a clean water diversion from the Powell Marsh Stepping Stone impoundment is proposed only if additional water is needed. The diversion of water from the Powell Marsh Stepping Stone impoundment may not be required if sufficient water inflow from Powell Marsh's Main Pool is not reduced and a minimum lake level can be sustained. If additional surface water source is required, Stepping Stone Impoundment would be a surface water source with lower concentrations of iron compared to the inflow at Powell Road from the main ditch (1.97 mg/L vs 3.52 mg/L in 2017) and lower concentrations of phosphorus (18.2 μg/L vs 40.6 μg/L).

However, Stepping Stone Impoundment functions as an important open water system with natural aquatic and wetland plant communities. If water levels on Stepping Stone Impoundment are lowered or altered, the open water habitat would be reduced and secondary impacts to the aquatic and wetland plant communities would be expected. These shifts in habitat would result in changes to the use of this area by many species of animals and birds.

The goals of any designed diversion would be to supplement the water supply to the Stepping Stone Impoundment to maintain the existing aquatic and wetland habitat communities. Flow could be diverted from the Little Trout Impoundment to Stepping Stone rather than to the Main Pool. Ultimately, if a clean water diversion was necessary to maintain minimum lake elevations, a full assessment of the potential impacts to Stepping Stone Impoundment and Powell Marsh would need to be made with amendments to the Powell Marsh State Wildlife Area Master Plan.

11 Lake Management Alternatives

The recommended management actions are described in detail in Chapter 2 and this Chapter provides an overview of the different lake management alternatives evaluated as part of developing this lake management plan.

For decades, the Dead Pike Lake Association has been interested in implementing watershed and in-lake management actions to address the water quality concerns associated with iron, manganese and phosphorus. In 2017, surface water and groundwater monitoring and modeling work was completed by WDNR and Applied Ecological Services (AES), hired by the Town with financial support from WDNR. AES has extensive experience using STELLA, a dynamic modeling platform, to evaluate lake management actions to reduce iron and phosphorus loading (Apfelbaum, 2018).

Table 19. Lake and Watershed Management Alternatives

Management Alternative	Description	Operations & Management	Regulatory Rank	Cost Rank	Notes
No Change	No significant changes to Powell Marsh or lake.	Low	Low	Low	Not selected DPL water quality goals not achieved
Rewilding of Powell Marsh	Return Powell Marsh to pre-ditch and pre-impoundment conditions.	Low	High	High	Not selected PMSWA master plan goals not achieved
Inflow Diversion	Bypass inflow at Powell Road around Lake to west, directly into Lost Creek	Low	High	Medium	Not selected Groundwater iron load not addressed DPL water quality goals not achieved
PMSWA Master Plan, Main Ditch flow redirection structure	Install wetland ditch plugs in N-S ditch from Main Pool Flowage	Low	Medium	Low	Not selected Ditch plugs will increase groundwater flow of iron into lake DPL water quality goals not achieved
PMSWA Master Plan – Remove Little Trout Dam	Divert Little Trout Flowage flow into marsh for treatment by existing wetland	Low	Low	Low	Not selected Increased nutrients have already promoted the growth of reed

					canary grass downstream of flowage – risks expansion of RGC in marsh.
Biofilter in Lower Marsh	Backfill North-South and East-West ditch to seal from groundwater. Install wetland biofilter vegetation	Low	Medium	Medium	Selected Reduces 50% to 70% of iron and phosphorus loading from marsh DPL water quality goals achieved
Clean Water Diversion	Divert lower iron and phosphorus water from Stepping Stone impoundment into lake combined with biofilters as needed	Low	High	Medium	Selected if required supplemental flow is needed to maintain minimum lake levels DPL water quality goals achieved
Increase Surface Water pH	Install limestone in ditches and along lake shoreline for passive increase of pH. After iron loading has been reduced, treat lake basin with lime.	Low	Medium	Low	Selected following reduction of iron and phosphorus loads DPL water quality goals achieved
Maintain a Minimum Lake Elevation	Increase the bottom elevation of the outlet stream at DPL.	Low	High	High	Selected Significantly reduces groundwater inputs of iron and phosphorus DPL water quality goals achieved

Modified from Applied Ecological Services final report (Apfelbaum, 2018)

12 Summary

The completion of the 2018 Dead Pike Lake Management Plan has been accomplished through an open partnership between the Dead Pike Lake Association, the Town of Manitowish Waters and the Wisconsin Department of Natural Resources with direction and support from the Natural Resources Board. Applied Ecological Services provided modeling, lake and wetland ecosystem analysis and toxicology information. Many other partners have contributed to the collection and analysis of data including:

- GFlow model development by DNR Groundwater staff,
- Local water quality and flow monitoring by DNR water quality and wildlife staff,
- Shared specialized equipment and technical assistance from USGS,
- Technical and field assistance Wisconsin State Laboratory of Hygiene and DNR toxicologist staff, and Aquatic plant survey work by UW-Trout Lake and DNR water quality staff.

The management actions recommended in Chapter 2 of the lake management plan are based upon extensive monitoring and modeling work. Implementation of the management actions are set forward in a step by step manner using evaluation monitoring for adaptive and reversible management actions.

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14 Figures

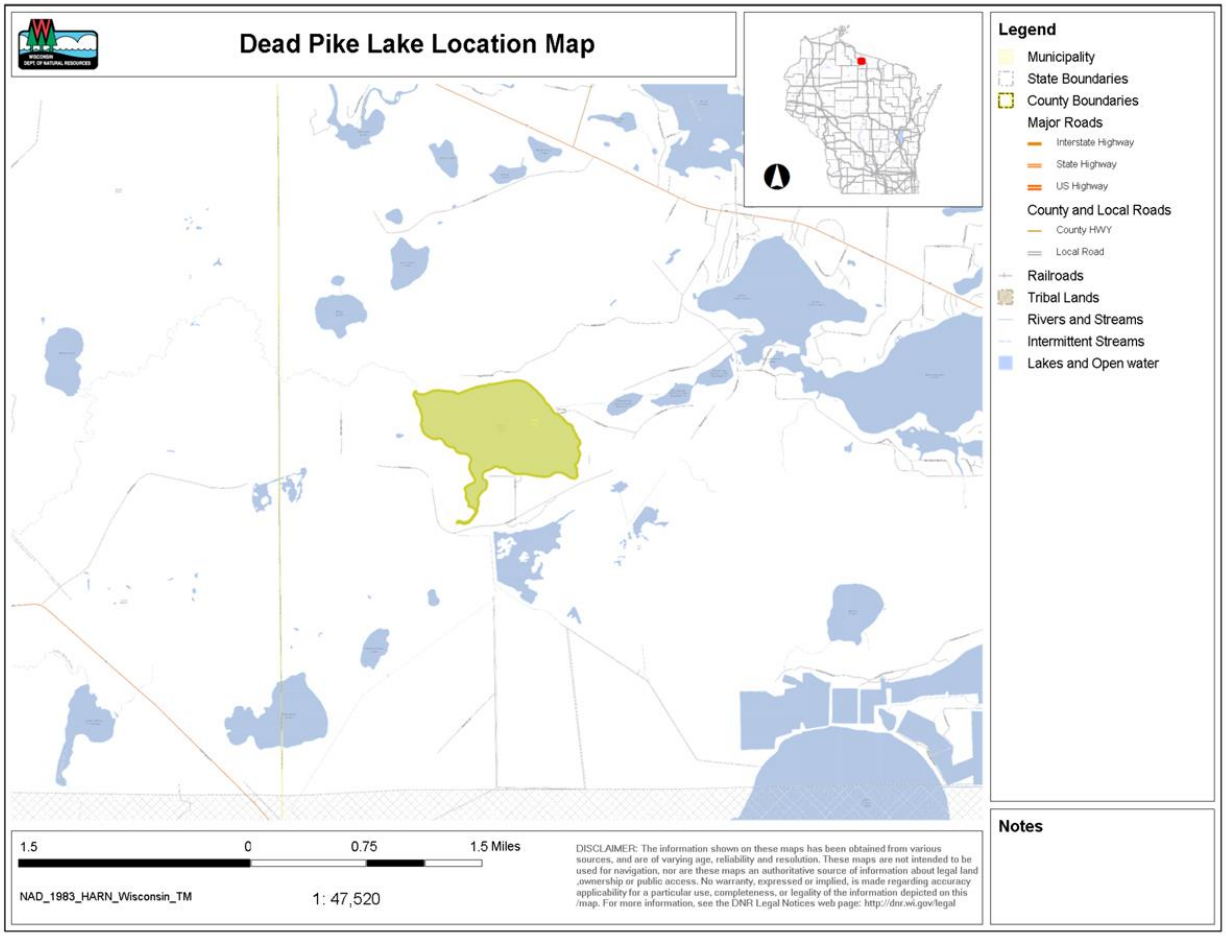


Figure 2. Dead Pike Lake Location Map

Figure 3. Glacial Deposits Near Dead Pike Lake and Powell Marsh
Glacial deposits described by Attig ((1985) around Dead Pike Lake and Powell Marsh.

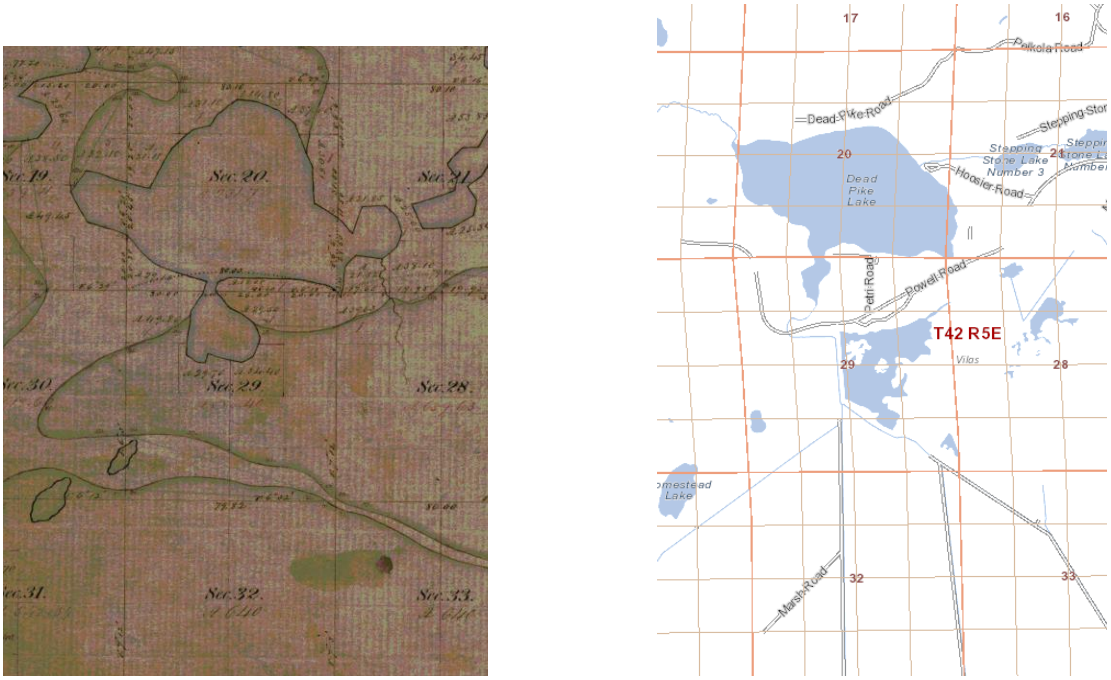


Figure 4. 1860 Original Government Survey and Present-day Surface Water Map.
Dead Pike Lake and Powell Marsh area from 1860 (left) Original Government Survey (BCPL, 2018) and present-day surface water features (right) mapped in Department of Natural Resources Surface Water Data Viewer (WDNR, Surface Water Data Viewer, 2018a)

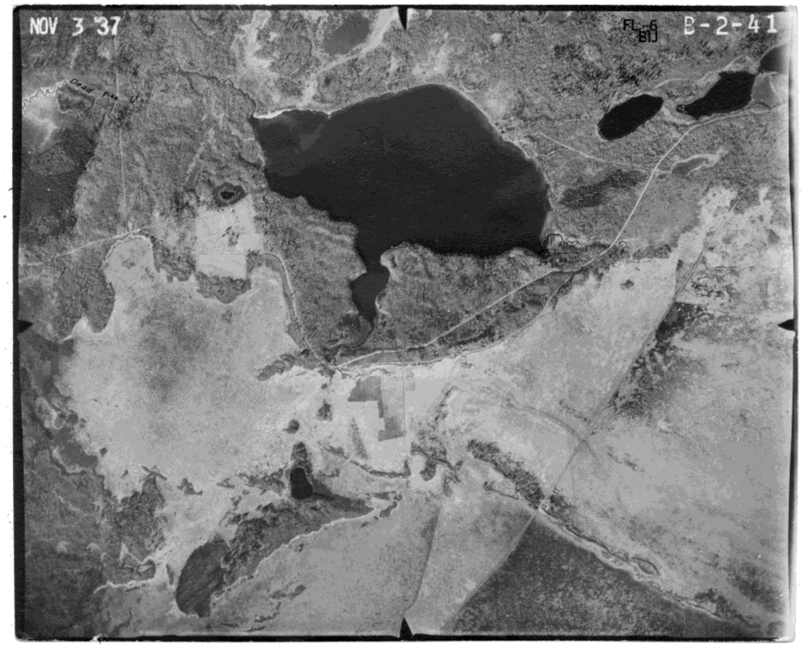


Figure 5. 1937 Air Photography
The 1937 air photo ((SCO, 2018) showing extensive lower water levels, agricultural row cropping and some ditching south of Powell Road and the railroad track running from the Northeast corner to the Southcentral portion of the photo.

Figure 6. Dead Pike Lake Watershed Area
Watershed area delineated with PRESTO (WDNR, 2013) using Vilas County lidar elevation data and ground truthing in the field.

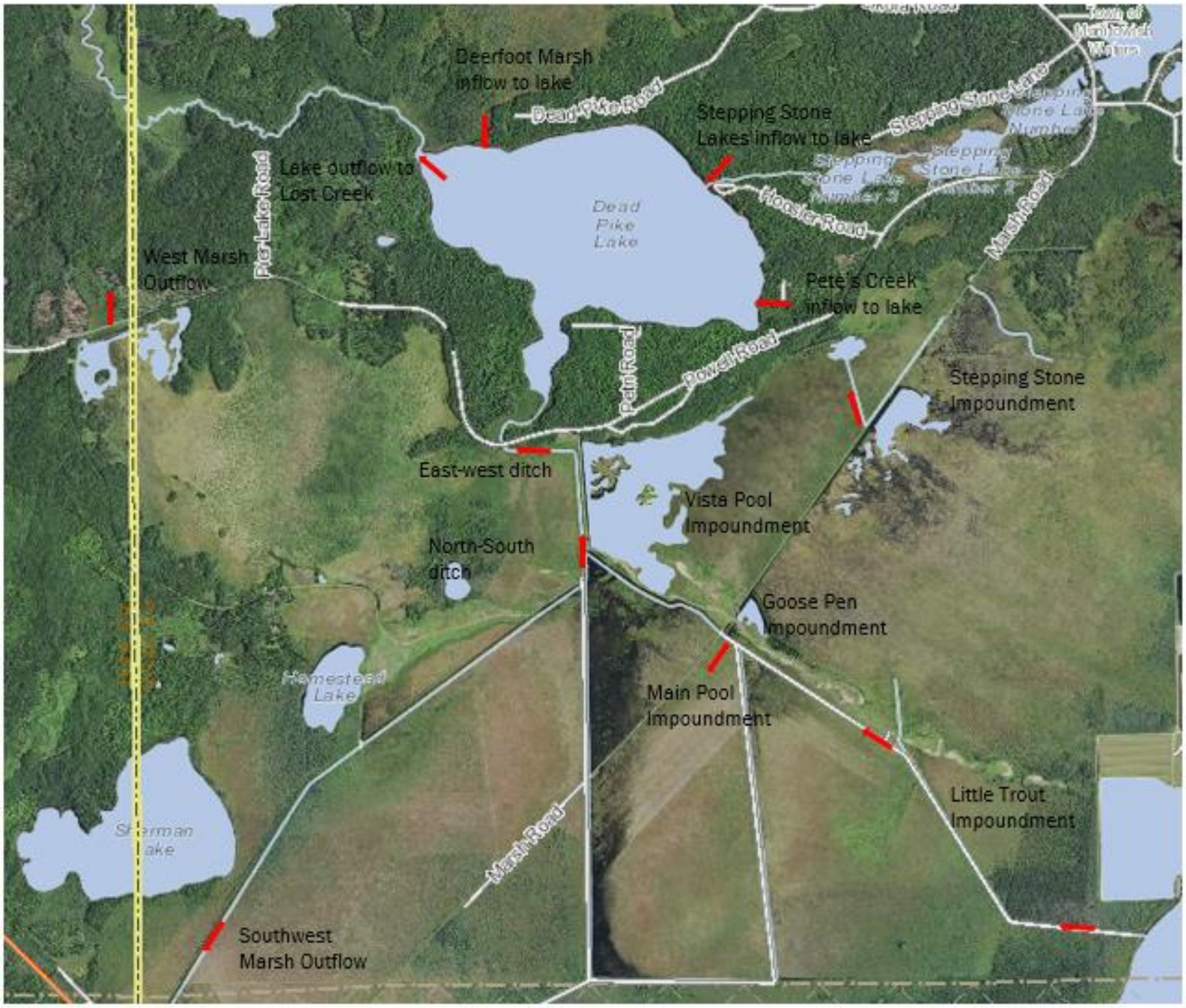


Figure 7. Surface Water Flow at Dead Pike Lake and Powell Marsh
Surface water inflow and outflow locations for Dead Pike Lake and the Powell Marsh State Wildlife Area.

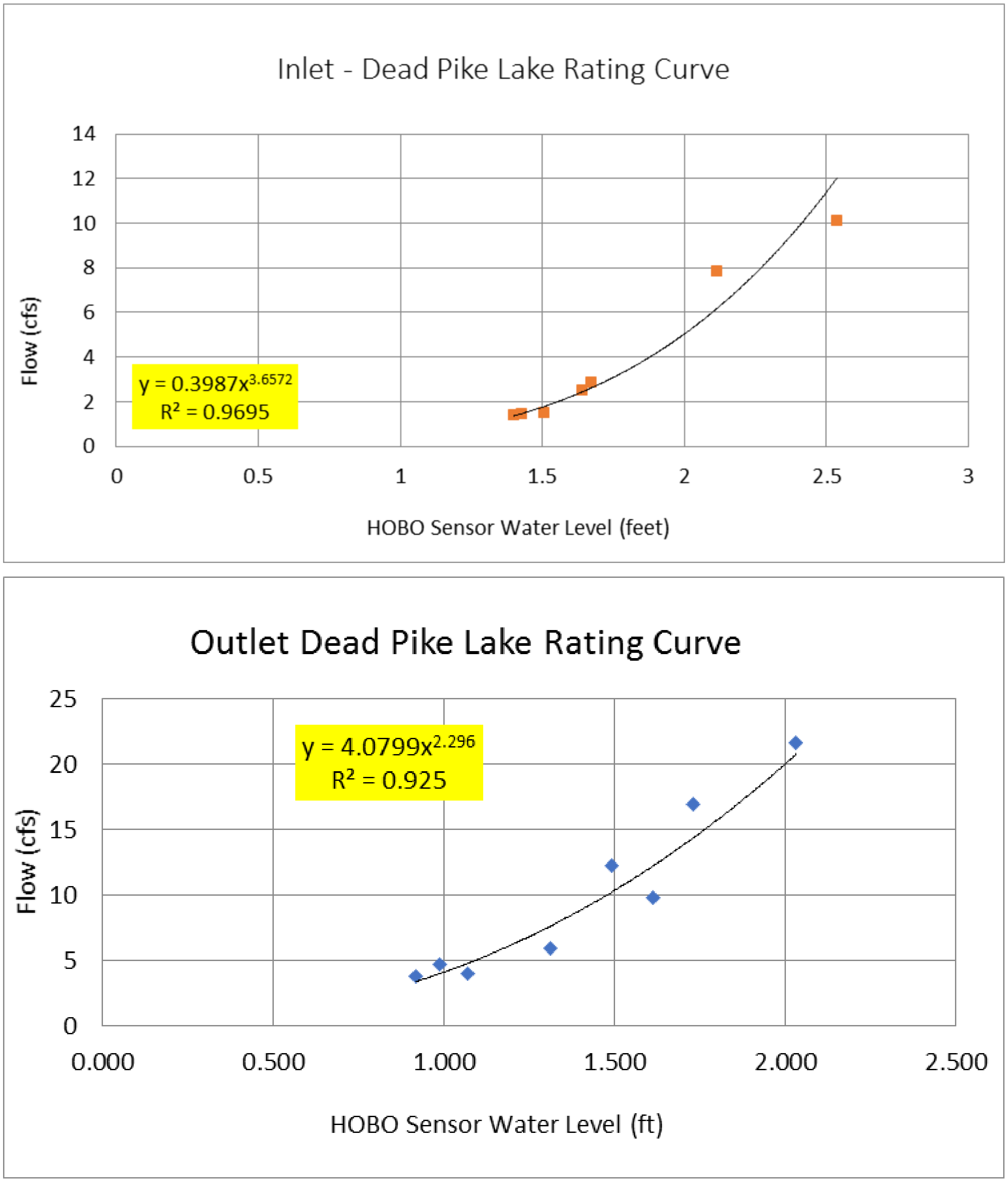


Figure 8. Dead Pike Lake Inlet and Outlet Rating Curves
Dead Pike Lake surface elevation as recorded by HOBO pressure sensors adjusted for atmospheric pressure and relationship to flow measurements in the field (Rating Curves).

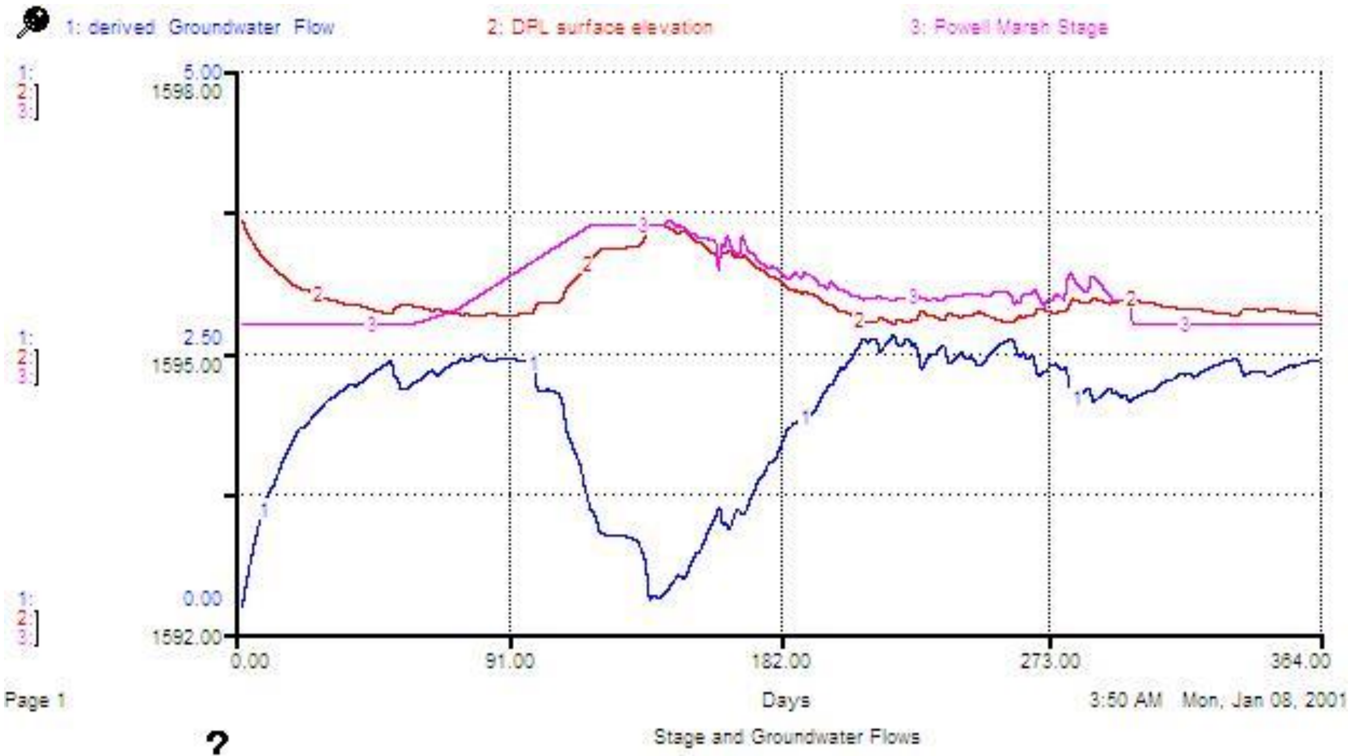


Figure 9. Dead Pike Lake Level and Groundwater Inflow
From AES STELLA water budget analysis showing lake elevation (red line) and groundwater contribution of the water budget (blue line) for a yearlong period starting in April 2017.

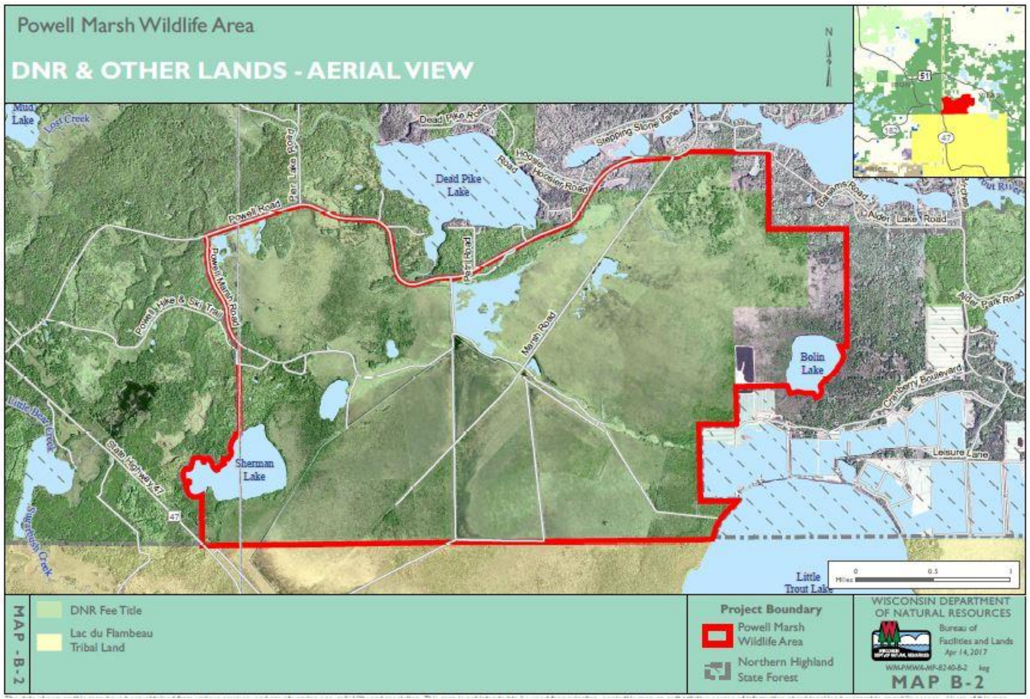
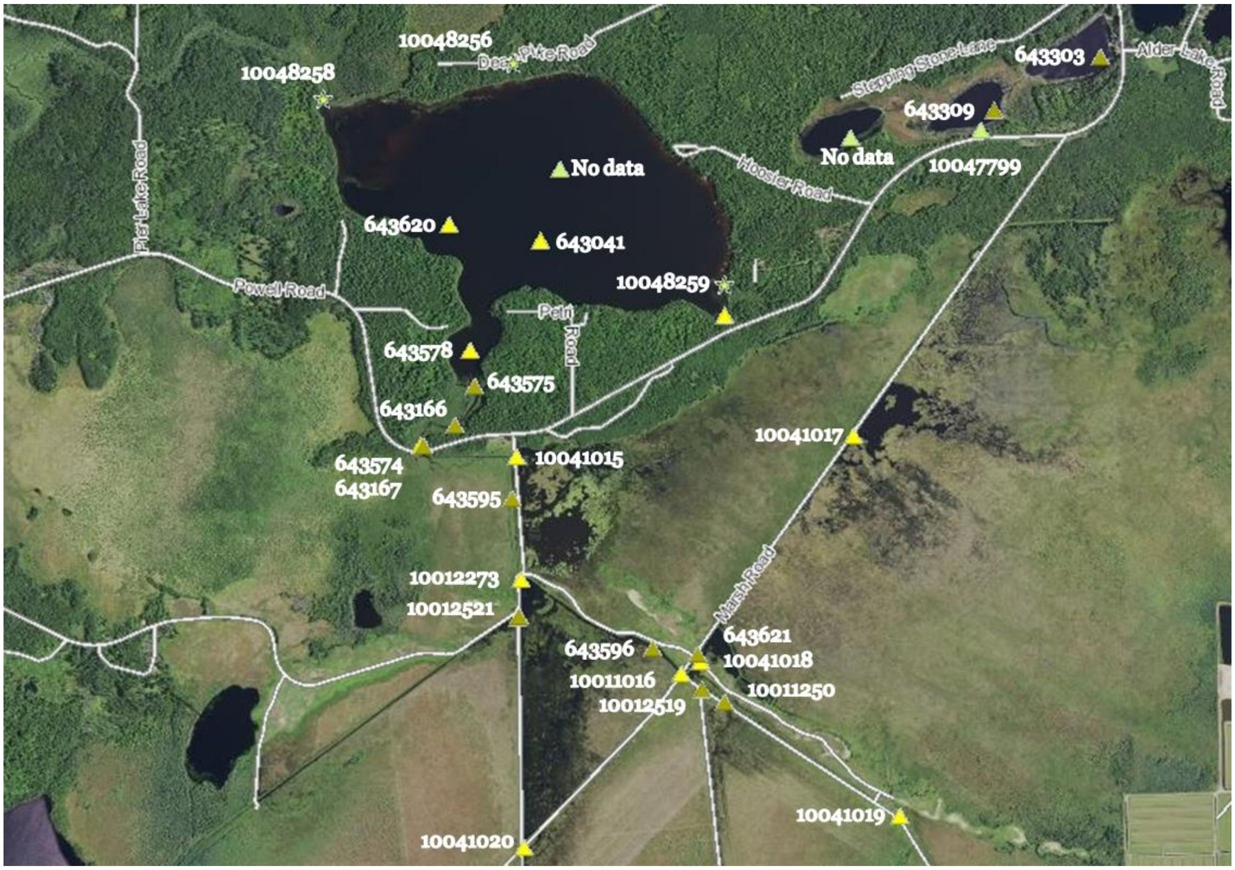


Figure 10. Powell Marsh Property Map
Powell Marsh State Wildlife Area property map from the master plan (WDNR, 2016a), map B-2.



Station #	Station Name	Data Range	Station #	Station Name	Data Range
643041	Dead Pike Lake – Deep Hole	1989 – 2017	10012273	Main Pool – Above Control Structure	2005 & 2006, 2017
643166	Dead Pike Lake – South inlet	1989	10012519	Unnamed Ditch – East South Ditch	2006
643167	Dead Pike Lake – East inlet	1989 - 2006	10012520	Main Ditch (Powell Marsh)	2006, 2013, 2014, 2016
643303	Stepping Stone Number 1	1985	10012521	West Ditch (Powell Marsh)	2006
643309	Stepping Stone Number 2	1985	10018653	Dead Pike Lake - Access	2006 & 2010 - Clean Water, Clean Boats
643574	Unnamed Ditch – Below Powell Road	2003, 2013 - 2017	10041015	Vista Pool Water Control Structure	2013, 2014 & 2016
643575	Dead Pike Lake Powell Marsh Ditch Inlet	2003	10041016	East Main Water Control Structure	2013 & 2014
643578	Dead Pike Lake – Neck of South Bay	2005 - 2017	10041017	Stepping Stone Water Control Structure	2013, 2014 & 2016, 2017
643595	Powell Marsh – Vista Ditch	2004 - 2006	10041018	Goose Pen Water Control Structure	2013, 2014 & 2016, 2017
643596	Powell Marsh – Main Ditch	2004 - 2006	10041019	Little Trout Water Control Structure	2013, 2014 & 2016, 2017
643620	Dead Pike Lake – South Bay	2002, 2005 - 2016	10041020	South Main Water Control Structure	2013, 2014 & 2016

Figure 11. Historic SWIMS Stations and Data Ranges
Historic and current surface water monitoring stations and yearly data ranges for primary sites within the Dead Pike Lake watershed, including Powell Marsh State Wildlife Area.

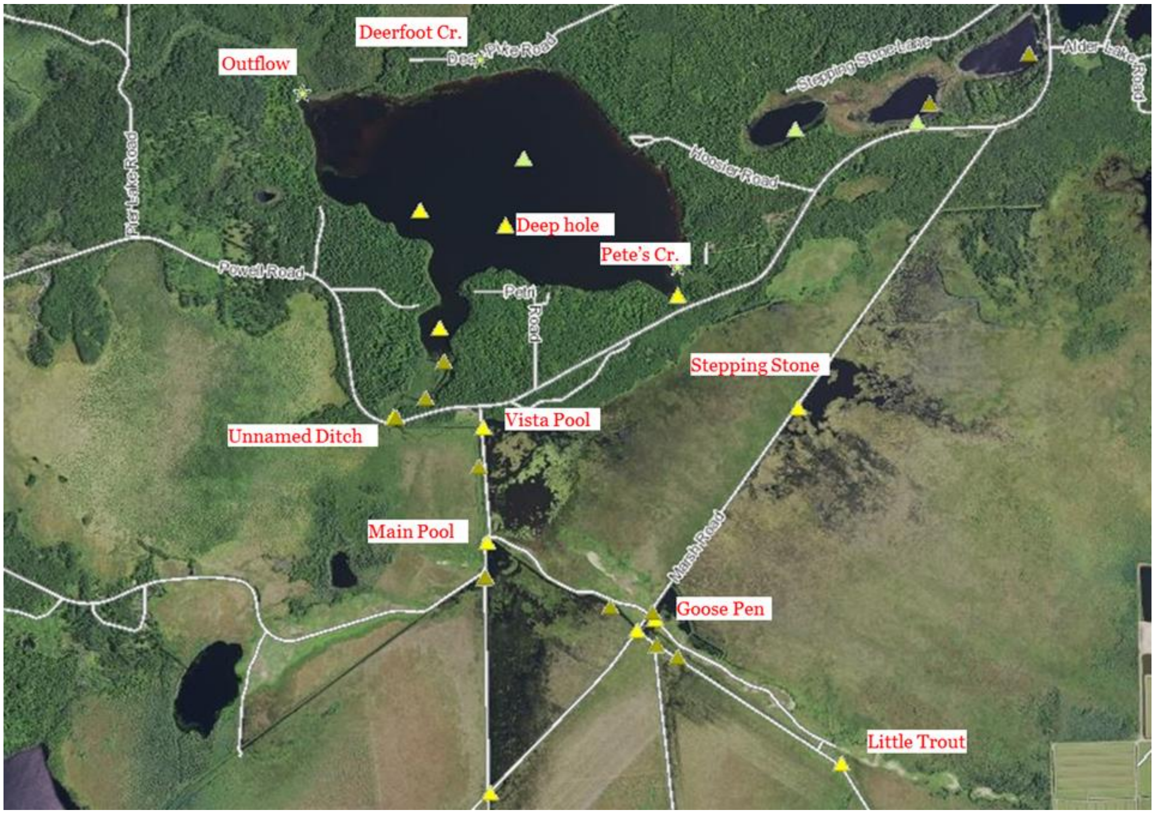


Figure 12. Surface Water Chemistry Monitoring Sites
Location of bi-weekly, surface water chemistry and flow monitoring locations at Dead Pike Lake and Powell Marsh State Wildlife Area.

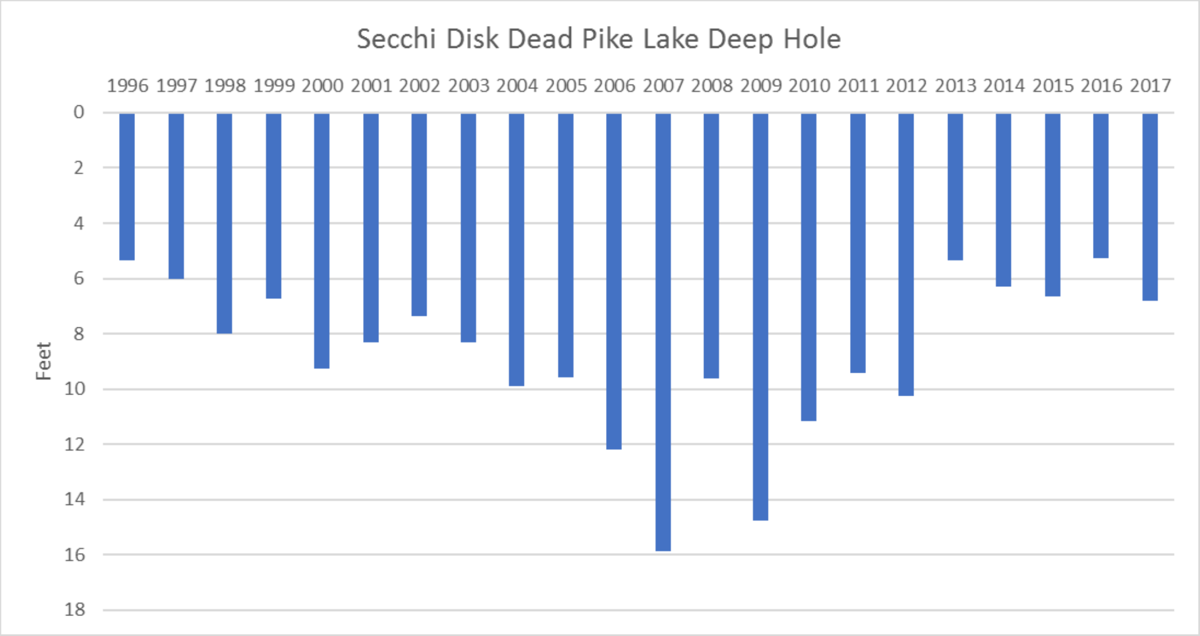


Figure 13. Dead Pike Lake Annual Summer Secchi Disk
Annual summer Secchi disk measurements from the deep hole at Dead Pike Lake.

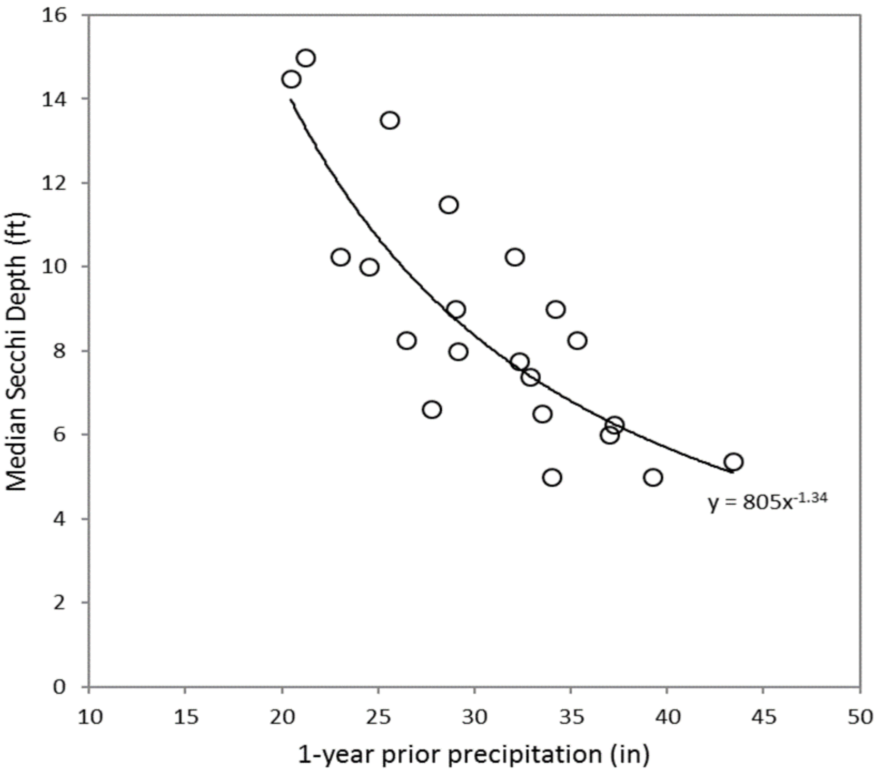


Figure 14. Secchi Disk Relation to Precipitation
Dead Pike Lake Secchi disk measurements from the deep hole compared to the previous 365 days of total precipitation

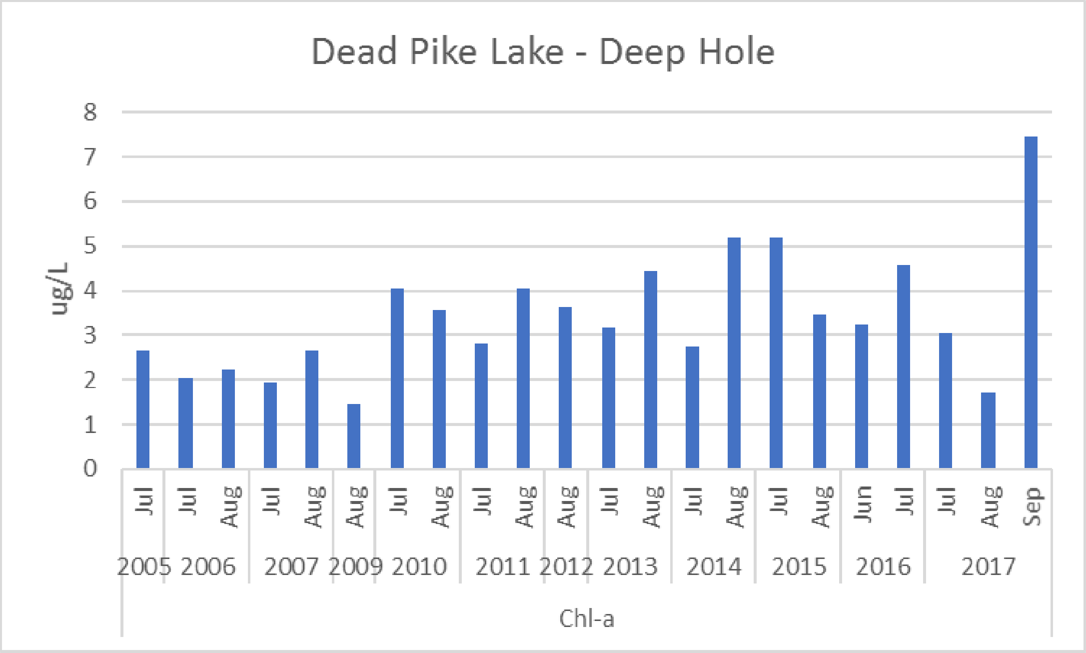


Figure 15. Dead Pike Chlorophyll-a
Chlorophyll-a concentrations collected from the deep hole at Dead Pike Lake.

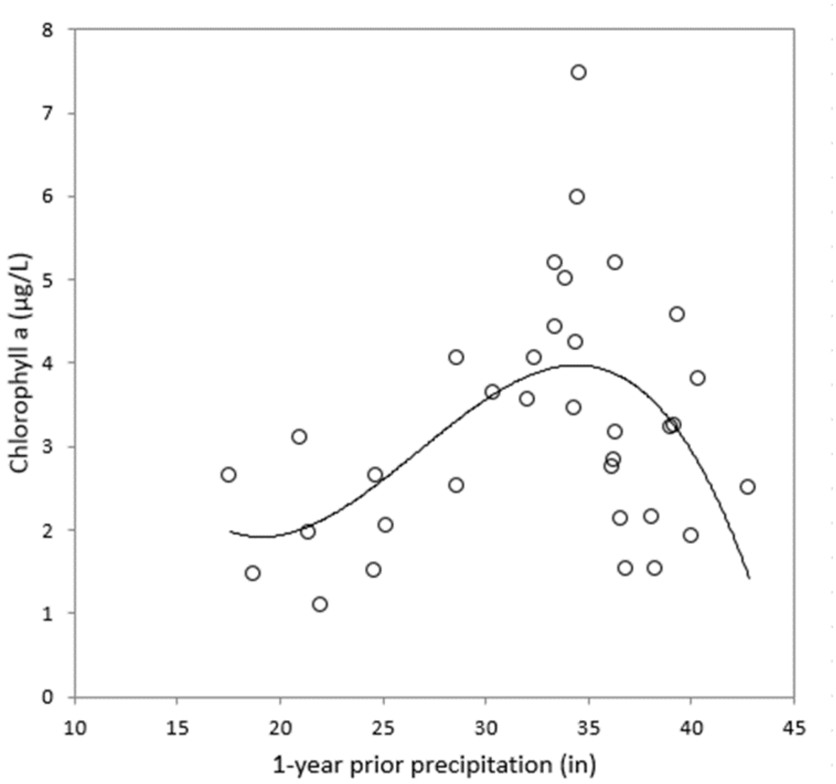


Figure 16. Chlorophyll-a and the Previous 365-day Total Precipitation
Chlorophyll-a concentrations were graphed verse the previous year's total precipitation used to account for the drought conditions from 2004 – 2009.

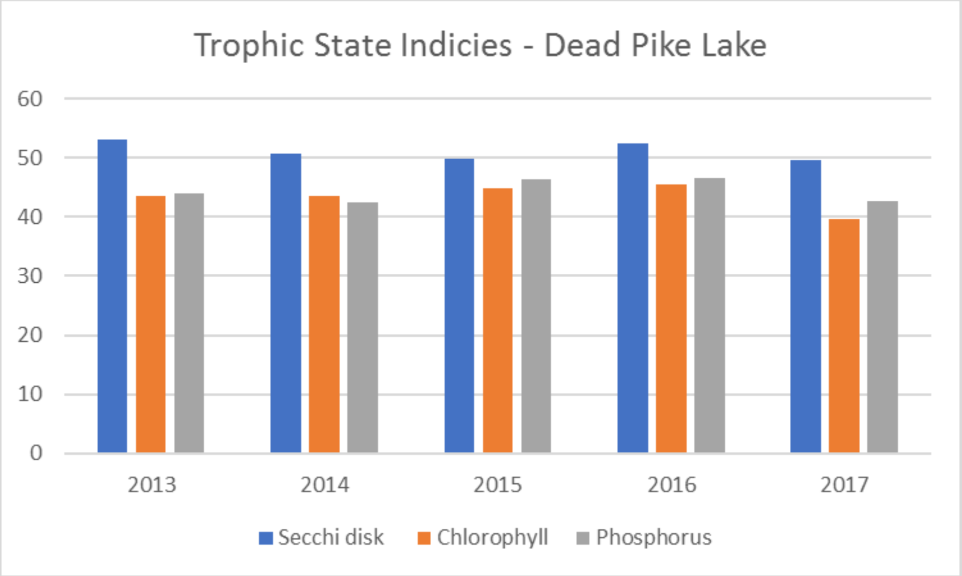


Figure 17. TSI Values for Dead Pike Lake.
Annual average TSI values for Secchi disk, Chlorophyll-a and Total Phosphorus at Dead Pike Lake deep hole for 2013 thru 2017.

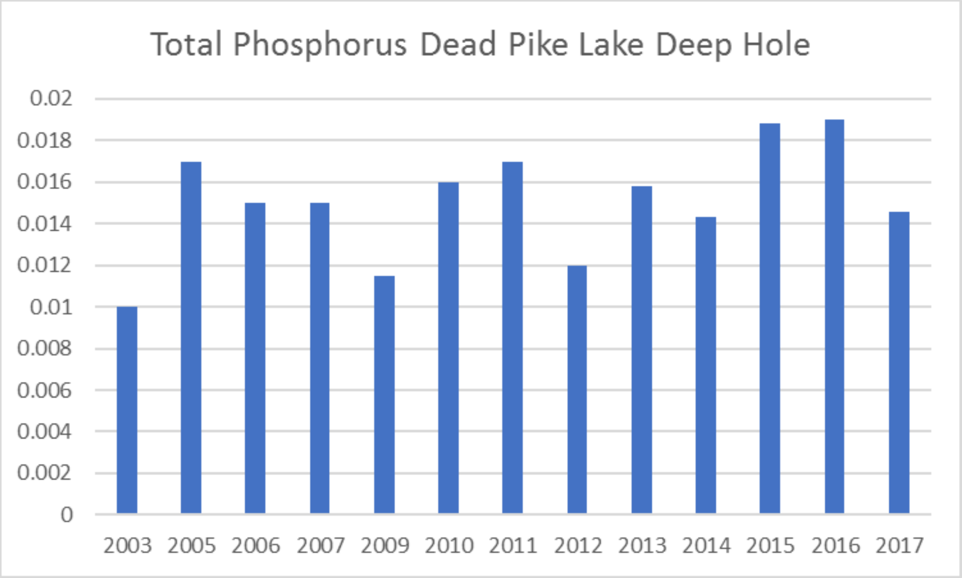


Figure 18. Dead Pike Lake Average Annual Total Phosphorus
Average annual total phosphorus from Dead Pike Lake Deep Hole for the WisCALM ((WDNR, 2017b) assessment period of June 1 thru Sept 30.

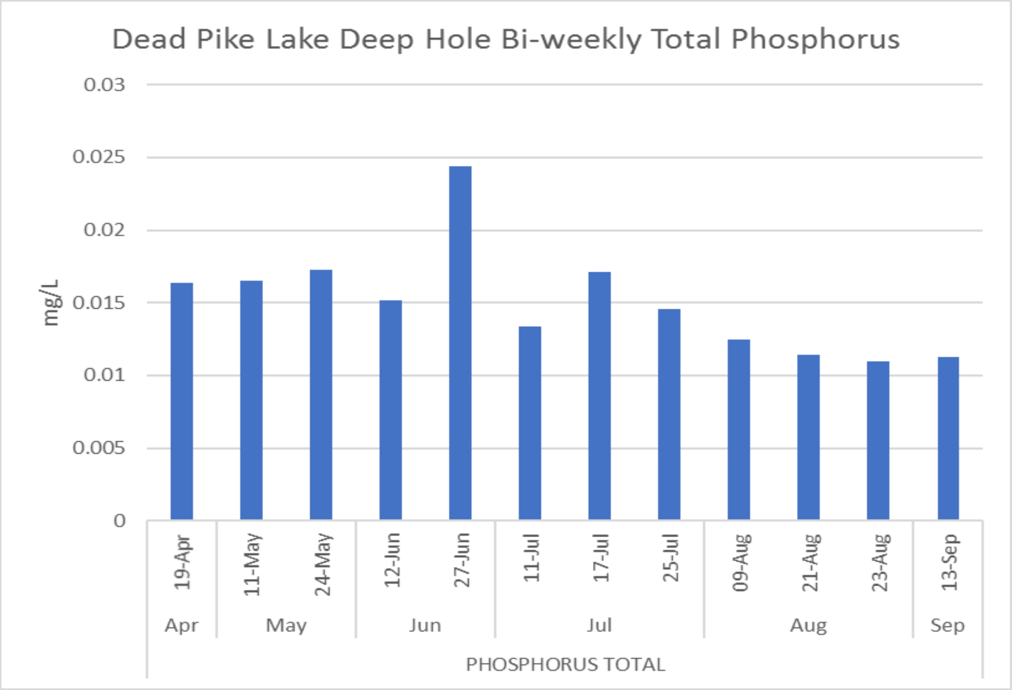


Figure 19. 2017 Bi-weekly Deep Hole Phosphorus
2017 Bi-weekly Dead Pike Lake deep hole surface water concentrations of total phosphorus

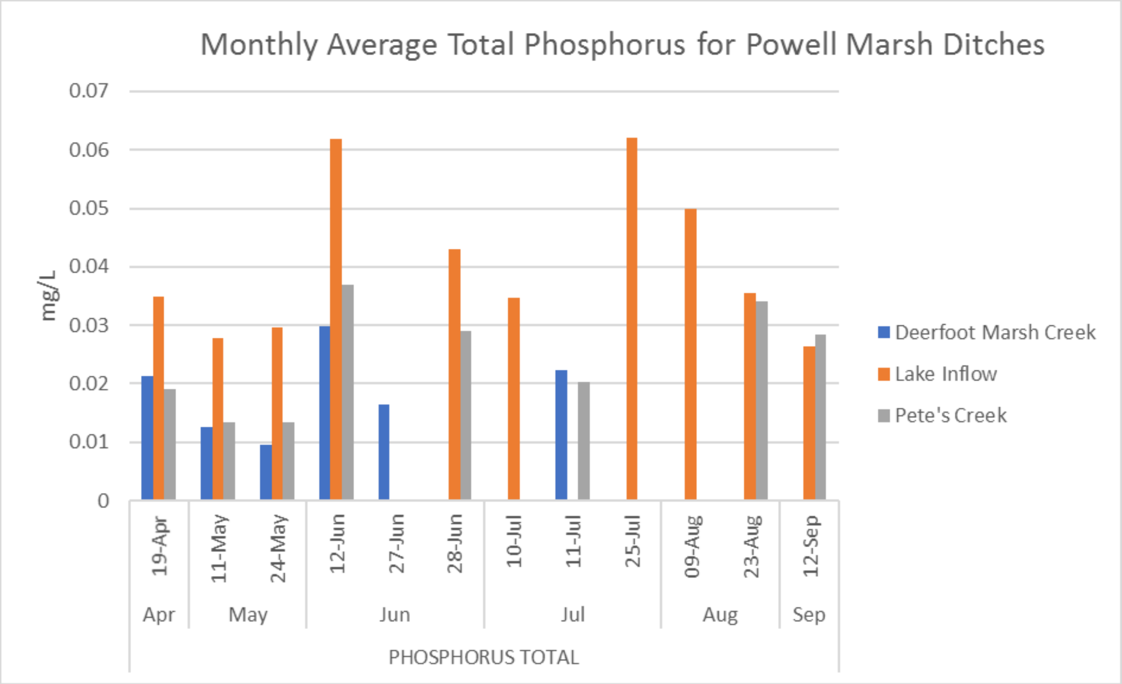


Figure 20. 2017 Average Monthly Total Phosphorus of Inflowing Streams
2107 average monthly total phosphorus of the primary lake inflow from Powell Marsh and the two intermittent streams, Deerfoot Marsh and Pete's Creeks.

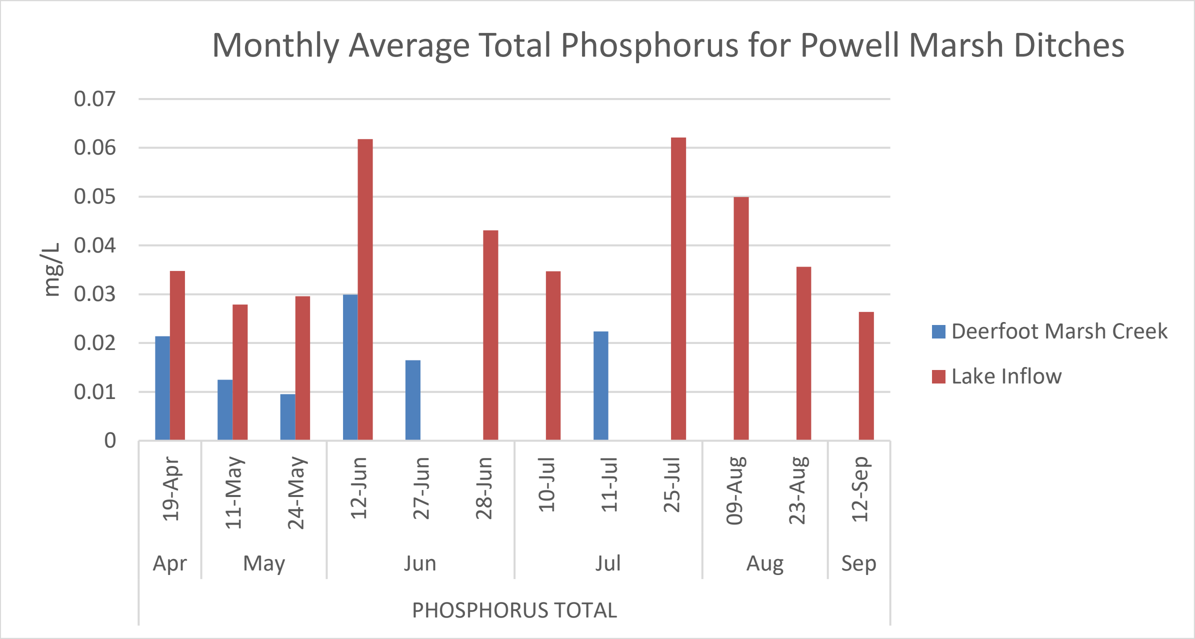


Figure 21. 2017 Average Total Phosphorus for Powell Marsh Ditches
Monthly average total phosphorus concentrations for Powell Marsh ditches in 2017.

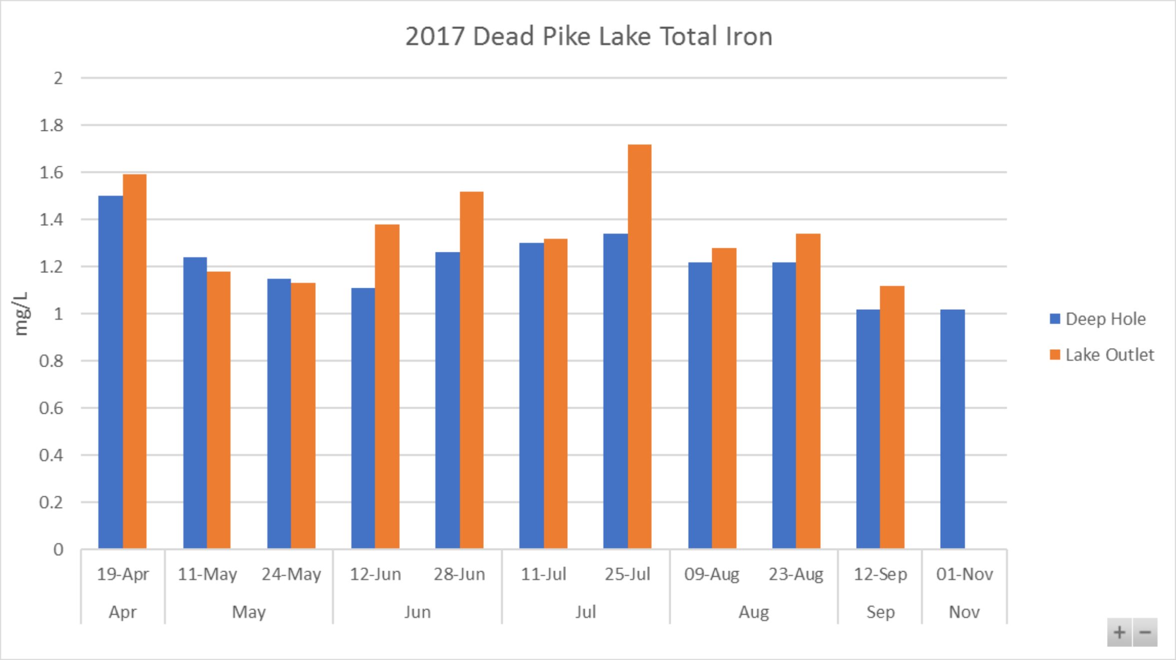


Figure 22. 2017 Dead Pike Lake Total Iron Concentrations
2017 Dead Pike Lake total iron concentrations at the deep hole and the lake outlet.

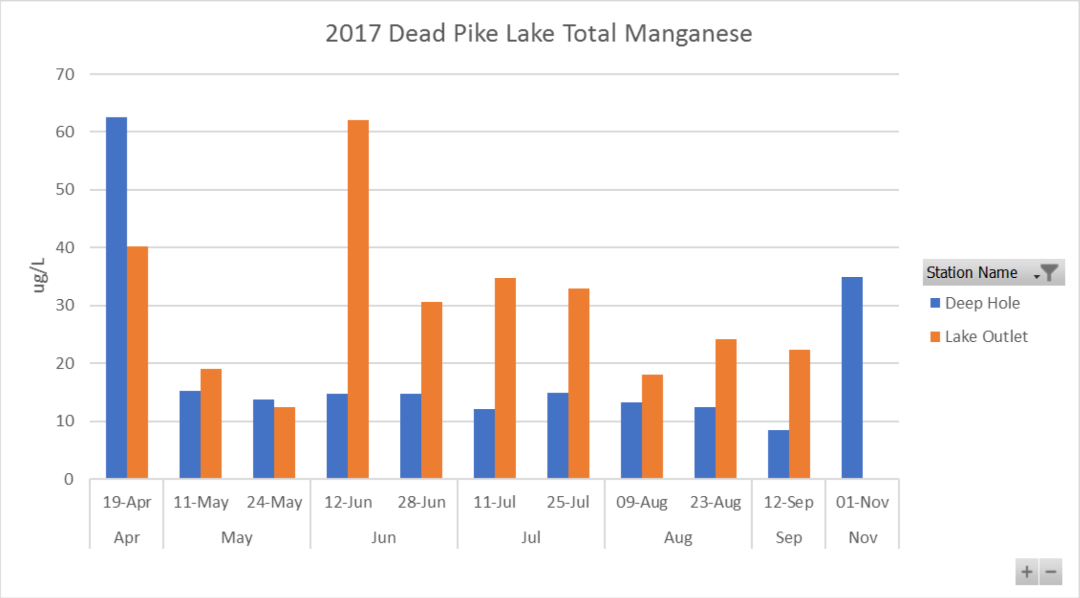


Figure 23. 2017 Dead Pike Lake Total Manganese Concentration.
2017 Total manganese concentrations collected bi-weekly from the deep hole and lake outlet

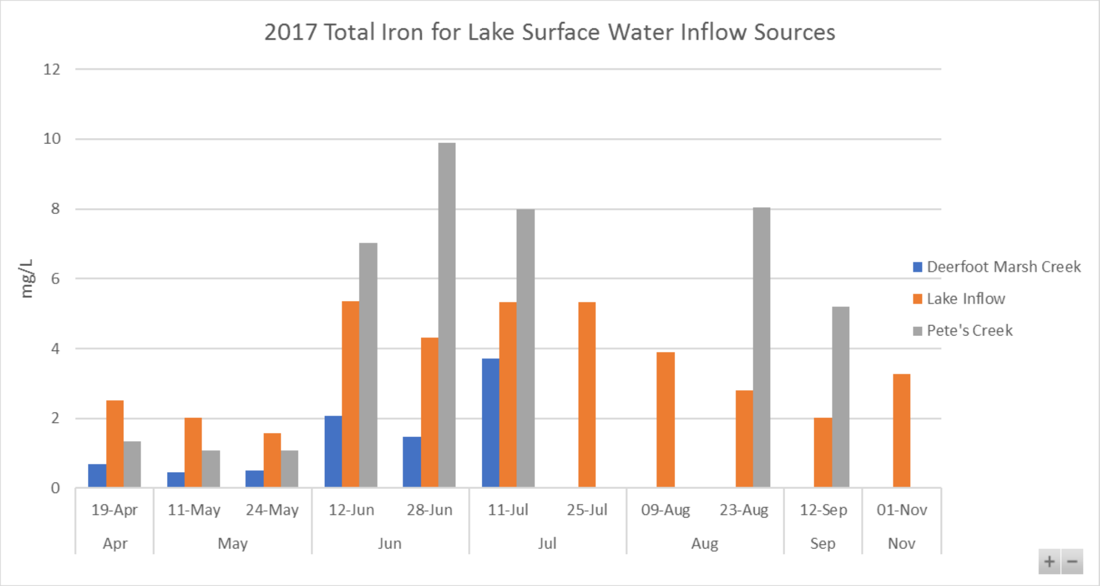


Figure 24. 2017 Total Iron of Lake Surface Water Inflow Sources
2017 total iron of the primary inflow to Dead Pike Lake and two intermittent streams, Deerfoot Marsh and Pete's Creek.

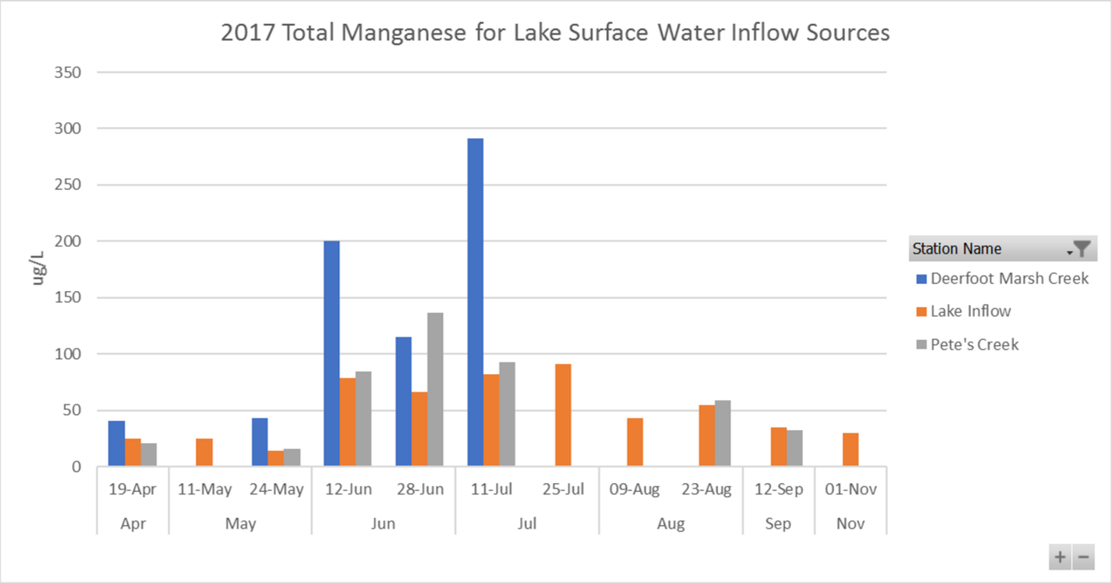


Figure 25. 2017 Total Manganese for Lake Surface Water Inflow Sources
2017 total manganese concentrations of the primary inflow to Dead Pike Lake and two intermittent streams, Deerfoot Marsh and Pete's Creek.

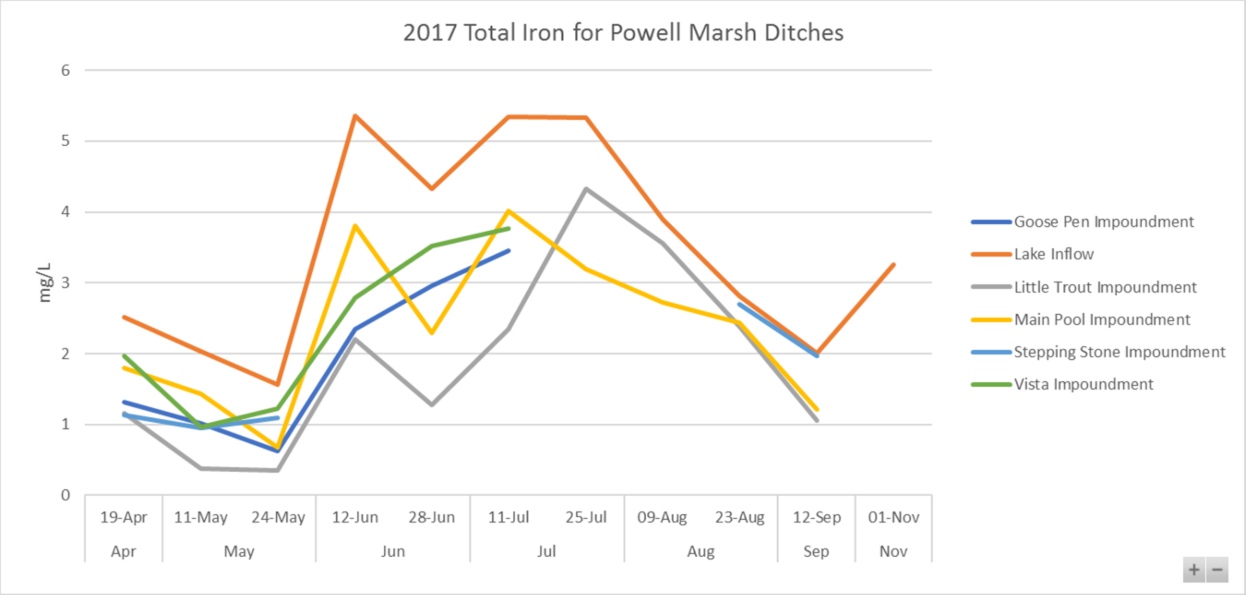


Figure 26. 2017 Total Iron at Powell Marsh Ditches
2017 total iron concentrations at the control structures of Powell Marsh ditches and including the primary lake inflow at Powell Road.

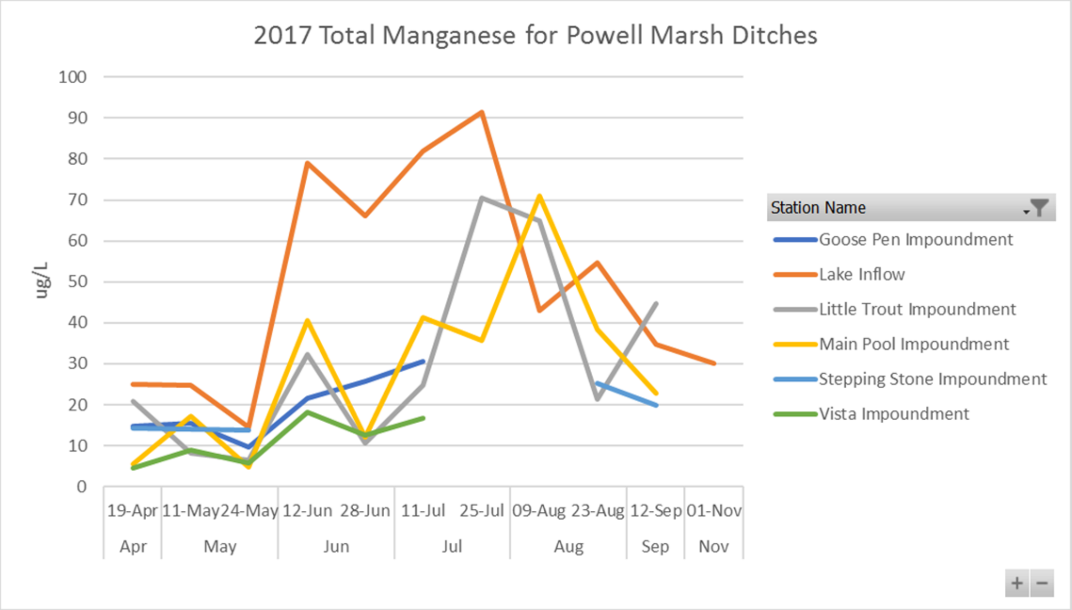


Figure 27. 2017 Total Manganese for Powell Marsh Ditches
2017 total manganese concentrations at the control structures of Powell Marsh ditches and including the primary lake inflow at Powell Road.

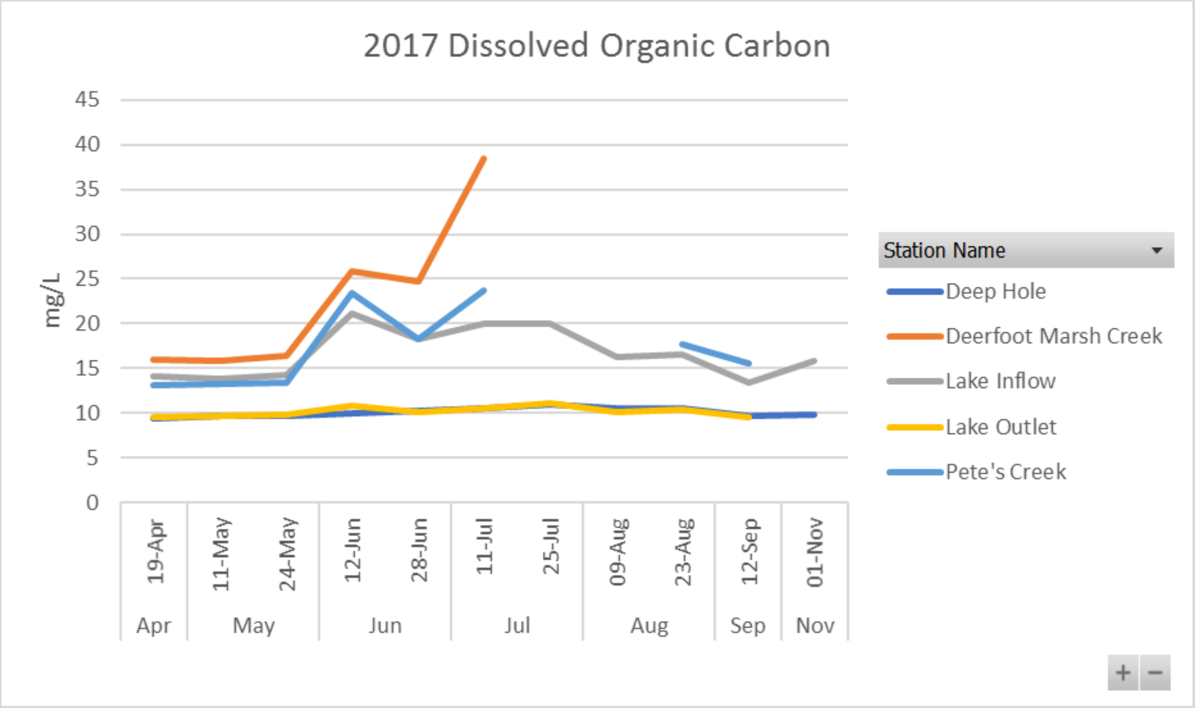


Figure 28. Dissolved Organic Carbon at Lake Surface Water Inflow Sources
Dissolved organic carbon concentrations at five locations collected during flowing water conditions.

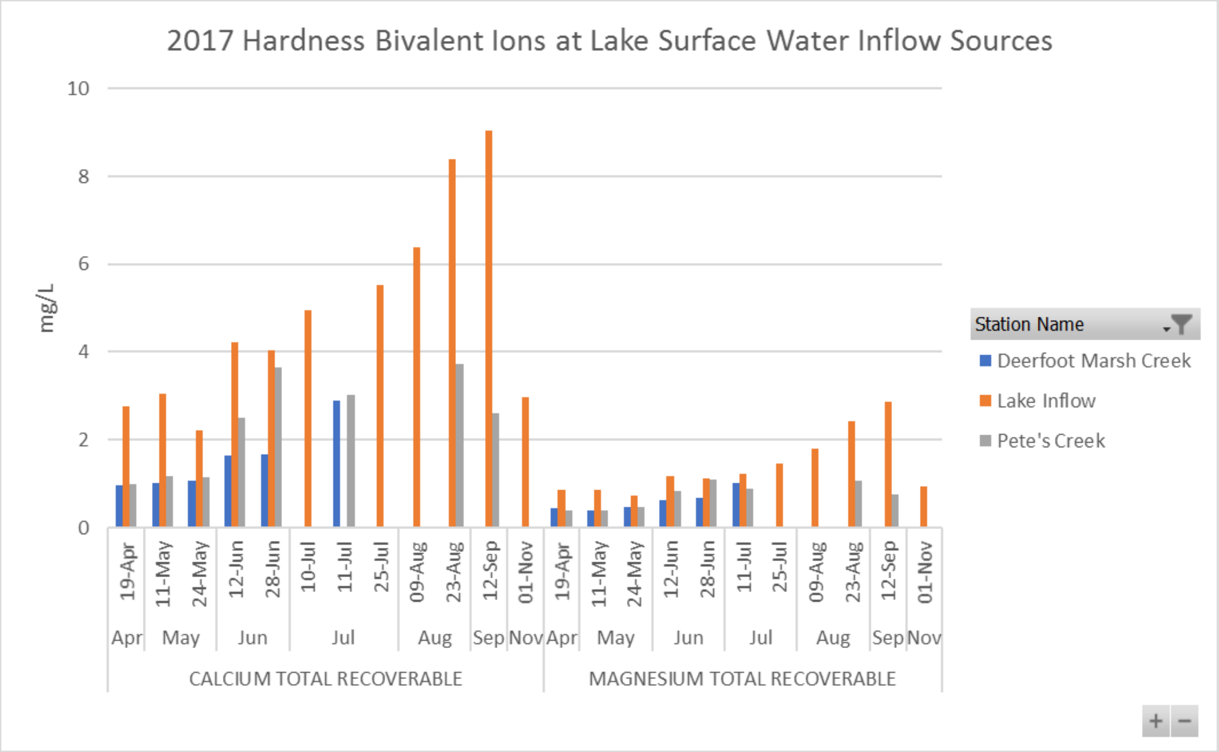


Figure 29. Calcium and Magnesium of Lake Surface Water Inflow Sources
2017 calcium (left) and magnesium concentration in the surface water inflow sources to Dead Pike Lake, April through Nov. Samples collected during surface water flows.

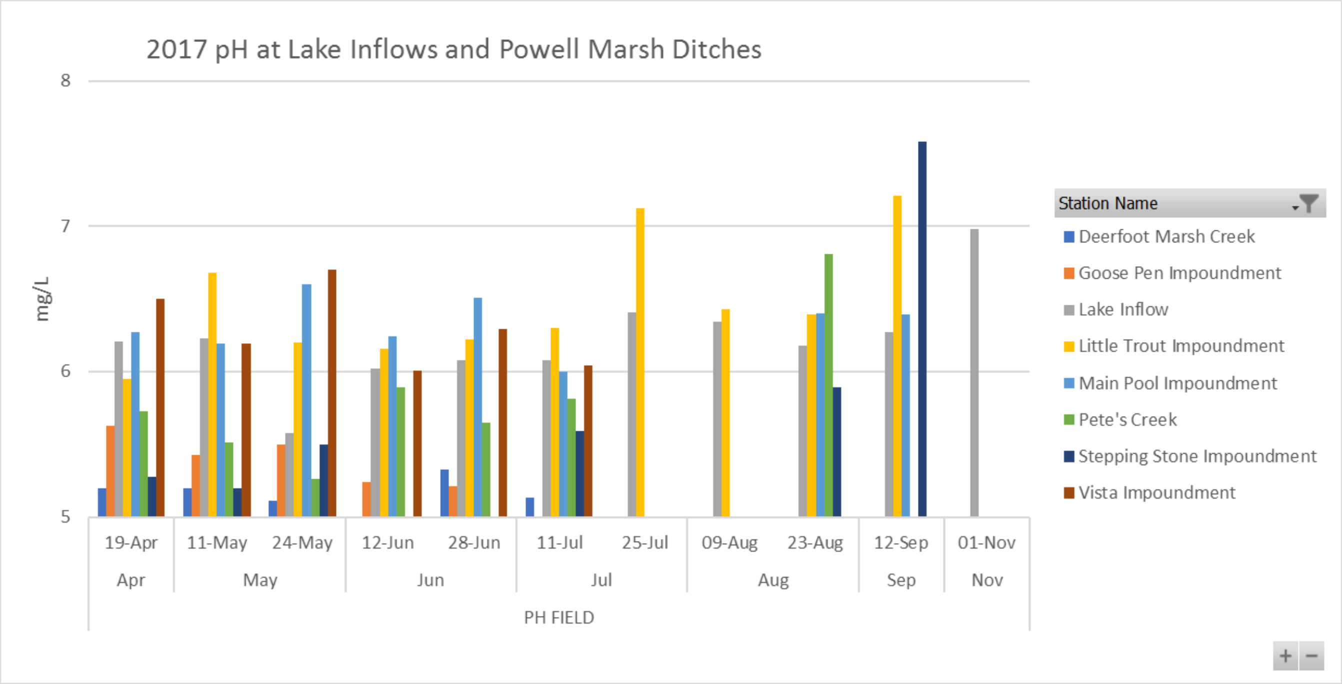


Figure 30. 2017 pH of Lake Inflows and Powell Marsh Ditches
2017 field pH readings from the lake inflows including Deerfoot Marsh Creek, Pete's Creek and the Lake Inflow from Powell Marsh and from Powell Marsh Ditches when there was flow through the outlet structures.

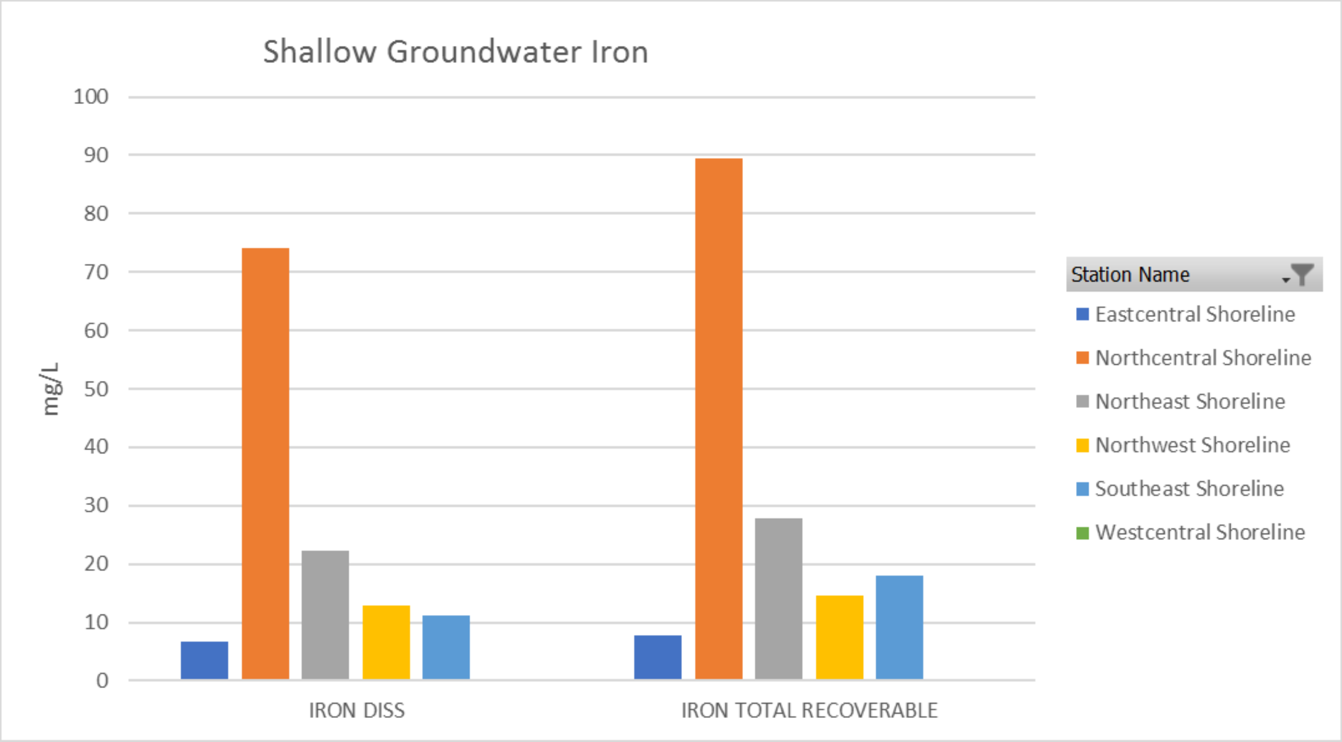


Figure 31. Total Iron in Shallow Groundwater Around Dead Pike Lake
Total iron concentrations in shallow groundwater sampled with a sipper around Dead Pike Lake. Samples were collected between 16 cm and 30 cm below ground surface and landward and within 2-3 meters of the water's edge.

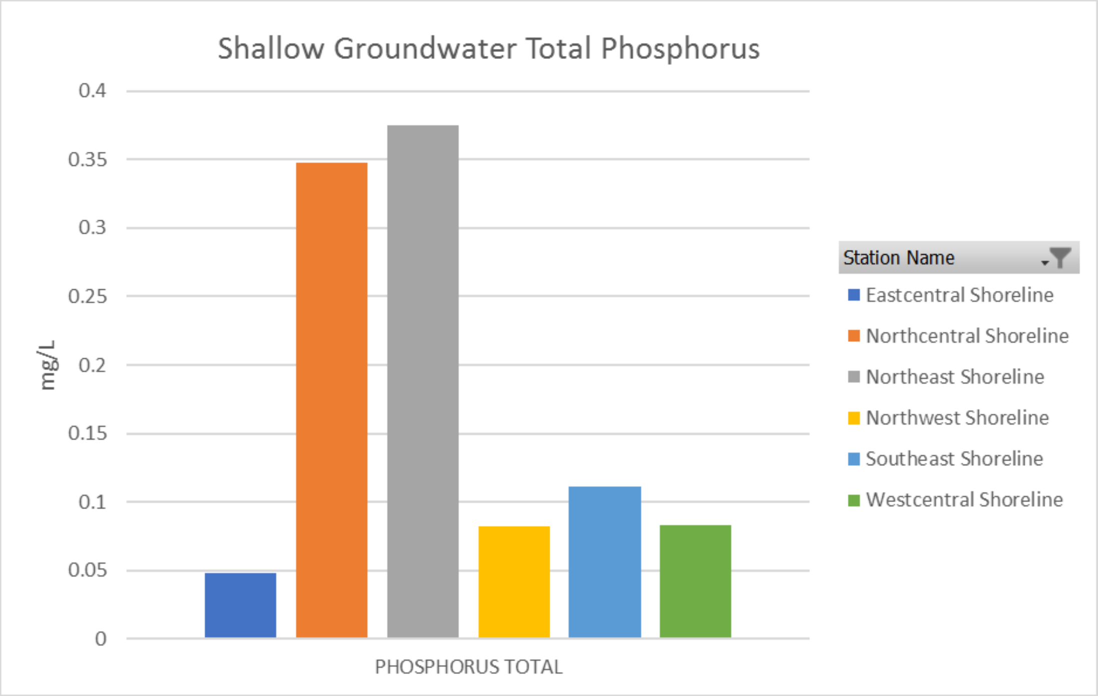


Figure 32. Shallow Groundwater Total Phosphorus
Shallow groundwater sample results for total phosphorus from landward sites within 3 meters of the water's edge around the circumference of Dead Pike Lake.

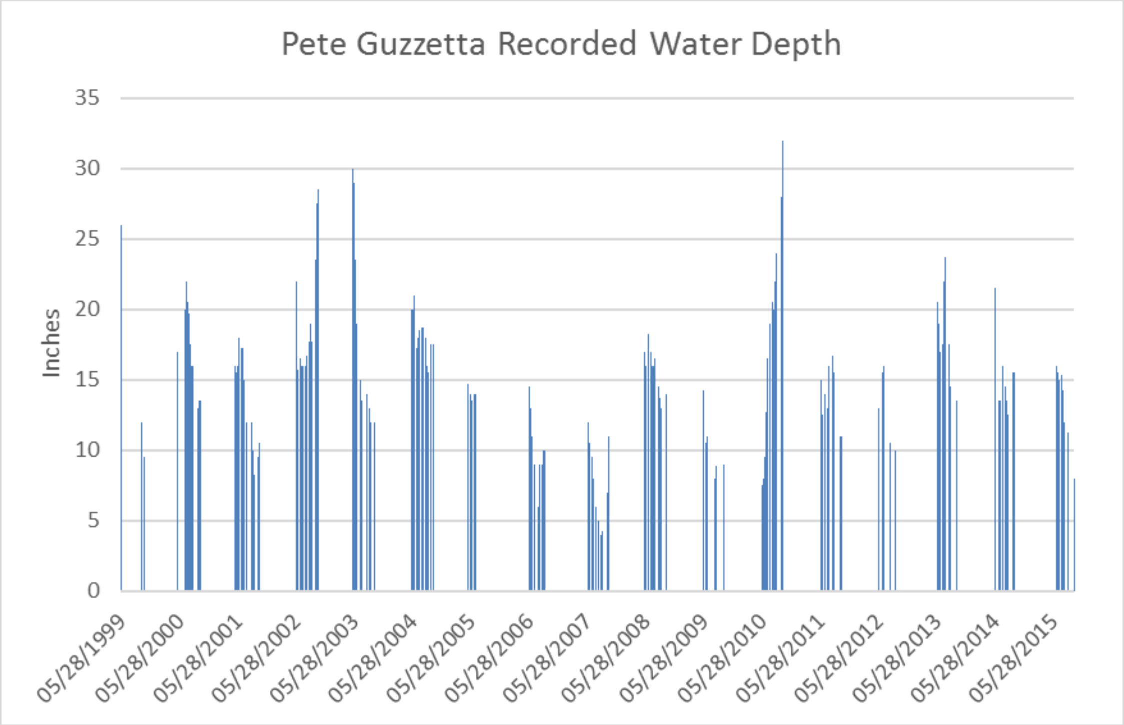
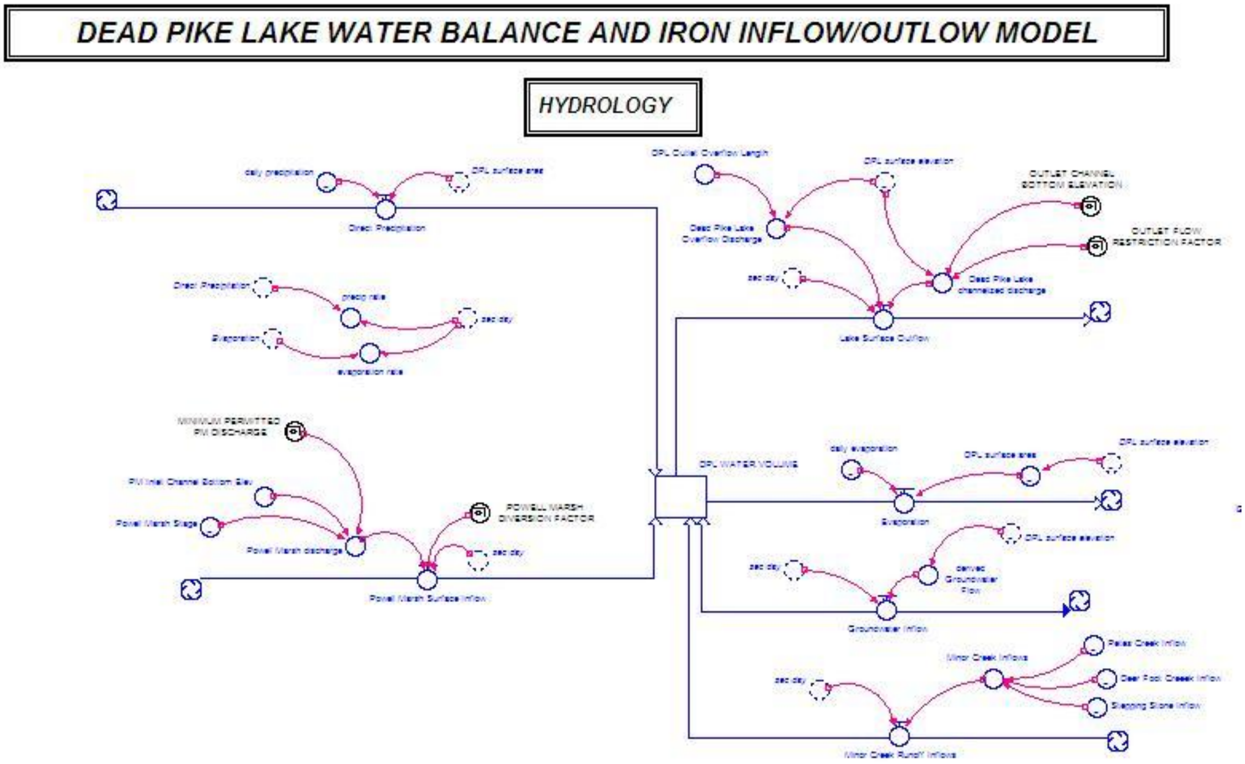
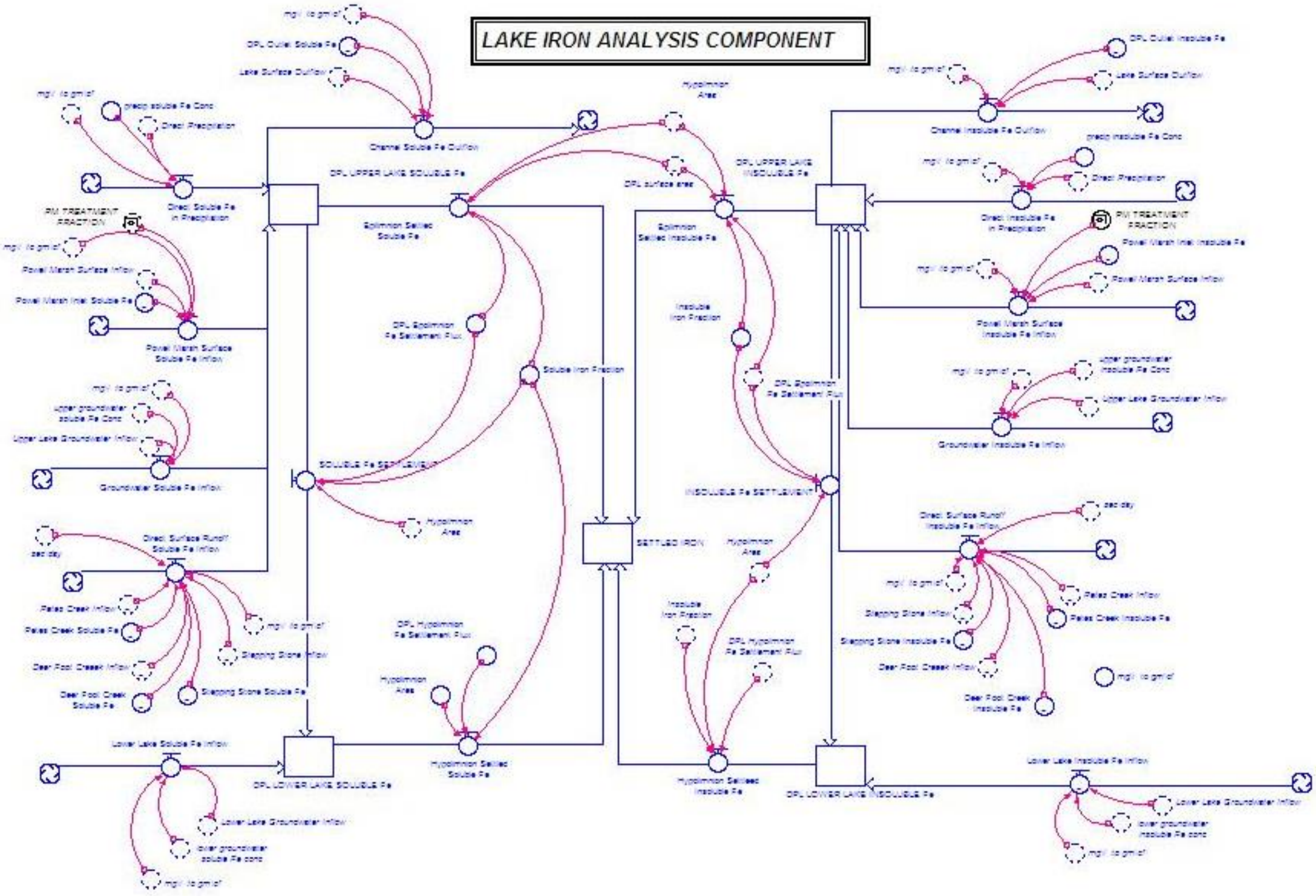


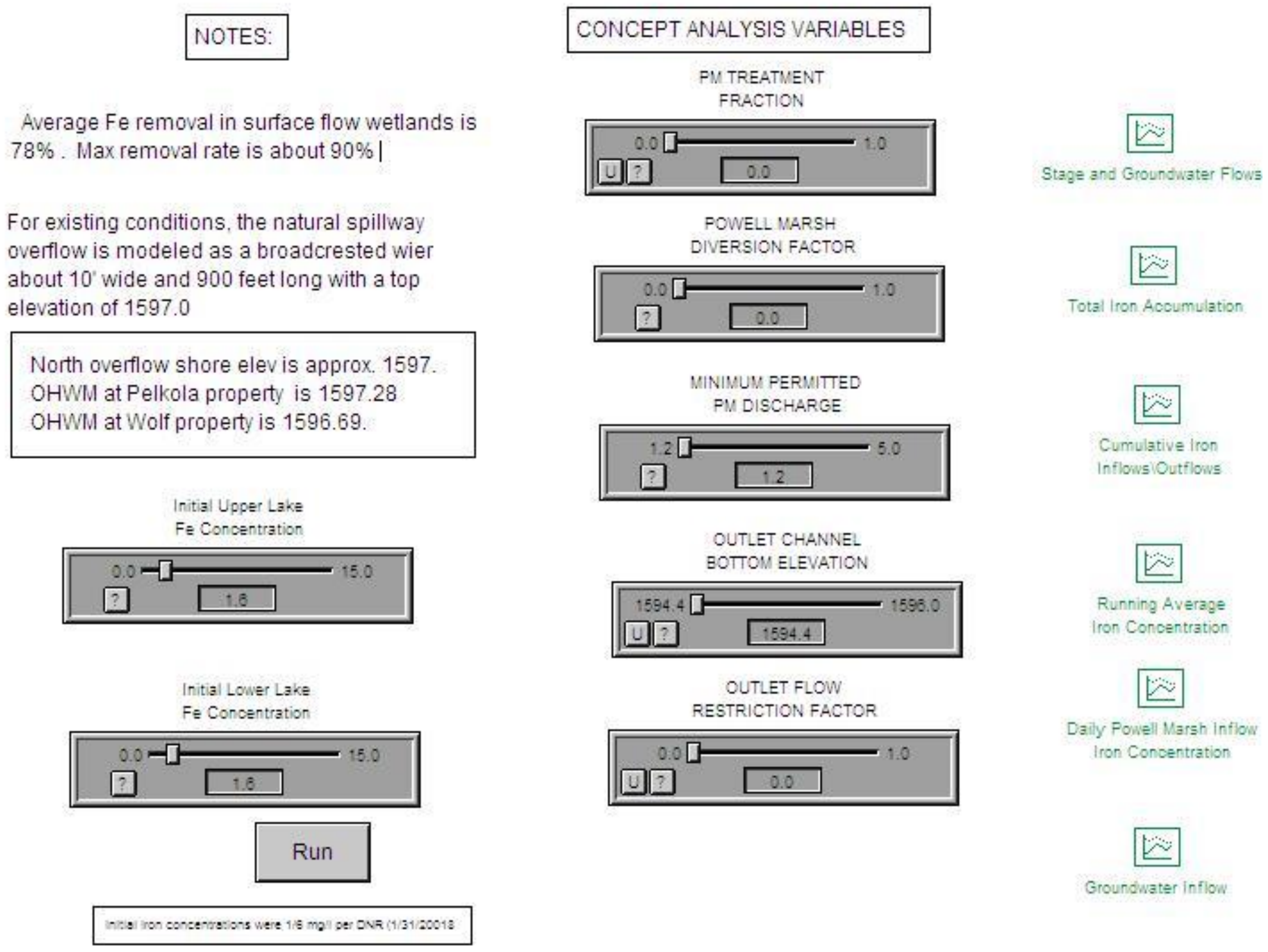
Figure 33. Dead Pike Lake Water Levels
Dead Pike Lake recorded water depths at the end of Pete Guzzetta' 90-foot pier installed at the same location on his property on the southeast shoreline of the lake.

15 Appendices

15.1 STELLA Modeling Construct and Represented Output




LAKE IRON ANALYSIS COMPONENT
mg/l to gm/cf
DPL Outlet Soluble Fe
Lake Surface Outflow
precip soluble Fe Conc
Direct Precipitation
Channel Soluble Fe Outflow
DPL UPPER LAKE SOLUBLE Fe
Direct Soluble Fe in Precipitation
PM TREATMENT FRACTION
Powell Marsh Surface Inflow
Powell Marsh Inlet Soluble Fe
Powell Marsh Surface Soluble Fe Inflow
Epilimnion Settled Soluble Fe
DPL Epilimnion Fe Settlement Flux
Soluble Iron Fraction
upper groundwater soluble Fe Conc
Upper Lake Groundwater Inflow
Groundwater Soluble Fe Inflow
SOLUBLE Fe SETTLEMENT
Hypolimnion Area
sec day
Direct Surface Runoff Soluble Fe Inflow
Pelas Creek Inflow
Pelas Creek Soluble Fe
Stepping Stone Inflow
Deer Foot Creek Inflow
Deer Foot Creek Soluble Fe
Stepping Stone Soluble Fe
DPL Hypolimnion Fe Settlement Flux
SETTLED IRON
Lower Lake Soluble Fe Inflow
DPL LOWER LAKE SOLUBLE Fe
Hypolimnion Settled Soluble Fe
Lower Lake Groundwater Inflow
lower groundwater soluble Fe conc
DPL surface area
DPL UPPER LAKE INSOLUBLE Fe
Epilimnion Settled Insoluble Fe
Insoluble Iron Fraction
INSOLUBLE Fe SETTLEMENT
DPL Outlet Insoluble Fe
Channel Insoluble Fe Outflow
precip insoluble Fe Conc
Direct Insoluble Fe in Precipitation
Powell Marsh Inlet Insoluble Fe
Powell Marsh Surface Insoluble Fe Inflow
upper groundwater insoluble Fe Conc
Groundwater Insoluble Fe Inflow
Direct Surface Runoff Insoluble Fe Inflow
Pelas Creek Insoluble Fe
Stepping Stone Insoluble Fe
Deer Foot Creek Insoluble Fe
Hypolimnion Settled Insoluble Fe
DPL LOWER LAKE INSOLUBLE Fe
Lower Lake Insoluble Fe Inflow
lower groundwater insoluble Fe conc



NOTES:

Average Fe removal in surface flow wetlands is 78% . Max removal rate is about 90%

For existing conditions, the natural spillway overflow is modeled as a broadcrested wier about 10' wide and 900 feet long with a top elevation of 1597.0

North overflow shore elev is approx. 1597.
OHWM at Pelkola property is 1597.28
OHWM at Wolf property is 1596.69.

Initial Upper Lake Fe Concentration: 0.0 – 15.0; 1.6

Initial Lower Lake Fe Concentration: 0.0 – 15.0; 1.6

Initial iron concentrations were 1/6 mg/l per DNR (1/31/20018

CONCEPT ANALYSIS VARIABLES

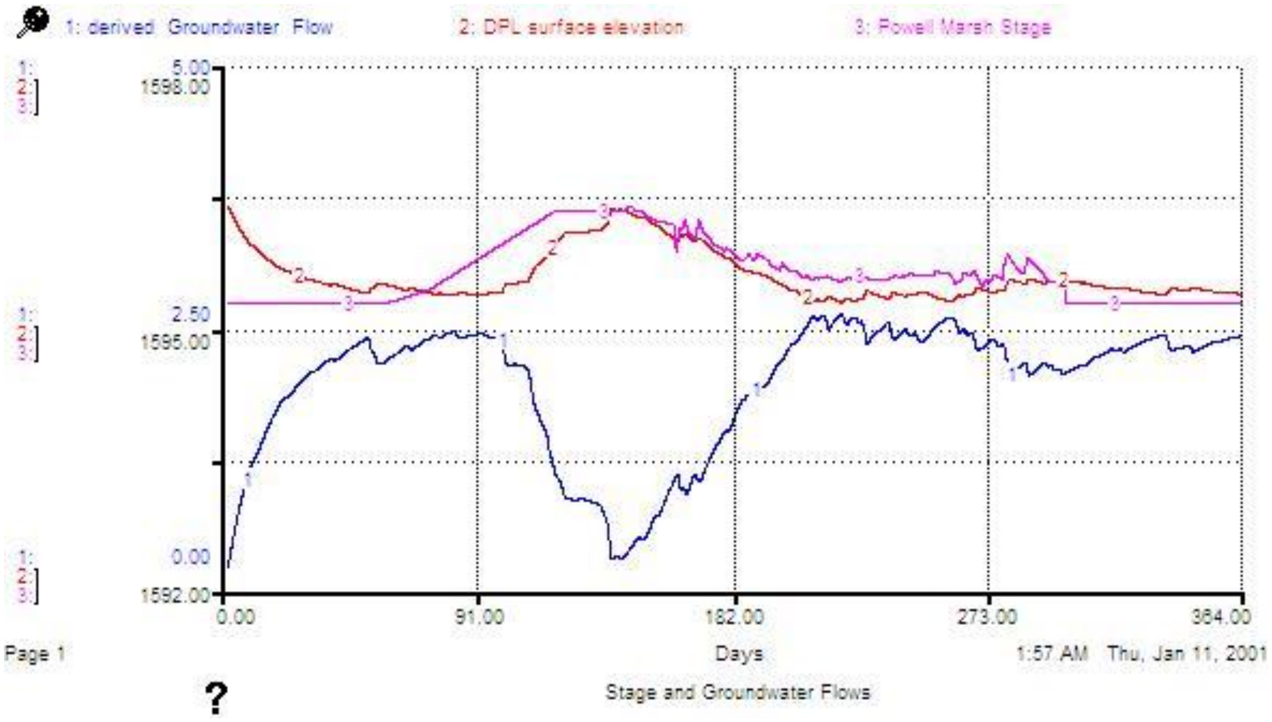
PM TREATMENT FRACTION: 0.0 – 1.0; 0.0

POWELL MARSH DIVERSION FACTOR: 0.0 – 1.0; 0.0

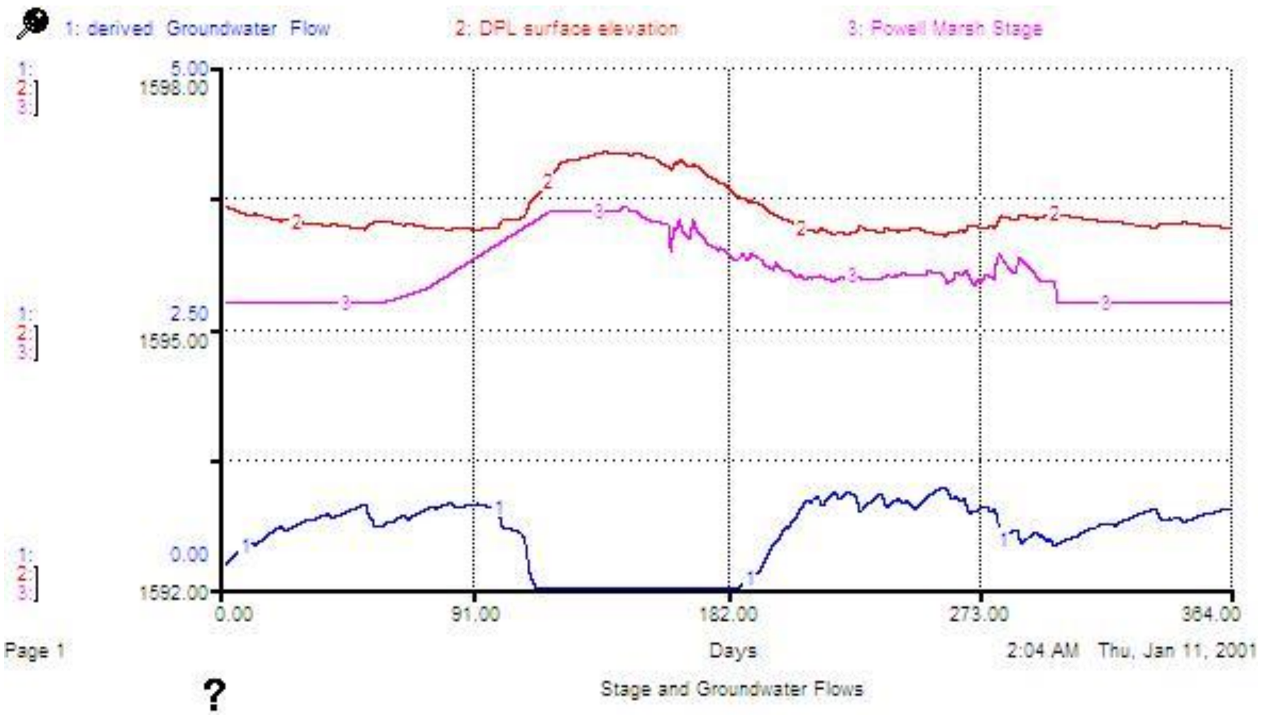
MINIMUM PERMITTED PM DISCHARGE: 1.2 – 5.0; 1.2

OUTLET CHANNEL BOTTOM ELEVATION: 1594.4 – 1596.0; 1594.4

OUTLET FLOW RESTRICTION FACTOR: 0.0 – 1.0; 0.0



STELLA GRAPH 1. Dead Pike Lake surface water elevations and derived groundwater inflows starting in April 2017. The Red line (#2) is the surface water elevation of Dead Pike Lake. The Purple line (#3) is the surface water elevation of the Powell Marsh discharge ditch at Powell Road. The Blue line (#1) is the derived groundwater inflow.



STELLA GRAPH 2. This graph models the difference from GRAPH 1 with a 1 foot increase in the elevation of the outlet at Dead Pike Lake Dead Pike Lake surface water elevations and derived groundwater inflows starting in April 2017. The Red line (#2) is the surface water elevation of Dead Pike Lake. The Purple line (#3) is the surface water elevation of the Powell Marsh discharge ditch at Powell Road. The Blue line (#1) is the derived groundwater inflow.

STELLA GRAPH 3. The total accumulated iron load to Dead Pike Lake starting in April 2017. The Blue line (#1) represents the iron groundwater load. The Red line (#2) represents the iron load from Pete's and Deerfoot Marsh creeks. The Purple line (#3) represents the iron load from Powell Marsh. The Green Line (#4) represents the iron load leaving Dead Pike Lake.

STELLA GRAPH 4. This graph models the difference from GRAPH 3 with a 1 foot increase in the elevation of the Dead Pike Lake outlet stream and a wetland biofilter system in Powell Marsh. The Blue line (#1) represents the iron groundwater load. The Red line (#2) represents the iron load from Pete's and Deerfoot Marsh creeks. The Purple line (#3) represents the iron load from Powell Marsh. The Green Line (#4) represents the iron load leaving Dead Pike Lake.

15.2 Wisconsin Lake Modeling Suite Scenarios

Date: 02/05/2018   Scenario: 1

Lake Id: Dead Pike Lake Default Watershed

Hydrologic and Morphometric Data

```
Tributary Drainage Area: 3466.2 acre
Total Unit Runoff: 14 in.
Annual Runoff Volume: 4043.9 acre-ft
Lake Surface Area <As>: 297 acres
Lake Volume <V>: 7580 acre-ft
Lake Mean Depth <z>: 25.5 ft
Precipitation - Evaporation: 5.5 in.
Hydraulic Loading: 4180.0 acre-ft/year
Areal Water Load <qs>: 14.1 ft/year
Lake Flushing Rate <p>: 0.55 1/year
 Water Residence Time: 1.81 year
Observed spring overturn total phosphorus (SPO): 0.0 mg/m^3
Observed growing season mean phosphorus (GSM): 17 mg/m^3
% NPS Change: 0%
% PS Change: 0%
```

```
NON-POINT SOURCE DATA
      Land Use        Acre        Low    Most Likely    High    Loading %   Low    Most Likely    High
                      (ac)     |---- Loading (kg/ha-year) ----|            |-----  Loading (kg/year) ----|
Row Crop AG             0.0       0.50       1.00       3.00        0.0          0          0          0
Mixed AG                1.3       0.30       0.80       1.40        0.3          0          0          1
Pasture/Grass          11.5       0.10       0.30       0.50        0.9          0          1          2
HD Urban (1/8 Ac)       0.0       1.00       1.50       2.00        0.0          0          0          0
MD Urban (1/4 Ac)       0.0       0.30       0.50       0.80        0.0          0          0          0
Rural Res (>1 Ac)       0.0       0.05       0.10       0.25        0.0          0          0          0
Wetlands             1439.3       0.10       0.10       0.10       37.6         58         58         58
Forest               1589.8       0.05       0.09       0.18       37.4         32         58        116
Open water            424.3                                         0.0          0          0          0
Lake Surface          297.0       0.10       0.30       1.00       23.3         12         36        120
```

POINT SOURCE DATA

Point Sources	Water Load (m^3/year)	Low (kg/year)	Most Likely (kg/year)	High (kg/year)	Loading % _

SEPTIC TANK DATA

Description	Low	Most Likely	High	Loading %
Septic Tank Output (kg/capita-year)	0.3	0.5	0.8	
# capita-years	15			
% Phosphorus Retained by Soil	98	90	80	
Septic Tank Loading (kg/year)	0.09	0.75	2.40	0.5

TOTALS DATA

Description	Low	Most Likely	High	Loading %
Total Loading (lb)	227.4	341.2	660.8	100.0
Total Loading (kg)	103.2	154.8	299.7	100.0
Areal Loading (lb/ac-year)	0.77	1.15	2.22	0.0
Areal Loading (mg/m^2-year)	85.82	128.78	249.37	0.0
Total PS Loading (lb)	0.0	0.0	0.0	0.0
Total PS Loading (kg)	0.0	0.0	0.0	0.0
Total NPS Loading (lb)	200.7	260.1	390.5	99.5
Total NPS Loading (kg)	91.0	118.0	177.1	99.5

Phosphorus Prediction and Uncertainty Analysis Module

Date: 02/05/2018   Scenario: 5
Observed spring overturn total phosphorus (SPO): 0.0 mg/m^3
Observed growing season mean phosphorus (GSM): 17.0 mg/m^3
Back calculation for SPO total phosphorus: 0.0 mg/m^3
Back calculation GSM phosphorus: **17 mg/m^3**
% Confidence Range: 70%
Nurenberg Model Input - Est. Gross Int. Loading: 0 kg

Lake Phosphorus Model	Low	Most Likely	High	Predicted	% Dif.
	Total P	Total P	Total P	-Observed	

	(mg/m^3)	(mg/m^3)	(mg/m^3)	(mg/m^3)	
Walker, 1987 Reservoir	10	14	28	-3	-18
Canfield-Bachmann, 1981 Natural Lake	11	15	24	-2	-12
Canfield-Bachmann, 1981 Artificial Lake	11	14	22	-3	-18
Rechow, 1979 General	5	8	15	-9	-53
Rechow, 1977 Anoxic	14	21	40	4	24
Rechow, 1977 water load<50m/year	7	10	20	-7	-41
Rechow, 1977 water load>50m/year	N/A	N/A	N/A	N/A	N/A
Walker, 1977 General	N/A	N/A	N/A	N/A	N/A
Vollenweider, 1982 Combined OECD	9	13	22	5	59
Dillon-Rigler-Kirchner	N/A	N/A	N/A	N/A	N/A
Vollenweider, 1982 Shallow Lake/Res.	7	10	17	2	24
Larsen-Mercier, 1976	N/A	N/A	N/A	N/A	N/A
Nurnberg, 1984 Oxic	7	10	19	-7	-41

Lake Phosphorus Model	Confidence Lower Bound	Confidence Upper Bound	Parameter Fit?	Back Calculation (kg/year)	Model Type
Walker, 1987 Reservoir	9	24	FIT	183	GSM
Canfield-Bachmann, 1981 Natural Lake	5	43	FIT	**177**	**GSM**
Canfield-Bachmann, 1981 Artificial Lake	4	40	FIT	181	GSM
Rechow, 1979 General	5	13	FIT	342	GSM
Rechow, 1977 Anoxic	14	35	FIT	126	GSM
Rechow, 1977 water load<50m/year	6	17	FIT	258	GSM
Rechow, 1977 water load>50m/year	N/A	N/A	N/A	N/A	N/A
Walker, 1977 General	N/A	N/A	N/A	N/A	N/A
Vollenweider, 1982 Combined OECD	7	23	FIT	225	ANN
Dillon-Rigler-Kirchner	N/A	N/A	N/A	N/A	N/A
Vollenweider, 1982 Shallow Lake/Res.	5	18	FIT	299	ANN
Larsen-Mercier, 1976	N/A	N/A	N/A	N/A	N/A
Nurnberg, 1984 Oxic	6	18	FIT	268	ANN

```
Phosphorus Prediction and Uncertainty Analysis Module
Date: 02/05/2018
Observed spring overturn total phosphorus (SPO): 0.0 mg/m^3
Observed growing season mean phosphorus (GSM): 17.0 mg/m^3
Back calculation for SPO total phosphorus: 0.0 mg/m^3
Back calculation GSM phosphorus: 15 mg/m^3
% Confidence Range: 70%
Nurenberg Model Input - Est. Gross Int. Loading: 0 kg

           Lake Phosphorus Model              Low   Most Likely   High     Predicted  % Dif.
                                            Total P   Total P    Total P   -Observed
                                            (mg/m^3) (mg/m^3)   (mg/m^3)   (mg/m^3)
 Walker, 1987 Reservoir                         10       14         28         -3       -18
 Canfield-Bachmann, 1981 Natural Lake           11       15         24         -2       -12
 Canfield-Bachmann, 1981 Artificial Lake        11       14         22         -3       -18
 Rechow, 1979 General                            5        8         15         -9       -53
 Rechow, 1977 Anoxic                            14       21         40          4        24
 Rechow, 1977 water load<50m/year                7       10         20         -7       -41
 Rechow, 1977 water load>50m/year              N/A      N/A        N/A        N/A       N/A
 Walker, 1977 General                          N/A      N/A        N/A        N/A       N/A
 Vollenweider, 1982 Combined OECD                9       13         22          5        59
 Dillon-Rigler-Kirchner                        N/A      N/A        N/A        N/A       N/A
 Vollenweider, 1982 Shallow Lake/Res.            7       10         17          2        24
 Larsen-Mercier, 1976                          N/A      N/A        N/A        N/A       N/A
 Nurnberg, 1984 Oxic                             7       10         19         -7       -41

         Lake Phosphorus Model          Confidence Confidence  Parameter    Back       Model
                                           Lower      Upper      Fit?   Calculation   Type
                                           Bound      Bound              (kg/year)
 Walker, 1987 Reservoir                        9         24         FIT       161       GSM
 Canfield-Bachmann, 1981 Natural Lake          5         43         FIT       149       GSM
 Canfield-Bachmann, 1981 Artificial Lake       4         40         FIT       150       GSM
 Rechow, 1979 General                          5         13         FIT       302       GSM
 Rechow, 1977 Anoxic                          14         35         FIT       111       GSM
 Rechow, 1977 water load<50m/year              6         17         FIT       227       GSM
 Rechow, 1977 water load>50m/year            N/A        N/A         N/A       N/A       N/A
 Walker, 1977 General                        N/A        N/A         N/A       N/A       N/A
 Vollenweider, 1982 Combined OECD              7         23         FIT       193       ANN
 Dillon-Rigler-Kirchner                      N/A        N/A         N/A       N/A       N/A
 Vollenweider, 1982 Shallow Lake/Res.          5         18         FIT       259       ANN
 Larsen-Mercier, 1976                        N/A        N/A         N/A       N/A       N/A
 Nurnberg, 1984 Oxic                           6         18         FIT       236       ANN
```

15.3 Lake Technical Team Comments and Responses

Dr. Carl Watras, DNR Research Scientist

Brief Comments on Dead Pike Lake Management Plan of 26 February 2018

1. Water Budgets.

Problem: Water budgets based on measured surface flows (Qi and Qo) and water level (ΔS) contain three unknowns: groundwater inflow (Gi), groundwater outflow(Go) and evaporation(E). Any solution would necessarily have high uncertainty, potentially explaining the large difference between existing budgets (Krohelski etal 2002;, Barr 2011; and AES 2017).

Remedy. A sensor network could be installed to continually monitor lake stage, stream stage, precipitation, evaporation, and the nearshore water table, thereby tightening the water budget. Estimates of net seepage would be better constrained; and since Gi is purportedly a major contributor of the Fe, DOC and P entering the lake, confidence in the solute budgets and a remediation strategy would be improved.

Response: Supplementing the water budget with site specific measurements of precipitation and evaporation, combined with additional surface water and groundwater data would improve the accuracy of the water budget estimates. Similar projects conducted by the USGS range between $100,000 and $200,000 (Dale Robertson, pers. comm). No comparable resources have been allocated toward Dead Pike Lake; however, the project would benefit from additional evaluation monitoring in partnership with the UW system or other partners.

The plan highlights the substantial differences between water budget developed in 2002 and 2010 and explains the rationale for these differences noted by Garrison (2012). However, the both 2017 independently developed annual water budgets – one developed using surface water information and the second developed with the groundwater model GFlow – are similar enough to sufficiently develop and evaluate lake management actions.

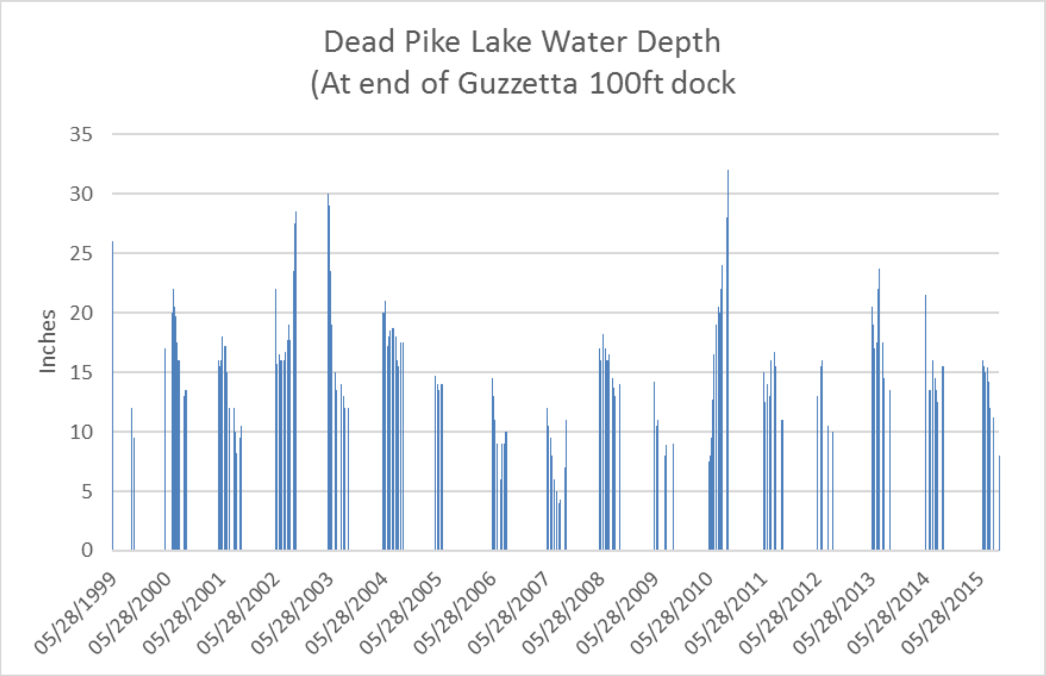
2. Damming the outflow.

Problem. The proposal to raise the bottom of the outflow stream assumes that a higher average lake stage will reduce groundwater inflow and DOC-P-Fe inputs. In terms of a simple water budget this assumption makes sense. However, it is not consistent with empirical data for the lake. Water clarity in DPL is actually highest when the lake stage is low (Fig 1A). This is likely because the surrounding water table is more dynamic than the lake surface. In other words, when the lake level is low, the water table is even lower (and the converse) due to the lower specific yield of soils. Figure 1B indicates that high water clarity during low water years may be partly due to phytoplankton dynamics (or vice versa). The phosphorous signal is unclear (Fig. 1C)

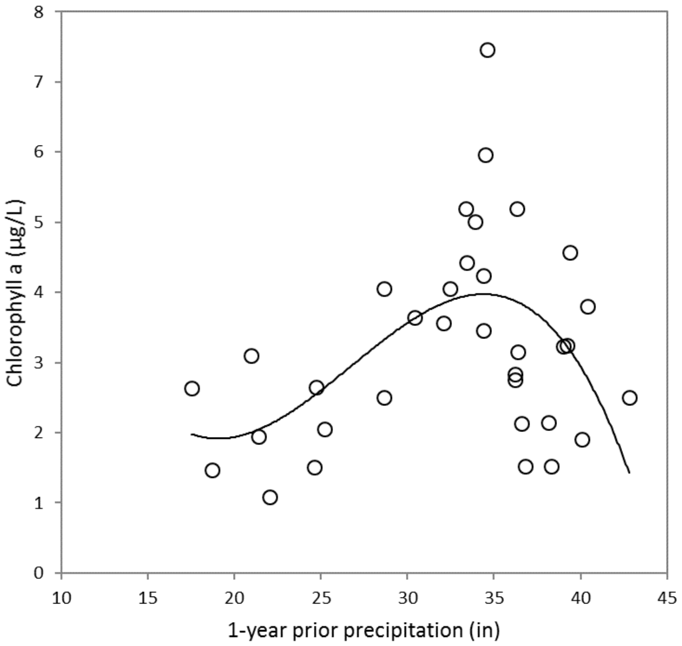
Remedy. Perhaps reconsider the proposed outflow dam. Use sensor network data to better constrain the relationship between S and Gi (especially during precipitation events) and the relationship between Gi and water clarity. Note that if an outflow dam floods nearshore wetland or other vegetated riparian areas, increased methylmercury production is a likely consequence due to the well-known "reservoir effect."

Response: During drought conditions both surface water and groundwater inputs are likely reduced and water clarity (Secchi disk) is "decidedly correlated" with precipitation (p. 23). The plan notes that over the years, the Dead Pike Lake water levels are affected by beaver dams and man-made alterations at the outlet stream such that lake surface water elevations (Appendix 15.3, Figure 1) do not necessarily align with regional water levels patterns (e.g. 2010 shows regionally low water while DPL experienced high water). Phytoplankton (i.e. chlorophyll-a) peaks during moderately wet conditions, then decreases during very wet conditions, perhaps due to light limitation due to increased organic matter and associated increased color

(Matt Diebel, pers. comm., Appendix 15.3, Figure 2). An appropriate time to examine the potential methylmercury production would be after the conceptual design plans for the outlet control structure and during permitting in a manner consistent with how the Department evaluates other proposed water level manipulations on impoundments.



Appendix 15.3 Figure 1



Appendix 15.3 Figure 2

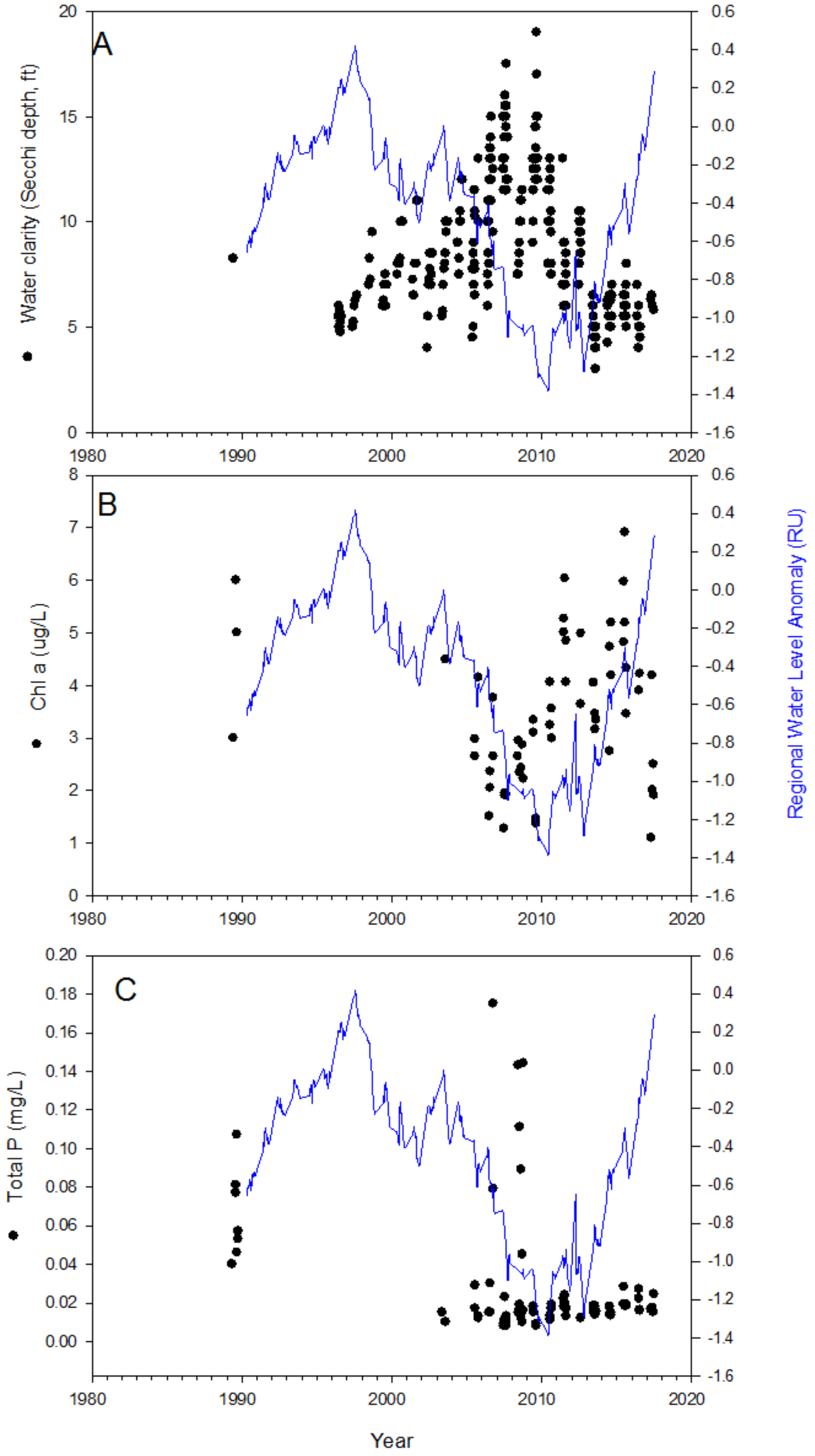
3. Liming the lake.

Problem. The proposal to lime DPL is based on the assumption that adding calcium will favor the formation of Ca-DOC-P-Fe aggregates that will sink faster than the existing aggregates. Although Iron-lime sludge conditioning is used in some wastewater applications to dewater sludge, its use in natural waters having high DOC and Fe is largely untested. There is a lack of empirical data on comparative sinking rates for the two types of colloid, especially in a deep, well-mixed epilimnion. Several questions arise, for example:

- Could the Ca-enriched colloids be even more problematic when driven ashore by wind?
- How often would lime need to be re-applied?
- Will plankton be adsorbed to Ca-enriched colloids, altering the food web?
- How will the acid-base status of the lake actually be affected

Remedy. More tests needed.

Response: The plan has recommended liming as a one-time application to increase the rate of iron and phosphorus precipitation and some preliminary "column" testing has been conducted by AES. The plan provides some "rough" estimates for the addition of 200 metric tons; However, additional testing and empirical data collection are anticipated as part of the permitting review for the application of lime to the system necessary to answer the questions above.



A
Water clarity (Secchi depth, ft)
20
15
10
5
0
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
1980
1990
2000
2010
2020
B
Chl a (ug/L)
8
7
6
5
4
3
2
1
0
Regional Water Level Anomaly (RU)
C
Total P (mg/L)
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Year

Dr. Susan Knight, Interim Director, Trout Lake Station, UW-Madison Center for Limnology

p.v. (5?) Where did water quality goal of reducing Fe inflow from 3.5 to 1.49 come from? Why reduce by 74%? This seems to be a purely aesthetic goal to reduce the floc, with no grounding in any ecological recognition of a problem.

Response: The iron surface water inflow goal of 1.49 mg/L is set as background conditions from an un-ditched marsh watershed and is derived from the average iron concentration from Deerfoot Marsh Creek that drains into Dead Pike Lake on the north. This description has been added to page 9. The 1.0 mg/L iron goal is set to meet recommended USEPA water quality standards.

The plan states the percent iron load reductions for are based primarily upon what reductions can be obtain by the management actions. The Fe groundwater load reduction goal of 41% to 72% (18,500 kg/yr to 33,800 kg/yr) is based upon projected Fe loading reductions from incremental increases in minimum lake levels. The plan provides a thorough literature review of the ecological impacts of iron floc formation on benthic aquatic organisms and both aesthetic and recreational impacts (pg. 36)

p.v. (5?) "Well-developed and peer reviewed lake response models that predict reductions in-lake iron (Fe) concentrations or iron floc densities in response to load reduction are not available. The STELLA model provides a coarse estimate of the relationship between Fe loading and in-lake concentrations but not for iron floc accumulations." There is no information on how any of these management alterations will affect the floc.

Response: As noted above, the plan states the tools to predict how reductions in the surface water and groundwater load to the Fe load will affect the abundance of floc do not exist (pg. 10). However, chemistry and mass balance principles indicate that there should be a correlation between iron floc formation and iron loading. This is one of the primary reasons an adaptable management approach to implementation has been developed.

p.6. 80-90% of the iron comes from the groundwater, and is not due to human influences. It is an iron-rich region, and is a characteristic of this watershed.

Response: This is correct and expressed in the estimated iron budgets in Table 17.

p.8. Where did the in-lake goals come from?

Response: The plan states that conventional water quality goals using predictive lake models are used for phosphorus and goals are set to meet state standards (pg. 7). The plan states that iron goals are set based upon what is achievable with the recommended management actions since lake response models for iron are not available (pg. 8) as noted above.

p.8. Who established the 15mg/l 2-story fishery threshold? The TP levels are barely above that recommended for two-story fishery. What are the TP levels (mean, sd) for other 2-story lakes in WI? Do water quality experts within the WDNR agree DPL is impaired regarding TP to such a degree warranting these ecosystem-level manipulations? Why risk this healthy ecosystem with these drastic alterations?

Response: Revisions to Wisconsin's Phosphorus Water Quality Standards became effective on December 1, 2010. Section NR 102.06(4)(b)1. Wis. Adm. Code establishes a phosphorous water quality criterion of 15 μg/L for stratified, two-story fishery lakes. Additional guidance is published in the Wisconsin Consolidated Assessment and Listing Methodology (WDNR 2017b). Analyses of water quality from other 2-story lakes is beyond the scope of this management plan. Surveying other water quality experts is also beyond the scope of this management plan. The plan does not classify Dead Pike Lake as a healthy ecosystem based upon the *exceedance of a State WQS and the recreational, aesthetic and ecological impacts of iron floc.*

p.8. "Elevated iron (Fe) concentrations in Dead Pike Lake cause excessive iron floc and iron bacteria formation resulting in aesthetic impairments, potential toxicity and habitat degradation in shallow bays and nearshore areas of the lake." Who decided the iron floc was "excessive"? What organisms find the iron floc and iron bacteria potentially toxic? How is the habitat degraded? The plants do not seem to be suffering. Any indication that other benthic organisms are suffering? This is an aesthetic issue, not an ecological issue.

Response: The plan documents local lake residents and property owners' complaints about iron floc excessive iron floc densities for decades (pg. 7) and describe the economic impacts of poor water quality (pg. 39). The plan provides a literature based assessment of the ecological impacts of iron floc to benthic aquatic organism (pg. 36) and recognizing measuring insitu benthic impacts is difficult.

p.9. Where and when in the lake (% shoreline, location, how often) experiences the iron floc?

Response: No quantitative data is available for iron floc distribution and the authors are unaware of readily available iron floc monitoring protocols. A WDNR lake planning grant is funding the development of a pilot iron floc monitoring protocol in the summer of 2018.

p.12. If you elevate the water level, what will happen to the high quality emergent plants near the outlet?

Response: The plan recommends establishing a minimum lake water elevation 1 foot higher and estimates a reduction the annual water level fluctuation from 1 foot to 0.94 feet and increase the maximum water level 8.88 inches from 1596.31 to 1597.03 (pg. 11). Since change in lake level is within historic lake surface water level fluctuations (Appendix 15.3 Figure 1), the plan states the aquatic plant community is not expected to change (pg. 38).

p.13. What effect will the lime have on lake organisms, such as plants that use CO_2 as opposed to HCO_3, which will be more abundant with higher pH? How will benthic animals react to the liming?

Response: The plan has recommended liming as a one-time application to increase the rate of iron and phosphorus precipitation and some preliminary "column" testing has been conducted by AES. The plan provides some "rough" estimates for the addition of 200 metric tons; However, additional testing and empirical data collection are anticipated to derive the final dosing recommendation and will be required as part of the permitting review for the application of lime to the system. This additional information is needed to specifically answer the questions above.

p.13. Where is the Stepping Stone Impoundment? Is this the same as one or all of the Stepping Stone Lakes? I think it is east of the lake, and SE of the Stepping Stone Lakes, but Figure 7 is so difficult to read I am not sure.

Response: The figure was difficult to read and Figure 7 has been improved to more clearly show the locations of the Stepping Stone Impoundment and Stepping Stone Chain of Lakes.

p.13. There must be a list of pros and cons for each management suggestion, aside from the P and Fe reductions.

Response: Section 10.4 broadly covers the environmental impacts of the recommended management actions. Each finalized management actions will require State and Federal permitting which provide for the Integrated Analysis and procedures for public disclosure and environmental analysis. Collectively, the State permitting procedures will serve as the environmental analysis and include detailed analysis that evaluates *a proposed action effect on the human environment.*

p.13. Be scientific and consider one (if any) experimental alteration at a time. If you do all four, and there is any success, it will be impossible to know which one was effective.

Response: The plan outlines an adaptive management approach to implementing the least costly and least environmental intrusive actions first accompanied with evaluation monitoring, it will be important to be able to distinguish the impacts of individual management actions. This will be accommodated in the permitting and implementation planning steps to the extent possible.

p.15. "Secondary biological indicators that respond to improvements in water clarity and reductions in iron floc such as aquatic plants, mussels and fisheries." There is no indication aquatic plants are affected by the iron floc.

Response: The aquatic plant community is characterized as highly diverse and healthy (pg. 32). The plan highlights the anticipated shifts in aquatic plant community because of increases in water quality and less iron floc deposition on the aquatic plants (pg. 40).

p.21. I do not understand how estimates of the parameters of the water budget could be so different for one lake from different people, even if they are computed for different years.

Response: The plan highlights the rationale that Garrison (2012) used in reviewing the differences between the 2002 and 2010 water budgets (pg. 20). The plan relied on the 2017 water budgets, which are similar enough to develop lake management actions.

p.25. Some shallow groundwater P values seemed out of whack so you dismissed them? Any explanation of why they were so high? Any other data discarded because they seemed out of whack?

Response: The plan reviews groundwater P values used by Garrison (2012) and literature values reported by Juckem (2014) and Robertson (2003) (pg. 25) and decided did not use two P groundwater samples that were 4 or more times these values. The high P values may have been associated with particulate P in the shallow groundwater sample. Both total and soluble phosphorus would have been helpful in determining if the high values were associated with particulate P in the unfiltered sample.

p.39. Liming: "A small increase in pH in the range of 0.6 to 0.8 to the lake basin and within the Powell Marsh ditches will facilitate iron precipitation and reduce the formation of the iron and dissolved organic carbon complexes." So there will be more iron precipitate, but less organic iron floc? Are inorganic iron precipitates somehow better or less objectionable?

Response: The plan recommends liming following the reduction of groundwater and inflow iron inputs to settle the existing iron within the lake basin to decrease the amount of time (i.e. lake flushes) required for the lake basin to reflect the reduced loads (pg. 13). Lime used within the marsh will reduce the organic carbon-based transport of iron into the lake with the formation of inorganic iron precipitates. Any biofiltration wetland actions will have to account for this likely increase in inorganic iron precipitation.

p.39. "With the use of aquatic vegetation within the channels, primarily targeting phosphorus uptake, no loss of aquatic vegetation or wetland plant community impacts are expected. Plants used in the design for bio-filtration will be native and compatible with the existing communities of Powell Marsh. " Plants take up P, die and release P. How will this help?

Response: The P assessment period specified in WisCALM (2017), from June through September, is during the period when wetland plants are up taking P and the P reductions will directly affect the P impairment evaluation. The comment accurately reflects the need to properly accommodate for the seasonal functionally of biofiltration wetland complexes and potential increased P loading during wetland plant *senescence.*

p.39. Diverting water from Stepping Stone Impoundment if not enough water flows into DPL: “However, Stepping Stone Impoundment functions as an important open water system with natural aquatic and wetland plant communities. If water levels on Stepping Stone Impoundment are lowered or altered, the open water habitat would be reduced and secondary impacts to the aquatic and wetland plant communities would be expected. These shifts in habitat would result in changes to the use of this area by many species of animals and birds.” This plan (diversion of water from Stepping Stone Impoundment) should be abandoned for the reasons stated.

Response: Addition groundwater monitoring and hydrology work through a 2018 lake planning grant will provide supplemental information necessary to evaluate the Stepping Stone Impoundment diversion option. As the diversion evaluation proceeds, the Department and stakeholders are aware of the possible competing interest of maintaining a desired water level in both Stepping Stone Impoundment and Dead Pike Lake. It is premature to abandon this management action at the current time.

p.40. This table needs an ecological cost column.

Response: The plan lists the rationale for not further examining lake management alternatives based upon not achieving lake water quality goals or potential environmental damages. Additional descriptions of ecological costs for management actions that will not achieve water quality goals seems unnecessary.

p.49. Figure 4. I think this might be Star Lake, not DPL? See Stepping Stone Lakes in lower left?

Response: The figure was confusing and the caption and separation between the two maps shown in Figure 4 have clarified these are two distinct maps of Dead Pike Lake.

p.51. Figure 7. Very difficult to read the words on this map. This figure has critical information, including the location of many key water bodies, and should be within the body of the text, and should be of much better quality.

Response: The figure was difficult to read and Figure 7 text has been enlarged and changed from blue to black to improve readability.

p. v. Why do you use a geometric mean?

Response: WisCALM (2017) prescribes the use of geometric mean.

p. iv, v, 6. Why are some page numbers roman numerals, and some are Arabic?

Response: Corrected

p.36. Photo 6. What’s with the toad? Toads do not live in the water. They enter the water to breed, and juveniles spend a couple of months in the water as tadpoles. They then spend almost all their lives out of the water. What is the point of this photo? It is not referred to in text.

Response: The photo caption describes the toad covered in iron oxide encrustations that is part of the discussion on benthic iron floc impacts (pg. 36). Given several comments, this photo has been removed from the plan

Hadley Boehm, DNR Fisheries Biologist

One thing I see throughout is use of the term "2-story fisheries," should it be "2-story lake" since it's a water quality based standard, and not really based on the fishery. Yes, there are cisco, but few. To me, the way it reads it implies coldwater fish are in peril unless something is done. Smelt are likely the primary reason cisco numbers are low and walleye are having a hard time naturally reproducing. There are studies, many of them local, that show that to be the case. Will fish passage be affected (yes). How? The lake has smelt, will they be able to spread? I'm a little nervous about liming the lake. What is the anticipated impact on the fishery for each of the proposed actions, how will impacts be assessed? I think it's likely there will be effects on the fishery, but not sure entirely what they'll be.

Response: Section NR 102.06(2)(i) Wis. Adm. Code defines stratified, two-story fishery lake as "stratified lake which has supported a cold-water fishery in its lower depths within the last 50 years." The plan and WisCALM (2017b) uses both 2-story fisheries and 2-story lake terms interchangeably and officially in WisCALM where the methodology for impairment evaluation is described, names the lake class as Two-Story Fisheries Lakes. The plan describes the management actions and reductions in iron floc and reduced phosphorus as positive impacts to the fisheries (pgs. 38-40). There is no outlet structure on the lake and smelt are not presently restricted from moving out of the lake. The plan concludes that maintaining the ability of fish to pass through any outlet structure should be feasible and will be incorporated into the design and evaluates the potential impacts to fisheries of each management actions (pg. 38 - 40). Evaluation monitoring recommendations in the plan calls for the continued routine assessment of the fisheries (pg. 16).

Kevin Gauthier, Sr., DNR Lakes Biologist

- Take home thoughts from reading the plan:
    - Iron (86-92%) and most of P (66%) is naturally occurring and input into the lake via groundwater

Response: Correct

- Aquatic plants indicate a healthy environment

Response: Correct

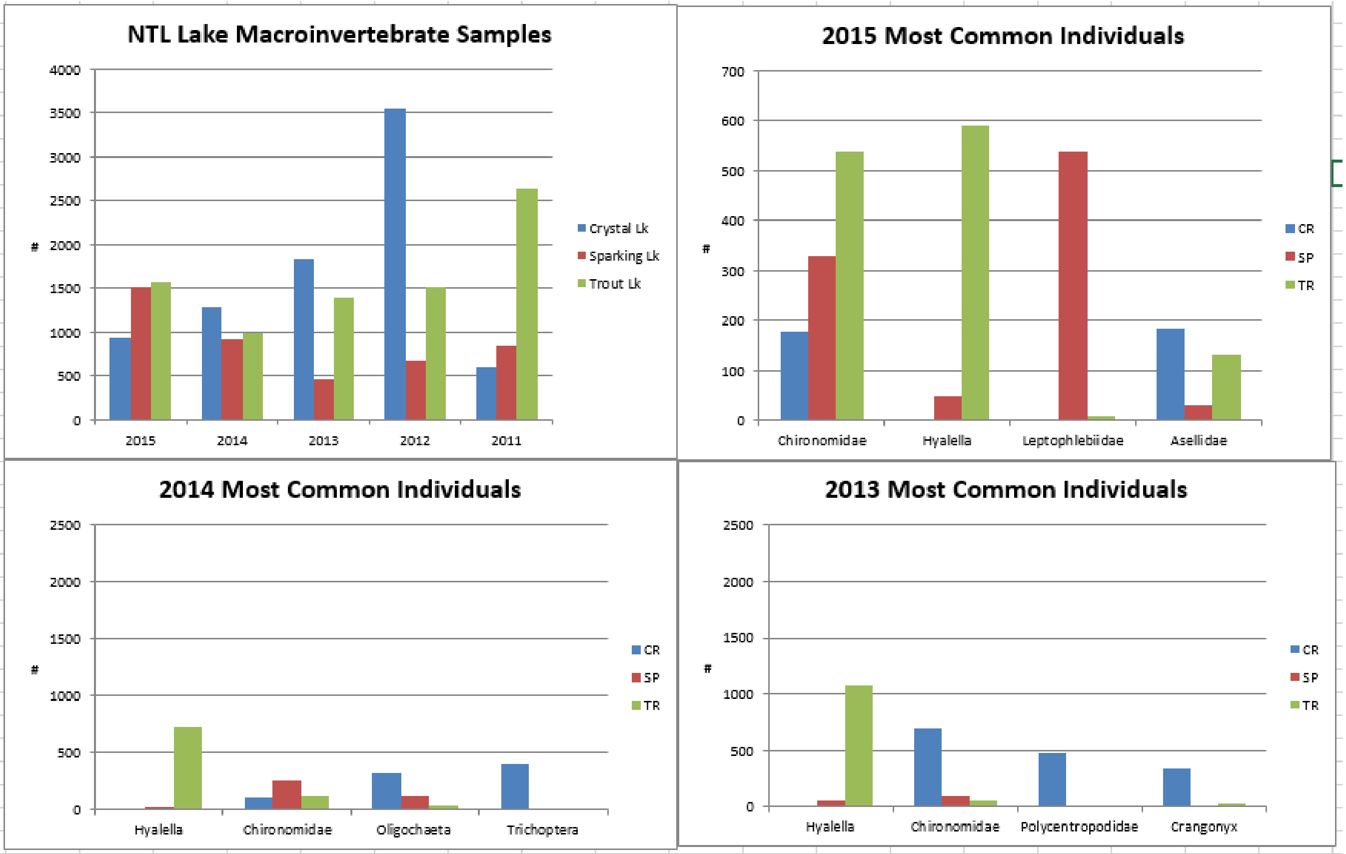
- Fisheries info is limited, but I believe indicate a healthy environment, other than potentially a smelt/walleye interaction

Response: Wisconsin does not have any biotic indices for lake fisheries and the plan uses the narrative assessment information from recent fisheries reports which include "average length of northern pike was poor," panfish population characterized as low density and lacks numbers of quality sized fish," and "walleye population is sustained through stocking."

- Plan is lacking in other biotic measurements

Response: The plan currently presents data for lake biotic features that have developed assessment metrics - namely chlorophyll and aquatic plants. The plan provides narrative descriptions of the fisheries community based upon DNR fish reports. Biotic measurements of macro-invertebrates, phytoplankton and mussels, etc. were not collected primarily because there are no assessment tools developed or specified in WisCALM (2017b) for these features and due to budget constraints.

Long-term lake macro-invertebrate samples collected by UW-Trout Lake from Crystal, Sparkling and Trout lakes were examined with hopes of using as reference lakes in comparison to proposed Dendy samples collected from Dead Pike Lake. However, the annual variation of macro-invertebrate population numbers and most common species were highly variable (15. 3 Appendix Figure 3) and not useful in establishing reference conditions – thus macro-invertebrate samples from Dead Pike Lake were not collected.



Appendix 15.3 Figure 3

- ○ Plan intends on reducing harmful environmental conditions (referenced repeatedly in the document) – I didn't see data indicating the impaired biota and how evaluation will occur to know if impaired biota will have recovered or not

Response: The plan recommends evaluation monitoring of the aquatic plants, fisheries, Secchi, chlorophyll and phosphorus and iron surface water quality. The plan provides a foundation to assess changes in the aquatic plant and fisheries community as well as chlorophyll concentrations. Presently, quantitative data is not available for iron floc distribution and the plans notes the lack of readily available iron floc monitoring protocols. A WDNR lake planning grant is funding the development of a pilot iron floc monitoring protocol in the summer of 2018. The plan recognizes that iron floc distribution and density monitoring does not directly assess the effects on the benthic biota. With the lack of biotic assessment tools for lake macroinvertebrates, mussels etc., the plan relies on the body of literature related to impacts of iron floc, though direct measurements are not feasible.

- ○ Water quality is listed as impaired in 2016 and continued in 2017 – however, measurements taken in 2017 indicate a mean average of 14.5 below the standard with the 90% conf limit of one sample above the standard (impairment threshold) at 15.7 (on top of page 25). Recommendations to mitigate the measured impairment seem quite large as compared to the level of impairment – I don't have a lot of experience working with impaired water quality lakes, but would think that recommendations that cost a lot and have large ecological considerations themselves would be resorted to last and smaller, less aggressive techniques first?

Response: The plan recognizes the importance of using an adaptive management approach to implementation, with the step by step progression of reversible management actions accompanied with evaluation monitoring (pg. 6).

- Plan references aesthetics/floc repeatedly as a driver of recommendations also – no info on floc location/time of year – just hard to grasp from a pre/post evaluation what sort of impairment and correction may have or may have not occurred and how one would evaluate if conditions aesthetically have improved?

Response: The plan does present photos that exemplify the iron floc build up. Presently, quantitative data is not available for iron floc distribution and the plans notes the lack of readily available iron floc monitoring protocols. A WDNR lake planning grant is funding the development of a pilot iron floc monitoring protocol in the summer of 2018.

- I think the data collected as part of this plan was some of the info that was wanted as part of the previous plan and review.

Response: Within the time frame prescribed by the Natural Resources Board and budget allotted through Water Quality and Wildlife funding to the project, the plan was responsive to lake management plan requirement set forth in NR 191, Wis. Adm. Code.

- I defer to other specialists on the modeling, impaired waters status based on info presented, and 9-key element eligibility

Response: Review and approval of the Dead Pike Lake management plan under the 9-key element and Environmental Accountability criteria is important for future federal funding considerations.

- It seems that from the data presented, the surface water entering Dead Pike Lake from the Marsh is meeting P water quality standards, if this true, is the marsh going to be required to mitigate even further?

Response: The plan sets forth the estimated reductions required in P loading to meet the P water quality standard and addresses both surface water loading from the Marsh and groundwater loading. The goal is a reduction of 33 kg/yr or less than 100 lbs/year. The plan presents construction of in-channel wetland biofiltration on the marsh as contributions to reducing the surface water load as the initial adaptive management action. Evaluation monitoring is proposed to assess whether additional mitigation is necessary. Management actions recommended in this plan are voluntary and the plan is careful not to state any of these management actions are required by Administrative Code or Statute.

- Note regarding cranberry operations and a change in operation during 2017 from pages 20 and 22 – comment below.

Response: See responses below

- Individual page comments:
  - Page v. Exec Summary. 1st Par. Last sent. I don't believe the plan has shown data to support harmful environmental conditions and effects within Dead Pike Lake. The aquatic plant community metrics show a high quality community and I don't believe the plan has indicated measurements indicating harmful/unhealthy biota.

Response: The plan describes the literature available on both water column iron and iron floc harmful impacts to the biota and concludes that "Couple these factors with the wide range of sensitivities among the biota and their different life stages, it's very difficult to make a definitive statement that the surface water column of Dead Pike Lake is toxic to the native species. Overall the available data and literature support the conclusion that iron concentrations in Dead Pike Lake and Powell Marsh have the potential to have toxic effect on the biota – whether considering sensitive species like mussels or benthic macroinvertebrates and *fish eggs that live in the presence of the iron floc." (pg. 37 & 38).*

The plan concludes, based upon FQI, the aquatic plant community is healthy. The plan notes the 303d listing status of the lake for exceeding phosphorus water quality standards and notes Chlorophyll-a is meeting state standards. Other biotic indices for lake assessment have not been established in WisCALM.

- ○ Page v. Section 1.1. Last Par. Lists 1.49 mg/L and reducing Fe groundwater loads by 74% - where were these numbers derived – this paragraph indicates these were derived by a maximum amount that could be achieved with proposed management recommendations – goals and actions are supposed to be set based on mitigating a documented impairment, not what maximum amounts of mitigation can occur. Maybe I missed something here, but I think this is how those parameters were derived?

Response: Without specific lake response models for iron floc, like those well documented for phosphorus, correlating specific iron loading reduction goals with iron floc densities in not possible.

- ○ Pages 8-9. Table 1 and Secchi disc section. Confusing numbers – in-lake goals of 8.4 feet with a 24% increase in clarity and a 38% in clarity last 5 years?

Response: The reference to the reduction goal of 8.4 relative to the annual average for the last 5 years (i.e. 38%) has been removed and the plan now references changes in water clarity compared to 2017 average Secchi disk only.

- ○ Page 8. Iron and Manganese. 1st sent. ….and habitat degradation in shallow bays and nearshore areas of lake. Where are the data/maps to support this in-lake degradation?

Response: The plan presents photos that exemplify the iron floc build up. Presently, quantitative data is not available for iron floc distribution and the plans notes the lack of readily available iron floc monitoring protocols. A WDNR lake planning grant is funding the development of a pilot iron floc monitoring protocol in the summer of 2018.

- ○ Page 9. Secchi disc section. 5th and 6th sent. ….reduction in dissolved organic carbon and iron….. Low water equals less iron and P inputs into lake – does this contradict the recommendation of elevating the water level?

Response: During drought conditions – not just lower lake levels – both surface water and groundwater inputs are reduced resulting in reductions in total nutrient and dissolve organic matter color inputs -- a condition noted at some Vilas County lakes (Steve Carpenter and Matt Diebel, pers. comm.).

- ○ Pages 20 and 22. Table 6 and Powell Marsh Surface Water Flows (1st par. Last sent). Page 22 indicates that cranberry operations pumped water from Little Trout Lake back into Little Trout Lake during 2017 and Table 6 indicates such. I believe this is a different practice than pre-2017, as I think the discharge from cranberry operations may have been into the Marsh. There is no mention how cranberry operations will be in the future. This seems to be important regarding P and impairment. If pre-2017 operations/discharges were to resume what affect(s) does this have on this plan and the future?

Response: The Dead Pike Lake Management Plan work group met with one of the cranberry growers and DNR staff met with another grower and both seem receptive to helping reduce the nutrient loads to the marsh and lake. Discussions with the growers is anticipated to continue. Recognizing the discharge from the cranberry operations is not regulated, consideration of the potential for increased flows and increased phosphorus from the cranberry discharges will need to be considered in the design of the wetland biofiltration system.

- Page 34. Section 10. Bullet point 3. What are the negative environmental impacts in Dead Pike Lake?

Response: The plan describes the literature based impacts of iron floc on the biota on page 36-37 including the summary findings of Craig Roesler's work on Crex Meadow associated with the environmental impacts of iron.

- Page 36. Section – Benthic Iron…. 2nd Par. 3rd sent. Although….. If the iron is 86-92% coming from groundwater and is part of the natural geology in the lake/area. This is not a fair sentence – the fauna that exist have been here and lived in this water since the glaciers…..I think that is why it is important to note what species, if any, are impacted by iron and/or manganese from anything "recent", not to make broad statements and assumptions.

Response: The plan recognizes the "daunting task" of assessing the environmental impacts of toxic effects (top of pg. 36) and goes on to use established literature to represents the environmental impacts of iron floc to the aquatic environment. The dates of the literature cited ranges from 1985 to 2018 and is contemporary or more recently than the USEPA "red book" (1988). The most recent work of Cadmus in 2018 would suggest a final chronic iron concentration of 0.499 mg/L

- Page 36. Section – Benthic Iron…. 3rd Par. Is there mapping/data of this build-up - How much of a build-up exists?

Response: Presently, quantitative data is not available for iron floc distribution and the plans notes the lack of readily available iron floc monitoring protocols. A WDNR lake planning grant is funding the development of a pilot iron floc monitoring protocol in the summer of 2018.

- Page 36. Picture of toad – will defer to wildlife specialists to determine if this is iron oxide encrustations? If this is not, recommend this be removed.

Response: *Response: The photo caption describes the toad covered in iron oxide encrustations that is part of the discussion on benthic iron floc impacts (pg. 36). Given several comments, this photo has been removed from the plan*

- Page 37-38. Last sent page 37 and first sent page 38 – contradict each other. The last sentence of page 37 would be appropriate for the executive summary.

Response: The plan recognizes the difficulty and complexity in assessing iron toxicity and making a definitive statement specifically about the surface water column toxicity. The next statement on page 38 has been clarified to address the "overall condition of the lake" including the consideration of the environmental effects of the benthic iron floc.

- Page 38. Section 10.4. 1st Par. Is a half foot or a foot permanent rise in minimum water level elevation a relatively small change? Ecologically seems to be at least a little more than relatively small.

Response: In 2017 the water level on Dead Pike Lake fluctuated 8.8 inches and historical annual lake water levels have varied between 4.5 and 24.5 inches (1.53 Appendix Figure 1). In the context of historic water level changes and established ordinary high-water marks (Jefferson 2017) and the water level increases created by the dam structures on Powell Marsh, a ½ to 1 foot water level change is relatively small.

- Page 38. Establishing a minimum…. 1st Par. 1st sent. The aquatic plant….. I would expect that the current emergent beds near the outlet may see changes/declines with either minimum elevation change (and other emergent/floating leaved communities around the lake). These are really important communities and changing them would have an effect on the ecology of the lake.

Response: The aquatic plant community is characterized as highly diverse and healthy (pg. 32). The plan *highlights the anticipated shifts in aquatic plant community because of increases in water quality and less iron floc deposition on the aquatic plants (pg. 40). The increase in minimum lake level could shift the distribution of aquatic plants. In consideration of the lake historic periods of high water/low water and higher/lower periods of water clarity (Figure 13), the plan predicts maintenance of a highly diverse and healthy plant community.*

- Page 38. Establishing a minimum…. 2nd Par. 1st sent. How will the fisheries community respond positively?

Response: The plan describes the anticipated positive responses in the fisheries as "The fisheries community is expected to respond positively to the reduction of iron floc accumulation due to the reduction in potential toxicity effects on sensitive egg and larval life stages, as well as the reduction in potential physio-biological impacts of the iron floc on gills" (pg. 38).

- Page 38. Establishing a minimum…..3rd Par. It seems as though that if the water is elevated in the lake it is unknown where the ground water will go?

Response: The plan describes the diverted groundwater flow will go to either Lost Creek and surrounding stream groundwater discharge points or released into the atmosphere through increased evapotranspiration. Estimating what portion of the 1.45 cfs would be diverted to either discharge point was not done given the increases would be likely small relative to the groundwater shed and number of groundwater discharge points.

- Page 39. 2nd Par. 1st sent. What?

Response: The comments is a bit unclear. The first sentence is substantiated by the discussion points within the paragraph below.

Dr. Katie Hein, DNR Monitoring Section

Phosphorus Criterion, Goals, and Phosphorus Response Indicators

Although the lake is listed as impaired for phosphorus, our draft guidance says that phosphorus would not need to be listed if phosphorus response indicators show that the lake is healthy. It appears that chlorophyll *a*, aquatic plants, and dissolved oxygen are all in good condition in Dead Pike Lake. One suggestion is to actually calculate the oxythermal layer thickness with existing oxygen profiles to make sure. I also suggest calculating the aquatic plant biocriteria, particularly the phosphorus response indicator, to ensure that the plant community is healthy with the given concentration of phosphorus.

Response: The plan used the existing WisCALM approved guidance. The plan specifies the importance of monitoring the hypolimnetic oxygen levels (pg. 15) as part of the evaluation and adaptive management approach. The plan uses the standards set in WisCALM and assumes those are protective to maintain a 2-story fisheries lake classification. Construction of an individual phosphorus concentration relationship with the oxythermal layer for Dead Pike Lake is beyond the scope of this project.

Also, note that the phosphorus concentration has not significantly increased (or decreased) over time. I had done trend analysis on data going back to 2005. The lack of a trend indicates to me that the ambient concentration of phosphorus is near the criterion, but isn't necessarily getting worse.

Response: This is a correct analysis of the phosphorus data. The plan reports on the phosphorus impairment listing of Dead Pike Lake and uses the procedures in WisCALM (2017b) to evaluate the phosphorus data which does not prescribe evaluating increasing or decreasing trends.

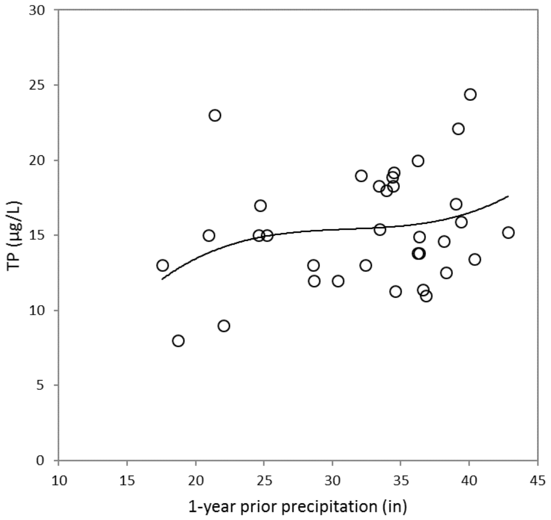
I am concerned about the proposed management strategy to raise the water levels. As Carl Watras pointed out, the lake is actually more clear during the drought years. The models in this report did not evaluate whether raised water levels will increase erosion and inputs of organic matter from the riparian zone. Raising water levels could increase phosphorus and oxygen demand by washing in sediment and organic matter. Given the small amount of phosphorus reduction necessary to meet the statewide concentration (which might not be necessary given biological responses), I would recommend smaller management actions to begin. Have septics been evaluated recently?

Response: During drought conditions both surface water and groundwater inputs are likely reduced and water clarity (Secchi disk) is "decidedly correlated" with precipitation (p. 23) and phosphorus increases slightly with increasing precipitation (Matt Diebel, pers. comm. 15.3 Appendix Figure 4). The plan notes that over the years, the Dead Pike Lake water levels are affected by beaver dams and man-made alterations at the outlet stream such that lake surface water elevations (Appendix 15.3, Figure 1) do not necessarily align with regional water levels patterns (e.g. 2010 shows regionally low water while DPL experienced high water). Phytoplankton (i.e. chlorophyll-a) peaks during moderately wet conditions, then decreases during very wet conditions, perhaps due to light limitation due to increased organic matter and associated increased color (Matt Diebel, pers. comm., Appendix 15.3, Figure 2).

The recommended increase in the minimum lake level holds the lake at water levels more compatible with shoreline erosion control measures put in place by many property owners (Photo 4 and discussion on pg. 39).

The plan recognizes the importance of using an adaptive management approach to implementation, with the step by step progression of reversible management actions accompanied with evaluation monitoring (pg. 6).

The annual septic loading was evaluated using WILMS and estimated to be less than 0.5% of the annual phosphorus load.



Appendix 15.3 Figure 4

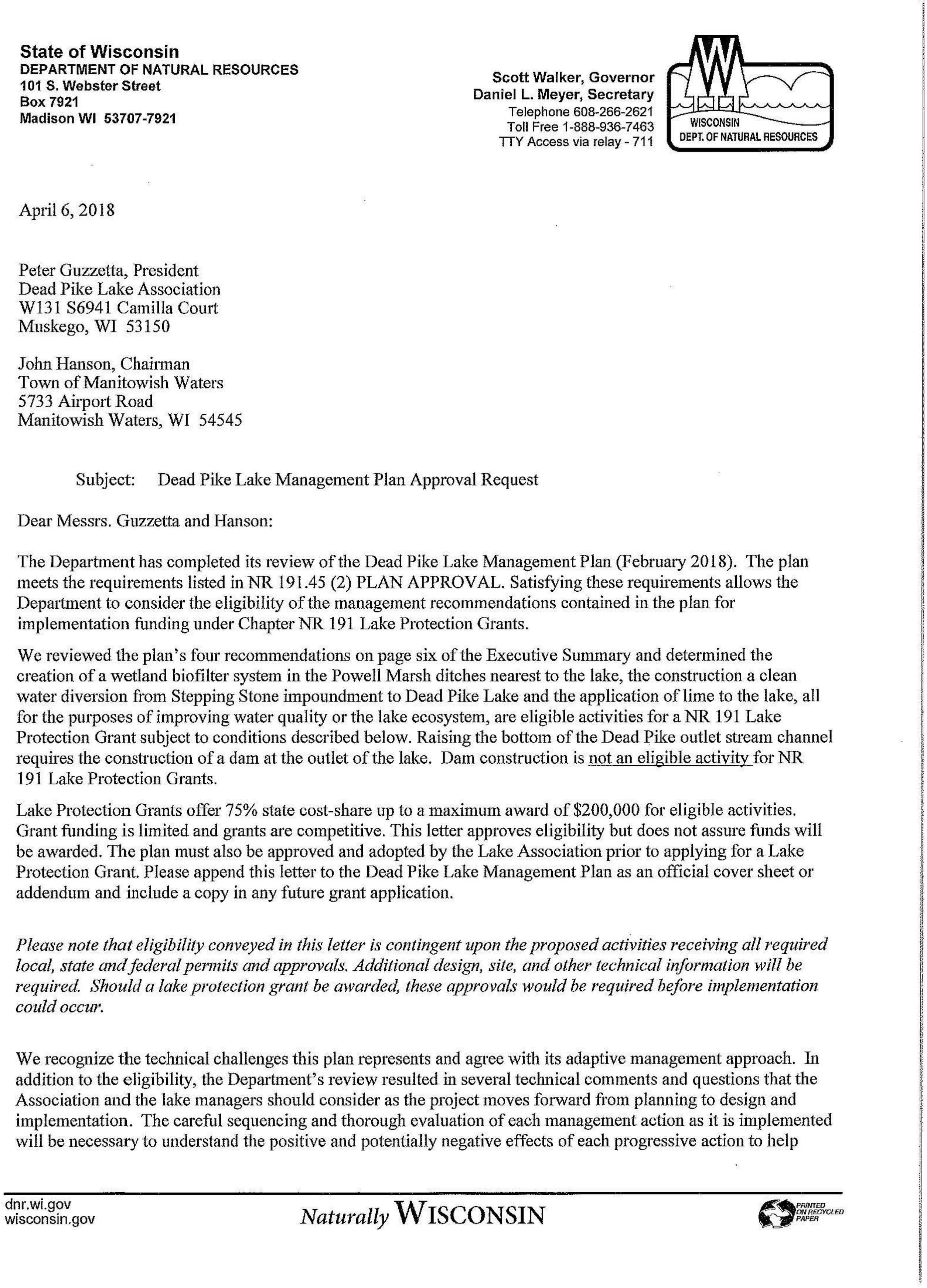
Iron: I did a quick download of all surface water iron concentrations from lakes and reservoirs in the state. Dead Pike Lake is not the only lake with iron > 1 mg/L, though not many lakes are > 1 mg/L. There is no evidence to show the iron reduction that would be necessary to attain an acceptable aesthetic quality for the lake. Thus, caution should be exercised when using very dramatic management tools with the purpose of solving the aesthetic problem.

Response: The plan recognizes the importance of using an adaptive management approach to implementation, with the step by step progression of reversible management actions accompanied with evaluation monitoring (pg. 6).

It might be worthwhile to take the viewing bucket to a variety of lakes and streams with varying iron concentrations. I realize that flocculent formation will not be the same in all lakes based on iron concentrations alone. We have used photos to help the advisory committee for the designated uses and biocriteria package understand what various chlorophyll *a* concentrations look like. It might help the group to see what other lakes look like with various levels of iron concentrations.

Response: The plan briefly describes the activity of developing a qualitative tool to assess iron floc densities using the viewing bucket. More detail is provided in the Town of Manitowish Water's 2018 Lake Planning Grant Application. One of the first steps is to work with the DNR to develop a pilot viewing bucket rating protocol for iron floc/bacteria and initiate a pilot monitoring program in 2018. Any assistance toward completion of this task would be much appreciated.

15.4 Department Approval Letter



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DEPT. OF NATURAL RESOURCES

April 6, 2018

Peter Guzzetta, President
Dead Pike Lake Association
W131 S6941 Camilla Court
Muskego, WI 53150

John Hanson, Chairman
Town of Manitowish Waters
5733 Airport Road
Manitowish Waters, WI 54545

Subject: Dead Pike Lake Management Plan Approval Request

Dear Messrs. Guzzetta and Hanson:

The Department has completed its review of the Dead Pike Lake Management Plan (February 2018). The plan meets the requirements listed in NR 191.45 (2) PLAN APPROVAL. Satisfying these requirements allows the Department to consider the eligibility of the management recommendations contained in the plan for implementation funding under Chapter NR 191 Lake Protection Grants.

We reviewed the plan's four recommendations on page six of the Executive Summary and determined the creation of a wetland biofilter system in the Powell Marsh ditches nearest to the lake, the construction a clean water diversion from Stepping Stone impoundment to Dead Pike Lake and the application of lime to the lake, all for the purposes of improving water quality or the lake ecosystem, are eligible activities for a NR 191 Lake Protection Grant subject to conditions described below. Raising the bottom of the Dead Pike outlet stream channel requires the construction of a dam at the outlet of the lake. Dam construction is not an eligible activity for NR 191 Lake Protection Grants.

Lake Protection Grants offer 75% state cost-share up to a maximum award of $200,000 for eligible activities. Grant funding is limited and grants are competitive. This letter approves eligibility but does not assure funds will be awarded. The plan must also be approved and adopted by the Lake Association prior to applying for a Lake Protection Grant. Please append this letter to the Dead Pike Lake Management Plan as an official cover sheet or addendum and include a copy in any future grant application.

Please note that eligibility conveyed in this letter is contingent upon the proposed activities receiving all required local, state and federal permits and approvals. Additional design, site, and other technical information will be required. Should a lake protection grant be awarded, these approvals would be required before implementation could occur.

We recognize the technical challenges this plan represents and agree with its adaptive management approach. In addition to the eligibility, the Department's review resulted in several technical comments and questions that the Association and the lake managers should consider as the project moves forward from planning to design and implementation. The careful sequencing and thorough evaluation of each management action as it is implemented will be necessary to understand the positive and potentially negative effects of each progressive action to help

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assure a successful outcome. These additional comments have been provided to your consultants for consideration.

On behalf of the Department's Bureau of Water Quality Lakes Section, I want to thank you both and all the Association members who voluntarily contributed to preparation of this plan. Please feel free to contact me at (608) 261-6423 if you have any questions or require further assistance.

Sincerely,

Carroll Schaal

Carroll Schaal
Lakes and Rivers Section Chief

C: Kevin Gauthier, WQ/Woodruff
Dan Helsel, FIL/BRF
Michele Woodward, WM/Woodruff
James Yach, SD/Rhinelander