Technical Memo

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To: Tiffany Determan, Isanti Soil and Water Conservation District

From: Jeff Strom, Wenck Associates, Inc.

Date: January 22, 2019

Subject: Blue Lake Diagnostic Study

Blue Lake is a deep lake located in southwest Isanti County. Recent water quality monitoring efforts for Blue Lake's south basin (Attachment A) suggest the lake meets state water quality standards and therefore the lake has not been placed on the State of Minnesota's 303(d) list of impaired waters. While the lake is not currently impaired, average summer growing season total phosphorus (TP) concentrations are close to exceeding State standards and chlorophyll-a concentrations commonly exceed State standards.

The Isanti Soil and Water Conservation District (SWCD) contracted with Wenck Associates, Inc. (Wenck) to conduct a diagnostic study to better understand phosphorus sources from external and internal sources and provide recommendations to reduce phosphorus loading to the lake. This technical memorandum presents the results of this work which includes the following components:

- Review existing data
- Development of lake phosphorus budget and model
- Phosphorus goals and reduction scenarios
- Recommended strategies

Existing Data Review

Table 1 summarizes the data, studies and models that were compiled and reviewed for this study. All information in Table 1 was supplied by Isanti SWCD staff or was available online.

Table 1. Data, studies and models reviewed for this study

Data/Study	Description	Source
Blue Lake water quality data (2015-2018)	Includes temperature/DO profiles and surface TP, Chl-a, TSS and Secchi measurements for Upper/Lower Blue Lake basins	Isanti SWCD
Blue Lake water quality data (pre-2015)	Includes various surface parameters (1981-2014) for both basins as well as hypolimnion TP concentrations (1988-1989, 2014)	EDA (link)
Blue Lake tributary monitoring data	Includes TP, TSS, Secchi tube, DO, gauged flow and water level measurements for six tributary stations (Figure 1)	Isanti SWCD
Blue Lake curly-leaf pondweed delineations	Pre and/or post curly-leaf pondweed treatment delineations performed by Isanti SWCD staff in 2016-2018	Isanti SWCD
Blue Lake DNR Vegetation Surveys	Vegetation surveys performed by MnDNR in 2004, 2005, 2006, 2010 and 2013	MnDNR
Rum River TMDL and WRAPS Reports (2017)	No TMDL completed for Blue Lake since it is not impaired. Protection strategies for Blue Lake were included in WRAPS.	MPCA (link)

Data/Study	Description	Source
Rum River HSPF-SAM Model	HSPF Simulation Application Manager (SAM) tool developed by the MPCA and used in the Rum River TMDL and WRAPS	MPCA (link)
Blue Lake Stormwater Retrofit Analysis	Report providing recommendations for treatment of stormwater from to Blue Lake direct watershed and tributaries	Isanti SWCD

In order for Blue Lake to be considered an impaired waterbody, the 10-year average growing season TP concentration and at least one "response variable" (Chl-a or Secchi depth) must exceed State water quality standards. Growing season TP concentrations in Blue Lake's south basin have averaged 37 µg/L over the most recent 10-year period, which is below the 40 µg/L standard for deep lakes in the North Central Hardwood Forest (NCHF) Ecoregion. Planktonic algae, which is measured by chlorophyll-a (chl-a), has averaged 22 µg/L which is above the 14 µg/L standard for deep lakes. Secchi depth, a measure of water clarity, is generally good in Blue lake Lake and has met the 1.4-meter Secchi depth standard every year since 2003. Although chl-a has not met State water quality standards over the past 10 years, Blue Lake is not considered impaired since TP has met State standards.

Isanti SWCD staff have monitored flow and water quality throughout the watershed draining to Blue Lake (Figure 1) from 2015-2018. Continuous water levels (transducers) and gauged flow measurements were recorded and measured at four of these stations (Tribs 1-4). Based on review of these data, Tributary #1 monitoring station (S008-449) was the only site that demonstrated a reliable (R^2 of 0.75) stage-discharge relationship that could be used to convert the continuous water level readings to continuous flow. The other monitoring stations are located in wetlands (i.e. very low velocities) or are too close to the lake to produce reliable stage-discharge relationships.

Water quality monitoring results for the four tributaries are summarized in Attachment B. Monitoring parameters included TP, total suspended solids (TSS), Secchi tube, temperature and DO. Results indicate average TSS concentrations were highest in Tributaries #3 and #4. Elevated TSS in these tributaries coincided with storm events and higher flow conditions suggesting sediment loading from upland sources and/or in-channel re-suspension. TSS concentrations in Tributaries #1, #2 and #6 were lower than Tributaries #3 and #4 and never exceeded the State's Central River Nutrient Region standard (30 mg/L).

Average TP concentrations were highest in Tributary #4 (191 µg/L) followed by Tributary #2 (128 µg/L), Tributary #3 (121 µg/L), Tributary #6 (114 µg/L) and Tributary #1 (86 µg/L). Elevated TP concentrations for Tributary #4 coincide with high TSS levels and therefore are likely driven by particulate phosphorus sources (i.e. phosphorus attached to sediment) rather than dissolved/soluble sources. Ortho-phosphorus samples collected by Isanti SWCD in 2016 and 2017 in Tributary #4 suggest dissolved/soluble phosphors is relatively low (average of 20 µg/L) and only accounts for approximately 13% of the TP. Ortho-phosphorus data has not been collected at any of the other tributary monitoring stations so it is difficult to determine whether TP sources are primarily particulate or dissolved/soluble. It is likely that Tributary #3 has high particulate phosphorus levels since this tributary had TSS concentrations similar to Tributary #4. Tributaries #1, #2 and #6 likely have higher dissolved/soluble phosphorus levels since these tributaries demonstrated lower TSS concentrations compared to Tributaries #3 and #4.

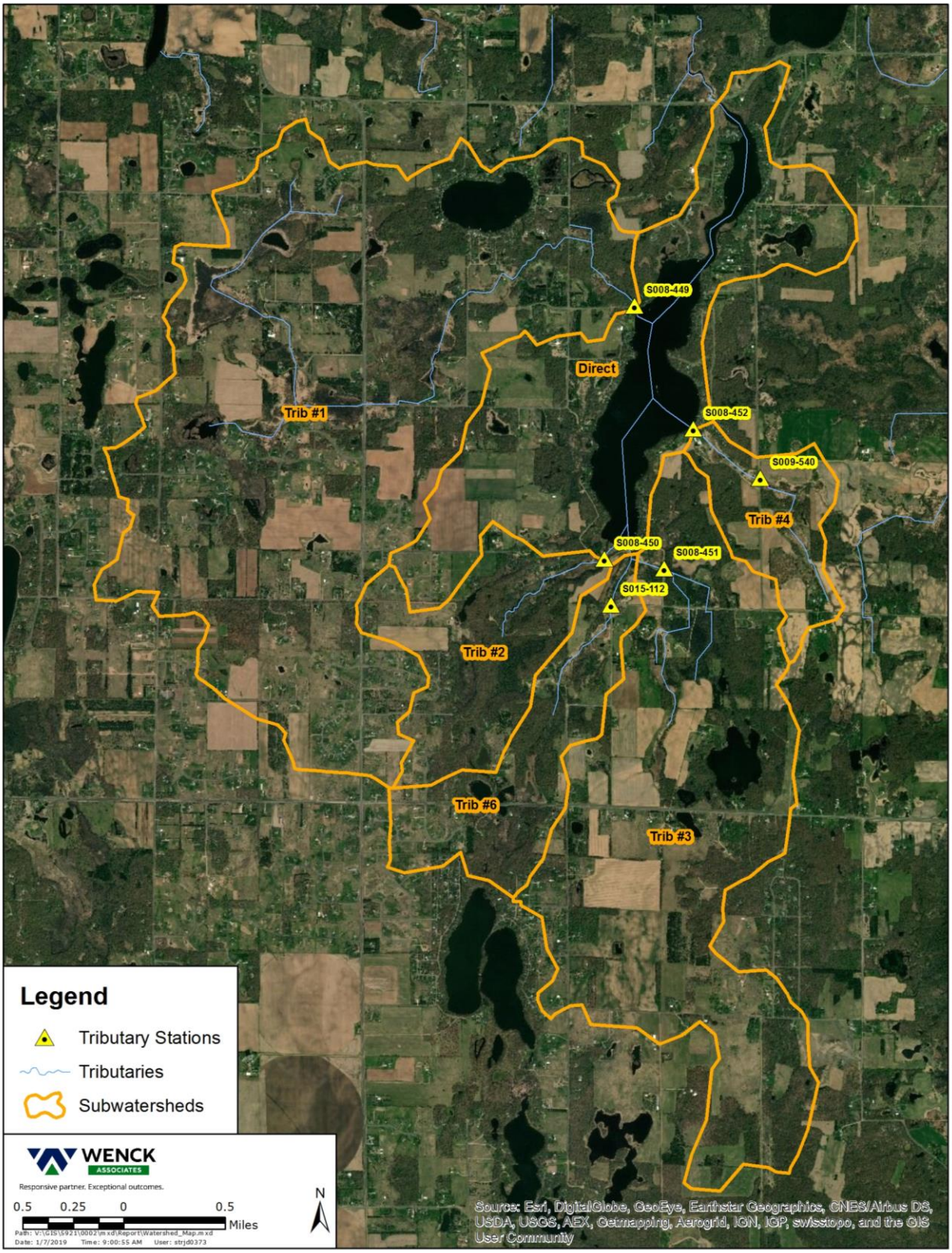

Figure 1. Blue Lake subwatersheds and tributary monitoring stations.

Blue Lake Phosphorus Budget and Model

Methods

A lake response model was setup to estimate the TP budget for Blue Lake for years that have in-lake TP monitoring data over the most recent 10-year period (2014-2018). The lake response model selected for this exercise was the Canfield-Bachman lake equation (Canfield and Bachman, 1981). This equation estimates the lake phosphorus sedimentation rate, which is needed to predict the relationship between in-lake phosphorus concentrations and phosphorus load inputs. The phosphorus sedimentation rate is an estimate of net phosphorus loss from the water column through sedimentation to the lake bottom, and is used in concert with user supplied lake-specific characteristics such as annual phosphorus loading, mean depth, and hydraulic flushing rate to predict in-lake phosphorus concentrations. Model predictions are then compared to measured data to evaluate how well the model describes the lake system. If necessary, the model parameters are adjusted appropriately to achieve an approximate match to monitored data.

To setup the lake response model for Blue Lake, Wenck used methods similar to the lake TMDLs in the Rum River Watershed TMDL Study (MPCA, 2017) and other TMDL studies throughout the State. The four major phosphorus sources defined in the Blue Lake response model were watershed load, internal load, loading from curly-leaf pondweed (CLP) senescence, loading from subsurface sewage treatment systems (SSTSs) near the lake and atmospheric load.

Watershed TP loading was estimated using the tributary monitoring data described in the previous section that was collected by Isanti SWCD from 2015-2018. Since Tributary #1 was the only tributary in which a reliable continuous flow record could be developed, monitored runoff depths from Tributary #1 were applied to the other tributaries throughout the watershed and adjusted based on comparison of paired gauged flow measurements between Tributary #1 and the other tributaries. Results of this analysis indicate average (2014-2018) runoff depth for the entire Blue Lake watershed is ~2.7 inches per year. This runoff rate is low and significantly less than the ~7.9 inches per year predicted by the Rum River HSPF model (average for model years 1996-2015). The monitored data suggests a significant portion of rainfall across the Blue Lake watershed is being lost to evapotranspiration and/or deep/shallow groundwater that is not returned to the tributaries as baseflow. Once the the annual flow volumes for each tributary were calculated they were multiplied by the average monitored TP concentrations to estimate annual TP loads for each tributary.

Internal phosphorus loading from lake sediments can be a major component of a lake's phosphorus budget. Internal loading is typically the result of organic sediment releasing phosphorus to the water column. This often occurs when anoxic conditions are present, meaning that the water in and above the sediment is devoid of oxygen. To estimate internal loading of phosphorus from the lake sediments in Blue Lake, an assumed sediment phosphorus release rate ($mg/m^2/day$) was multiplied by an anoxic factor calculation (Nürnberg 2004), which estimates the period where anoxic conditions exist over the sediments. The best way to estimate sediment phosphorus release rates is by collecting sediment cores and incubating them in the lab under anoxic conditions to measure phosphorus release over time. At this time sediment cores have not been collected or analyzed for Blue Lake. Instead, sediment phosphorus release rates were estimated by

calculating the observed rate of change in hypolimnetic TP concentrations during the summer growing season for years (1988, 1989 and 2014) in which hypolimnion TP samples were collected. Results of these calculations suggest Blue Lake has an average sediment phosphorus release rate of 9.8 mg/m^2/day. Anoxic factors for Blue Lake were calculated using DO profiles collected by Isanti SWCD staff from 2014-2018.

Phosphorus loading from CLP senescence was estimated using CLP phosphorus content and areal density relationships developed by Three Rivers Park District (MPCA, 2015) for other Minnesota lakes. These relationships were combined with the percent occurrence and relative density ratings from recent point intercept vegetation surveys done by MnDNR and pre/post treatment CLP delineations performed by Isanti SWCD staff. A CLP phosphorus content to internal load ratio of 1:½ (James et. al, 2002) was used in the Blue Lake response model since not all of the phosphorus in the decaying plant matter is believed to be released to the water column.

Phosphorus loading to Blue Lake from SSTSs located near the lake were estimated using methods similar to the Lower Minnesota River Watershed TMDL (MPCA, 2018). An estimate of the total number of SSTSs immediately surrounding the lake (~128 systems) was provided by Isanti County staff and assumptions were made regarding number of people per household (~2.8 people) and the number of days per year each household is occupied (~245 days/yr). It was also assumed that SSTSs that are imminent public health threats (IPHTs) or are failing to protect groundwater contribute more phosphorus than SSTSs that comply with State design/performance standards. At this time, we do not know the number SSTSs immediately surrounding Blue Lake that are IPHTs or fail to protect groundwater. Therefore, Wenck used 2009 county-wide SSTS compliance rates for Isanti County reported in the *Recommendations and Planning for Statewide Inventories, Inspections of Subsurface Sewage Treatment Systems* report (MPCA, 2011). This report indicates that approximately 1% of the SSTSs in Isanti County are IPHTs and 14% fail to protect groundwater.

Finally, atmospheric phosphorus loading to Blue Lake was estimated using literature rates for dry (<25 inches of rainfall), average (25-38 inches), and wet (>38 inches) precipitation years (Barr Engineering, 2004). Atmospheric loading to lakes is typically small compared to other sources and is very difficult, if not impossible, to manage.

Results

With the watershed, sediment, CLP, SSTS and atmospheric phosphorus loads defined, the lake response model predicted average annual TP concentrations over the most recent 10-year period were compared to available monitored in-lake TP concentrations. The model predicted the in-lake TP concentrations for Blue Lake were higher than monitored values, and therefore adjustments were made to increase phosphorus settling in the model to better match the monitored TP data.

Lake response model results suggest internal loading from Blue Lake sediments are likely the largest source (45%) of TP loading to the lake (Figure 2). Watershed loading is the second largest contributor and accounts for approximately 38% of the lake's annual TP budget. Septic system inputs (8%), atmospheric loading (5%) and CLP senescence (4%) account for relatively small portions of the overall budget. Attachment C contains detailed information of the lake response model inputs and results.

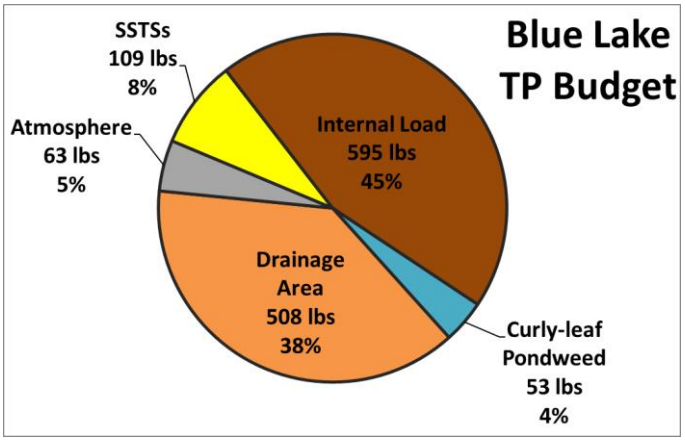

Figure 2. Blue Lake Phosphorus Budget (2014-2018)

Blue Lake Phosphorus Goals and Reduction Scenarios

As discussed above, surface water quality conditions in Blue Lake currently meet State water quality standards. Summer growing season surface water TP concentrations have averaged 37 µg/L over the most recent 10-year period which is slightly below the 40 µg/L standard for deep lakes in the NCHF ecoregion. The Rum River WRAPS report identified Blue Lake as a Type A (highest priority) protection lake and recommended a surface water TP concentration target/goal of 31 µg/L. This target is based on the 25th percentile of the standard deviation of Blue Lake's historical dataset. With this target/goal in mind, Wenck used the current condition Blue Lake response model to estimate TP load reductions (all sources) needed to meet this target/goal. The model suggests TP loading to Blue Lake will need to be reduced by approximately 360 pounds per year in order to meet the 31 µg/L in-lake concentration target/goal.

Wenck reviewed each phosphorus loading source to Blue Lake and performed a series of model scenarios to determine which source(s) could be reduced to achieve the 360 TP load reduction target/goal. Below is a discussion of these scenarios.

SSTS Reduction Scenario

The first scenario reviewed by Wenck was to evaluate the benefits of upgrading all "failing" (i.e. IPHTs and failing to protect groundwater) SSTSs immediately surrounding the lake. This scenario resulted in a TP load reduction of approximately 16 pounds/year (4% of goal target) and improved average summer TP concentrations by less than 1 µg/L (Table 2).

Watershed Reduction Scenarios

Wenck performed two watershed TP reduction scenarios. For the first scenario, TP loads from each tributary were reduced to meet the 100 µg/L standard for rivers/streams in the Central River Nutrient Region. Average TP concentrations for Tributary #1 (~84 µg/L) currently meet the Central River Nutrient Region standard, while TP concentrations for Tributaries #2 (~138 µg/L), #3 (~118 µg/L), #4 (~195 µg/L), and #6 (~112 µg/L) do not meet the standard. This scenario resulted in a TP load reduction of approximately 102

pounds/year (28% of target/goal) and improved average summer TP concentrations by approximately 2 µg/L (Table 2).

For the second watershed scenario, TP loads from each tributary were reduced so that average TP concentrations were 50 µg/L. This scenario presents an aggressive watershed TP goal that is well below the 100 µg/L standard which may be very difficult, if not impossible to achieve. While this scenario did result in a TP load reduction of approximately 295 pounds/year, it still failed to meet the 360 pounds/year load reduction target/goal for the lake (82% of target/goal).

Internal Load Reduction Scenario

The final scenario evaluated by Wenck was phosphorus load reductions benefits of internal load management. Based on our experience, chemical treatments, such as aluminum sulfate (alum), can reduce phosphorus release from lake sediments by approximately 90% (or greater) if designed and dosed correctly. Based on our modeling analysis, sediment phosphorus release in Blue Lake would need to be reduced by approximately 60% to meet the 360 pounds/year reduction goal/target. It is estimated that an internal load project designed to achieve a 90% reduction would result in a TP load reduction of approximately 536 pounds/year and improve summer TP concentrations by approximately 10 µg/L (Table 2).

Table 2. Blue Lake BMP reduction scenario summary

Scenario	Condition	Estimated Load Reduction[1]	% of Load Reduction Goal Achieved	Estimated Surface Water Concentration
SSTS	All IPHT and failing to protect GW SSTSs upgratded	16 lbs/yr	4%	37 µg/L
Watershed [100 µg/L]	All tributaries reduced to meet 100 µg/L standard	102 lbs/yr	28%	35 µg/L
Watershed [50 µg/L]	All tributaries reduced to 50 µg/L	295 lbs/yr	82%	32 µg/L
Internal	Alum treatment designed for ~90% internal load reduction	536 lbs/yr	100%	27 µg/L

Recommendations

Based on our review of available information/data for Blue Lake, the modeling analysis presented above and local knowledge of the lake and its watershed, we recommend the following next steps: 1) determine feasibility of wetland hydrologic restorations throughout the watershed; 2) conduct an internal load feasibility study; and 3) minor adjustments to current monitoring program. Each of these recommendations is described below in more detail.

Recommendation: Determine Feasibility of Wetland Hydrologic Restorations

The watershed draining to Blue Lake accounts for approximately 38% of the lake's annual phosphorus budget. The 508-pound annual phosphorus load is split up between several different tributaries/subwatersheds (Table 2 and Attachment D). The number of tributaries makes it difficult to identify regional BMPs that are both cost effective and remove a

significant amount of TP. All of the tributaries draining to the lake have flow-through wetland complexes that have been ditched and/or altered at one point in an effort to move water off the landscape and through these wetlands faster. Based on local knowledge and the sandy soil conditions throughout the watershed, runoff/loading from upland sources is believed to be low and elevated TP concentrations in the tributaries are likely driven by dissolved/soluble phosphorus exported from the wetland complexes and/or suspension of fine organic material within the channelized wetland during higher flow conditions (Wenck, 2017).

Wenck recently explored BMP options for Tributary #4 and identified a small berm and sand filter as a feasible and cost-effective option to manage particulate phosphorus sources from the wetland complex in this tributary (Wenck, 2017). Based on desktop review by Wenck staff and discussion with Isanti SWCD staff, it was determined that similar sand filter BMPs would be very difficult and/or expensive to implement in the other tributaries throughout the watershed due to low gradients and proximity to the lake.

For these reasons we recommend exploring restorations for Tributaries #1, #2, #3 and #6 (Figure 4) that attempt to restore hydrology (i.e. remove/limit impact of channelization) in the flow-through wetlands closer to natural/historic conditions. This would include a sheet pile weir with rock/riprap/limestone on the upstream and downstream sides (Figure 3). Additional surveying, engineering, and discussion with adjacent/upstream landowners would need to be conducted to determine the exact location, design and elevation of the top of the weirs so that there are no impacts to upstream infrastructure and private property.

Figure 3. Example weir in wetland in Shingle Creek Watershed

Table 3 presents planning level TP reductions for each proposed wetland restoration assuming a 38% TP removal efficiency. This removal efficiency is based on MPCA's Minnesota Stormwater Manual (link to website) recommended pollutant removal efficiencies for constructed wetlands and assumes all of the reduction would be through removal of particulate phosphorus. Currently, there is no ortho-phosphorus data available for Tributaries #1, #2, #3 and #6 to estimate the amount of particulate versus dissolved/soluble phosphorus. We strongly recommend that this baseline data be collected and evaluated prior to moving forward with final design and construction.

Even if the particulate/dissolved phosphorus concentrations are known, it can be very difficult to predict the water quality benefits of wetland restorations. Moving the flow of water out of the channels should increase residence time in the wetland complexes and reduce particulate phosphorus, however dissolved/soluble phosphorus levels may not improve. Thus, we recommend implementing 1-2 of these restorations to start with and conduct follow-up monitoring to evaluate water quality and hydrologic benefits. It should be pointed out that these restorations have the potential to provide several other benefits and ecosystem services including: increased infiltration, flow volume reduction, decrease in peak

flow rates, and potential improvement to the vegetation community (i.e. species diversity) and overall health of the wetland

Planning level estimates for these wetland restorations range from $60,000-$100,000 per site. This cost estimate includes wetland delineation and permitting ($6K-$10K), engineering/design (~$8K), bidding/construction oversight (~$8K) and final construction of the weirs ($45-$75K) which includes contingency for unforeseen construction costs and/or permitting. Final construction costs will depend on weir location, weir size, site access and restoration.

Table 3. Potential wetland restoration benefits and assumptions

Site	Current Load [lbs/yr]	Potential Load Reduction[1] [lbs/yr]	Planning Level Cost Range [total $]	Planning Level Cost-Benefit[2] [$/lb TP removed]
Trib #1	108	41	$60K - $100K	$49 - $81
Trib #2	109	41	$60K - $100K	$49 - $81
Trib #3	69	26	$60K - $100K	$77 - $128
Trib #6	82	31	$60K - $100K	$65 - $108
Total	368	139	$240K - $400K	$58 - $96

[1]Assumes 38% TP reduction efficiency (MPCA Stormwater Manual)
[2]Assumes 30-year life cycle and minimal maintenance

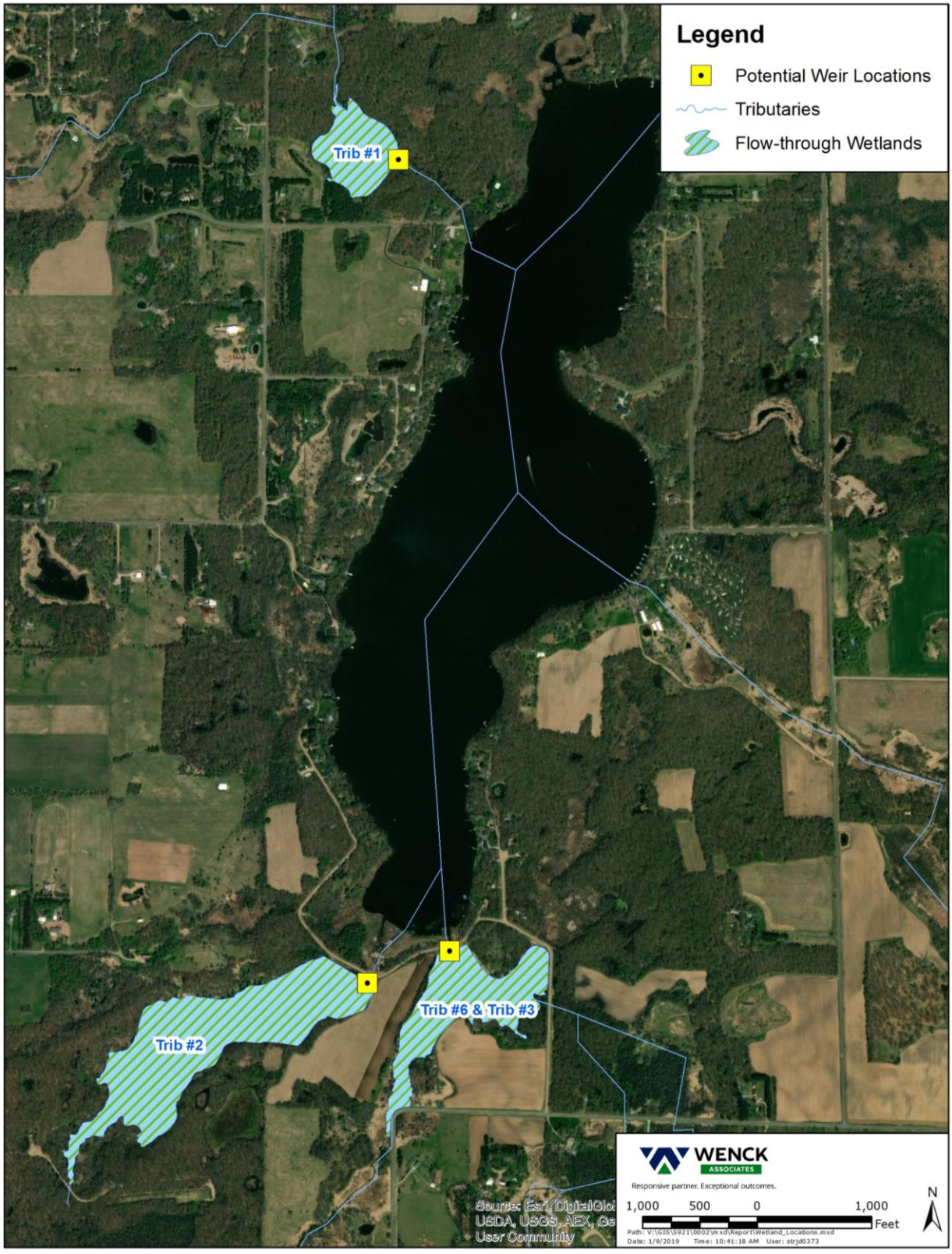

Figure 4. Potential wetland hydrologic restoration locations.

Recommendation: Conduct Internal Load Feasibility Study

The sediment phosphorus release rate used in the Blue Lake model (9.8 mg/m^2/day) is high and above the 75th percentile of release rates measured in lakes throughout Minnesota. While this rate was not directly measured in the lab, it was estimated using monitored hypolimnion phosphorus data and is further supported by the large spikes in surface water TP concentrations that commonly occur in the fall when stratification weakens (Appendix A). As discussed above, phosphorus release from the sediment represents the largest source (~45%) of TP loading to Blue lake and will likely need to be addressed at some point to meet the lake's 360 pounds/year load reduction target/goal.

Based on our experience, an alum treatment to manage internal loading in Blue Lake would likely cost between $200K-$650K depending on the size of the treatment area and the amount of alum needed. In order to refine these cost estimates, we recommend that an internal load feasibility study be conducted for Blue Lake in which a sediment cores are collected at a minimum of three sites and analyzed in the laboratory. Lab analysis of the cores should include the following parameters: sediment phosphorus release rate, moisture content-bulk density, loss-on-ignition, total iron, total aluminum, biologically-labile phosphorus and maximum allowable alum dosage. Results of these analyses will allow Wenck staff to validate and compare the release rate used in the Blue Lake model and develop a treatment plan to meet internal load reduction goals. The estimated cost of an internal load feasibility study for Blue Lake is ~$14K and includes sediment core collection (3 locations), laboratory analysis and and a final memo detailing recommended alum dosing rates, dosing schedule, treatment area and estimated treatment costs.

Monitoring Recommendations

Wenck recommends the following monitoring activities to complement current lake and tributary monitoring efforts for Blue Lake:

- Add ortho-phosphorus and dissolved phosphorus to the list of monitoring parameters for Tributaries #1, #2, #3 and #6
- Collect hypolimnion (i.e. 1 meter from bottom) TP and ortho-phosphorus samples during each sampling event for Blue Lake
- Continue water quality sampling for Blue Lake into the fall until the water column is completed (or nearly) mixed
- Perform early season (i.e. June) and late season (i.e. August) point-intercept submerged aquatic vegetation (SAV) surveys for Blue Lake to track effectiveness of CLP treatments and evaluate/track health of SAV community as BMPs are implemented

References

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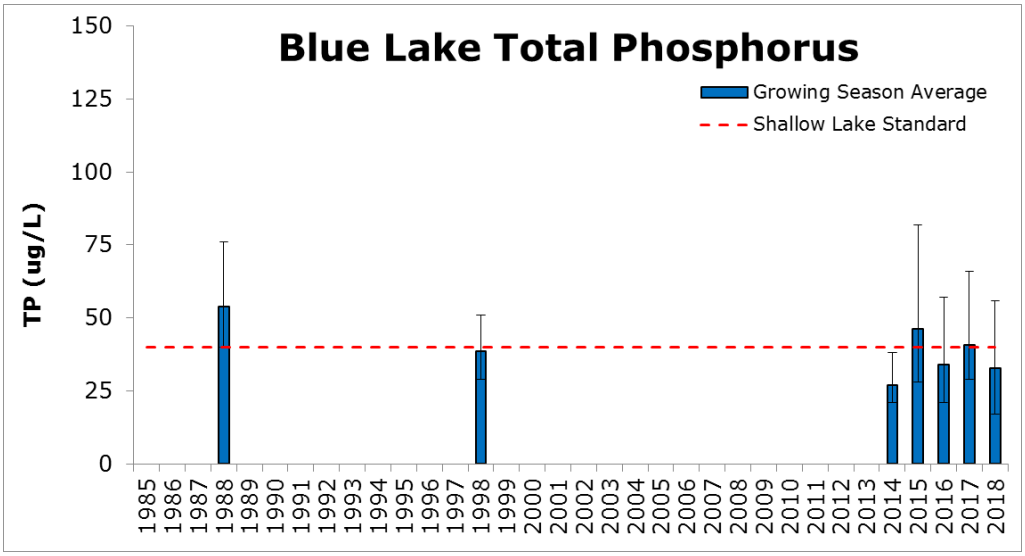
Attachment A

Blue Lake Historic Water Quality


Blue Lake Total Phosphorus
Growing Season Average
Shallow Lake Standard
TP (ug/L)
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125
100
75
50
25
0
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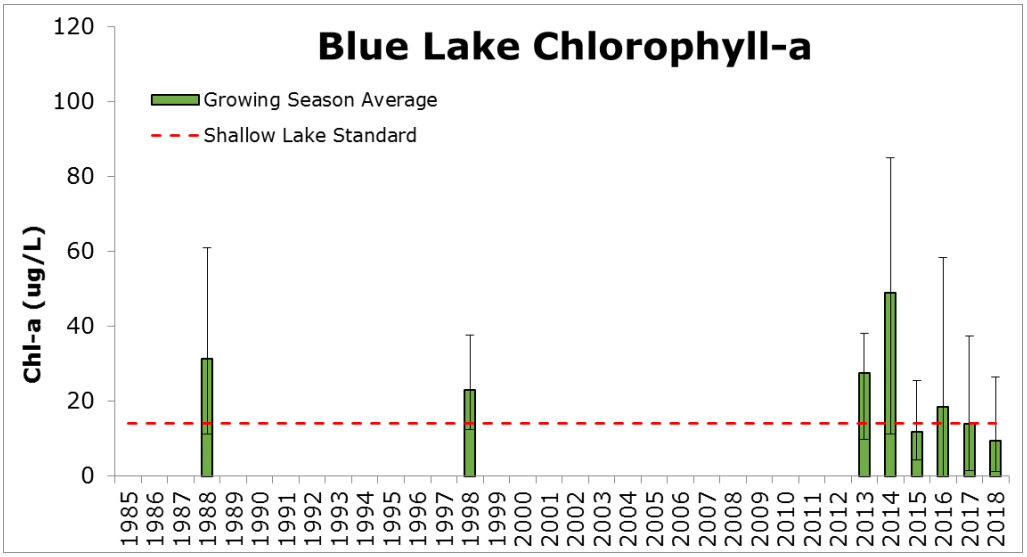
Blue Lake Chlorophyll-a
Growing Season Average
Shallow Lake Standard
Chl-a (ug/L)
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100
80
60
40
20
0
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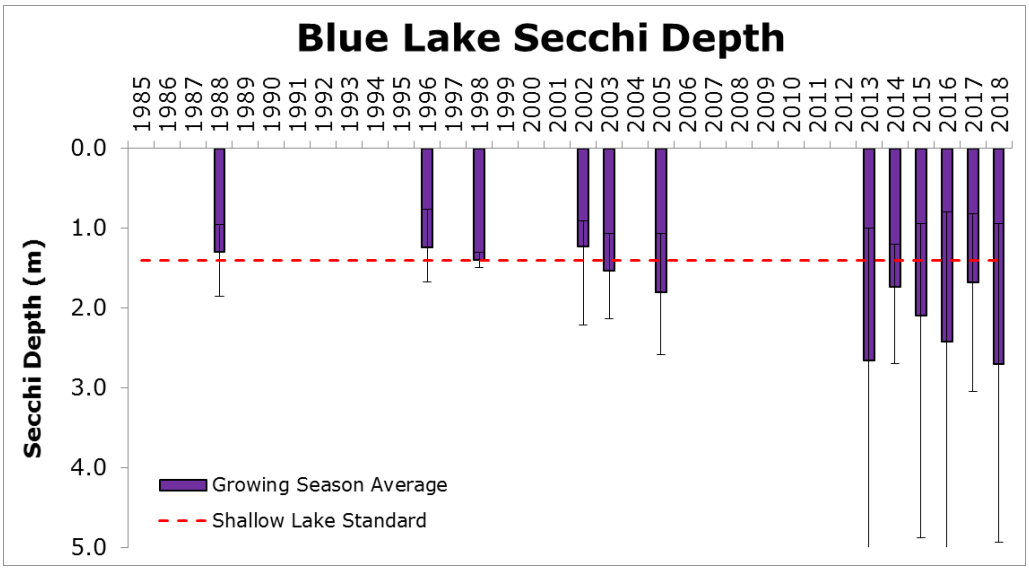
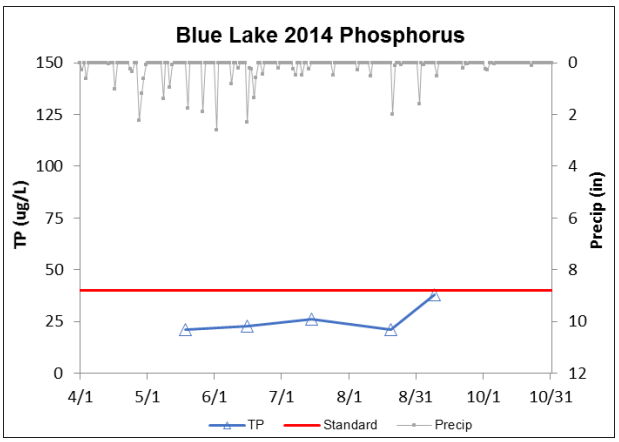

Blue Lake Secchi Depth
Secchi Depth (m)
0.0
1.0
2.0
3.0
4.0
5.0
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
Growing Season Average
Shallow Lake Standard


Blue Lake 2014 Phosphorus
TP (ug/L)
Precip (in)
150
125
100
75
50
25
0
0
2
4
6
8
10
12
4/1
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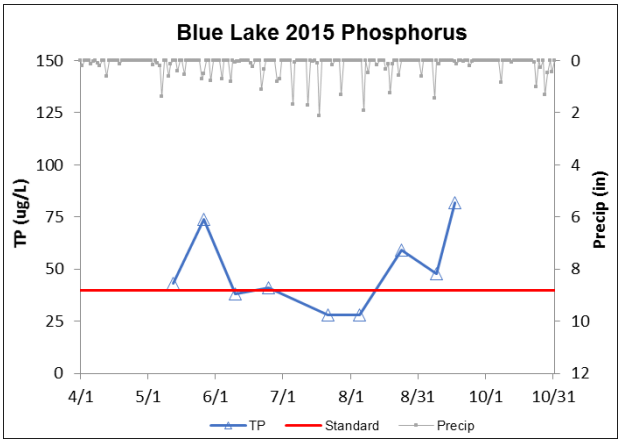
7/1
8/1
8/31
10/1
10/31
TP
Standard
Precip


Blue Lake 2015 Phosphorus
TP (ug/L)
Precip (in)
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125
100
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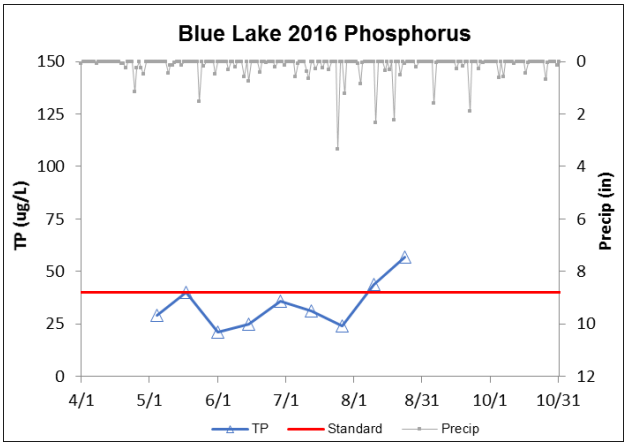
6/1
7/1
8/1
8/31
10/1
10/31
TP
Standard
Precip


Blue Lake 2016 Phosphorus
TP (ug/L)
Precip (in)
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2
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6/1
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8/1
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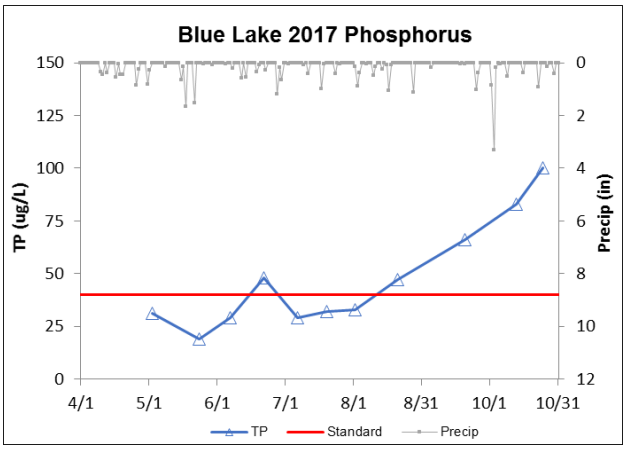
10/1
10/31
TP
Standard
Precip


Blue Lake 2017 Phosphorus
TP (ug/L)
Precip (in)
150
125
100
75
50
25
0
0
2
4
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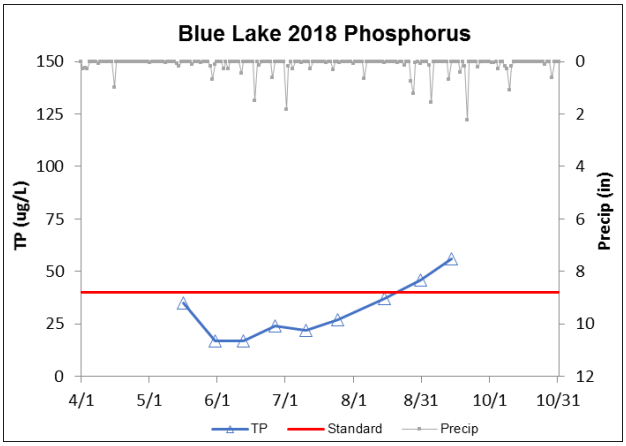
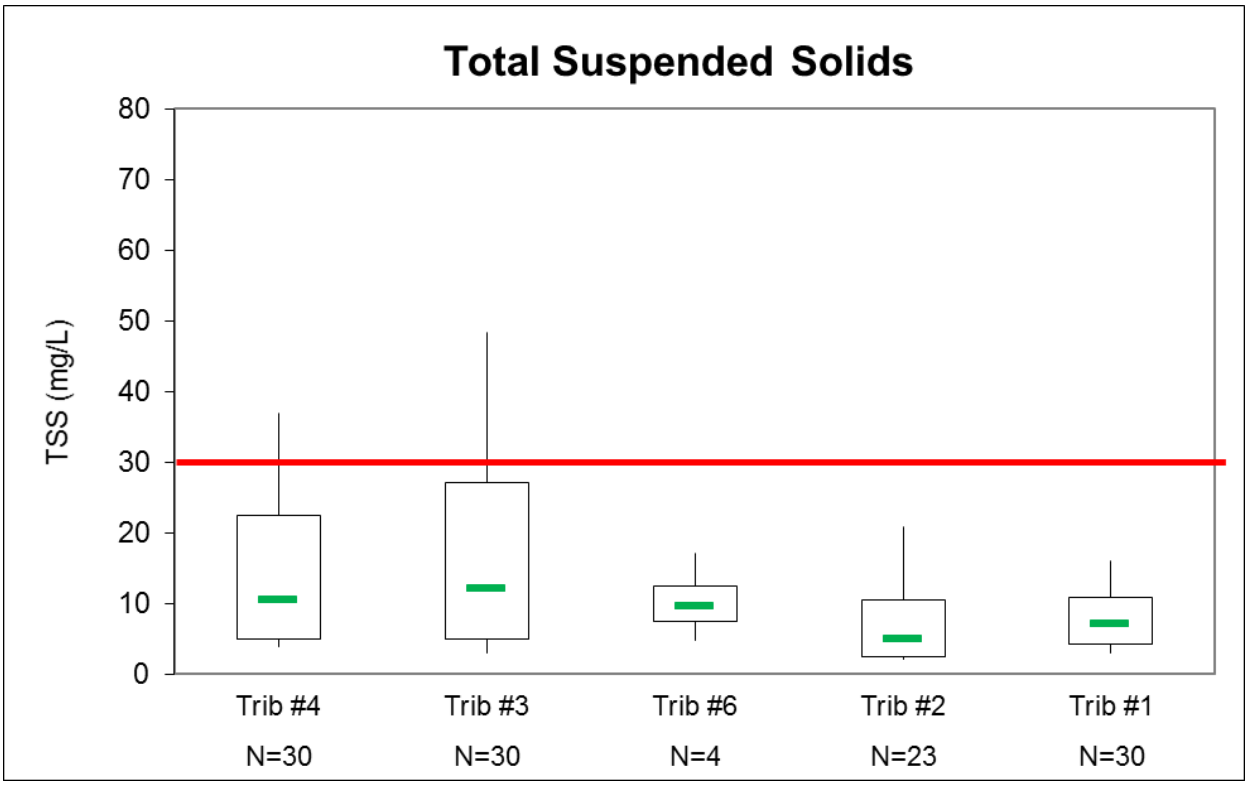
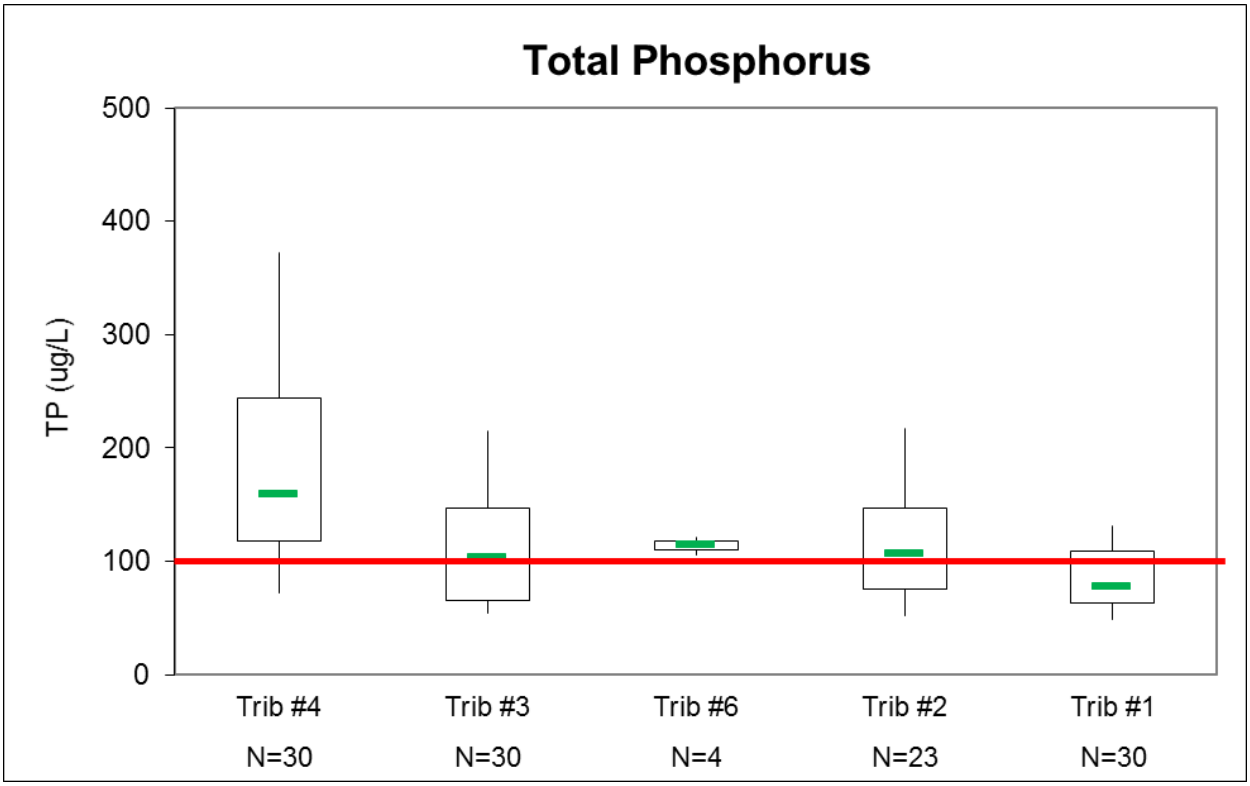
8
10
12
4/1
5/1
6/1
7/1
8/1
8/31
10/1
10/31
TP
Standard
Precip

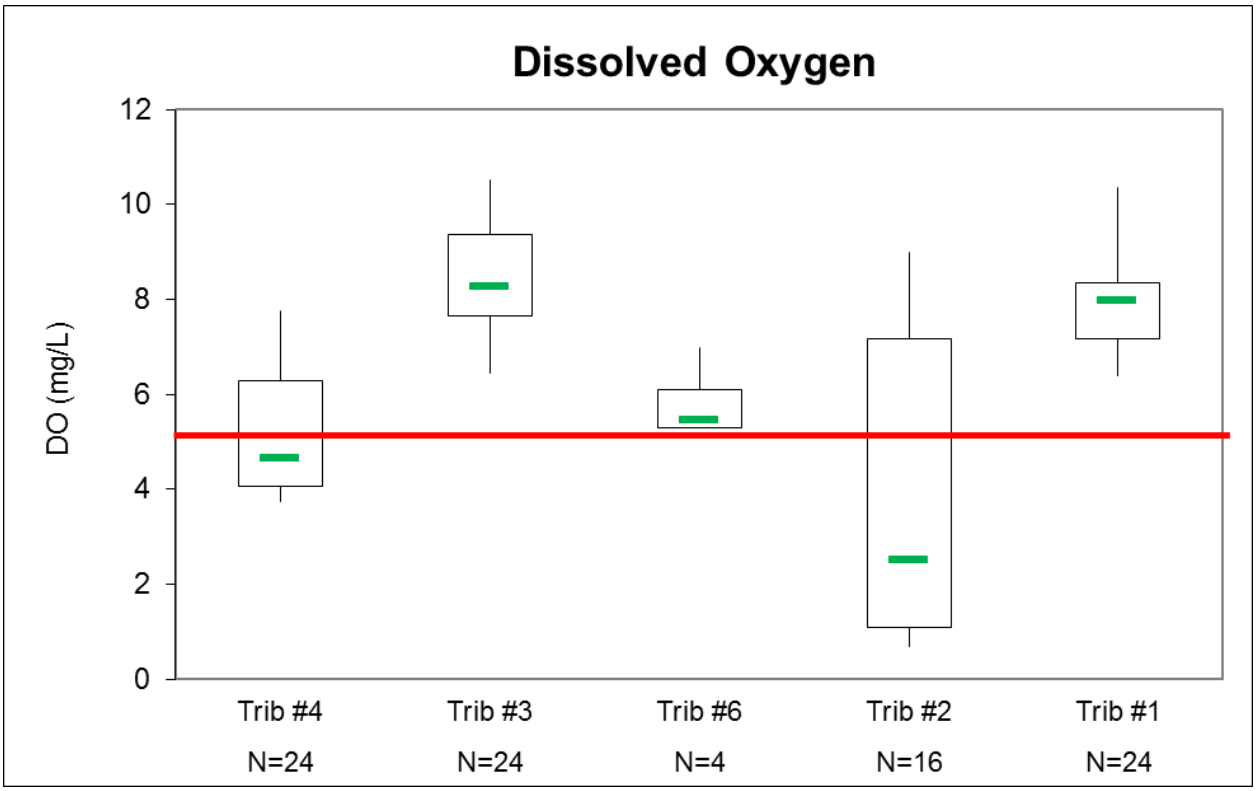

Blue Lake 2018 Phosphorus
TP (ug/L)
Precip (in)
150
125
100
75
50
25
0
0
2
4
6
8
10
12
4/1
5/1
6/1
7/1
8/1
8/31
10/1
10/31
TP
Standard
Precip

Attachment B

Blue Lake Tributary Monitoring Summary


Total Suspended Solids
TSS (mg/L)
80
70
60
50
40
30
20
10
0
Trib #4
N=30
Trib #3
N=30
Trib #6
N=4
Trib #2
N=23
Trib #1
N=30


Total Phosphorus
TP (ug/L)
500
400
300
200
100
0
Trib #4
N=30
Trib #3
N=30
Trib #6
N=4
Trib #2
N=23
Trib #1
N=30


Dissolved Oxygen
DO (mg/L)
12
10
8
6
4
2
0
Trib #4
N=24
Trib #3
N=24
Trib #6
N=4
Trib #2
N=16
Trib #1
N=24

Attachment C

Lake Response Model Documentation

Input Parameters

Lake Name:	Blue Lake	
Model Year:	Average	2014 - 2018

Average Loading Summary for Blue Lake

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Trib #1	2,925	1.9	469	84	1.0	108
2	Trib #2	507	6.9	290	138	1.0	109
3	Trib #3	1,758	1.5	215	118	1.0	69
4	Trib #4	281	6.9	161	195	1.0	85
5	Trib #6	469	6.9	268	112	1.0	82
6	Direct	1,004	1.9	161	125	1.0	55
	Summation	*5,940*	*2.71*	*1,564.64*			*507.9*

Curly-leaf Pondweed

	Name	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Curly-leaf Pondweed Load	1.0	53
	Summation		*53.1*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Directly surrounding Lake	0	0	0	#DIV/0!		109
2	0	0	0	0	#DIV/0!		0
3	0	0	0	0	#DIV/0!		0
4	0	0	0	0	#DIV/0!		0
5	0	0	0	0	#DIV/0!		0
	Summation	*0*	*0*	*0.0*	#DIV/0!		*109.0*

Atmosphere

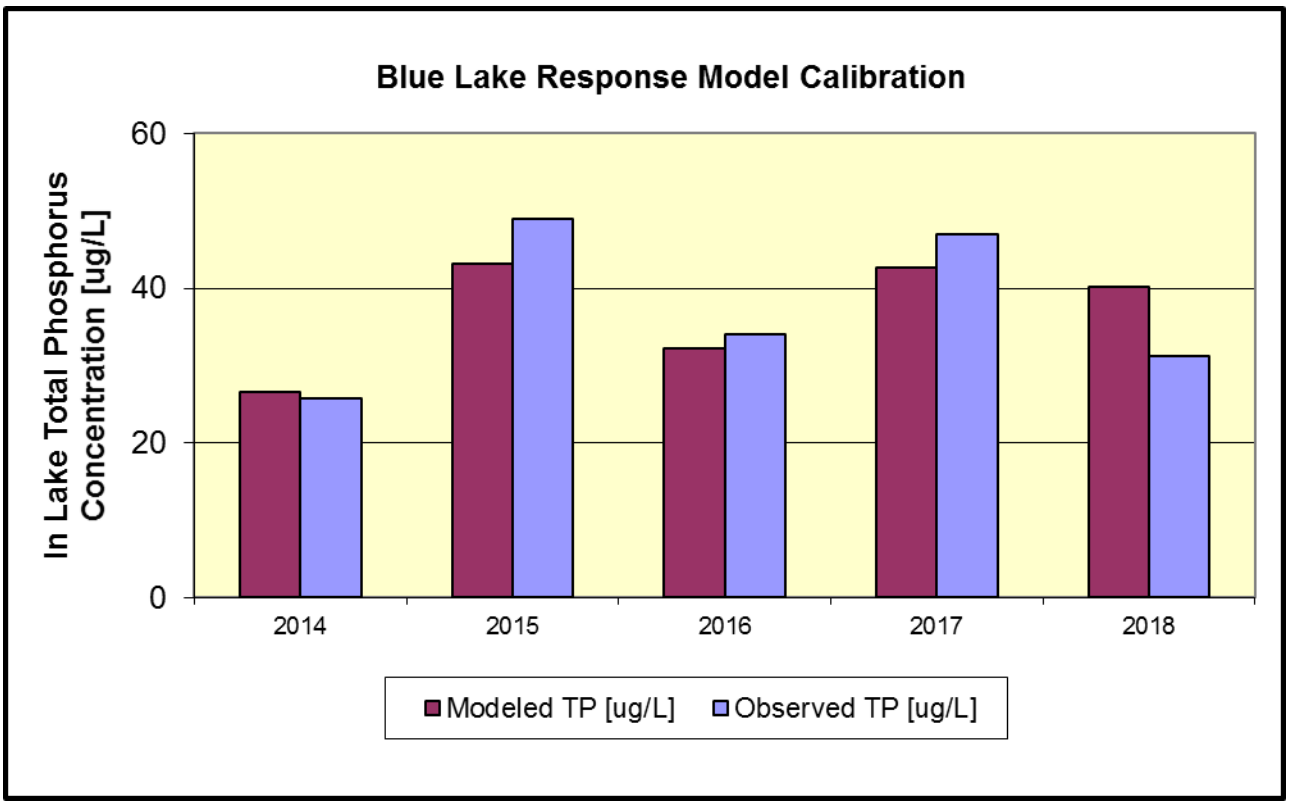
Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
263	33.5	33.5	0.00	0.24	1.0	62.9
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			

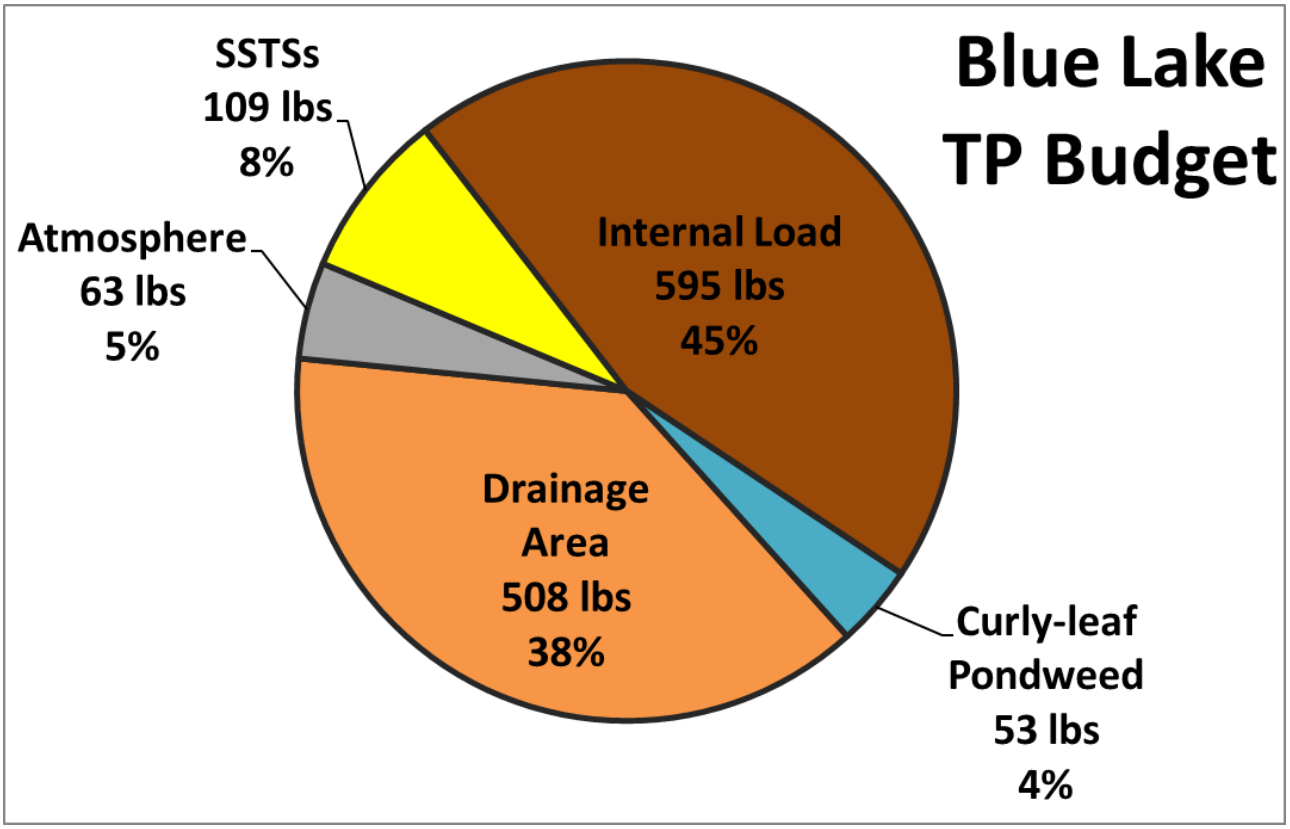
Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
1.06	0		Oxic		1.0	0
1.06	25.9		Anoxic	9.8	1.0	595
Summation						*595.1*
		Net Discharge [ac-ft/yr] =	**1,565**	**Net Load [lb/yr] =**		**1,328**

Average Lake Response Modeling for Blue Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	2.06	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	602	[kg/yr]
		Q (lake outflow) =	1.9	[10^6 m^3/yr]
		V (modeled lake volume) =	4.5	[10^6 m^3]
		T = V/Q =	2.33	[yr]
		P_i = W/Q =	312	[µg/l]
Model Predicted In-Lake [TP]			**37**	**[ug/l]**
Observed In-Lake [TP]			**37**	**[ug/l]**


Blue Lake Response Model Calibration
In Lake Total Phosphorus Concentration [ug/L]
60
40
20
0
2014
2015
2016
2017
2018
Modeled TP [ug/L]
Observed TP [ug/L]


Blue Lake TP Budget
SSTSs
109 lbs
8%
Atmosphere
63 lbs
5%
Internal Load
595 lbs
45%
Drainage Area
508 lbs
38%
Curly-leaf Pondweed
53 lbs
4%