Can Conservation Buffers Reduce Agricultural Sources of Nitrate Pollution and Restore Lower Wisconsin River Oxbow Lakes?

Friends of the Lower Wisconsin Riverway (FLOW)

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Background on Natural Resources and Issues

This report completes a five-year effort documenting the underlying causes for the recent water quality decline in Lower Wisconsin River oxbow lakes. We also investigated the potential use of conservation buffers to reduce groundwater nitrate levels before reaching oxbow lakes in the Town of Spring Green, Sauk County Wisconsin. This issue is the most recent chapter in the history of environmental changes to the Lower Wisconsin River that occurred during the 20th and early part of the 21st Century.

For generations farms had thrived and supported rural communities along the Lower Wisconsin River, one of the highest quality large rivers in the Midwest (Lyons 2005). The local farming economy coexisted with a biologically diverse large river ecosystem as part of the iconic Driftless Area quality of life. Aerial photos taken during the 1930s visually captured the decades long relationship and the extent of agricultural land uses spread across the river terrace landscape (https://maps.sco.wisc.edu/WHAIFinder/#).

The important cultural and historic attributes of the Lower Wisconsin River have been well documented (http://lwr.state.wi.us/index.asp). The river also supports a rich biodiversity of wildlife and fish that reflects a functioning large river floodplain. The important features of this large river ecosystem include the braided river channel, a well-connected floodplain forest, a vast network of floodplain lakes and a massive aquifer recharged through the sand terrace with discharge to the river and oxbow lakes. Functioning river ecosystems are otherwise rare occurrences in this modern era.

Prior to implementation of the 1972 Clean Water Act, industrial point source pollution had severely degraded parts of the Wisconsin River where many fish species and aquatic organisms could no longer survive. However, the Lower Wisconsin River was spared the worst pollution primarily due to the massive aquifer that functioned as a source of clean fresh water for the river. The aquifer was also a prominent source of spring water for the numerous oxbow lakes. The pristine oxbow lakes provided refuges for fish populations that escaped the worst periods of industrial pollution.

By the early 1980s, implementation of the Clean Water Act and the Wisconsin Pollutant Discharge Elimination System (WPDES) led to a reduction of about 95% pollutants from industrial point source discharges (Wisconsin DNR News and Outdoor Report Aug., 2003). As the water quality improved, and nuisance rafts of foam and sulfide odors subsided, the river became more popular than ever. The water quality improvements combined with “Wild and Scenic” river features and increasing recreational demands contributed to enactment of the 1989 Wisconsin Act 31, the Lower Wisconsin State Riverway.

As the river improved land uses had been changing as well. Since the 1950s, larger farms were gradually replacing smaller dairy farms due in part due to global market competition (Marshall et al. 2008). This change appeared to have reached critical mass during the first decade of the 21st Century as agriculture rapidly shifted to the industrial scale operations that we see today. Not long after this change in agriculture, environmental conditions in many oxbow lakes along the Lower Wisconsin State Riverway changed as well.

Our current study focuses on the formerly pristine spring lake oxbows including Jones Slough, Norton Slough, and Bakkens Pond, that became highly eutrophic and are now polluted at levels that violate the Clean Water Act. In addition to threating fish and aquatic life that inhabit the oxbows, water pollution poses an imminent threat to the survival of Wisconsin's largest population of State Endangered starhead topminnows (*Fundulus dispar*). The degradation is occurring in oxbow lakes that had been refuges when the main river channels were degraded from the paper and pulp mill industry decades ago.

Industrial scale agriculture across the sand terrace requires massive commercial and manure nutrient applications, often accompanied by irrigation. The aquifer that flows beneath the sand terrace farms has now become heavily contaminated with nitrate. As the contaminated groundwater reaches the oxbows, high nitrate concentrations feed dense surface mats of filamentous green algae and duckweeds that literally smother the lakes. The high nitrate levels are also toxic to environmentally sensitive fish and aquatic organisms (Camargo et al. 2005). The State of Minnesota is currently developing nitrate criteria for surface waters to address the toxicity problem (Minnesota Pollution Control Agency 2010). Secondary impacts include hypoxia beneath the dense floating mats since surface shading blocks light and photosynthesis below. Nuisance conditions have become so severe in some oxbows that recreational uses including fishing, paddling and swimming have ceased.

Our survey data indicate that the eutrophication is primarily caused by excessive nitrogen applications across the sand terrace. This form of eutrophication is unlike what typically happens in most glacial lakes and river impoundments, where phosphorus is the limiting nutrient and primary concern (Schindler et al. 2016). In eutrophic glacial lakes and impoundments, Cyanobacteria blooms arise when phosphorus increases. Groundwater discharge is the primary source of nutrients in the oxbows, including phosphorus. Phosphorus loading rates likely increased across the terrace, but groundwater concentrations remain within the range expected for mesotrophic lakes. Our oxbow lake surveys data demonstrated that phosphorus is not particularly high except when anoxia occurs under dense mats of free floating plants.

The recent free-floating plant problem can better be explained by the very high nitrate concentrations in upland groundwater entering the floodplain. In other studies, nitrogen has been identified as a significant role in eutrophication (Conley et al. 2009, Lewis et al. 2011 and Howarth and Marino 2006). In Upper Mississippi River backwaters nitrogen has been identified as a frequent limiting nutrient for free floating plant problems (Giblin et al. 2013).

The primary nitrate sources are manure and commercial fertilizer applications that are now prevalent across the sand terrace. The sandy soils have an extremely low moisture capacity resulting in rapid percolation of nitrate-contaminated water below the crop root zone. The sensitivity of the sand terrace to nitrate pollution had been known for decades. The sand terrace was identified as highly susceptible to contamination in maps and publications produced by WDNR and UW Extension in 1989 (Figure 8). The sand terrace has a groundwater vulnerability ranking score of 49.8, and greater than 30 is considered "highly susceptible to contamination (WDNR Lower Wisconsin River State of the Basin Report 2002).

So why are these nutrient intensive practices allowed to occur on the environmentally sensitive sand terrace? WDATCP, and WDNR WPDES permitting for farms exceeding 1,000 animal units, rely on the federal 590 Nutrient Management Standards that are agronomically focused or designed to achieve maximum crop yields. The 590 standards were not designed to protect groundwater or water quality. The late Professor Byron Shaw provided ample evidence to demonstrate the lack of water quality protections and environmental problems linked to the 590 standards. He organized a position paper that described these issues and was supported by scientists across the country.

During the 2013 nitrate pollution study, we documented what has become a common practice of trucking excess liquid manure for disposal on the sand terrace. In September 2013, FLOW volunteers counted 32 semitrailer tankers that hauled liquid manure for disposal across a 70-acre field, over a 24-hour period. The manure was produced in upland farms located miles north of the sand terrace. State regulators have determined that this type of waste disposal activity is compliant with the 590 Nutrient Management Standards. The rationale behind this determination is the need to sustain crop growth by replacing nitrogen that rapidly leaches below the root zone in sandy soils. Since the sand terrace is droughty, spray irrigation has also become a common practice that results in even greater nitrogen loss to the aquifer.

Beyond the agronomic considerations, the federal 590 Nutrient Management Standards clearly states that the exercise of the nutrient management standards cannot supersede laws and regulations: "Implementation of this standard may not eliminate nutrient losses that could result in a violation of law". That reference includes provisions of the Clean Water Act and the 1974 Safe Drinking Water Act. Agricultural practices across much of the sand terrace have resulted in groundwater nitrate concentrations that far exceed the Safe Drinking Water Act limit of 10 mg/l. Water Quality Standards violations, including hypoxia and water pollution in violation Antidegradation rules under the Clean Water Act, are prevalent in most of the oxbow lakes that lie adjacent to the sand terrace. In addition to the apparent regulatory contradictions mentioned above, existing nutrient management practices are heavily subsidized and sand terrace farms in Sauk and Richland Counties receive about $3,000,000 per year in taxpayer dollar support (EWG database).

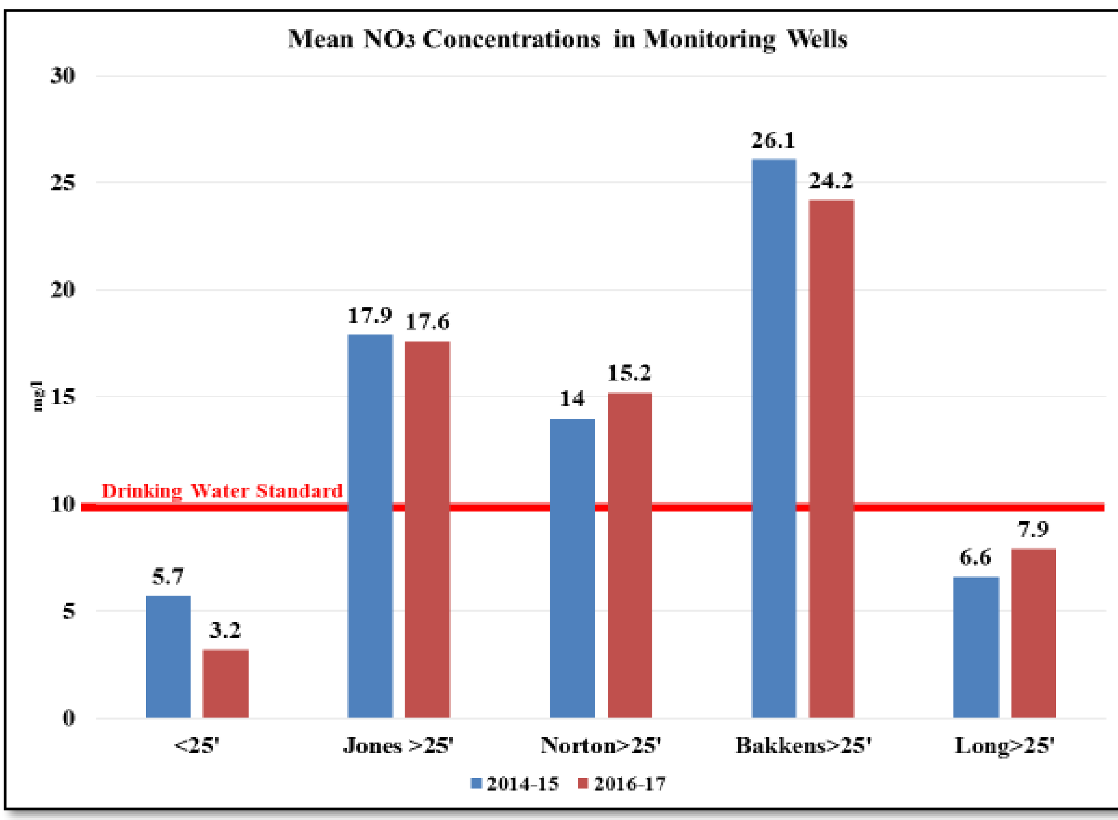
Summary

In 2016 and 2017, the Friends of the Lower Wisconsin Riverway (FLOW) sponsored two WDNR small-scale lake planning grants to test the hypothesis that expanding conservation buffers between the expansive terrace crop fields and the river floodplain can significantly reduce nitrate pollution. Reducing nitrates are needed to restore the oxbows. As a continuation of the 2014-15 study, we monitored Jones Slough and Bakkens Pond and adjacent groundwater monitoring wells representing locations where there was no change in buffer area. We continued to monitor Norton Slough and adjacent monitoring wells where Doug and Sherryl Jones had established an 11acre conservation prairie buffer in 2012. Long Lake and associated monitoring wells represented the original study reference site that lies down gradient of the expansive School Forest buffer. It was established decades ago and extends roughly 1.4 miles between sand terrace crop fields and Long Lake.

All of the evaluation monitoring wells are located in nonagricultural production or conservation buffer areas. The shallow monitoring wells (< 25') had relatively low nitrate concentrations due to clean recharge within these areas. These shallow wells are primarily influenced by local precipitation that seeps into the shallow aquifer below natural vegetation. In the Figure 1 histogram, the bars identified as <25' represent average groundwater nitrate data collected from the shallow monitoring wells. Whiles these concentrations are relatively low and help reduce overall nitrogen loading to the State Riverway, the buffer areas lack sufficient size to effectively lower nitrate loading to safe levels. As a result, nitrate levels remain very high in most of the deeper wells (>25'). The deeper monitoring wells allowed us to sample groundwater with long flow paths originating from distant agricultural production areas. At Long Lake, nitrate concentrations remained <10 mg/l in three of four wells due to the influence of the School Forest conservation buffer. Only the deepest Long Lake well had NO_3 concentrations that exceeded the drinking water standard. The deep groundwater flow paths remain contaminated and unaltered even though the School Forest is over a mile wide.

While conservation buffers can effectively reduce nitrate levels in shallow aquifers and overland flow (Ranalli and Macalady 2010), the sand terrace aquifer poses a difficult challenge due to the long flow paths and contamination at much greater depths. Conservation buffers are beneficial for a number of reasons including clean recharge, wildlife habitat and scenic beauty but buffers alone cannot solve the nitrate problem. A significant nitrogen loading reduction will be required as well. Groundwater monitoring was conducted on sand terrace cropland where modern state of the art nutrient management was practiced. However significant nitrogen leaching still occurred with groundwater nitrate concentrations exceeding the 10 mg/l standard (Krause PhD Thesis 2017). In another sand terrace study, the researcher suggested retiring some crop fields on the sand terrace near the bluffs as a way to reduce contamination of deeper long groundwater pathways to the river (Schlaudt MS Thesis 2017). Whether reducing nutrient inputs or changing agricultural land use practices, the nitrate contamination problem and oxbow pollution would likely continue for years given that groundwater flow can take 5 to 10 years to cross the sand terrace. Flow paths are identified in Figures 11 and 12 (Schlaudt 2017).

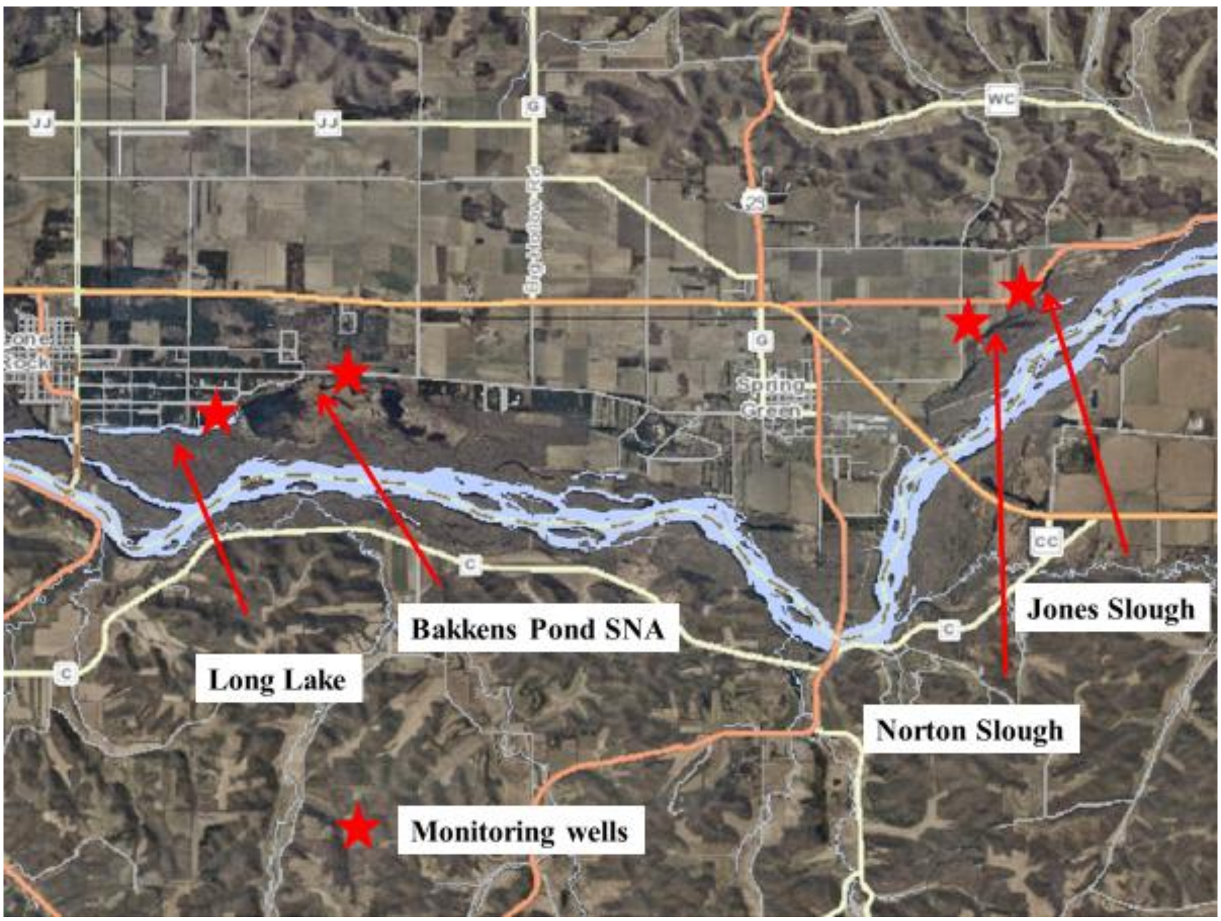
Figure 1: Mean Nitrate Concentrations in Groundwater Monitoring Wells (shallow wells < 25' and wells > 25')



Methods

Four oxbow lakes (Jones Slough, Norton Slough, Bakkens Pond and Long Lake) and four up-gradient clustered monitoring wells adjacent to the lakes were sampled during the open water seasons in 2016 and 2017 (Figure 2). Nitrate were measured in the field using a YSI Pro Plus meter that was calibrated using 1 mg/l and 100 mg/l NO_3 standards. Water samples were also collected and submitted to the State Laboratory of Hygiene (SLOH) for total phosphorus analysis. A YSI ODO meter was used to measure dissolved oxygen and temperature in the oxbows and wells. The meter was air calibrated according to manufacturer specifications. A YSI Model 63 meter was used to measure specific conductance. A Hach 2100P Turbidimeter was used to test oxbow water clarity. Percent free floating plant cover (filamentous algae and duckweeds - FFP) was estimated during each growing season survey.

Figure 2: Sampling Locations of Oxbow Lakes and Adjacent Monitoring Wells



Findings

Table 1 contains nitrate data for the monitoring wells sampled at Jones Slough and Norton Slough in 2016 and 2017. Table 2 contains the data for Bakkens Pond State Natural Area (SNA) and Long Lake. The JS1, NS1, BP1 and LL1 labels represent the shallow wells for each monitoring well nest. While all of but one shallow well sample had NO_3 concentrations less than 10 mg/l, most of the deeper well samples in Norton Slough, Jones Slough and Bakkens Pond SNA exceeded the drinking water standard of 10 mg/l

NO_3. Deep wells (>25') at Norton Slough, Jones Slough and Bakkens Pond and Long Lake exceeded nitrate drinking water standards in 91%, 86%, 100% and 33% of the samples tested respectively. Only the deepest well (52-54' deep) at Long Lake exceeded drinking water standards. The deeper flow paths represented groundwater originating a considerable distance north of the School Forest. Influenced by agricultural nitrate pollution, this deep groundwater level is located beyond the root zones of most trees and prairie plants that could otherwise extract some of the nitrogen that is a goal for conservation buffers. The Long Lake monitoring wells are also located within a private septic system drain field. In spite of the septic system influence, nitrate concentrations in the drain field well samples were lower than most wells influenced by agricultural sources. This data was consistent with general findings elsewhere that nitrate loading from most corn fields is about 32 times greater than from private household septic systems (https://wpt.org/University-Place/nitrate-wisconsins-groundwater).

Table 1: 2016-17 Groundwater Monitoring Well Nitrate Data for Jones Slough and Norton Slough

Date	JS1	JS2	JS3	NS1	NS2	NS3	NS4
5/22/2016	4.03	**25.6**	**24.4**	**12.8**	**17.1**	**34.8**	**28.6**
7/12/2016	2.9	**24.3**	**13.5**	4.8	**11.2**	**13.5**	**10.4**
9/10/2016	2.3	**35.6**	**14.7**	5	**14.6**	**17.9**	**12.5**
6/6/2017	7.48	**14.5**	**14.5**	2.94	**14.3**	**15.3**	**10.9**
8/17/2017	3.2	8.5	8.2	3.6	**18.6**	**17.7**	**13.4**
9/9/2017		**15**		1.6	**10.2**	**13.1**	8.2
10/10/2017	3.8	**18.7**	**13.6**	1.8	8.2	**14.2**	**13.6**

Table 2: 2016-17 Groundwater Monitoring Well Nitrate Data for Bakkens Pond SNA and Long Lake

Date	BP1	BP2	BP3	BP4	BP5	BP6	LL1	LL2	LL3	LL4
5/22/2016	1.1	**23.6**	**27.4**	**28.1**	**25.7**	**22.6**	2.8	6.5	8.3	**12.1**
7/13/2016	0.7	**19.2**	**26.1**	**21.8**	**22.1**	**19.3**	2.6	3.1	7.2	**13.0**
9/10/2016	0.5	**19.1**	**26.4**	**23.5**	**24.7**	**21.0**	2.3	5.2	7.4	**13.5**
6/6/2017	0.4	**17.4**	**24.4**	**29.7**			2.6	2.0	8.2	**13.9**
6/10/2017							2.5	2.1	7.7	**13.4**
8/21/2017	0.2	**23.7**	**28.0**	**31.7**	**23.2**	**18.9**	5.1	1.9	7.5	**12.2**
10/10/2017	0.4	**19.3**	**30.2**	**32.1**	**27.9**	**22.6**	7.8	1.2	6.3	**13.7**

Bold numbers indicate >10 mg/l NO_3

Nitrate concentrations in the oxbows was much more variable than in the wells (Tables 3-6, Figure 10). Free floating plant productivity often resulted in rapid nitrate uptake. When we found low NO_3 concentrations in the water column, much higher concentrations were measured at groundwater discharge areas. For example, at Jones Slough water column nitrate concentrations ranged from 1.4 to 4.2 mg/l (mean = 2.47) while groundwater discharge areas ranged from 10.5 to 21.4 mg/l (mean = 17.3). We occasionally found higher nitrate levels at the groundwater discharge area than in the adjacent monitoring wells. These data suggested that the discharge may have been linked to a deeper groundwater flow path than our sampling wells. The groundwater discharge areas were variable among the different oxbows, revealing different groundwater flow paths. At Jones Slough and Bakkens Pond, groundwater discharge areas were detected primarily near shore. Discharge from a significant spring, located adjacent to the Bakkens Pond monitoring wells, had nitrate concentrations of 13 to 18 mg/l. At Norton Slough the groundwater discharge occurred near the bottom based on both cold-water temperatures (Figure 7) and associated higher nitrate concentrations (Table 2). At Long Lake, the groundwater discharge was less obvious but higher concentrations were found near the bottom. A temporary piezometer placed in Long Lake 20 feet from shore documented discharging groundwater with a nitrate concentration of 10 mg/l on June 10, 2017.

Free floating plant cover was generally greater and associated with higher well nitrate concentrations. Some differences also likely reflected different flow paths, shore versus bottom, as well as surface water flow rates. Flowing water was not detectable at Jones Slough, Norton Slough and Long Lake during normal river stages but flowing water was evident at our Bakkens Pond SNA sampling location. The 2014-15 nitrate concentrations in Bakkens Pond were somewhat higher, before the impoundment was refilled. Returning the impoundment to full pool levels may have altered groundwater discharge locations. Figure 3 compares mean deep groundwater flow path NO_3 concentrations with estimated oxbow FFP cover.

Table 3: Jones Slough Sampling Data 2016-17

Date	TP mg/l	NO3 mg/l	Turb NTU	FFP %	Sp Cond uS/cm	
6/29/2016	0.0314	2.7	1.7	95	462	.5 meter
6/29/2016	0.0586	1.8				Bottom
8/1/2016	0.053	2.23	1.6	95	442	.5 meter
8/1/2016		4.2				Bottom
8/1/2016		21.4		95		Nearshore
8/29/2016	0.103	1.4	4	90	410	0.5 meter
8/29/2016		18.5				Nearshore
6/6/2017	0.282	10.5	1.6	70	408	Nearshore
8/17/2017	0.114	17.1	1.4	100	388	Nearshore
9/9/2017		21.1		100		Nearshore
10/10/2017		15.1		80		Nearshore
Mean	**0.107**	**10.55**	**2.06**	**90**	**422**	

Table 4: Norton Slough Sampling Data 2016-17

Date	TP mg/l	NO3 mg/l	Turb NTU	FFP %	Sp Cond uS/cm	
6/29/2016	0.0381	0.6	1.7	75	386	0.5 meter
6/29/2016		7.4				Bottom
8/1/2016	0.0418	1.7	3	70	393	0.5 meter
8/29/2016	0.0936	0.7	4.2	70	380	0.5 meter
8/29/2016		7.2				Bottom
6/6/2017	0.0732	1.67	1.4	60	305	0.5 meter
8/17/2017	0.0386	4.2	2	70	402	0.5 meter
10/10/2017		1.2		70		0.5 meter
Mean	**0.057**	**3.1**	**2.5**	**69**	**373.2**	

Table 5: Bakkens Pond SNA Sampling Data 2016-17

Date	TP mg/l	NO3 mg/l	Turb NTU	FFP %	Sp Cond uS/cm	
6/29/2016	0.0537	9.05	8.3	90	433	Nearshore
8/1/2016		8.8	1.3	50	470	Nearshore
8/29/2016	0.0633	8.13				Nearshore
6/6/2017	0.0358	12.5	2	50	440	Nearshore
8/17/2017	0.0241	9.78	0.7	95	420	Nearshore
9/9/2017		5.3				Nearshore
10/10/2017		10.7		70		Nearshore
Mean	**0.044**	**9.2**	**3.1**	**71**	**440.75**	

Table 6: Long Lake Sampling Data 2016-17

Date	TP mg/l	NO3 mg/l	Turb NTU	FFP %	Sp Cond uS/cm
6/29/2016	0.0461	4.04	4.7	5	376
8/1/2016		3.8	2.2	5	409
8/29/2016	0.0365	3.77		5	
9/10/2016					
6/6/2017	0.0596	3.64	1.7	5	356
6/10/2017					
8/21/2017	0.0315	6.2	2.5	5	394
10/10/2017		4.8		5	
Mean	**0.043**	**4.4**	**2.8**	**5**	**383.75**

Well total phosphorus concentrations were generally higher in the oxbows than in the wells (Figure 3). Given that the groundwater remains the principle source of phosphorus, higher levels in the oxbows reflected internal loading (Figure 9). This is particularly evident in Jones Slough where nearly a decade of dense FFP production has resulted in rich organic sediment deposits. Internal loading of phosphorus was evident during hypoxia episodes in 2014 and 2015. Regardless of the internal phosphorus loading, nitrate remains the principal eutrophication driver in the oxbows. Figures 5 and 6 demonstrate nitrate regression was a much better predicter of FFP cover than total phosphorus.

Figure 3: Mean Total Phosphorus Concentrations in Wells and Oxbow Lakes

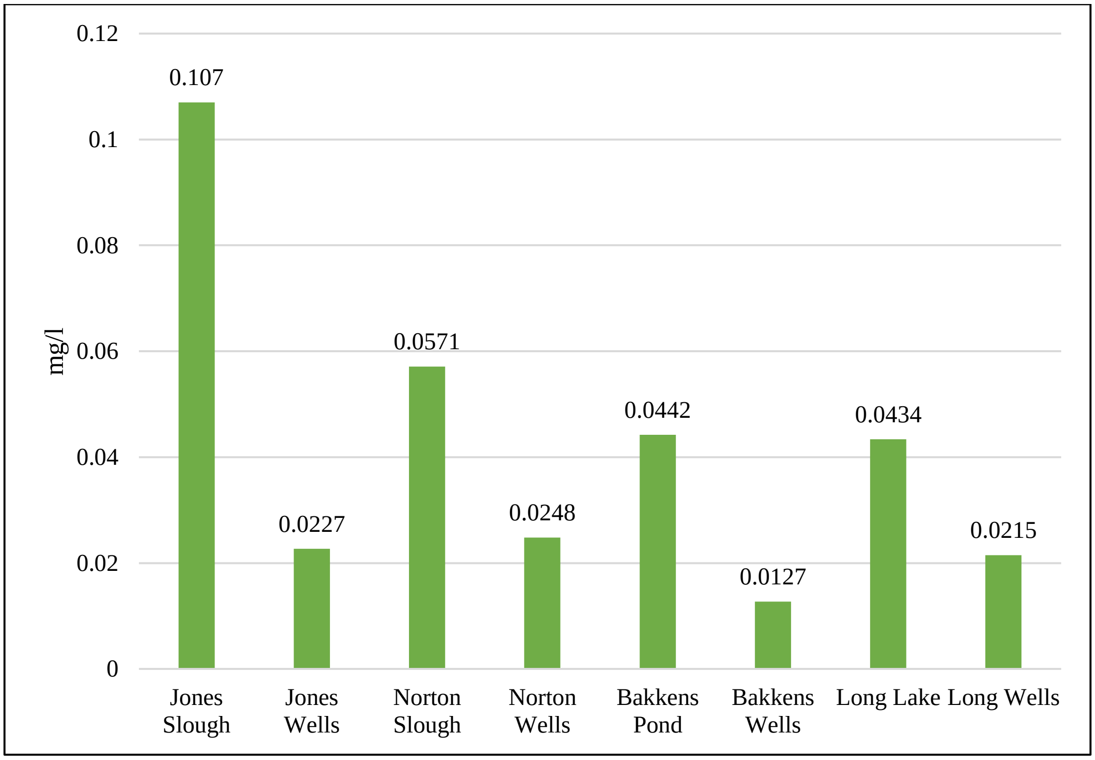


Figure 4: Mean NO_3 Concentrations in Wells > 25’ and Estimated Oxbow FFP Cover

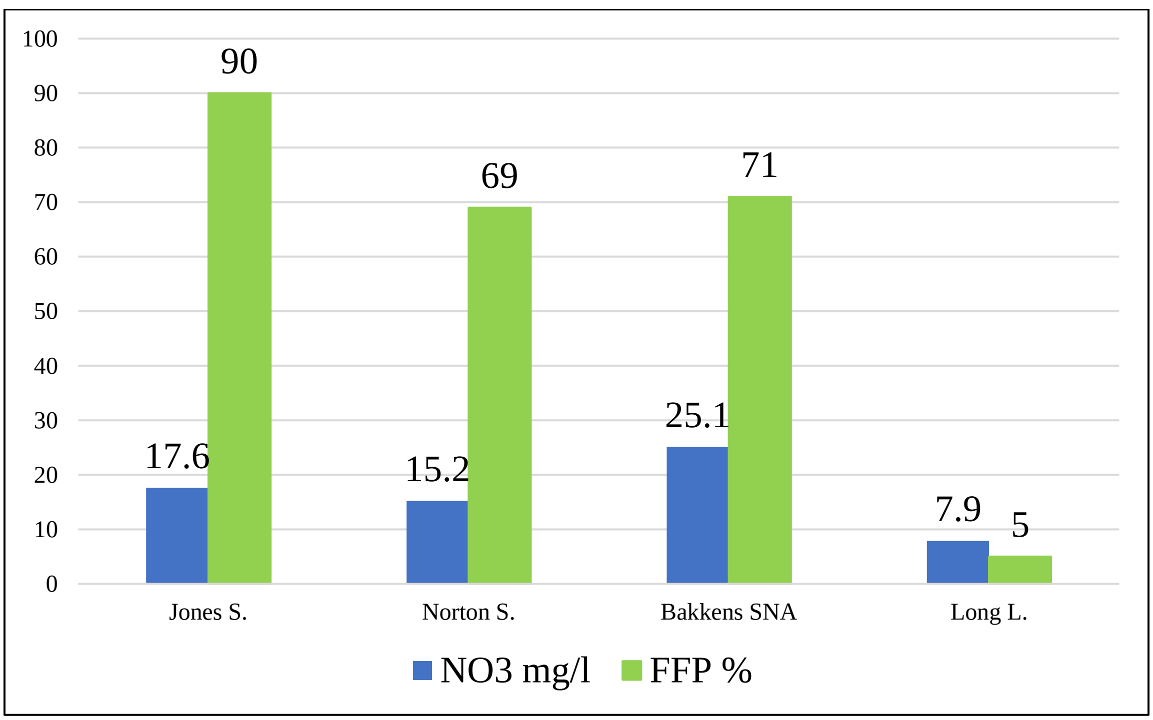


Figure 5: Oxbow Nitrate Levels at Discharge Points and Estimated Percent FFP

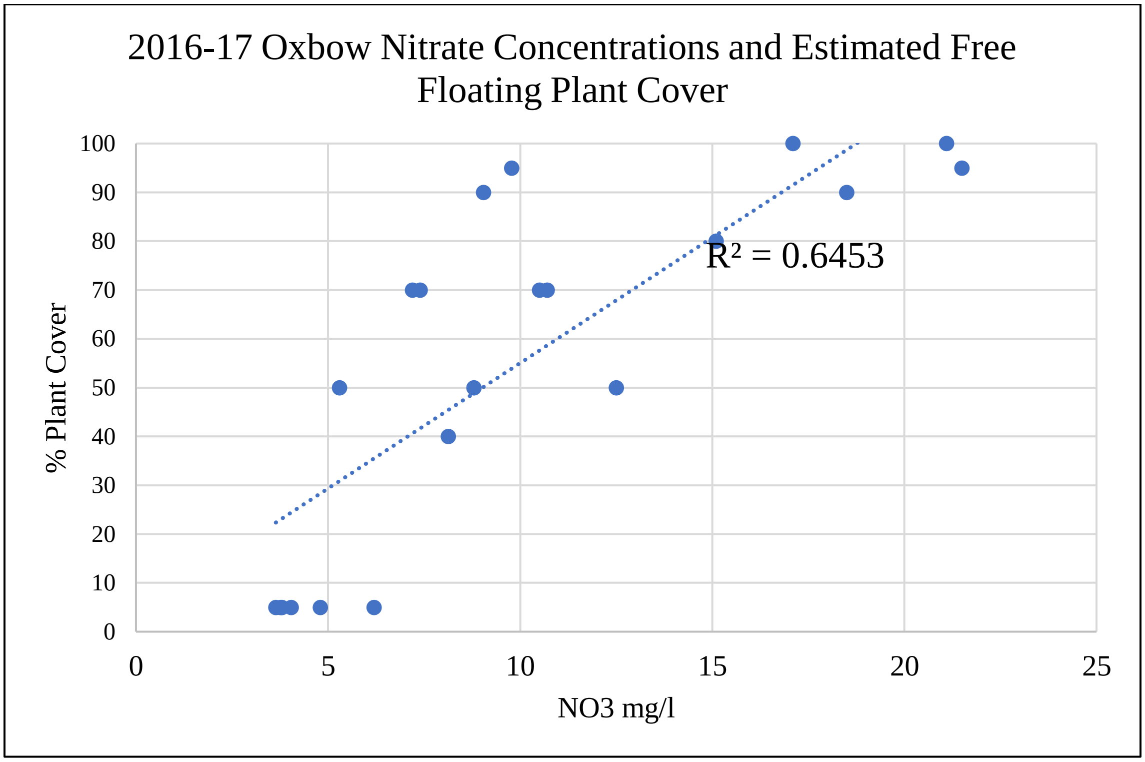
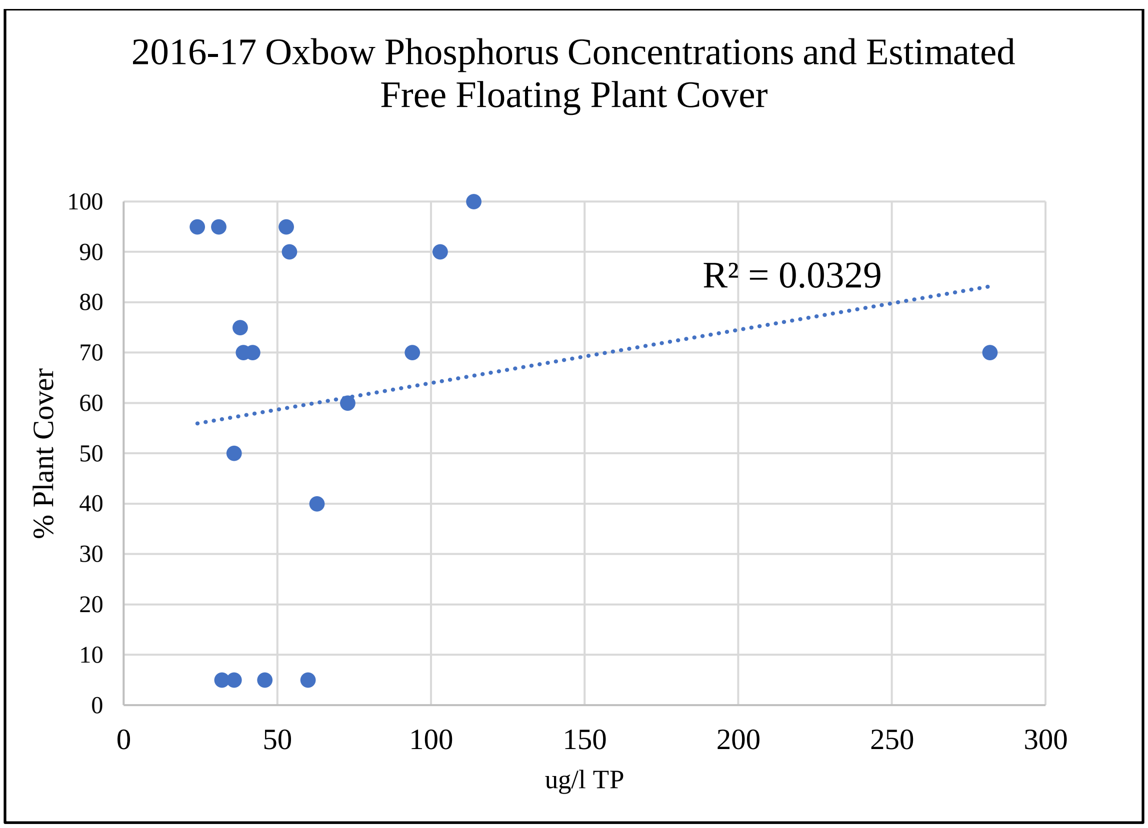
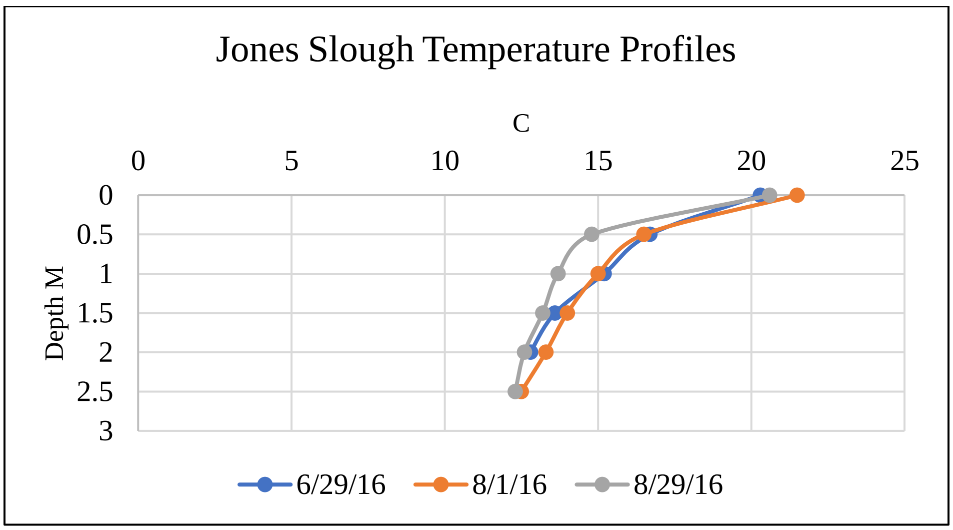


Figure 6: Oxbow Total Phosphorus Levels and Estimated Percent FFP



Our monitoring data cannot quantitatively reveal nor predict water groundwater discharge rates and nitrogen loading to the oxbow lakes. However, water samples revealed that higher groundwater discharge rates likely occurred at Jones Slough and Bakkens Pond. Both lakes also display the most significant water quality problems. Water temperature is generally colder in both lakes during peak summer growing season and longer open water periods during the winter. We demonstrated these observations in more detail as part of the 2014-15 study. Figure 7 provides examples of cold water temperatures that are sustained in Norton Slough and to a greater extent in Jones Slough. In addition to water temperatures, specific conductance level differences in deeper groundwater flow paths and oxbows can also reflect relative influence of groundwater. Specific conductance can be used as a crude tracer. In Figure 8, minimal conductivity change occurred between the wells and Jones Slough (slough water at 93% of well conductivity). Specific conductance in Norton Slough was 22% lower than in adjacent wells and likely reflects greater influence of the river floodplain. Specific conductance increased at Long Lake (114%) and likely reflected upstream influence of Bakkens Pond where relatively high levels were measured in both the deeper wells and oxbow.

Figure 7: Jones Slough and Norton Slough Temperature Profiles



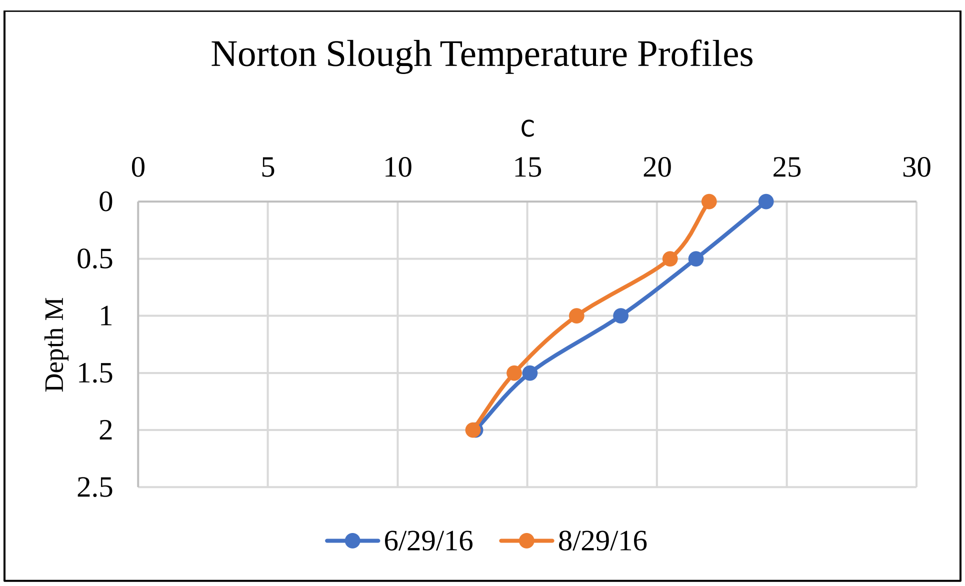


Figure 7: Specific Conductance Measurements from Deeper Wells and Oxbows

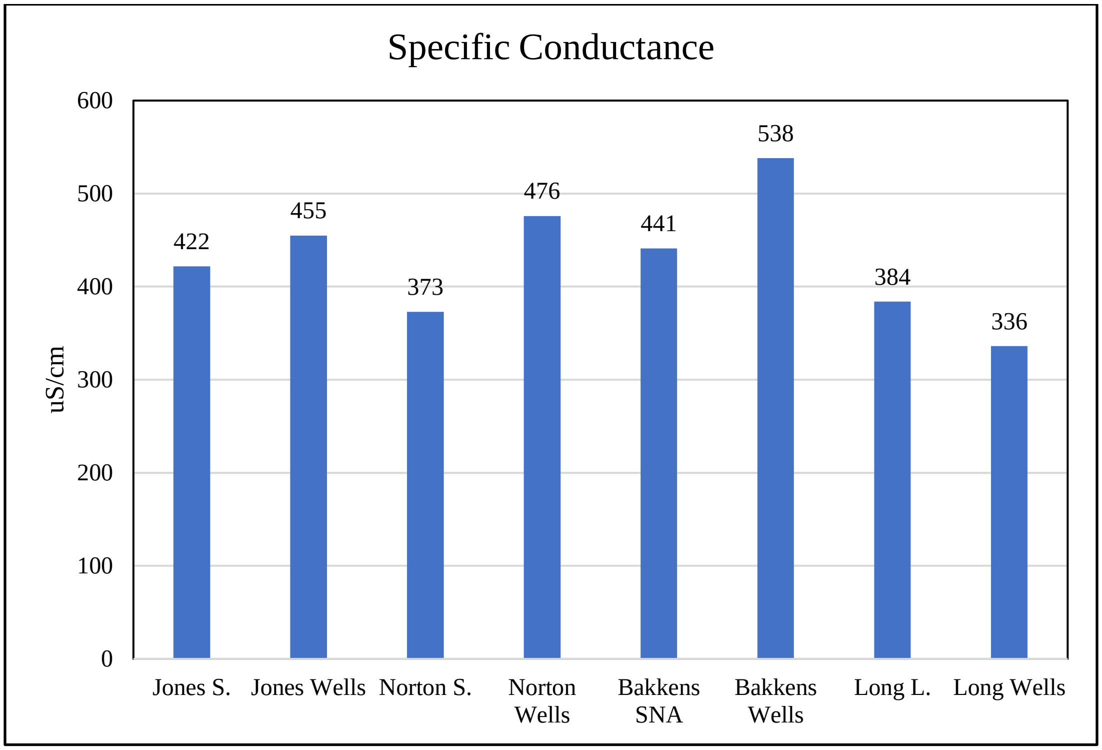


Figure 8: Sauk County areas susceptible to groundwater contamination

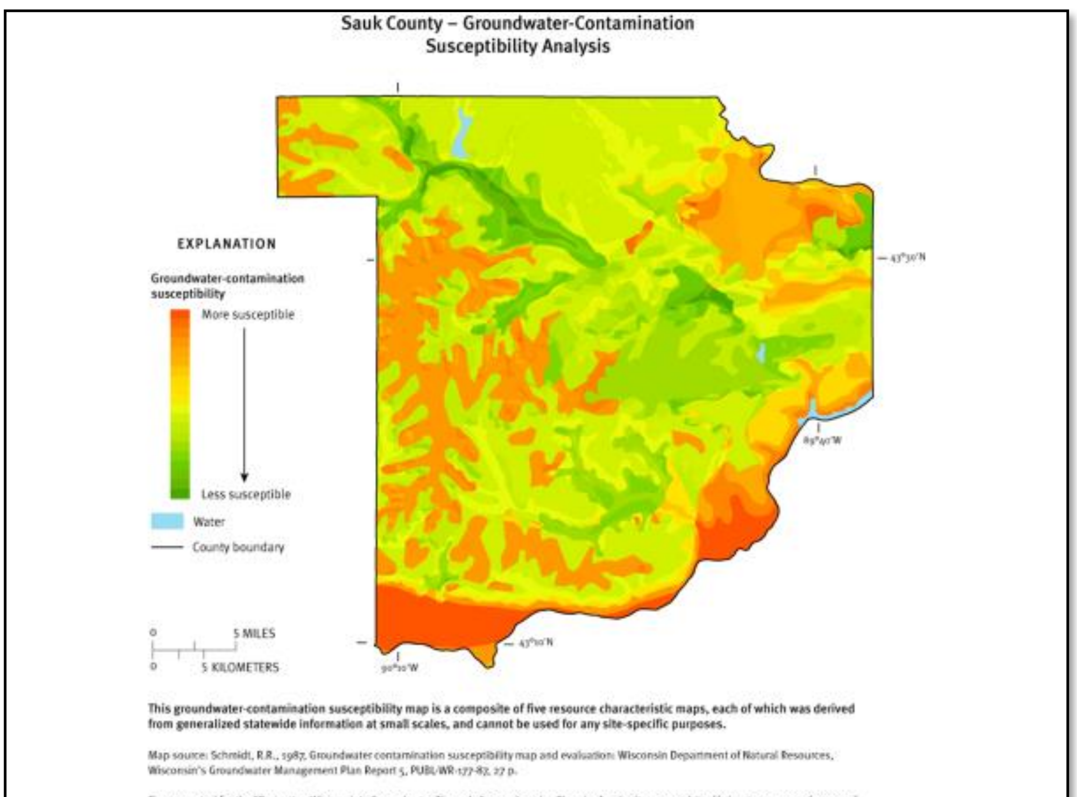


Figure 9: Oxbow Total Phosphorus Data 2014-17 (Phosphorus criterion red horizontal line)

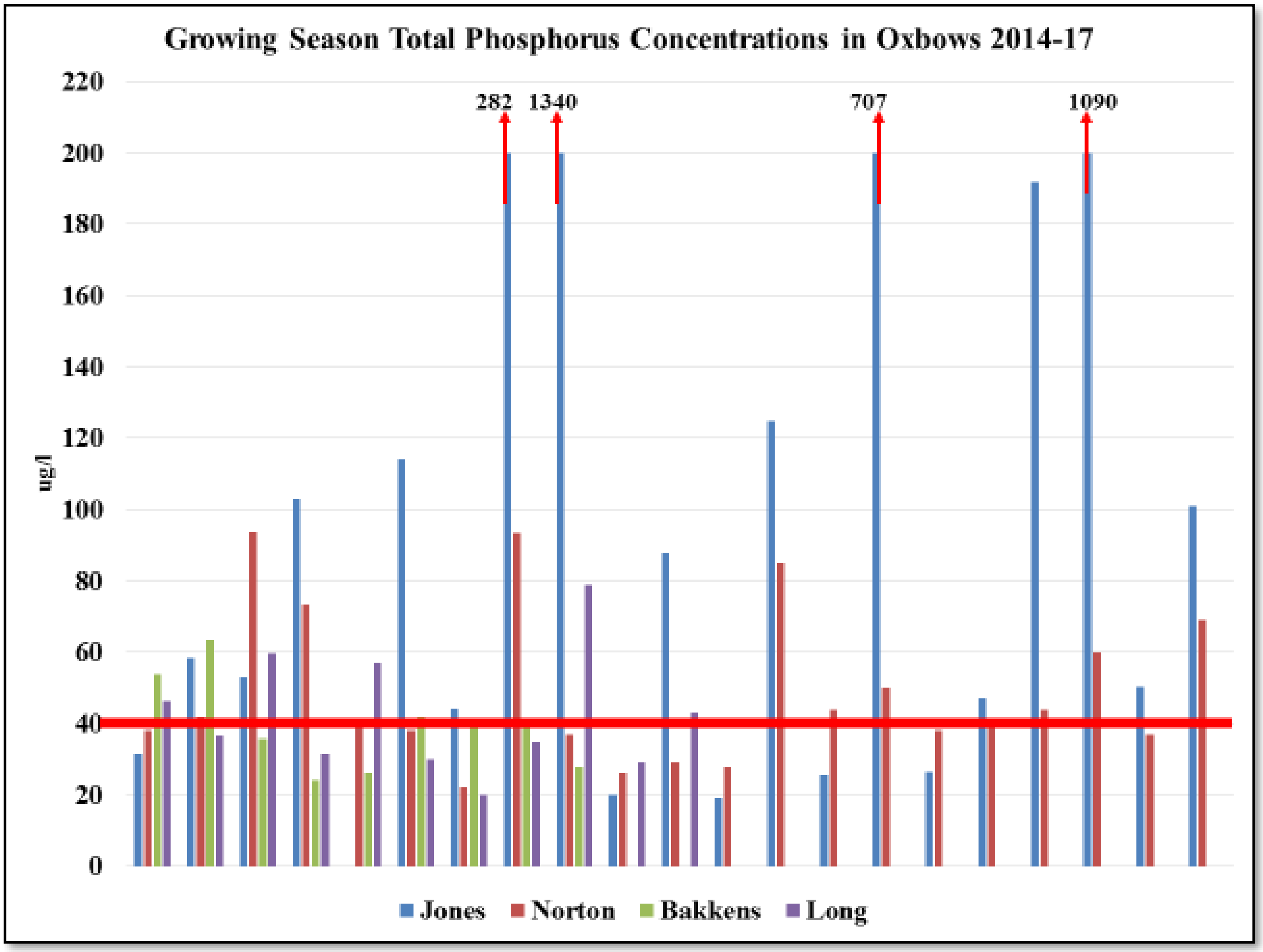


Figure 10: 2016-17 Oxbow Nitrate Concentrations in Relation to Camargo Recommended Limit

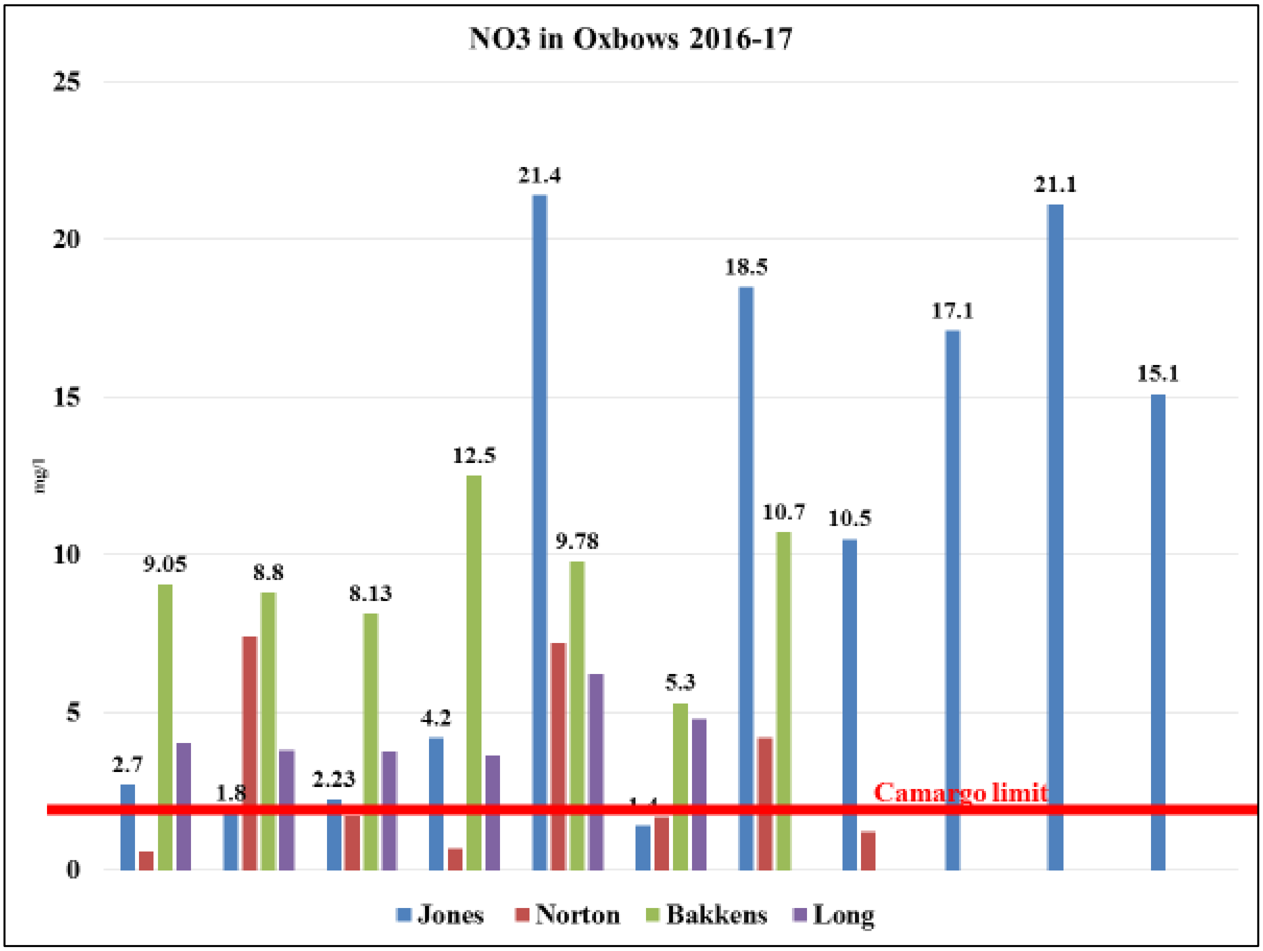


Figure 11: Jones Slough and Norton Slough Groundwater Flow Paths

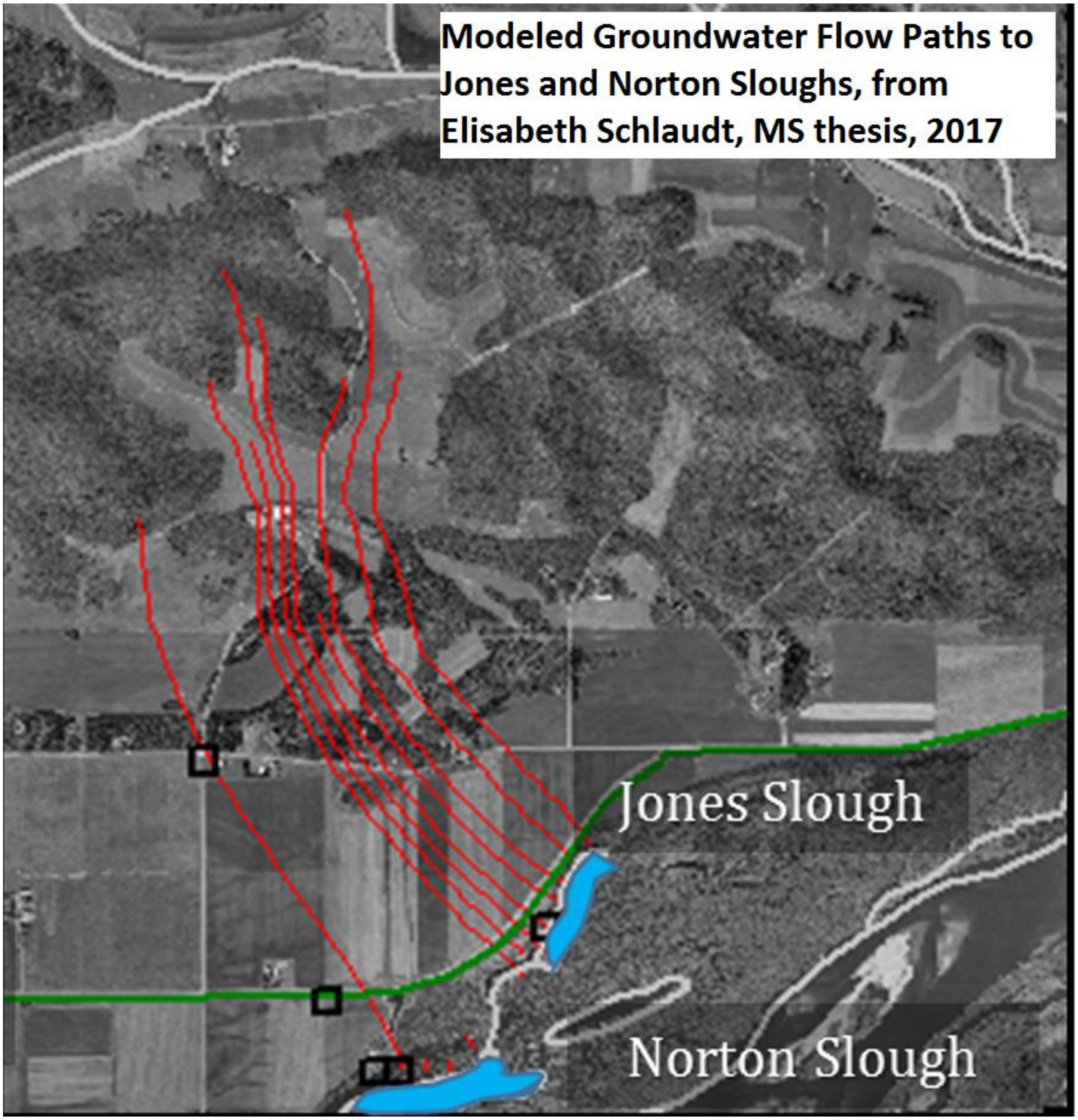
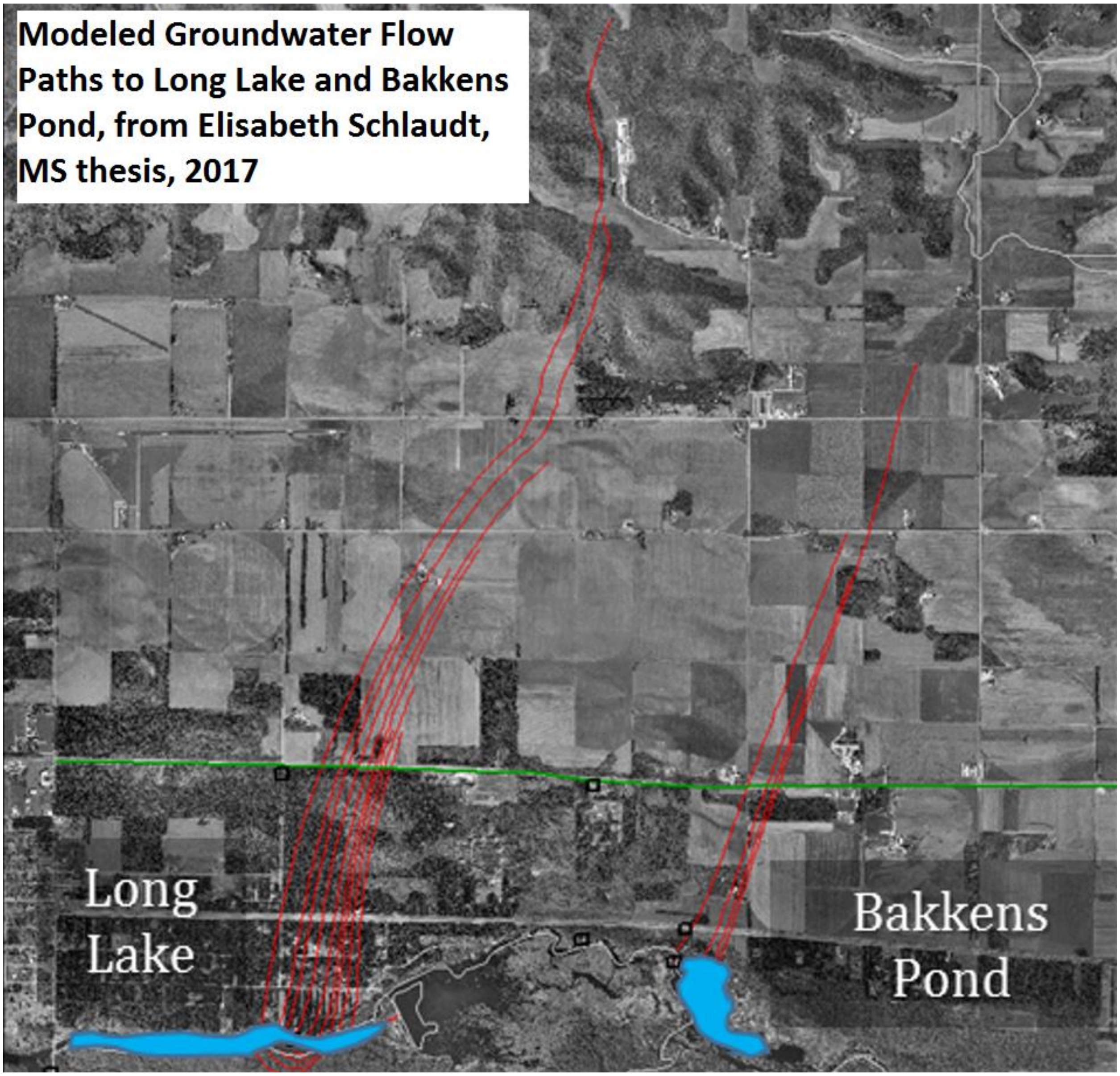


Figure 12: Bakkens Pond SNA and Long Lake Groundwater Flow Paths



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Jones Slough Monitoring Well Data

	JS1				JS2				JS3			
	TP mg/l	NO3 mg/l	Sp Cond uS/cm	Temp C	TP mg/l	NO3 mg/l	Sp Cond uS/cm	Temp C	TP mg/l	NO3 mg/l	SP Cond uS/cm	Temp C
5/22/16		4.03	213	8.3		25.6	563	9.7		24.4	483	10.6
7/12/16		2.9	213	10.7		24.3	530	10.6		13.5	408	10.7
9/10/16		2.3	241	13.2		35.6	608	10.9		14.7	470	10.7
6/6/17	0.0273	7.48	264	9.2	0.0235	14.5	471	10.1	0.0173	14.5		
8/17/17		3.2	202	12.7		8.5	403	10.9		8.2	351	10.9
9/9/17				10.82		15						
10/10/17		3.8	204	12.9		18.7	415	10.9		13.6	345	10.7

Norton Slough Monitoring Well Data

	NS1				NS2			
	TP mg/l	NO3 mg/l	Sp Cond uS/cm	Temp C	TP mg/l	NO3 mg/l	Sp Cond uS/cm	Temp C
5/22/16		12.8	260	9.7		17.1	467	10.3
7/12/16		4.8	233	11.6		11.2	503	10.4
9/10/16		5	313	13.1		14.6	530	11.2
6/6/17	0.0276	2.94			0.0163	14.3		
6/10/17		3.6	219	11.5		18.6	474	12.3
8/17/17		1.6	203	12.8		10.2	488	11.3
10/10/17		1.8	207	13.1		8.2	527	11.1

	NS3				NS4			
	TP mg/l	NO3 mg/l	Sp Cond uS/cm	Temp C	TP mg/l	NO3 mg/l	Sp Cond uS/cm	Temp C
5/22/16		34.8	496	10.8		28.6	427	10.7
7/12/16		13.5	501	10.7		10.4	402	10.7
9/10/16		17.9	587	11.1		12.5	449	10.9
6/6/17	0.0225	15.3			0.0329	10.9		
6/10/17		17.7	486	11.9		13.4	391	11.7
8/17/17		13.1	476	11		8.2	410	11.1
10/10/17		14.2	454	10.8		13.6	447	10.8

Bakkens Pond Well Monitoring Data

	BP1				BP2				BP3			
	TP mg/l	NO3 mg/l	Sp Cond uS/cm	Temp C	TP mg/l	NO3 mg/l	Sp Cond uS/cm	Temp C	TP mg/l	NO3 mg/l	Sp Cond uS/cm	Temp C
5/22/16		1.12	63	9.2		23.6	566	10.6		27.4	548	10.9
7/13/16		0.7	45	12.2		19.2	571	10.7		26.1	580	10.8
9/10/16		0.5	55.1	13.3		19.1	551	10.5		26.4	568	10.4
6/6/17	0.009	0.382			0.0145	17.4			0.0121	24.4		
8/17/17		0.2	64	13		23.7	580	10.7		28.2	573	10.6
10/10/17		0.4	46	11.6		19.3	585	9.9		30.2	558	10.1

	BP4				BP5			BP6		
	TP mg/l	NO3 mg/l	Sp Cond uS/cm	Temp C	NO3 mg/l	Sp Cond uS/cm	Temp C	NO3 mg/l	Sp Cond uS/cm	Temp C
5/22/16		28.1		10.5	25.7	501	10.6	22.6	529	10.5
7/13/16		21.8	517	10.6	22.1	516	10.6	19.3	544	10.6
9/10/16		23.5	517	10.4	24.7	520	10.5	21	535	10.5
6/6/17	0.015	29.7								
8/17/17		31.7	535	10.7	23.2	491	10.6	18.9	503	10.7
10/10/17		32.1	535	10.3	27.9	492	10.2	22.6	500	10.4

Long Lake Well Monitoring Data

	LL1				LL2			
	TP	NO3	Sp Cond	Temp	TP	NO3	SP Cond	Temp
5/22/2016		2.75	213	9.4		6.51	674	10
7/13/2016		2.6	364	12.3		3.1	265	10.6
9/10/2016		2.3	351	13.1		5.2	910	10.6
6/6/2017	0.0114	2.57			0.0521	1.97		
6/10/2017		2.5	217	9.9		2.05	204	9.8
8/21/2017		5.1	242	13.7		1.9	163	11.1
10/10/2017		7.8	340	13.4		1.2	147	

	LL3				LL4			
	TP	NO3	Sp Cond	Temp	TP	NO3	Sp Cond	Temp
5/22/2016		8.3	280	10.4		12.1	360	10.3
7/13/2016		7.2	313	10.2		13	374	10.4
9/10/2016		7.4	371	9.7		13.5	411	10.3
6/6/2017	0.0114	8.2			0.0111	13.9		
6/10/2017		7.7	288	12.6		13.4	351	10.4
8/21/2017		7.5	311	10.6		12.2	362	10.6
10/10/2017		6.3	315	10.6		13.7	366	10.6