Technical Memo

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To: Shingle Creek WMC

From: Ed Matthiesen, P.E. | Brian Beck | Tom Langer | Jeff Strom | Joe Bischoff | Diane Spector

Date: August 3, 2017

Subject: Bass and Pomerleau Lakes Alum Dosing Feasibility and Cost Estimate

INTRODUCTION AND BACKGROUND

Bass Lake is a shallow eutrophic lake and Pomerleau Lake is a deep eutrophic lake, both located in Plymouth, MN. Pomerleau discharges through upper Bass Creek to Bass Lake. In 2002 the Minnesota Pollution Control Agency (MPCA) listed both lakes as impaired for excess nutrients. In 2009, Wenck completed a TMDL and Implementation Plan for Bass, Pomerleau, and Schmidt Lakes to assess nutrient loading concerns and provide strategies to reduce excess nutrient loading (Wenck 2009a, 2009b). Since the TMDL was published, Schmidt Lake, which drains to Bass Lake, has been delisted because of improved water quality resulting from a number of actions taken by the City, residents, and lake association. Table 1 below shows physical characteristics of the lakes and their lakesheds. Information about water quality, fish, and aquatic vegetation may be found in Appendix A.

Table 1. Physical characteristics of Bass and Pomerleau Lakes.

Parameter	Bass Lake	Pomerleau Lake
Surface Area (ac)	175	30
Average (Maximum) Depth (ft)	10.1 (31)	10.9 (26)
Volume (ac-ft)	1,760	329
Residence Time (years)	0.47	0.73
Littoral Area (ac)	143 (82%)	19.8 (66%)
Watershed Size (ac)	3,183	266

In 2017 the Commission completed a TMDL Five Year Review, summarizing progress to date and updating the nutrient budgets and targets using more recent and complete monitoring data (Wenck 2017). Those nutrient budget updates used actual monitored flow and nutrient concentration data from the watershed, sediment core data, and more intensive in-lake data to update the lake response models. For both lakes the model updates indicated that internal loading accounts for a greater proportion of the nutrient budget than was assumed in the TMDL, which calculated budgets and targets using literature values, model residuals, and a more limited in-lake data set from the late 1990s. For Bass Lake, the updated estimates suggest internal load is approximately 21% of the total phosphorus (TP) budget (Figure 1). This is a significant departure from the TMDL nutrient budget which suggests that internal loading was a minimal component of the phosphorus budget. For Pomerleau Lake, the modeling update showed a need to reduce internal load by 130 pounds/year (92% reduction), which is significantly more than the 20 pound reduction estimated in the TMDL.

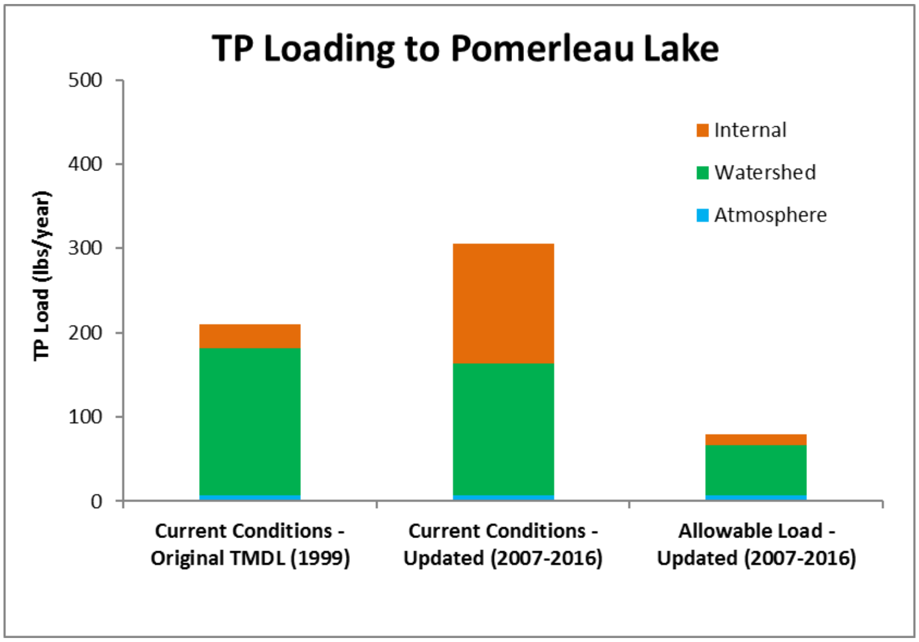

Figure 1. Current conditions and updated allowable load targets for Bass Lake.

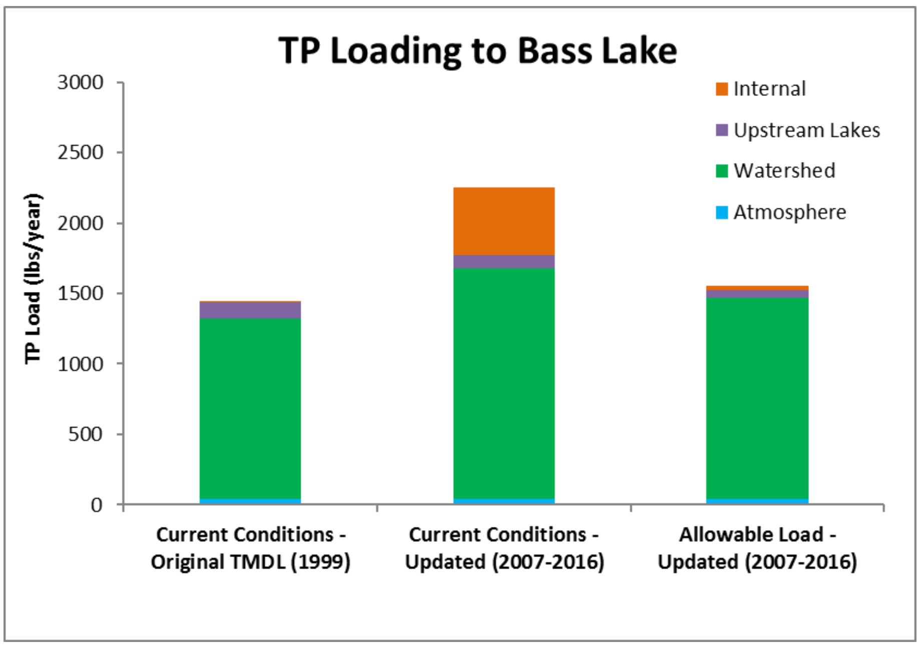

Figure 2. Current conditions and updated allowable load targets for Pomerleau Lake.

The TMDL Five Year Review estimated that BMPs constructed in the Bass and Pomerleau Lakes watershed have reduced TP loading by approximately 950 pounds of TP per year since the original TMDL was published, mostly by converting untreated agricultural land in the upper watershed to developed uses with stormwater treatment and 1" of volume control. However, the review estimated that in addition to internal load reduction, an external TP load reduction of 16% (215 lbs) is still needed for Bass Lake and a 62% (96 lbs) reduction for Pomerleau Lake to reach the target nutrient budgets. Since significant progress has been made in reducing watershed load, it is appropriate at this time to start to manage the internal load. This technical memorandum assesses the feasibility of an aluminum sulfate (alum) treatment on Bass and Pomerleau Lakes to reduce internal phosphorus loading and the estimated project costs and longevity of the treatment.

METHODS

We used sediment data collected in 2010 and 2013 to outline and determine the potential cost benefit of performing an alum treatment for Bass Lake and Pomerleau Lake, respectively. Triplicate sediment cores were collected from a single location and used to determine the sediment release rate. The uppermost 10 cm were homogenized for assessment to provide sediment chemistry data to aid alum dose calculations. A gravity sediment coring device equipped with an acrylic core liner was used to collect the sample.

Anoxic conditions within the lake were assessed by evaluating depth and oxygen profiles throughout the open water period (May to October). Profiles consisted of one meter intervals between profile readings. Depth of anoxia was considered the first occurrence of oxygen concentrations less than 2.0 mg/L within a given profile. All first anoxic conditions depths were averaged to determine the mean anoxic depth within the lake. Dissolved oxygen profiles were derived using data from the MPCA EDA webpage.

Depth contours of the lake were updated using logged sonar information and ciBioBase post processing software. Secondary processing was needed in shallow depth areas where contours were cut off due to lake boundary, however, these areas did not influence area mapping or calculation of the anoxic zone within the lake. The ciBioBase processing produced one foot contours that were used to calculate surface areas for this assessment.

PHOSPHORUS RELEASE AND SEDIMENT CHEMISTRY

Bass Lake profundal sediment exhibited an anoxic rate of P release of 14.5 $mg \cdot m^{-2} \cdot d^{-1}$. Pomerleau Lake profundal sediment exhibited an anoxic rate of P release of 11.8 $mg \cdot m^{-2} \cdot d^{-1}$. These rates were relatively high and comparable to anoxic P release rates measured in other eutrophic systems in the region.

Table 2. Mean phosphorus release rates under anaerobic conditions.

Station	Anaerobic P Release ($mg/m^2/day$)
Bass	14.5
Pomerleau	11.8

Iron-bound and loosely-bound phosphorus (redox-P) are the fractions of phosphorus associated with sediment P release during periods of low dissolved oxygen (<2 mg/L). Sediments with more iron-bound or redox-P typically have higher phosphorus release rates. Sediments that do have high internal release rates have a large peak of iron-bound P near the sediment-water interface (Figure 3). We find that redox-P concentrations greater than 0.1 mg/g are associated with lake sediments that have high phosphorus release rates.

Sediments collected from Bass Lake had redox-P concentrations of 0.398 mg/g in the uppermost 10 cm. These are moderately high and are consistent with the high release rates observed in Bass Lake sediments. Sediments collected from Pomerleau Lake have redox-P concentrations of 0.853 mg/g in the uppermost 10 cm. These redox-P concentrations are substantially higher than those typically observed in oligotrophic and mesotrophic lakes and consistent with the high release rates observed in Pomerleau Lake sediments.

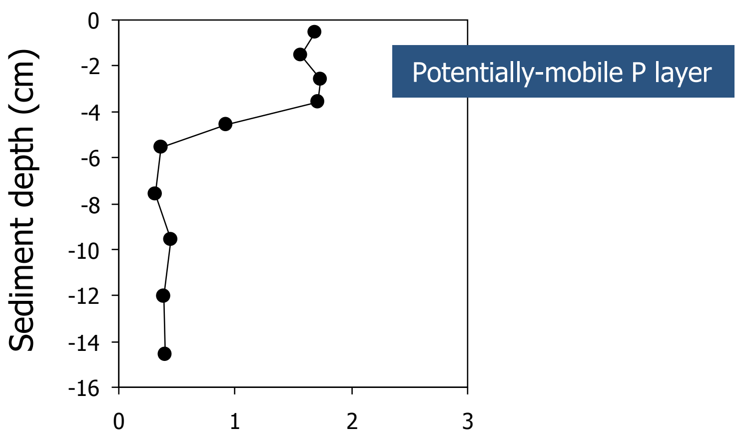

Figure 3. Hypothetical redox-P concentration profile in a lake with elevated release rates.

ALUM DOSING RECOMMENDATIONS

Two factors are considered when calculating an alum dose: redox-P concentration and the depth of anoxia. Anoxic depth is defined as the sediment area that is exposed to dissolved oxygen lower than 2 mg/L, which is represents the area that will be treated with alum. The second factor is the depth of sediment that will be treated with alum. We use sediment profiles similar to Figure 3 to determine the depth of elevated redox-P concentrations. DO data indicates that the average anoxic depth in Bass Lake is approximately 15 feet. Therefore, the 15 foot contour was selected as the alum treatment area (Figure 4; 27.6 acres). Lab results determined that the 0-10 cm sediment sample contained 0.398 mg/g redox P, which provides us the total amount of redox-P in the uppermost 10 cm of sediment. Sediment chemistry data indicates that an alum application rate of 135 g Al/m^2 is required to convert redox-P in the uppermost 10 cm to aluminum bound P.

DO data indicates that the average anoxic depth in Pomerleau Lake is about 7 feet. Therefore, the 7 foot contour was selected as the alum treatment area (Figure 5; 13.8 acres). Lab results determined that the 0-10 cm sediment sample contained 0.853 mg/g redox P, which provides us the total amount of redox-P in the uppermost 10 cm of sediment. Sediment chemistry data indicates that an alum application rate of 160 g Al/m^2 is required to convert redox-P in the uppermost 10 cm to aluminum bound P.

Alum should be applied in two doses. Between the doses, sediment cores should be taken to verify second dose application rates.

Table 3. Bass Lake alum application cost estimate for 10 cm treatment depth.

Bass Lake Alum Application Cost Estimate				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
Initial Aluminum Sulfate application	Gal $AlSO_4$	34,006	$ 1.80	$61,200
Secondary Aluminum Sulfate application	Gal $AlSO_4$	34,006	$ 1.80	$61,200
Application Total				$122,400
Application observation and monitoring				$5,000
Plans and specs, bidding, permitting				$15,000
Verification core monitoring				$20,000
Total Cost Estimate				**$223,600**

Table 4. Pomerleau Lake alum application cost estimate for 10 cm treatment depth.

Pomerleau Lake Alum Application Cost Estimate				
Item	**Unit**	**Quantity**	**Unit Cost**	**Total Cost**
Initial Aluminum Sulfate application	Gal $AlSO_4$	8,099	$ 1.80	$36,400
Secondary Aluminum Sulfate application	Gal $AlSO_4$	8,099	$ 1.80	$36,400
Application Total				$72,800
Application observation and monitoring				$5,000
Plans and specs, bidding, permitting				$10,000
Verification core monitoring				$5,000
Total Cost Estimate				**$97,800**

ESTIMATED LOAD REDUCTION AND ALUM LONGEVITY

Wenck's experience with internal load reduction using alum suggests that phosphorus release rates will decrease by greater than 90%. In many cases phosphorus release rates will decrease by 95-99%. Sediment core release rates suggest the current internal load in Bass Lake is about 479 pounds per year and the target load reduction of 446 pounds P/year is a 93% reduction. For Pomerleau the current internal load is about 142 pounds per year. The target load reduction of 130 pounds P/year is a 92% reduction. Both of these reductions are feasible and well within the range achieved on other lakes.

To estimate the effectiveness of the alum, we consider the questions, "What is the potential longevity of an alum treatment and what factors will impact longevity of alum treatments?" Our goal is to be able to assess how long it will take to bury the alum layer after the alum application. The important factor is how much P sedimentation is occurring and not just overall sediment. We focused on the P sedimentation from the lake response models. We used the Canfield-Bachmann sedimentation term (Equation 1) to estimate how long it would take to replace inactivated phosphorus in the top 10 cm of sediment. It is important to note that this analysis should not be interpreted as the exact life of an alum treatment. The goal of this analysis is to assess whether a treatment will be quickly buried based on phosphorus settling and if additional watershed load should be reduced prior to an alum treatment.

We ran two scenarios to assess potential longevity of an alum treatment in each lake. The first scenario was to assess the longevity based on current watershed loading conditions. The second scenario assessed the potential longevity assuming TMDL watershed load reductions have been met (Table 5). This data suggests that additional watershed reductions would increase the longevity of the alum treatment for both lakes. The Five Year Review identified several strategies for accomplishing additional watershed load reductions, especially in the Pomerleau lakeshed.

Equation 1.

$$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$$

Table 5. Expected longevity of alum treatment effectiveness.

Lake	Longevity (years) Current Watershed Load Rate	TMDL Watershed Load Rate
Bass	16	19
Pomerleau	11	30

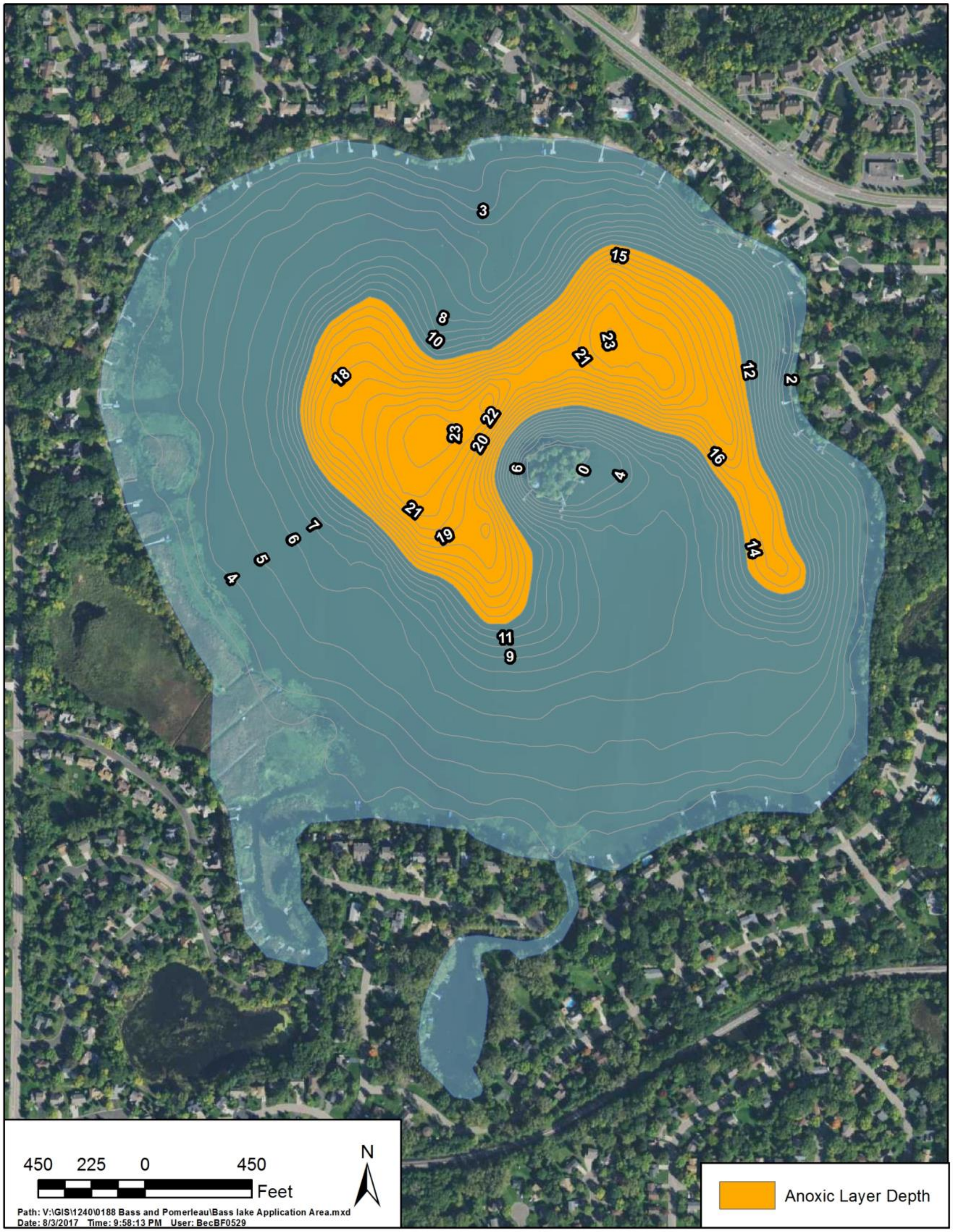

Figure 4. Bass Lake contours and anoxic zones.

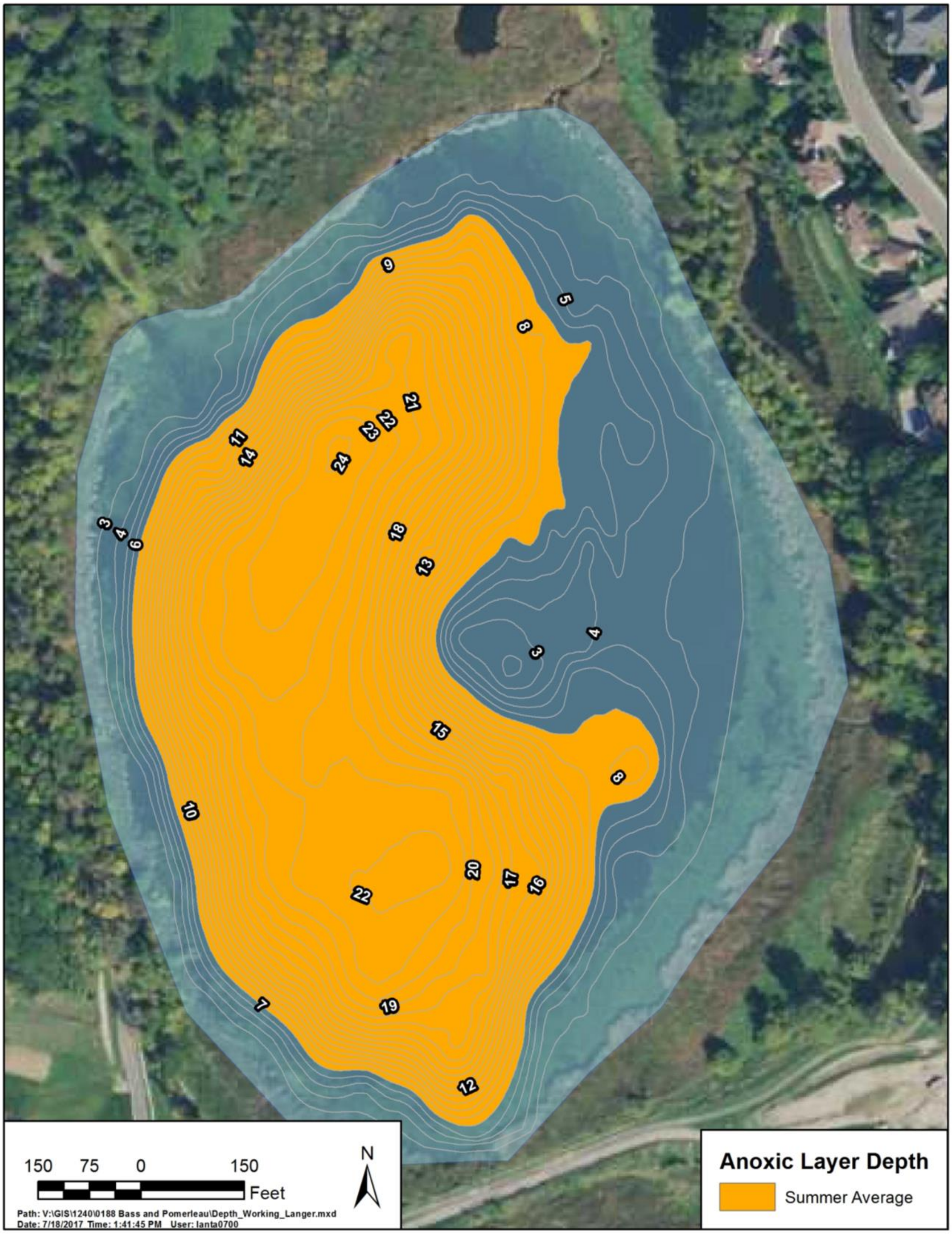

Figure 5. Pomerleau Lake contours and anoxic zones.

IN-LAKE RESPONSE TO AN ALUM TREATMENT

Improving water quality will increase the light availability to the submerged vegetation community. The exact response of the vegetation community to improved water quality conditions is not certain and difficult to predict, however, increased plant diversity, biomass and coverage within the lake can be expected. The availability of propagules and seeds, the amount of herbivory and the influence of current and remnant populations will largely influence which species will occur and respond to the change in light conditions. The preparation for and planning of a vegetation response to the alum treatment will be an important step as a conflict with recreational users may occur where vegetation reaches the water surface and impedes swimming and boating activities.

Aquatic vegetation surveys have been completed on Bass Lake and an initial survey has been completed on Pomerleau Lake. Eurasian watermilfoil was not detected in either lake. Curlyleaf pondweed is present in Bass Lake, and the Bass Lake Association has been actively managing that invasive for many years. Bass Lake exhibits fair diversity in native aquatic vegetation and with continued management of the CLP it is expected that native species will likely become more abundant as clarity improves. The lake is 82% littoral, and the Lake Association is aware that post-treatment vegetative coverage will likely increase. A fish survey completed on Bass Lake found only one common carp, which is unlikely to reduce the longevity of the alum treatment or otherwise influence the fish community.

An initial, early-season vegetation survey was completed on Pomerleau Lake in 2017 and did not detect curlyleaf pondweed. Coontail was the dominant species but other native species were also present. There are about 10 residences with views of Pomerleau Lake, although they are separated from the lake by riparian wetlands, stormwater ponds and a public trail. There is a public access on that lake, but overall the lake is currently lightly used for recreation. A fish survey found the lake was dominated by crappies and black bullhead at the upper range of typical abundance for this type of lake. No carp were detected. Post-alum treatment aquatic vegetation and fish management would likely be necessary to improve the attractiveness of on-lake recreation.

FEASIBILITY

The City of Plymouth has reduced watershed load to Bass and Pomerleau Lakes through BMPs and by land use conversion with stormwater treatment and volume control. Updated nutrient budgets and TMDL calculations suggest that Bass Lake requires an estimated 93% internal load reduction and Pomerleau Lake a 92% reduction. Alum treatments have reduced internal load by 90-99% on other Minnesota lakes. Sedimentation scenarios estimate a useful life of 11-16 years if no additional watershed load reductions are completed, and 19-30 years if the watershed load reduction targets are met.

Alum treatments on Bass and Pomerleau Lakes are feasible and will be cost-effective if dosed properly. Assuming an internal load reduction of 95%, the annual load reduction that could be achieved by alum is estimated as 455 pounds on Bass and 135 pounds on Pomerleau. A conservative approach to calculating dosing and estimating cost was used in this feasibility report. Additional sediment cores are recommended to refine the spatial extent and depth of dosing required. Based on current data the cost of refining the dosing and performing the alum treatment on the two lakes is estimated to be $350,000, or about **$600 per pound.** This does not include the cost of post-treatment vegetation and fish management or post-treatment monitoring.

References

Wenck Associates Inc. 2009a. Schmidt, Pomerleau and Bass Lakes Nutrient TMDL. pca.state.mn.us/sites/default/files/wq-iw8-17e.pdf

Wenck Associates Inc. 2009b. Schmidt, Pomerleau and Bass Lakes Nutrient TMDL Implementation Plan. pca.state.mn.us/sites/default/files/wq-iw8-17c.pdf

Wenck Associates, Inc. 2017. Schmidt, Pomerleau, and Bass Lakes Nutrient TMDL Five Year Review. shinglecreek.org/uploads/5/7/7/6/57762663/crystal_5-year_report_final.pdf

APPENDIX A

Extract from Bass, Schmidt, and Pomerleau Lakes TMDL Five Year Review

Data and Implementation Efforts Since TMDL (2007)

- Monitoring
  - Lake inflow monitoring (3-Rivers Park District)
  - Internal load measurements (sediment cores)
  - Vegetation surveys
  - Fish surveys
  - Intensive in-lake monitoring
- Watershed and in-lake projects
- Modeling and allocation updates

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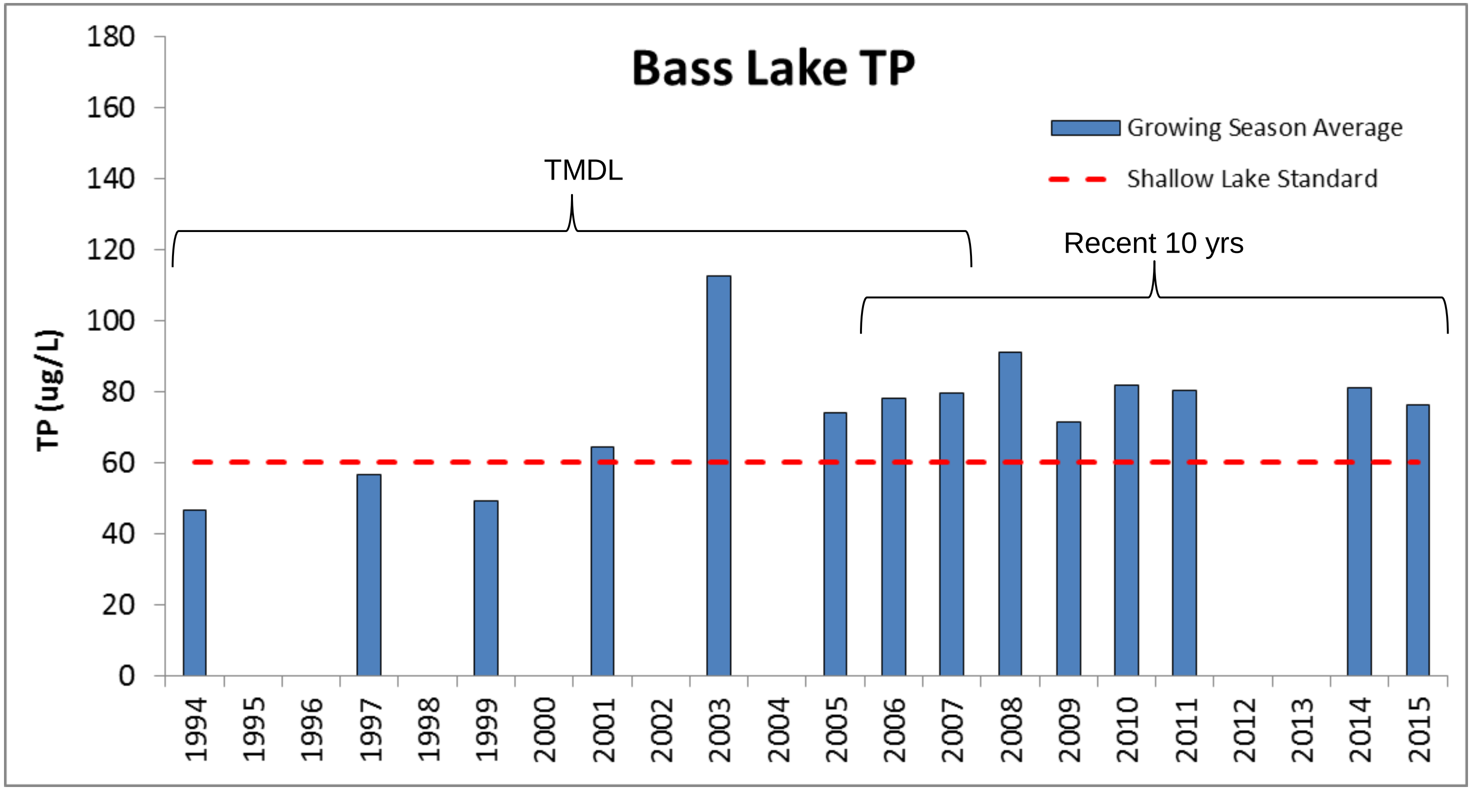
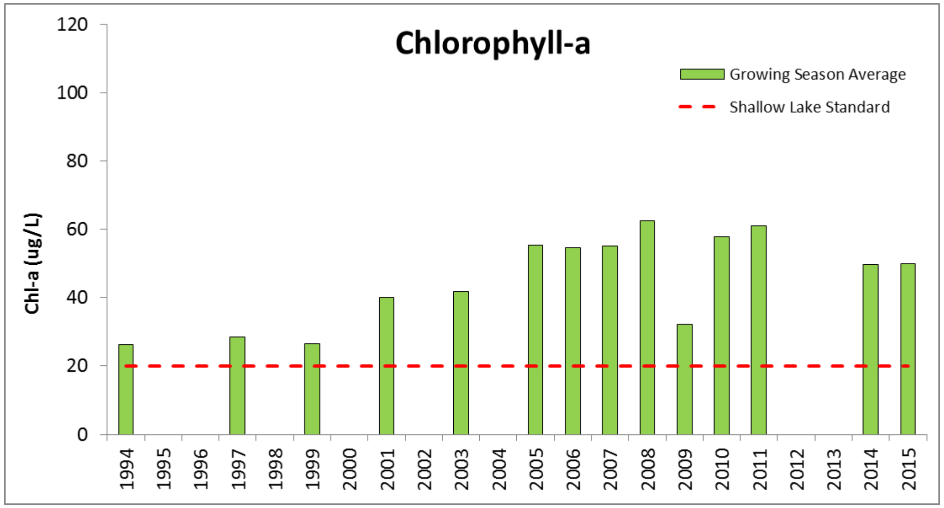
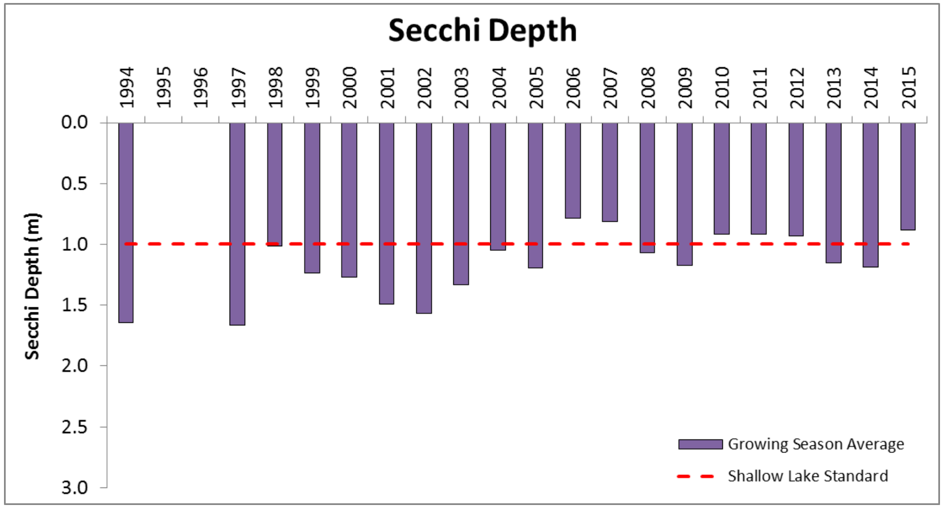
Bass Lake
5-year Review

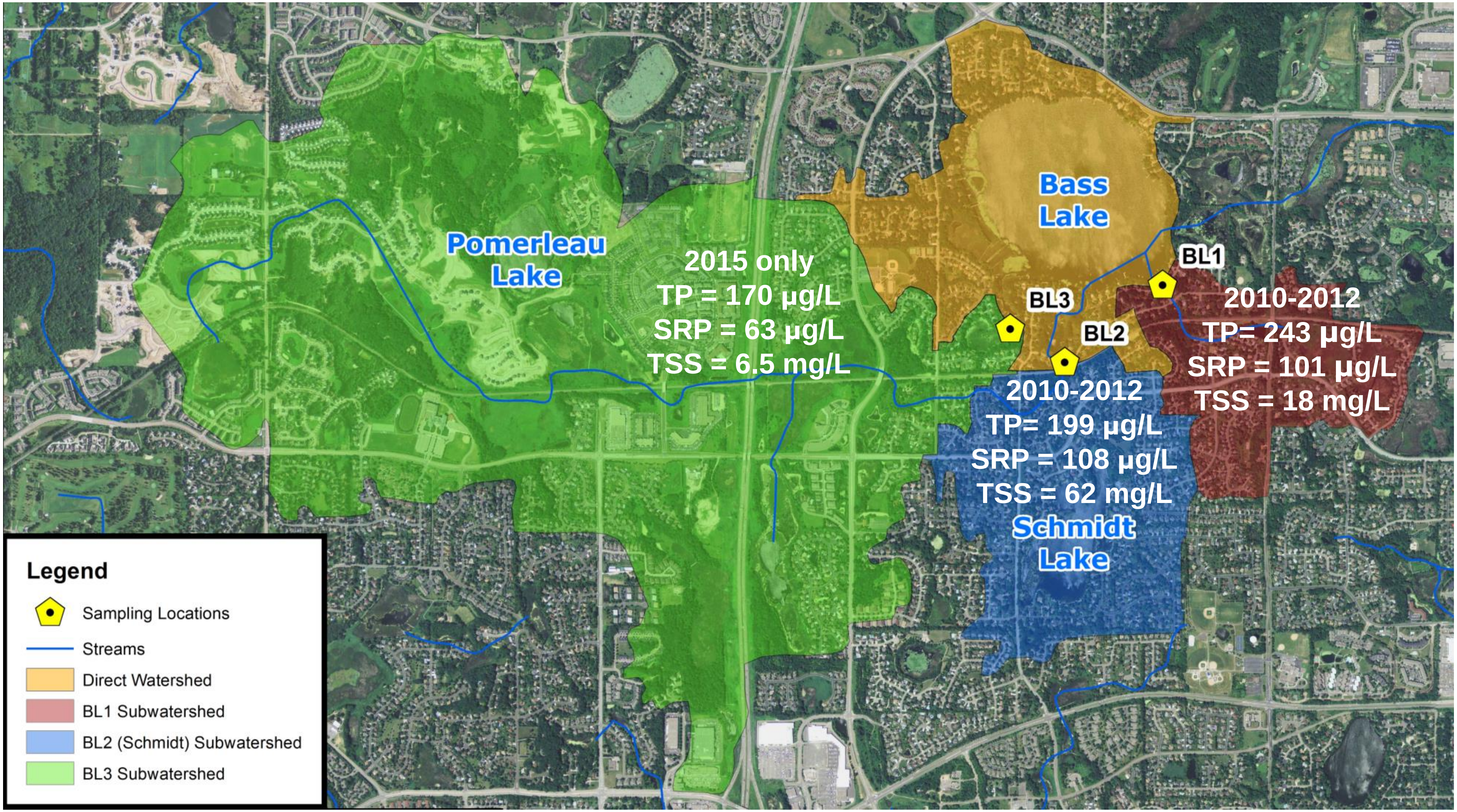
Bass Lake TMDL: 62 µg/L
Recent 10 yrs: 80 µg/L







Bass Lake Stream Monitoring



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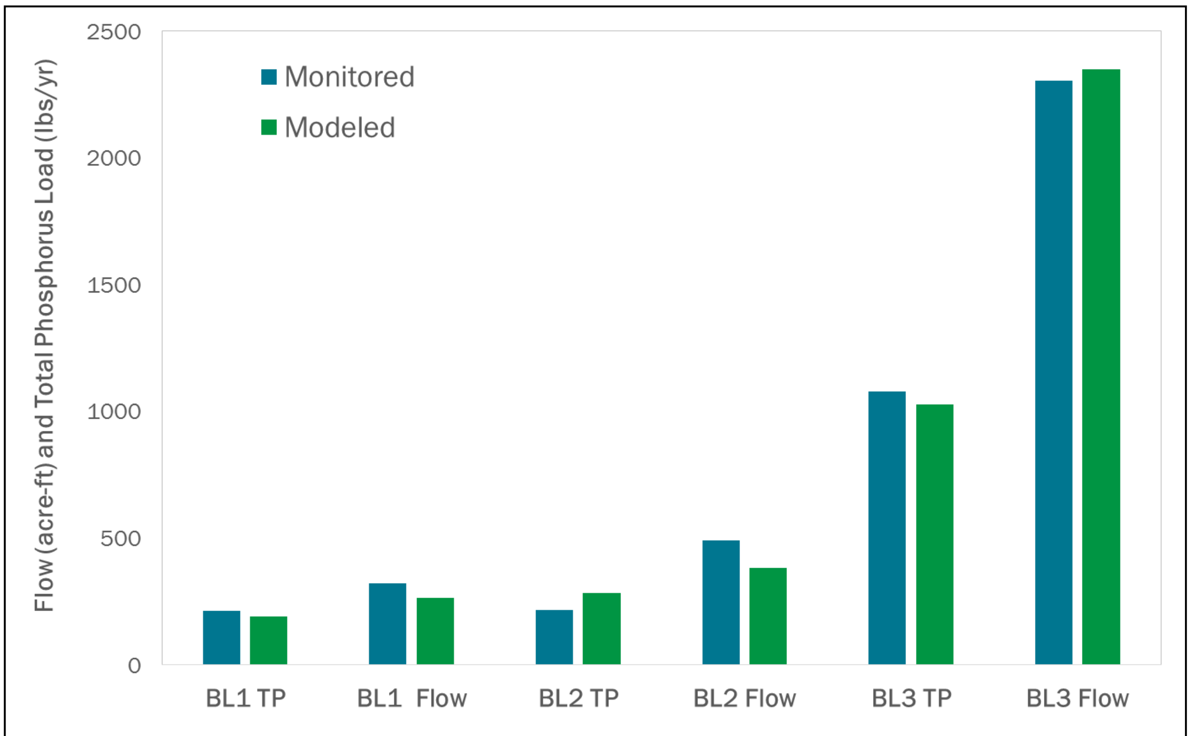
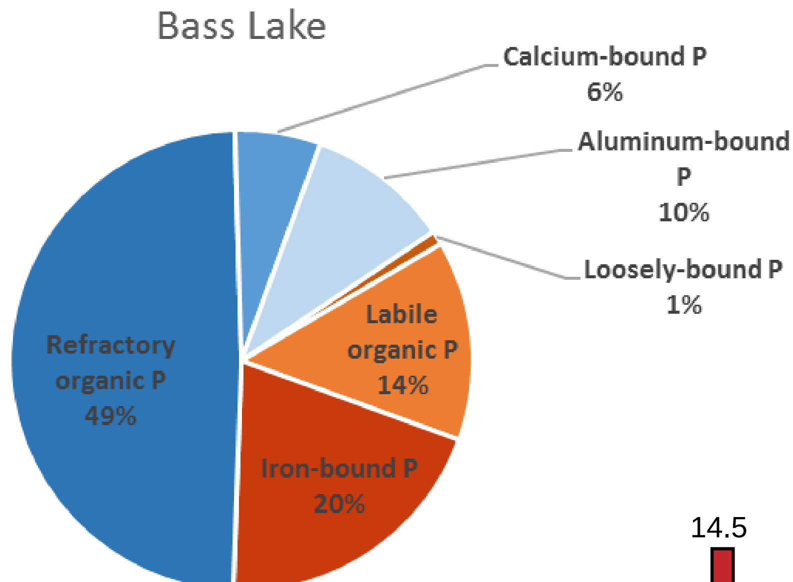
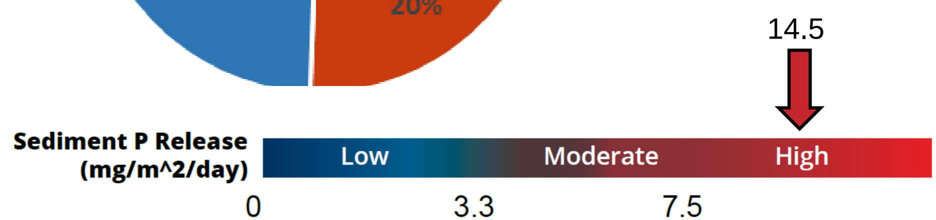
Bass Lake Watershed
Updated P8 Model

	TMDL [P8 Model]	Updated P8 Model[1]
Flow Volume (acre-ft/yr)	2,630	3,181
TP conc. (µg/L)	153	190
TP Load (lbs/yr)	1,279	1,640 (w/BMPs)



Bass Lake Internal Load (Sediment)





		TMDL	Measured*
Bass Internal Load	Anoxic Factor	NA	21 days
	P Release rate	0 mg/m²/day	14.5 mg/m²/day
	Internal P Load	0 lbs/yr	479 lbs/yr

*Sediment cores collected March 2010

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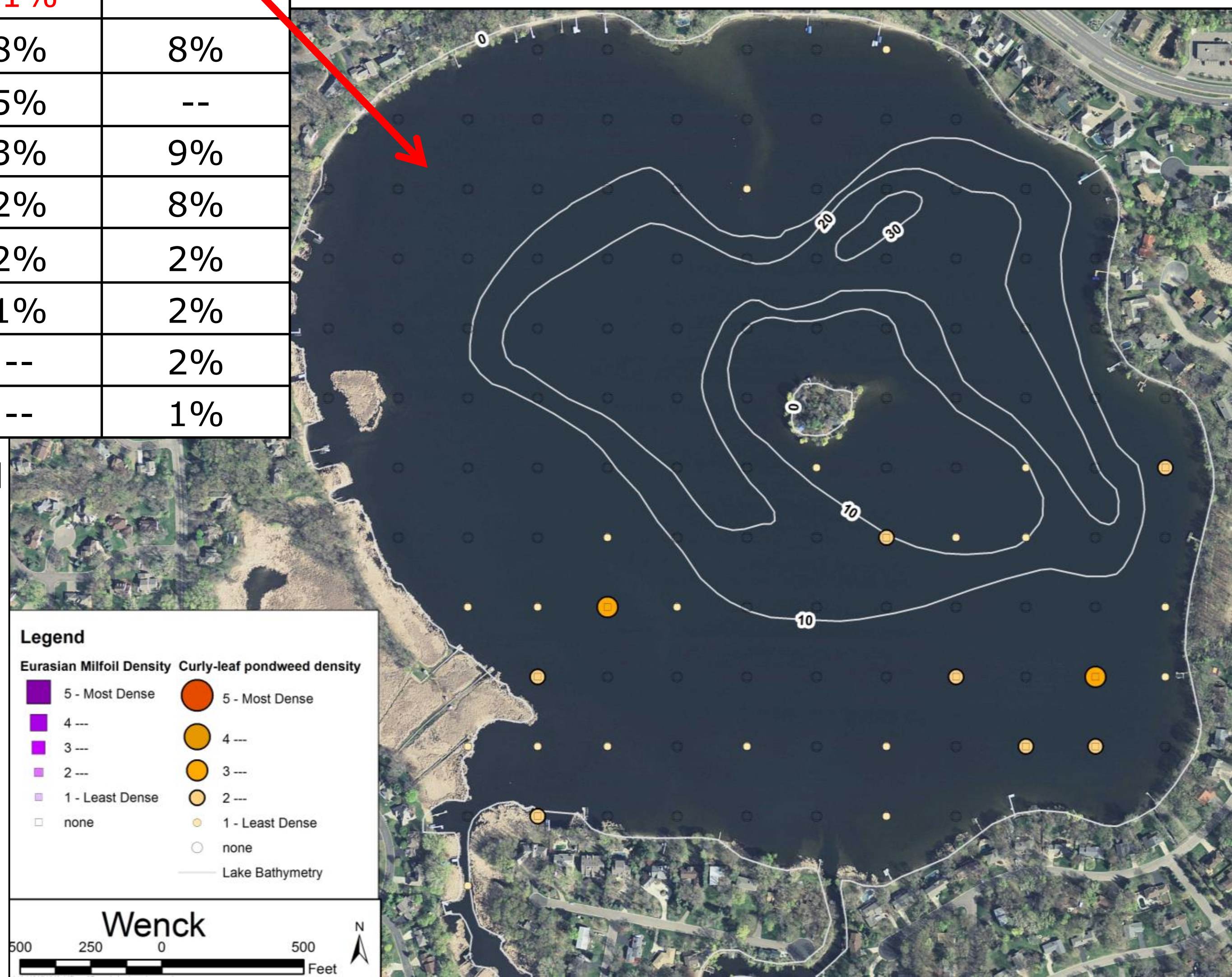
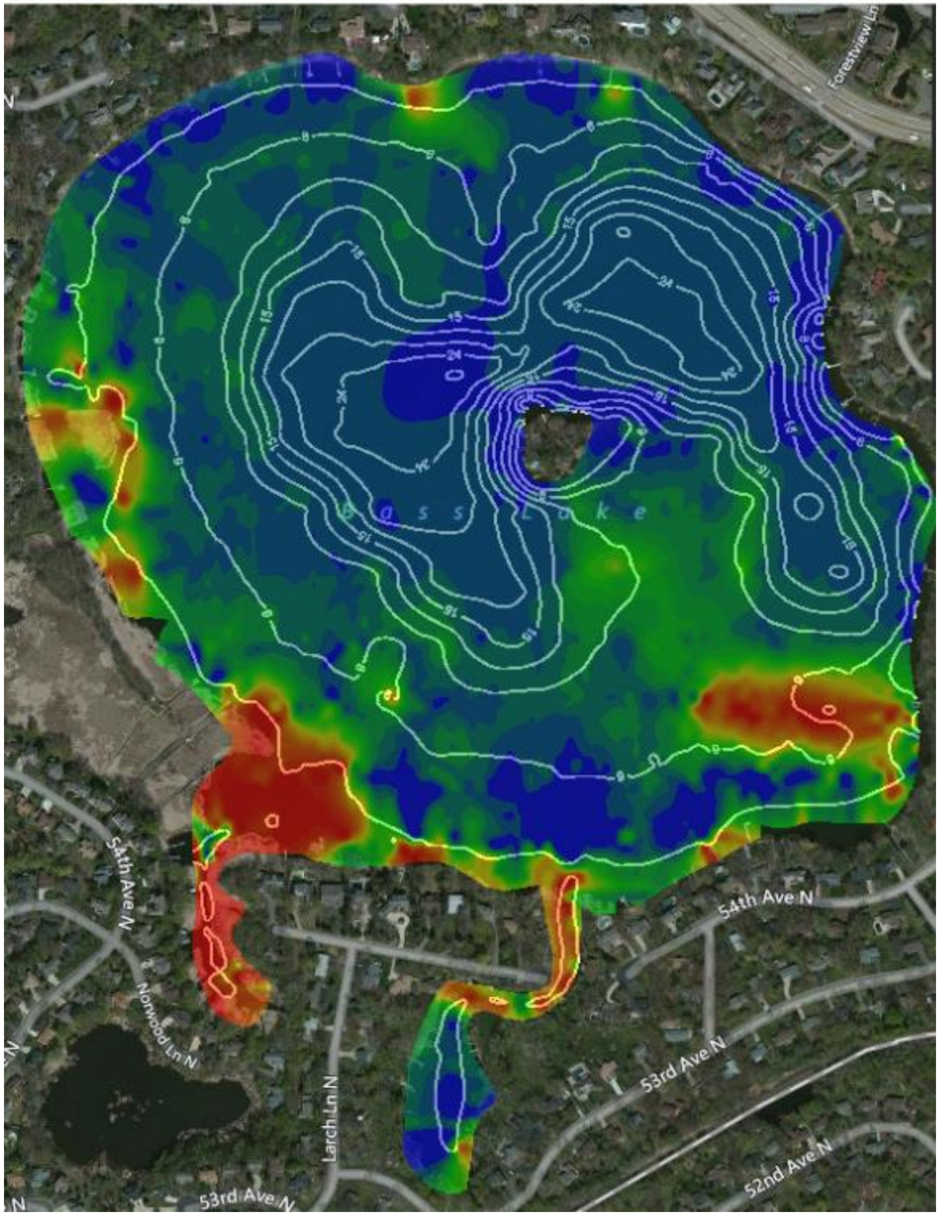
Bass Lake Vegetation Surveys (2014)

Common Name	Percent Occurrence	
	June 24	August 21
Coontail	22%	20%
Curly-leaf pondweed	21%	--
Yellow waterlily	8%	8%
Narrow-leaf pondweed	5%	--
Wild celery	3%	9%
White waterlily	2%	8%
Flat-stem pondweed	2%	2%
Chara	1%	2%
Bushy pondweed	--	2%
Leafy pondweed	--	1%

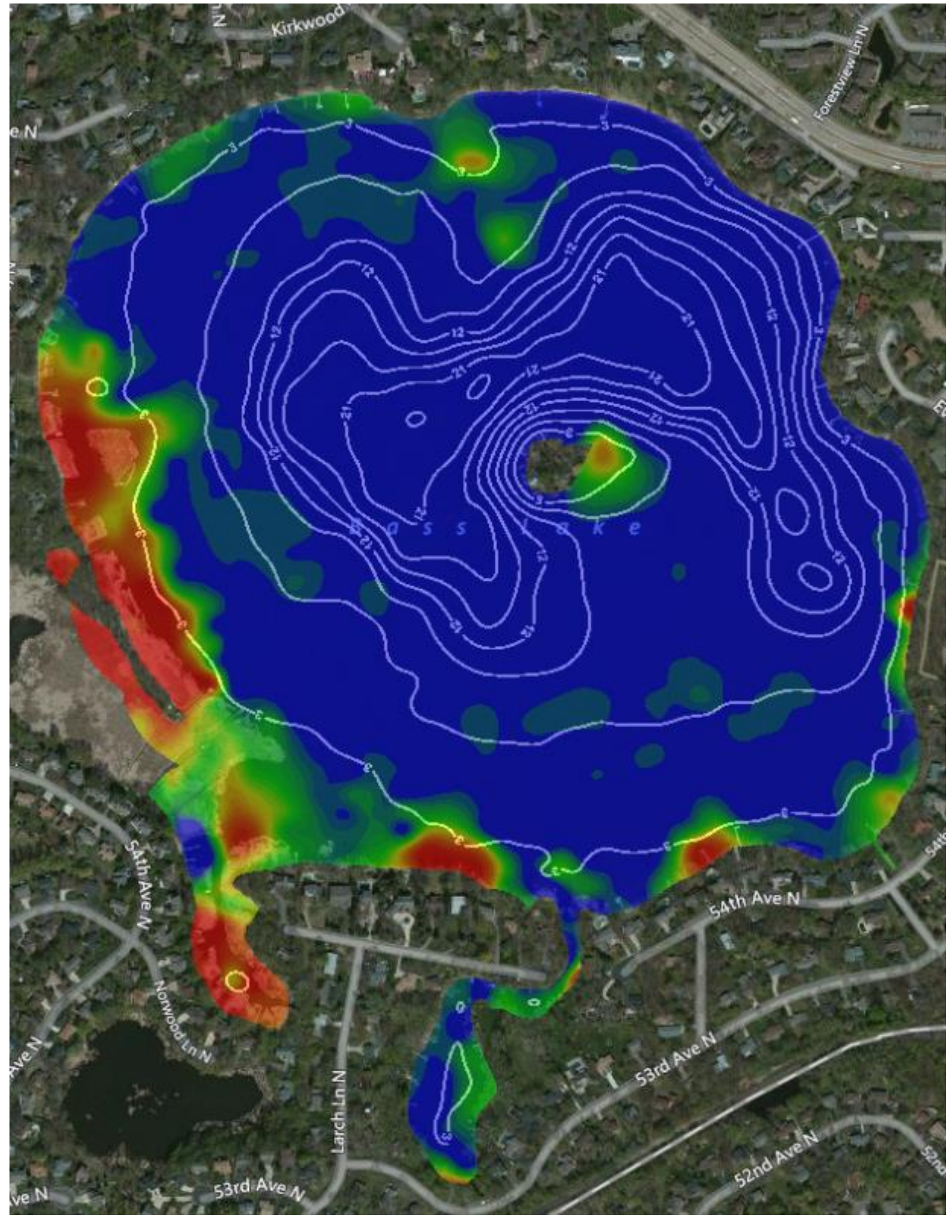
*No Eurasian milfoil observed



June 24



August 21



Bass Lake Fish Survey (2012)

- Only one carp, no bullheads
- Bluegills and crappies dominant
- Bass and Pike low #s and size

	Trapnet Results		
	Fish per Net 1991 (MnDNR)	Fish per Net (n=9) 2012 (Blue Water Science)	Normal Range (MnDNR)
Black bullheads*	60.3	0	1.5-58
Bluegills	179.8	77.5	3.5-57
Black Crappies	22.3	7.4	2.1-24.1
Hybrid sunfish	0.5	1	--
Largemouth bass	1.0	1.0	0.2-0.8
Northern pike	0.5	0.1	--
Pumpkinseeds	4.3	8.5	0.7-6.5
Common Carp	1.3	0.1	--
TOTAL FISH/NET	270	95.6	

Bass Lake Implementation Since TMDL

- **Watershed**
  - Development under rules
    - ~ 50% of watershed
    - 41 development/re-development BMPs since 2005
    - TP treated by BMPs = 816 lbs/year
  - Street sweeping
    - 3 times per year
    - Estimated TP removal = **132.2 lbs/yr**
- **In-Lake**
  - 7 shoreline restorations
  - CLP and EWM treatments
  - Winter aerators

Bass Allocations

TMDL Report

		Existing TP Load	Allowable TP Load	Estimated Load Reduction	
		lbs/yr	lbs/yr	lbs/yr	%
Wasteload	**Total WLA**	**1,395**	**904**	**491**	**35%**
	Watershed MS4	1,279	826	453	35%
	Upstream Lakes	116	78	38	33%
Load	**Total LA**	**48**	**48**	**0**	**0%**
	Atmospheric	46	46	0	0%
	Internal Load	2	2	0	0%
MOS		--	--	--	--
Total Load		**1,443**	**952**	**491**	**34%**

Updated Allocations

		Existing TP Load	Allowable TP Load	Estimated Load Reduction	
		lbs/yr	lbs/yr	lbs/yr	%
Wasteload	**Total WLA**	**1,733**	**1,477**	**256**	**13%**
	Watershed MS4	1,640	1,425	215	16%
	Upstream Lakes	93	53	41	44%
Load	**Total LA**	**521**	**75**	**446**	**86%**
	Atmospheric	42	42	0	0%
	Internal Load	479	33	446	93%
MOS		--	--	--	--
Total Load		**2,254**	**1,552**	**701**	**33%**

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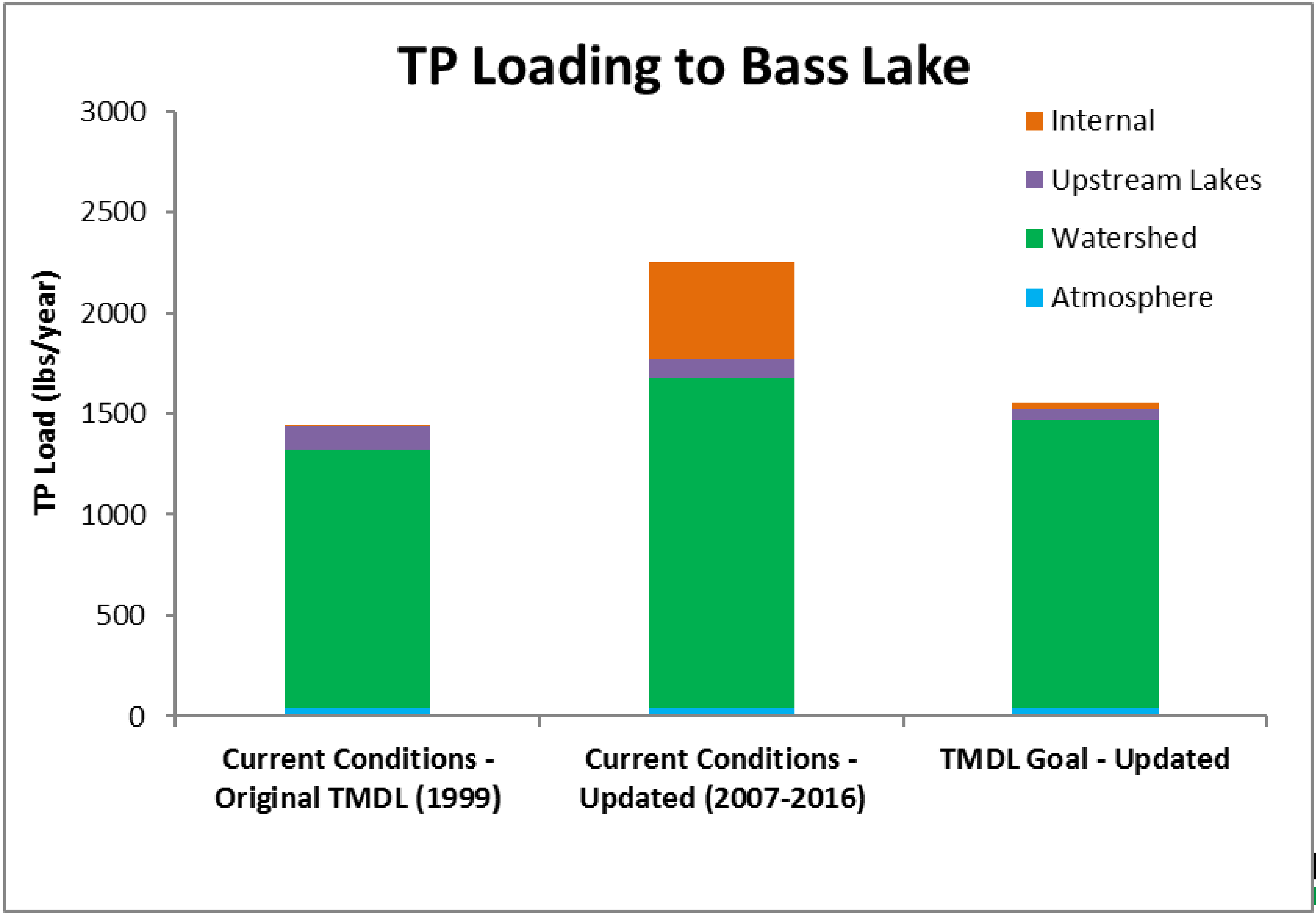
Bass Lake Goals



Bass Recommendations

- Internal
  - 446 lbs (93%) reduction
  - Internal load project
  - Fish & vegetation management plan
- Watershed
  - 215 lbs (13%) reduction still required
  - Modeling: BL3 sub currently treating to NURP standards
  - BL1, BL2 and Bass Lake Direct subs have highest P loading rates: need subwatershed assessments
  - Continue implementing projects
  - Monitor as projects implemented

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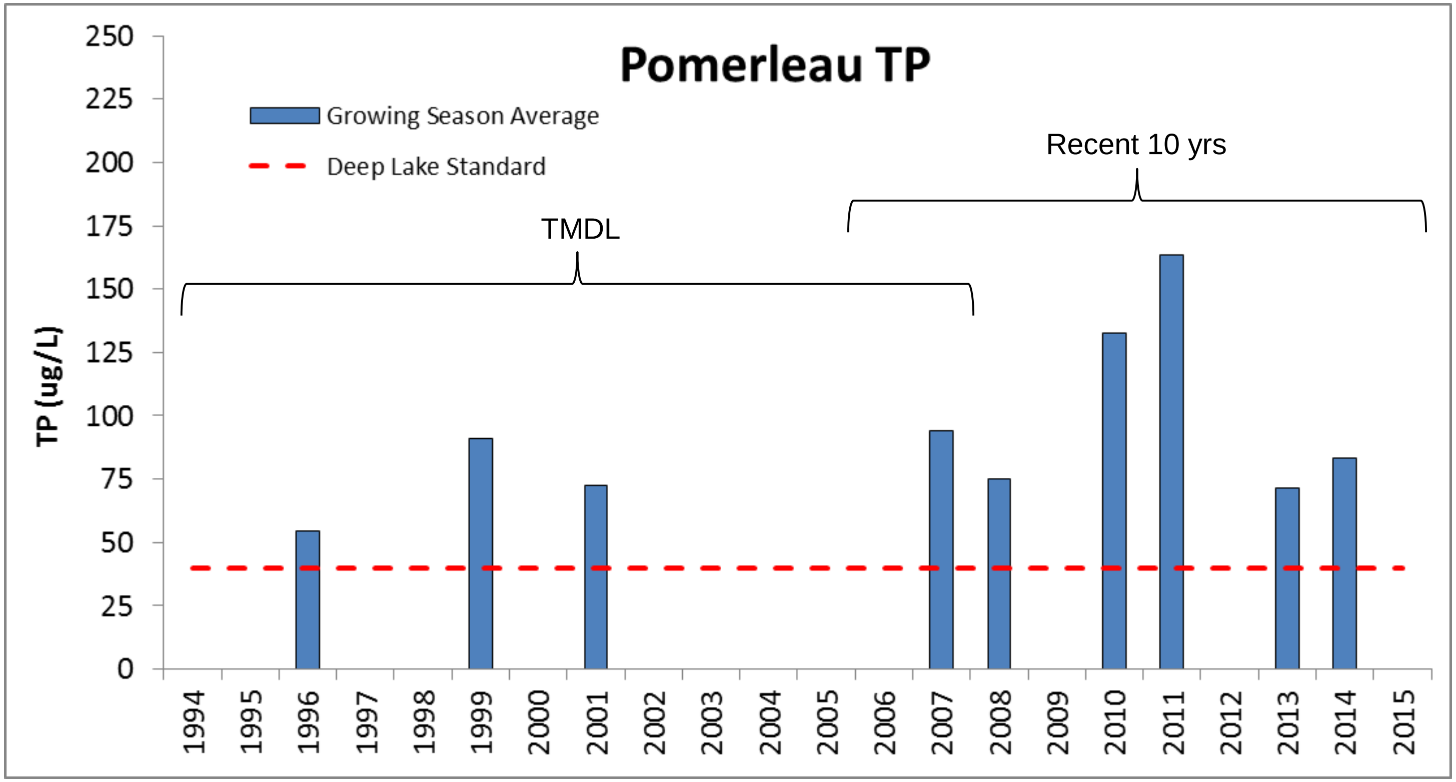
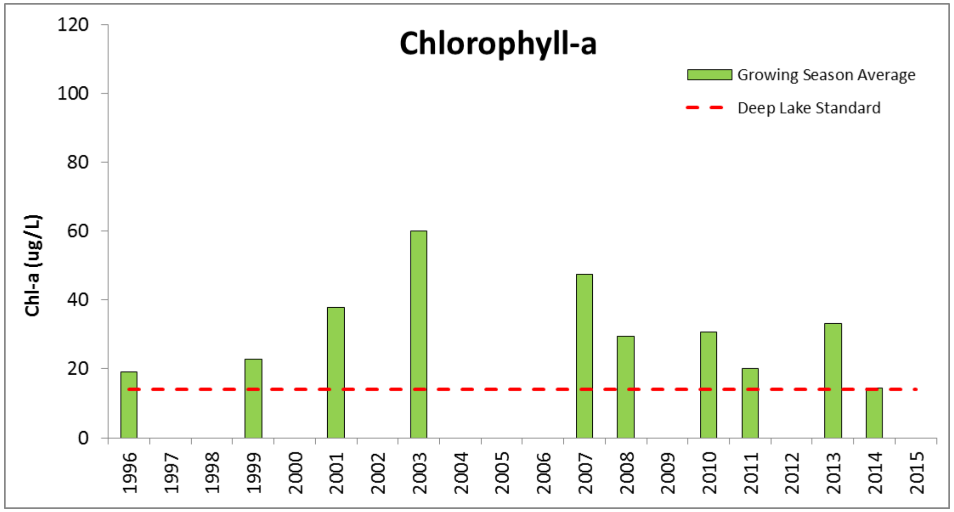
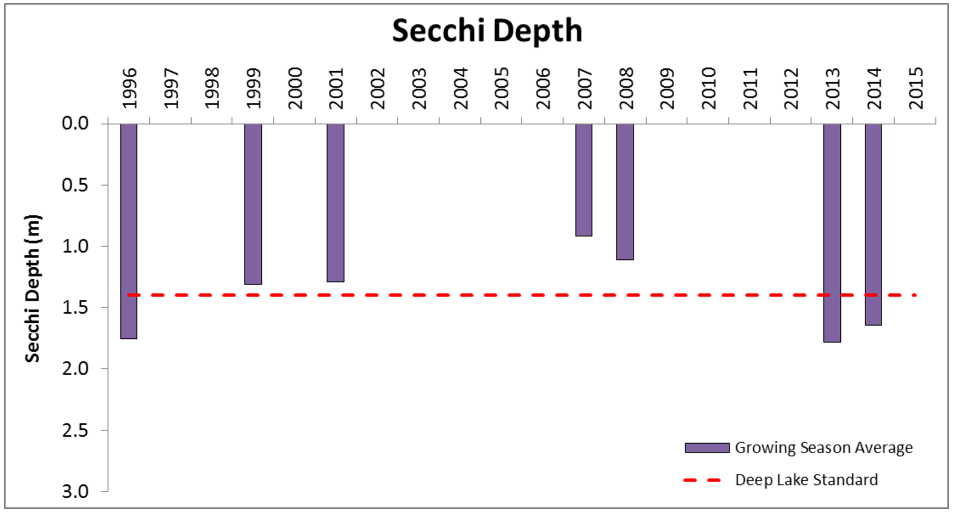
Pomerleau Lake
5-year Review

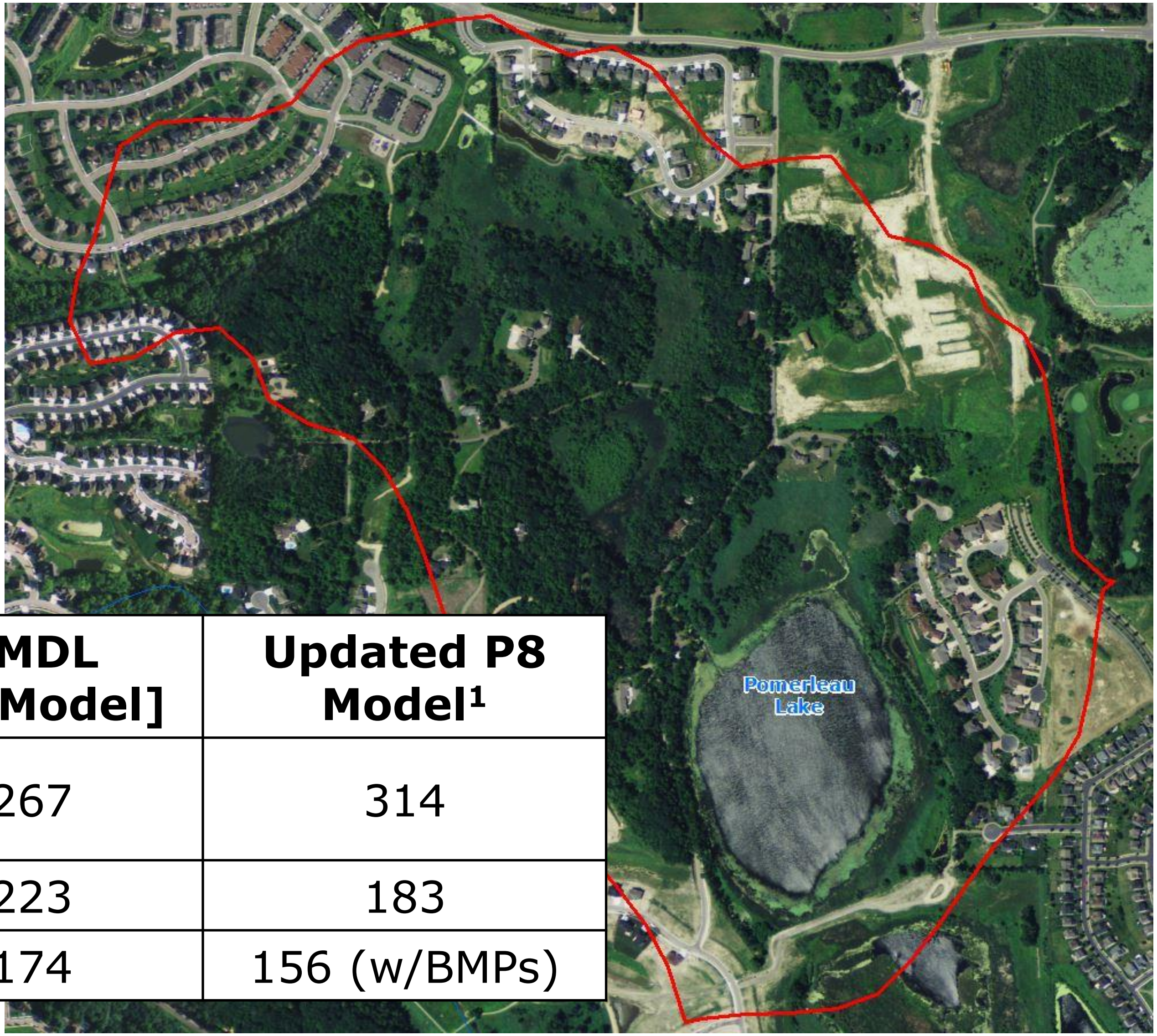
Pomerleau TMDL: 74 µg/L
Recent 10 yrs: 103 µg/L







Pomerleau Watershed Load



	TMDL [P8 Model]	Updated P8 Model[1]
Flow Volume (acre-ft/yr)	267	314
TP conc. (µg/L)	223	183
TP Load (lbs/yr)	174	156 (w/BMPs)

[1] Direct watershed to Pomerleau Lake not monitored, so loading estimates are based on updated P8 model for Bass Lake Watershed

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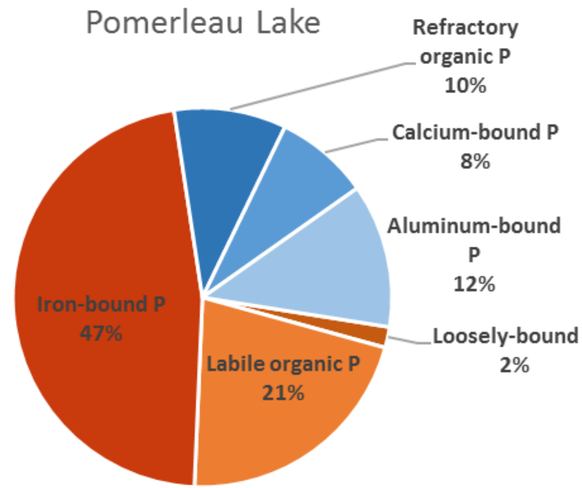
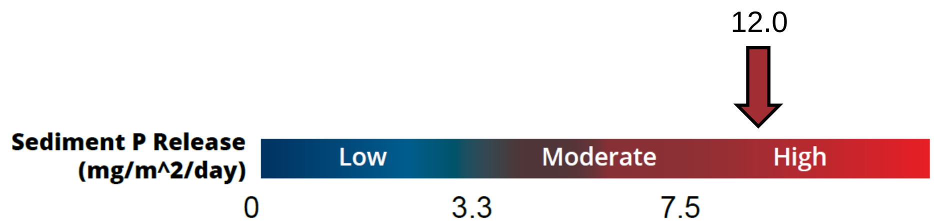
Pomerleau Lake Vegetation & Internal Load

- Vegetation survey in 2017





		TMDL	Measured
Pomerleau Internal Load	Anoxic Factor	22 days	45 days
	P Release rate	6 mg/m²/day	12 mg/m²/day
	Internal P Load	29 lbs/yr	142 lbs/yr

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Pomerleau Allocations

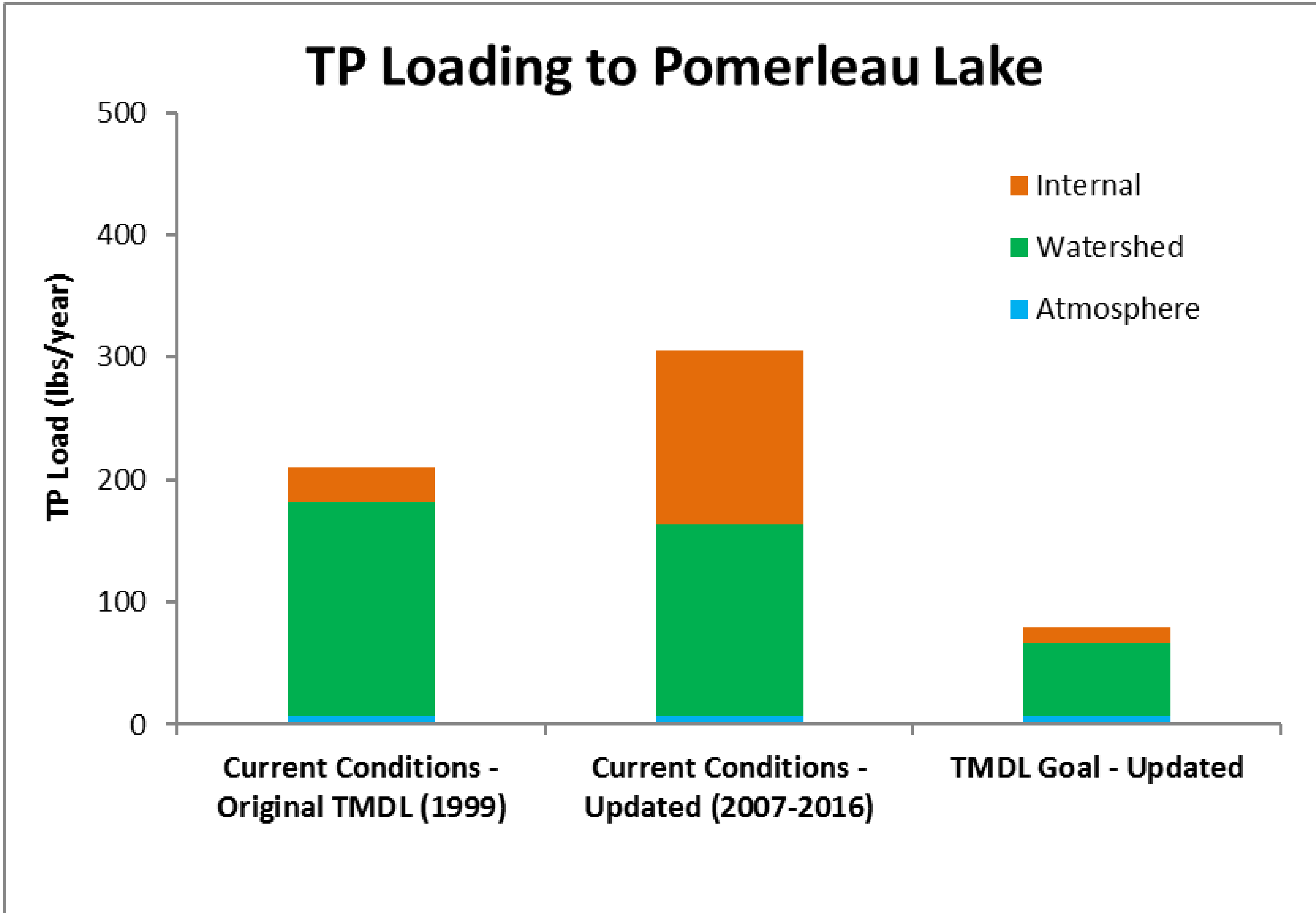
TMDL Report

		Existing TP Load	Allowable TP Load	Estimated Load Reduction	
		lbs/yr	lbs/yr	lbs/yr	%
Wasteload	**Total WLA**	**174**	**52**	**122**	**70%**
	Watershed MS4	174	52	122	70%
Load	**Total LA**	**36**	**16**	**20**	**56%**
	Atmospheric	7	7	0	0%
	Internal Load	29	9	20	69%
MOS		--	--	--	--
Total Load		**210**	**68**	**142**	**67%**

Updated Allocations

		Existing TP Load	Allowable TP Load	Estimated Load Reduction	
		lbs/yr	lbs/yr	lbs/yr	%
Wasteload	**Total WLA**	**156**	**60**	**96**	**62%**
	Watershed MS4	156	60	96	62%
Load	**Total LA**	**149**	**19**	**130**	**87%**
	Atmospheric	7	7	0	0%
	Internal Load	142	12	130	92%
MOS		--	--	--	--
Total Load		**305**	**79**	**226**	**74%**

Pomerleau Lake Goals



Pomerleau Lake Implementation since TMDL

- **Watershed**
  - Development under rules
    - ~50% of watershed
    - Since 2015: 14 development/re-development BMPs
    - TP treated by BMPs:
  - Street Sweeping74 lbs/yr
    - 3 times per year
    - Estimated removal: **10 lbs/yr**
  - Septics

- **In-Lake**
  - Monitoring in 2017
  - Fish Survey in 2012

Pomerleau Lake Fish Survey (2012)

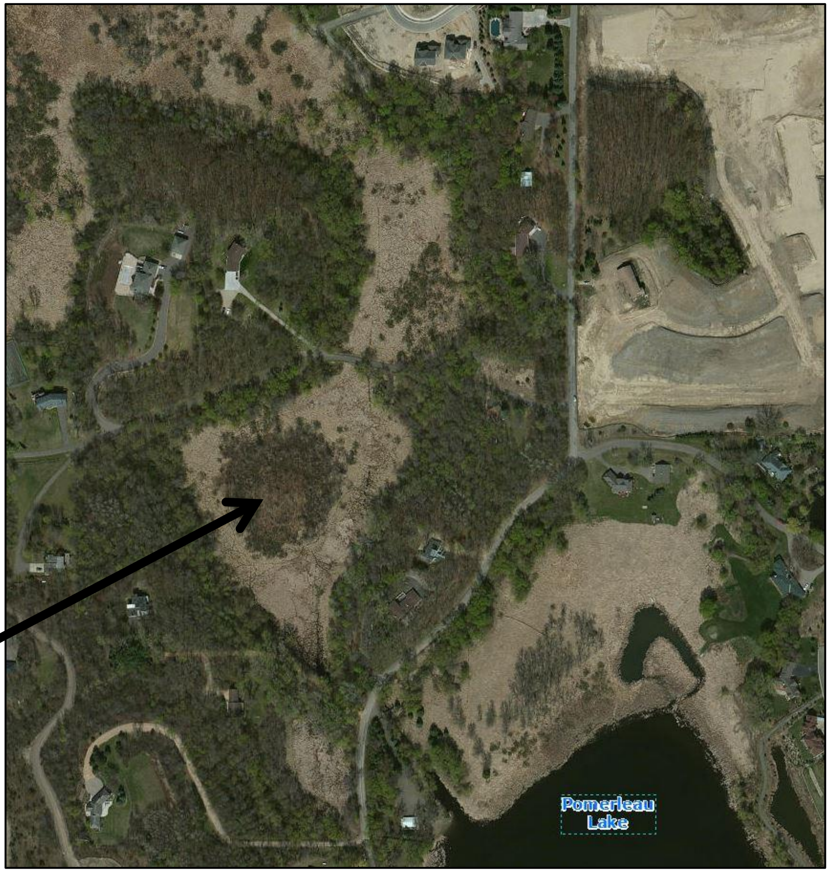
- No carp, bullheads and crappies dominant
- No bass, few pike
- Significantly different from 1994 survey (winterkills)

	Trapnet Results		
	Fish per Net 1994	Fish per Net (n=8) 2012	Normal Range (MnDNR)
Black bullheads	2.5	23.1	1.3 - 26
Bluegills	1.8	0.13	6.5 - 59.6
Crappies	4.3	15.8	1.8 - 18.1
Largemouth bass	19.8	0	0.3 - 0.8
Northern pike	0	0.6	NA
Green Sunfish	480.7	0	0.3 - 2.0
TOTAL FISH/NET	509	40	--

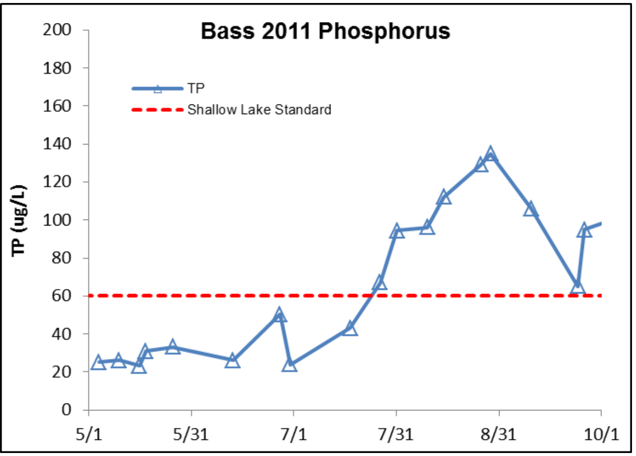


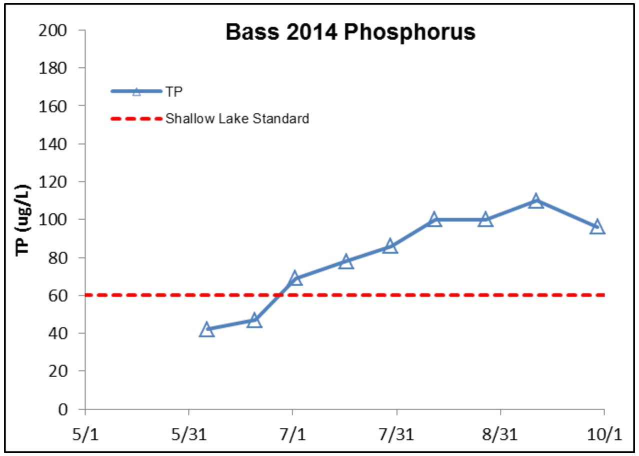
Pomerleau Recommendations

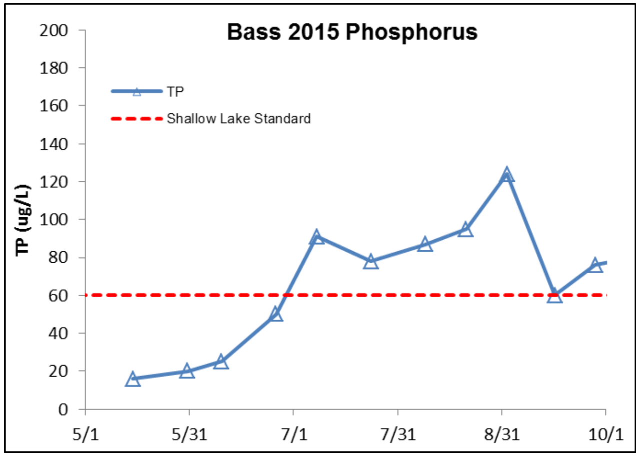
- Internal
  - 130 lbs (92%) reduction
  - Internal load project
  - Vegetation and fish mgt. plan
  - Vegetation surveys in 2017
- Watershed
  - 96 lbs (62%) reduction
  - Monitor inflows (wetland)
  - ISTS on north side
  - Review ponds and BMPs
  - New development

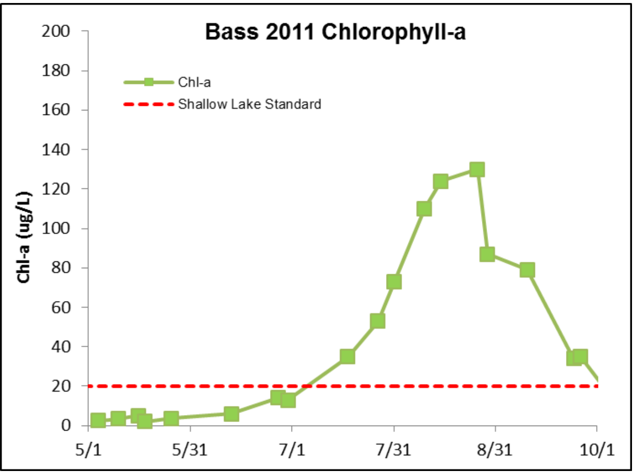


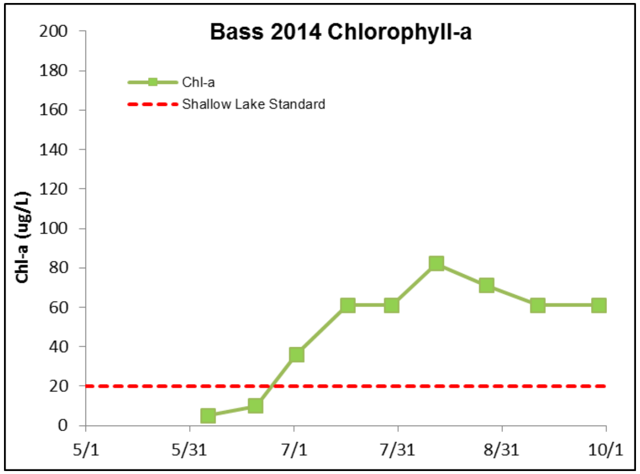
WENCK ASSOCIATES

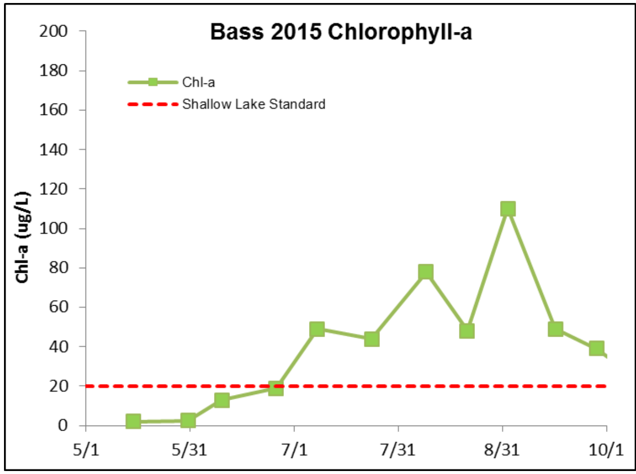

Bass 2011 Phosphorus
TP (ug/L)
TP
Shallow Lake Standard

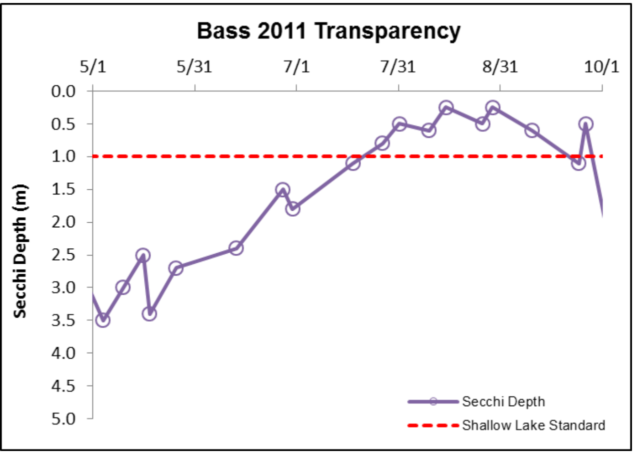

Bass 2014 Phosphorus
TP (ug/L)
TP
Shallow Lake Standard

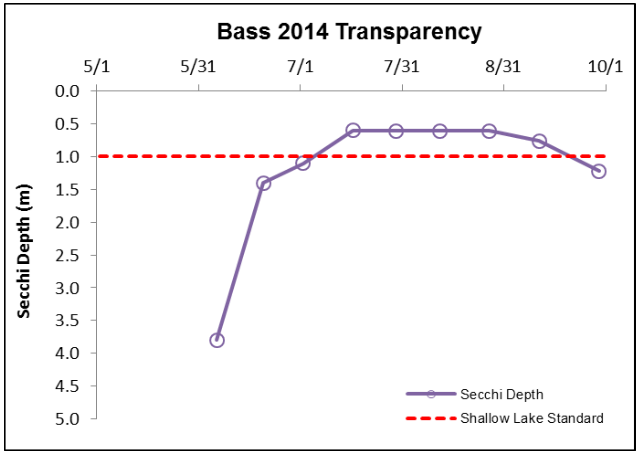

Bass 2015 Phosphorus
TP (ug/L)
TP
Shallow Lake Standard

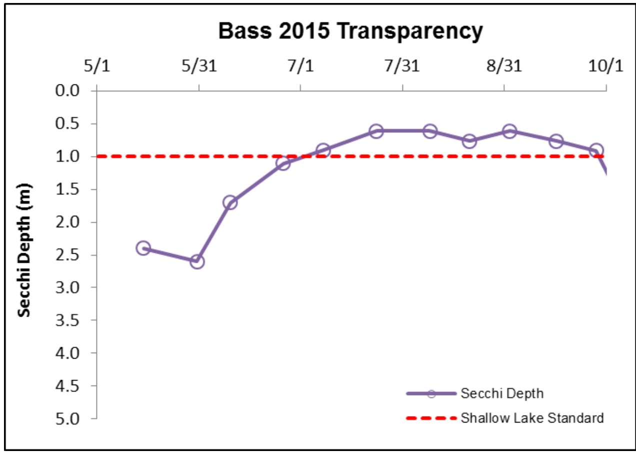

Bass 2011 Chlorophyll-a
Chl-a (ug/L)
Chl-a
Shallow Lake Standard

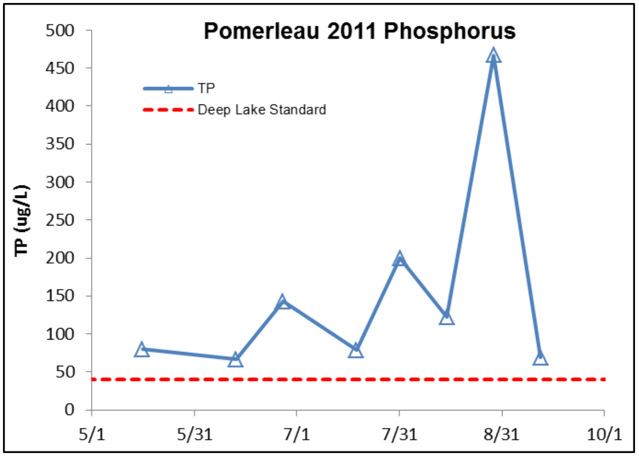

Bass 2014 Chlorophyll-a
Chl-a (ug/L)
Chl-a
Shallow Lake Standard

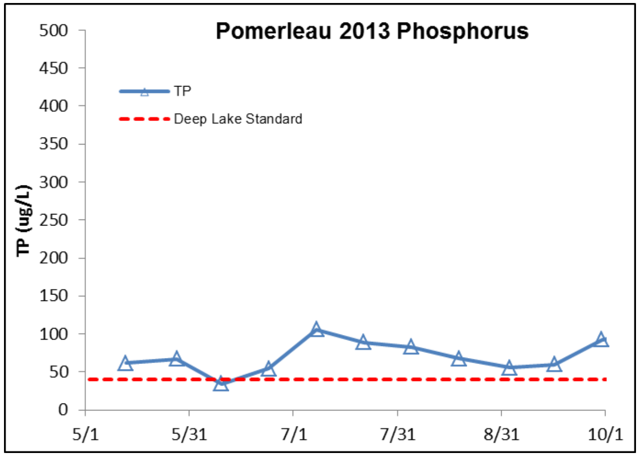

Bass 2015 Chlorophyll-a
Chl-a (ug/L)
Chl-a
Shallow Lake Standard

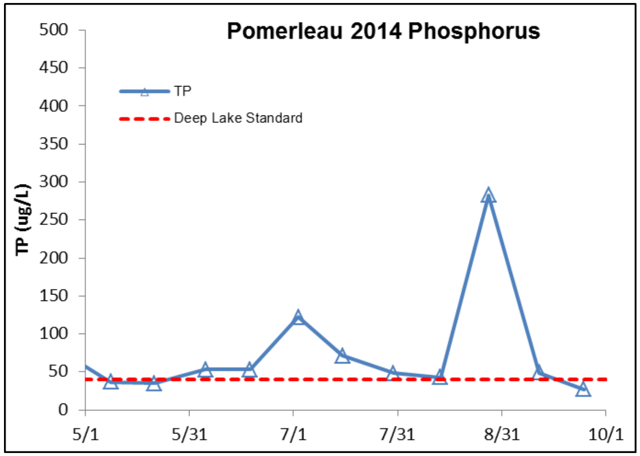

Bass 2011 Transparency
Secchi Depth (m)
Secchi Depth
Shallow Lake Standard


Bass 2014 Transparency
Secchi Depth (m)
Secchi Depth
Shallow Lake Standard


Bass 2015 Transparency
Secchi Depth (m)
Secchi Depth
Shallow Lake Standard


Pomerleau 2011 Phosphorus
TP (ug/L)
0
50
100
150
200
250
300
350
400
450
500
5/1
5/31
7/1
7/31
8/31
10/1
TP
Deep Lake Standard


Pomerleau 2013 Phosphorus
TP (ug/L)
0
50
100
150
200
250
300
350
400
450
500
5/1
5/31
7/1
7/31
8/31
10/1
TP
Deep Lake Standard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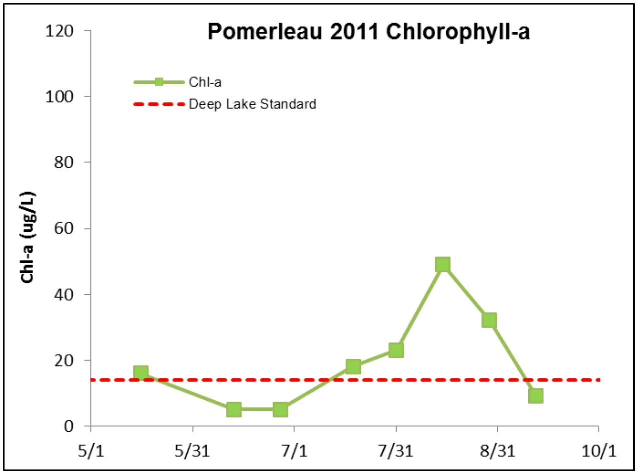
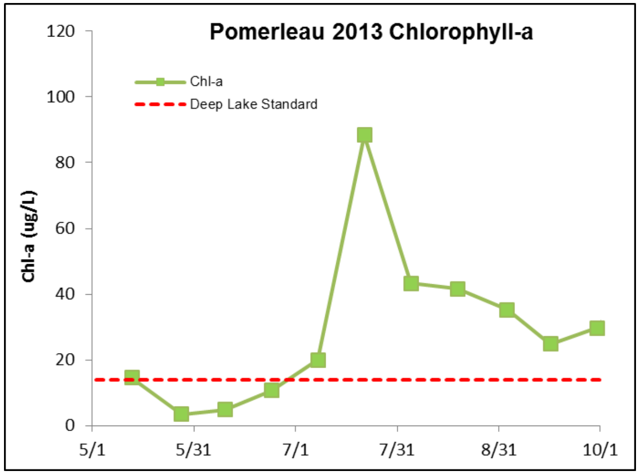
300
350
400
450
500
5/1
5/31
7/1
7/31
8/31
10/1
TP
Deep Lake Standard


Pomerleau 2011 Chlorophyll-a
Chl-a (ug/L)
0
20
40
60
80
100
120
5/1
5/31
7/1
7/31
8/31
10/1
Chl-a
Deep Lake Standard


Pomerleau 2013 Chlorophyll-a
Chl-a (ug/L)
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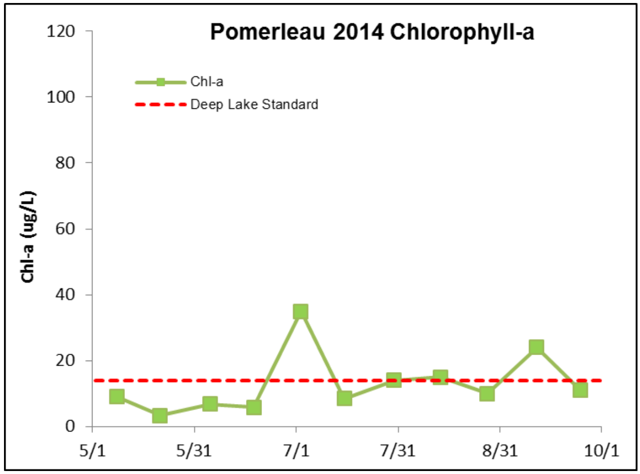
8/31
10/1
Chl-a
Deep Lake Standard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Chl-a (ug/L)
0
20
40
60
80
100
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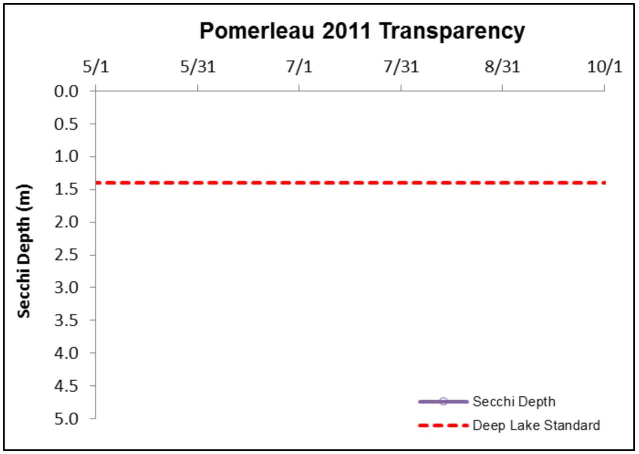
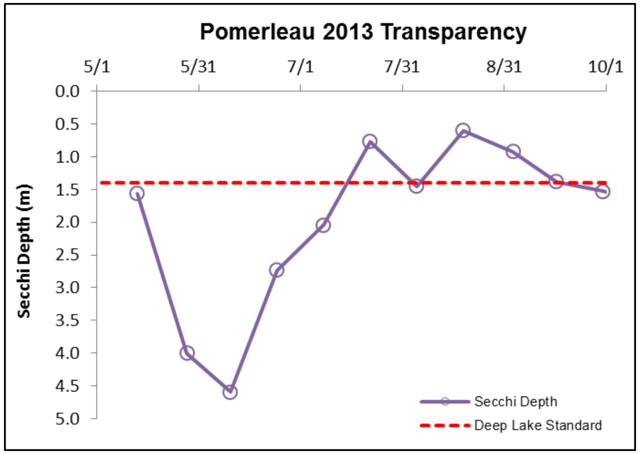
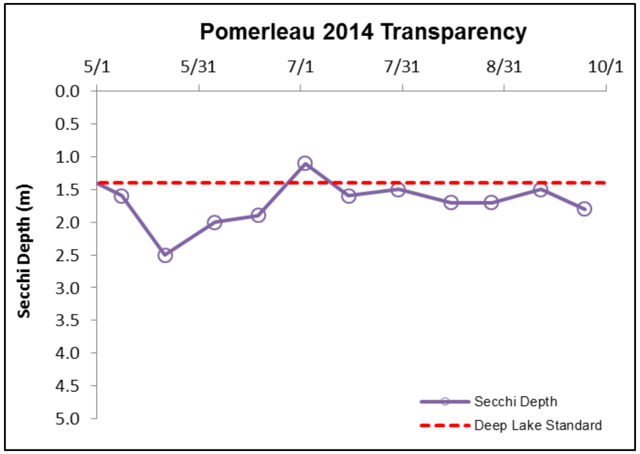
5/1
5/31
7/1
7/31
8/31
10/1
Chl-a
Deep Lake Standard


Pomerleau 2011 Transparency
Secchi Depth (m)
5/1
5/31
7/1
7/31
8/31
10/1
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Secchi Depth
Deep Lake Standard


Pomerleau 2013 Transparency
Secchi Depth (m)
5/1
5/31
7/1
7/31
8/31
10/1
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Secchi Depth
Deep Lake Standard


Pomerleau 2014 Transparency
Secchi Depth (m)
5/1
5/31
7/1
7/31
8/31
10/1
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Secchi Depth
Deep Lake Standard