Lower Wisconsin River Floodplain Lakes Water Pollution Investigation

Diagnostic and Feasibility Study Part 1

Bakkens Pond

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Project Sponsor: River Alliance of Wisconsin

WDNR Lakes Planning Grant Project

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Summary

During the growing season of 2013, severe impairments to recreation and water quality occurred in Jones Slough, Norton Slough and Bakkens Pond. Heavy metaphyton cover (Cladophora and duckweeds) rendered the sloughs unusable for recreational angling and boating. Significant environmental degradation included nitrogen hypersaturation, toxic levels of nitrates and low dissolved oxygen levels beneath the dense metaphyton cover. Nitrogen levels far exceeded the USEPA recommended criterion for the Driftless Area of 1.88 mg/l N. Very high nitrate levels were measured in most of the floodplain lakes that lie adjacent to the Pleistocene terrace but very low levels were detected in the Wisconsin River and Wagner Pond. The degraded conditions found in most of the floodplain lakes pose threats to the State Endangered starhead topminnow and other environmentally sensitive species, particularly darters that live in cutoff channel oxbow lakes. These problems are linked to excessive nutrient applications over coarse sandy soils that rapidly leach nitrates and likely phosphorus. A more detailed assessment of groundwater contaminants is needed to determine nitrogen and phosphorus loads and concentrations entering the cutoff channel oxbows.

Recommendations

1. Establish conservation buffers (~$1,300/ acre permanent easements and ~$3,300/acre fee title) around environmentally sensitive cutoff channel oxbow lakes with recommended widths of 100 meters or greater.

2. The Town of Spring Green should adopt Farmland Preservation Zoning. The town should not punish efforts to create buffers by raising property tax assessments since this activity should be considered an integral part of agricultural production.

3. Part 2 of the Lake Planning Grant Diagnostic and Feasibility Study should be conducted to better assess levels of nitrates and phosphorus entering cutoff channel lakes from the groundwater. Existing surface water data does not account for metaphyton nutrient uptake during the growing season. Additional monitoring should focus on nutrient cycling during high river flows since the floodplain may be a natural source of phosphorus and may affect de-nitrification. Groundwater monitoring should be conducted to assess the influence of existing buffers on nitrogen removal, such as the Sauk County School Forest, and this information may result in more effective buffer width recommendations. A survey of environmentally sensitive darters and other fish should be updated.

4. The State of Wisconsin should adopt USEPA recommended nitrogen criteria. Lower Wisconsin State Riverway floodplain lakes with excessive metaphyton, phosphorus and nitrogen should be placed on the USEPA 303d list of impaired waters.

Introduction

Below the Prairie du Sac dam, the Wisconsin River flows within a braided channel floodplain that remains in a relatively natural state. This high quality large river ecosystem was exemplified in an educational poster (SP River PAL River Planning Grant) that was produced in 2009 in conjunction with the 20 year anniversary of the Lower Wisconsin State Riverway. The State Riverway currently holds 99 fish species and the number of fish and overall biodiversity would be significantly lower without the vast network of oxbows, sloughs, delta ponds, beaver ponds and creek bottoms that support species adapted to off-channel habitats. The Lower Wisconsin River floodplain sustains a number rare fish species that thrive in these off-channel habitats including the State Endangered starhead topminnows (*Fundulus dispar*), State Special Concern mud darter (*Etheostoma asprigene*), State Special Concern pirate perch (*Aphredoderus sayanus*), State Special Concern weed shiner (*Notropis texanus*), State Special Concern pugnose minnow (*Opsopoeodus emiliae*), lake chubsucker (*Erimyzon sucetta*) and Mississippi grass shrimp (*Palaemonetes kadiakensis*). Off-channel habitats also provide refuges and nursery habitats for riverine fish species (Amoros 2001, Amoros and Bornette 2002, Kilgore and Miller 1995).

While the Lower Wisconsin River floodplain provides critical habitats for these species and the entire off-channel fish assemblage, the floodplain is a dynamic ecosystem that undergoes annual and seasonal changes that create both environmental opportunities and stressors. Amoros and Bornette (2002) demonstrated how hydrologic changes that occur in floodplains are closely linked to river stages. During very high river flow events, the river consumes the entire floodplain and cutoff channel oxbows become active river channels again. Scouring and removal of organic deposition can occur due to the relatively linear cutoff channel morphology. Under high river flows, alluvial groundwater moves toward the oxbows, causing significant water chemistry changes including lower dissolved oxygen, lower pH, stained water and increased organic carbon. Upland groundwater is the primary water source for cutoff channel oxbows during low flows and late summer median flows when water is very clear and alkalinity is higher. The upland groundwater is part of a massive Driftless Area groundwater flow system that begins in the bluffs, descends across the Pleistocene terrace and into the floodplain where cutoff channel oxbows and wetlands intercept groundwater before reaching the river (Pfeiffer et al. 2006). The combination of upland groundwater flows and well connected floodplain can sustain favorable oxbow water quality and habitat for rare off-channel species. Mud darters and pirate perch are often found within tree roots/woody debris along steep oxbow banks that intercept upland groundwater (Marshall 2012).

The Lower Wisconsin River was recently the focus of five lake planning grants, a river planning grant and two State Wildlife Grant projects that were conducted from 2007 to 2012 (Marshall 2012, Marshall 2009). These surveys demonstrated that water quality and habitats in some cutoff channel oxbows in the Spring Green area had become severely degraded due to contaminated groundwater. These problems were previously not assessed (Marshall and Lyons 2008, WDNR 2006) but became evident in Jones Slough in 2008 and later expanded in other oxbows in the area. By 2011, a diverse aquatic plant community in Norton Slough disappeared as it became smothered by a dense mat of metaphyton (Cladophora filamentous algae and duckweeds). The metaphyton cover shaded out the plants and significant amount of fish habitat. The dense metaphyton mat also eliminated photosynthesis and atmospheric exposure to the water that resulted in very low dissolved oxygen levels. Anecdotal reports from resident anglers also mirrored these recent findings.

In an effort to better define the rapid water quality decline that occurred in Norton Slough, WDNR Paleolimnologist Paul Garrison, Richard Wedepohl and Dave Marshall attempted to collect sediment cores from the lake in March 2012 (Marshall 2012). The sampling demonstrated that scouring had occurred during floods since the bottom was mostly sand with very little organic deposition. This finding was consistent with Amoros and Bornette (2002) but more importantly revealed that the water quality change was not linked to internal loading but rather reflected recent nutrient loadings. Vertical temperature profiles of the lake revealed the significant upland groundwater flow that dominates the lake hydrology. This information, coupled with the trend of increasing nitrates in adjacent wells, suggested that contaminated groundwater is the primary nutrient source.

This project was funded and designed to assess levels of pollutants and impairments in the Lower Wisconsin State Riverway cutoff channel oxbow lakes, identify potential pollutant sources and recommend restoration alternatives.

Methods

Floodplain lake water quality surveys were performed on May 9th, May 19th, June 1st, July 29th, August 13th, August 20th and August 30th in 2013. Nitrate sampling was not performed throughout most of June and July due to very high river flows that changed the hydrology and significantly reduced upland groundwater flows to the lakes. During each survey, a YSI Pro Plus meter was used to measure nitrates (0.5 m depth) and was calibrated each survey day using 1 mg/l NO_3 and 100 mg/l NO_3 standards. Additional quality assurance included paired SLOH nitrate samples that were collected from eight sloughs on May 19th and July 29th. The samples were also analyzed for total phosphorus and in a few instances Total Kjeldahl Nitrogen to calculate Total Nitrogen concentration. A YSI Model 52 meter was used to measure dissolved oxygen and temperature. The meter was air calibrated according to specifications. A YSI Model 63 meter was used to measure pH and specific conductance. A 120 cm secchi transparency tube was used to measure water clarity. Metaphyton cover (filamentous algae and duckweeds) was estimated using the following scale (Sullivan 2008): 0 = no filamentous algae or duckweeds present, 1 = 1 – 20 % metaphyton cover, 2 = 21 – 40 % metaphyton cover, 3 = 41 – 60 % metaphyton cover, 4 = 61 – 80 % metaphyton cover, and 5 = 81 – 100 % metaphyton cover. Most of the cutoff channel oxbow lakes had documented populations of state endangered starhead topminnows (SHTM). A long handed small mesh dip net was used to determine the presence/absence of this rare species in the lakes.

In addition to these five surveys, volunteers Doug and Sherryl Jones measured dissolved oxygen and temperature using a YSI Model 57 meter along with water levels (not linked to sea level) twice daily from their pier on Norton Slough. The water level data was also compared with the USGS flow gaging station water levels at Muscoda.

Findings

Norton Slough (WBIC 1247200 – 13 acres) and Jones Slough (WBIC 1247300 – 7 acres) drain a watershed area of approximately 1667 acres. Hutter (Rainbow, WBIC 1247000) Slough and Wood Slough (WBIC 1247100) are also part of this sand terrace oxbow drainage system. The watershed lies west of Wilson Creek where the low gradient Pleistocene terrace widens significantly, rendering surface watershed divisions somewhat nebulous.

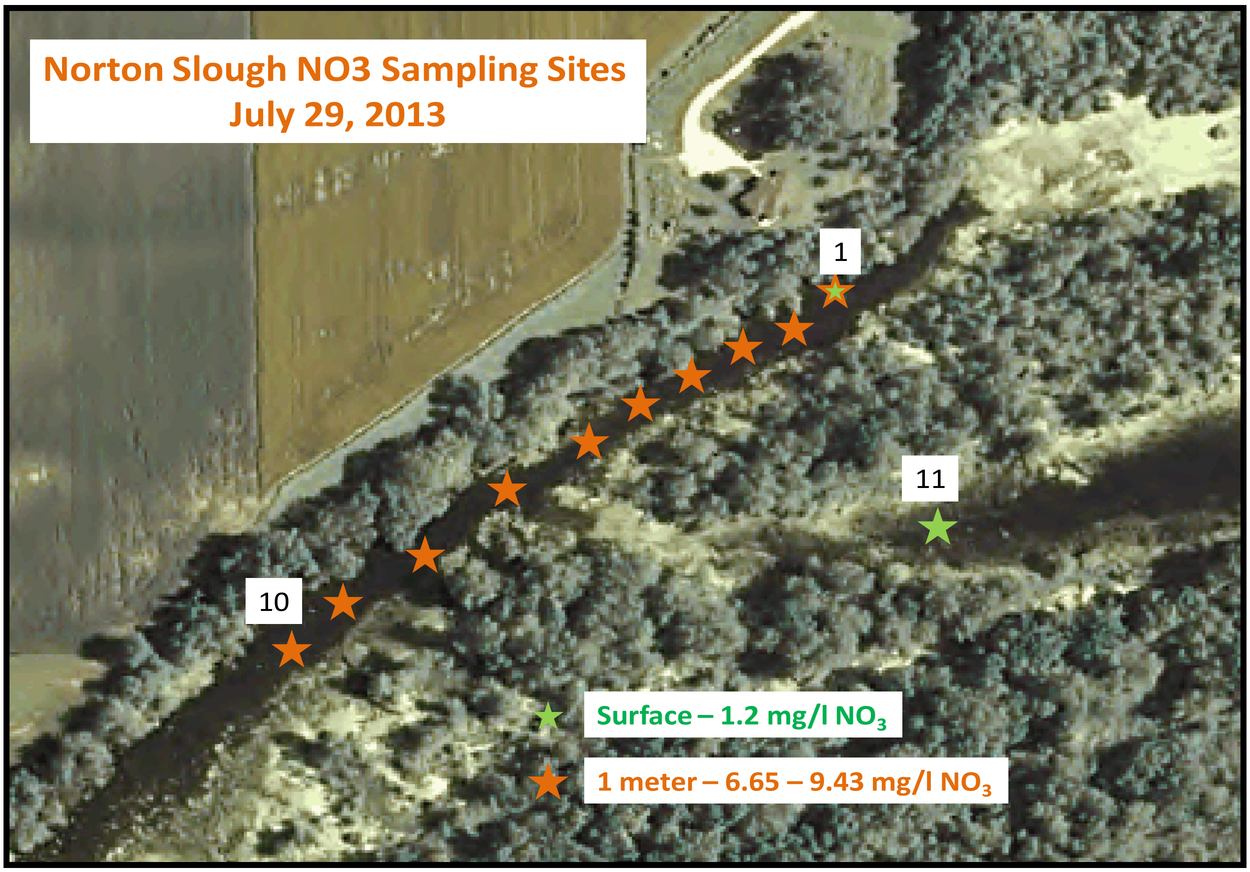
Norton Slough was sampled six times at Site 1 (Figure 1 map) in 2013 from May 9 to August 30. Nitrate levels were high (4 – 5.29 mg/l) early in the season but declined (1.2 - 2.02 mg/l) by early June (Figure 2). This trend coincided with increased metaphyton cover that was excessive and covered most of slough surface area throughout late summer. The nitrate decrease likely reflected nutrient uptake near the surface (0.5 m). On July 29th, numerous locations in Norton Slough were sampled for nitrates and significantly higher levels were found 1 – 1.5 meters below the surface where colder dense groundwater flows into the slough (Figures 3 and 4). Nitrate concentrations ranged from 6.65 to 9.43 mg/l across Norton Slough at 1 – 1.5 meters depth while the 0.5 meter samples were less than 1.5 mg/l (Figure 3).

Total phosphorus samples were also collected on May 19th and July 29th. Concentrations were below the recommended criterion of 40 ug/l at Site 1 but exceeded the concentration at Site 11 (93 ug/l) on July 29th. Site 11 was used as a surrogate for Wood Slough that was inaccessible due to low water levels and impassible metaphyton cover. Consistent with nitrates, variable phosphorus concentrations may have reflected metaphyton uptake and growth. The total kjeldahl nitrogen concentration on May 19th was 1.03 mg/l for a total nitrogen concentration of 5.15 mg/l based on State Lab of Hygiene sample results. The slough appeared to be phosphorus limited at the time given the phosphorus concentration of 0.038 mg/l (N:P > 20:1).

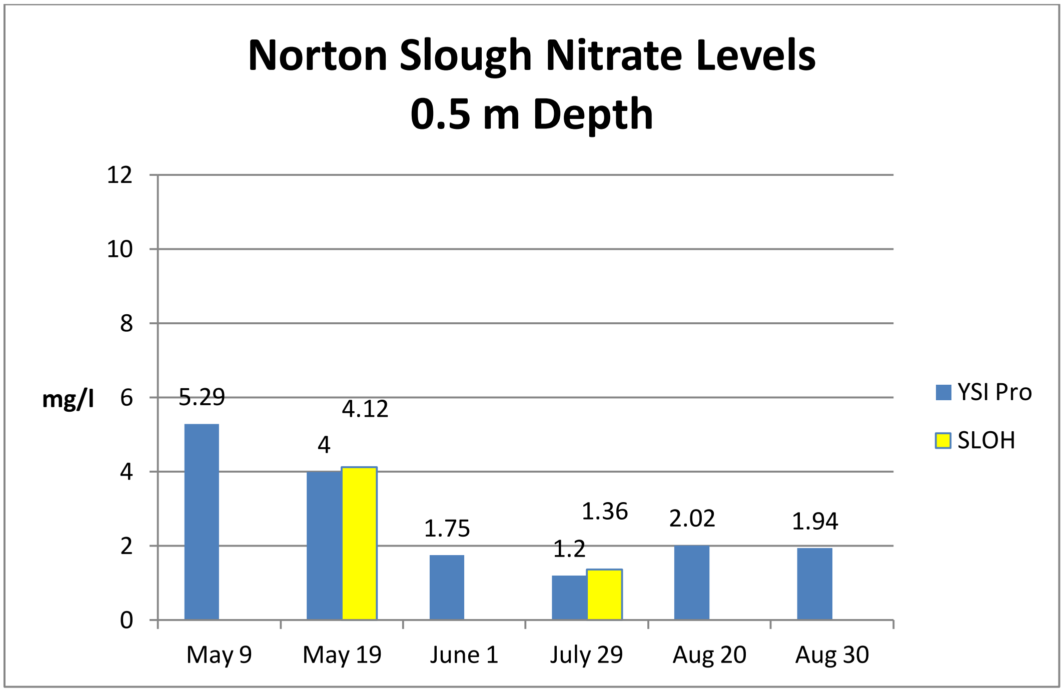
Metaphyton densities in Norton Slough are summarized in Figure 4. Over 80% of the surface was covered with metaphyton on July 29 and August 20, resulting in recreation impairments and negative effects on lake ecology and water chemistry. Doug and Sherryl Jones sampled Norton Slough twice daily for water temperature, dissolved oxygen and water level from May 20th to August 20th. Figure 5 displays dissolved oxygen versus water levels in Norton Slough and USGS stage data from the Muscoda flow station. Dissolved oxygen levels declined precipitously during high river stages when alluvial groundwater entered the slough. Extended periods of low dissolved oxygen were measured in the slough during the high river stages. During low flow periods, low dissolved oxygen levels (below water quality criterion of 5 mg/l) also occurred intermittently and likely reflected suppressed photosynthesis (and increased respiration) due to dense metaphyton cover that was somewhat variable due to shifting winds. SHTM were collected in Norton Slough on August 20th.

Jones Slough was sampled five times in 2013. It had the highest metaphyton densities, highest nitrate concentrations (13.3 mg/l on July 29th) and total phosphorus concentrations. Total phosphorus samples exceeded recommended 40 ug/l criterion (44 ug/l and 1340 ug/l). On May 19th, the total kjeldahl nitrogen concentration was 0.839 mg/l and total nitrogen concentration was 6.7 mg/l. As a result, the N:P > 20:1 ratio suggested that the slough was phosphorus limited. On July 29th, the N:P ratio was 12:1 or indeterminate. Moste likely neither nutrient was limiting given the very high concentrations at that time (TN = 16.23 mg/l and TP = 1.34 mg/l). SHTM were collected in Jones Slough on August 20th and August 30th.

Figure 1: Norton Slough sampling locations



Figures 2 and 3: Nitrate concentrations at Site 1 (0.5 m depth) and across Norton Slough on July 29th at both 0.5 and 1 meter depths.



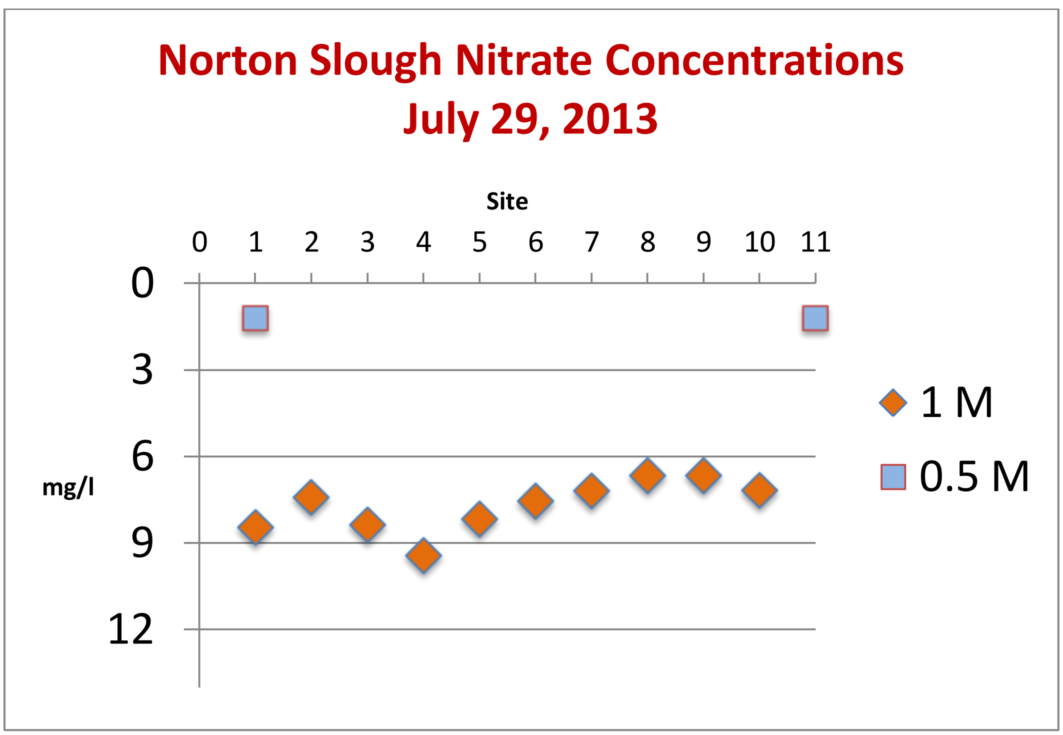


Figure 4: Norton Slough Metaphyton Cover (0 = none, 5 = 80 – 100%

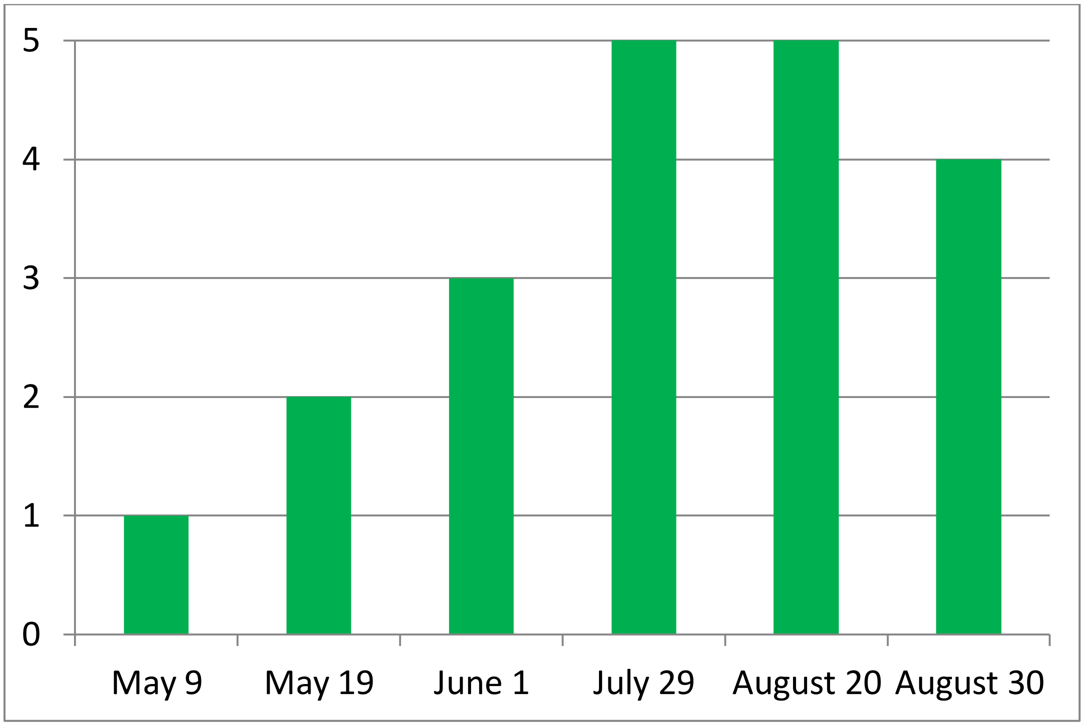


Figure 5: Water Level and Norton Slough Dissolved Oxygen Trends

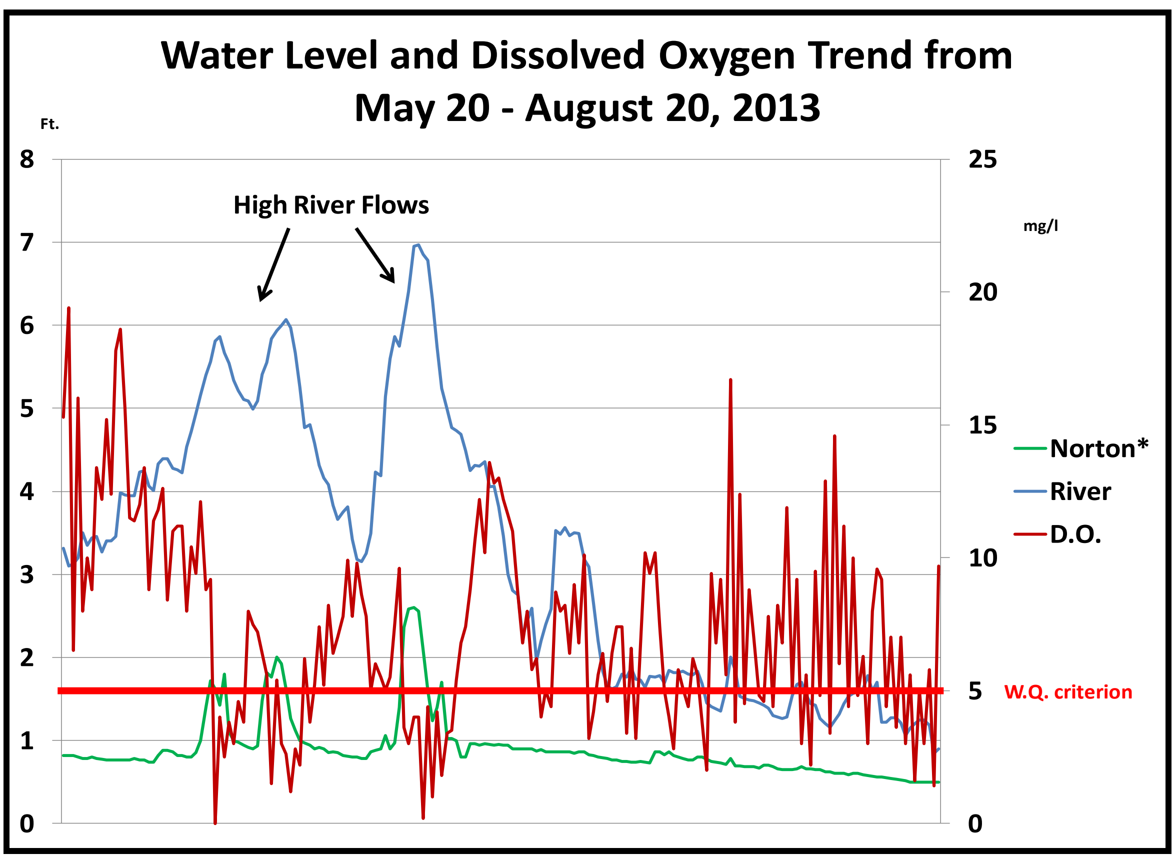


Figure 6: Jones Slough Nitrate Levels

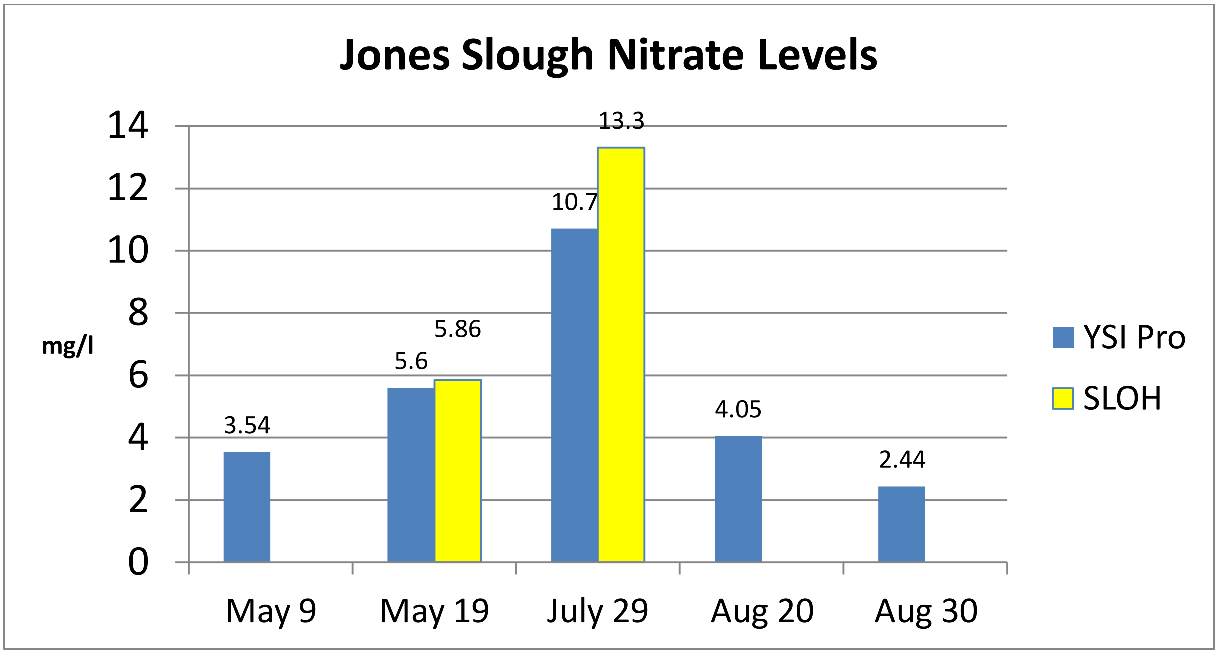
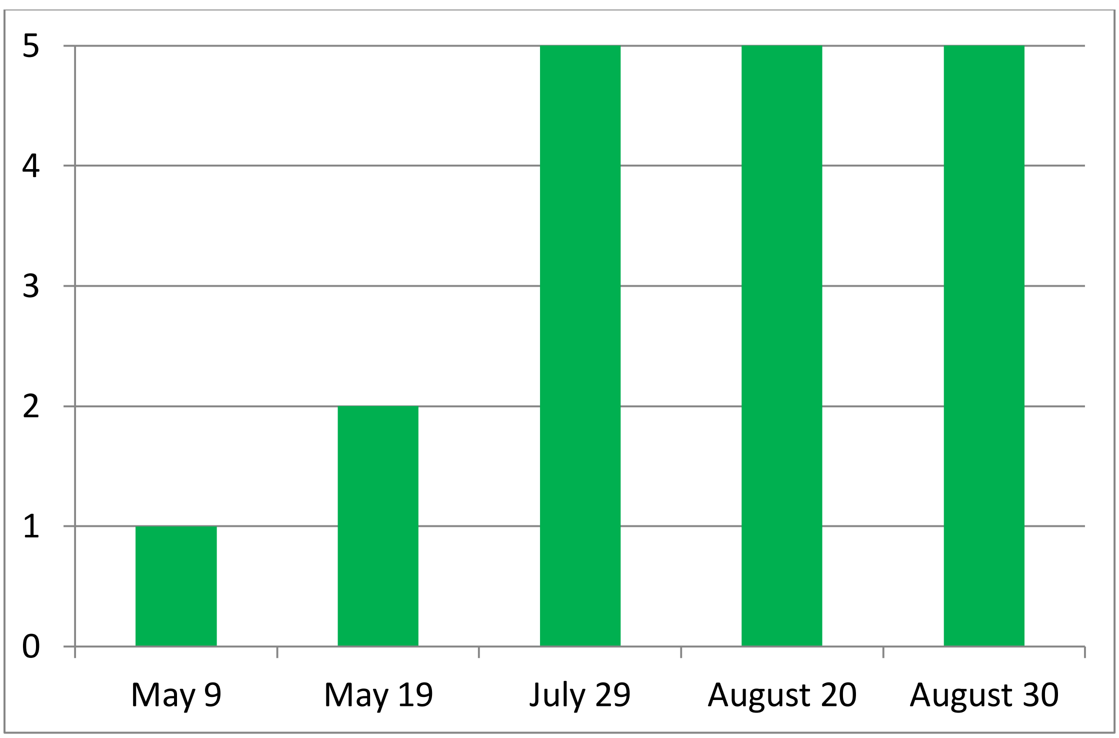
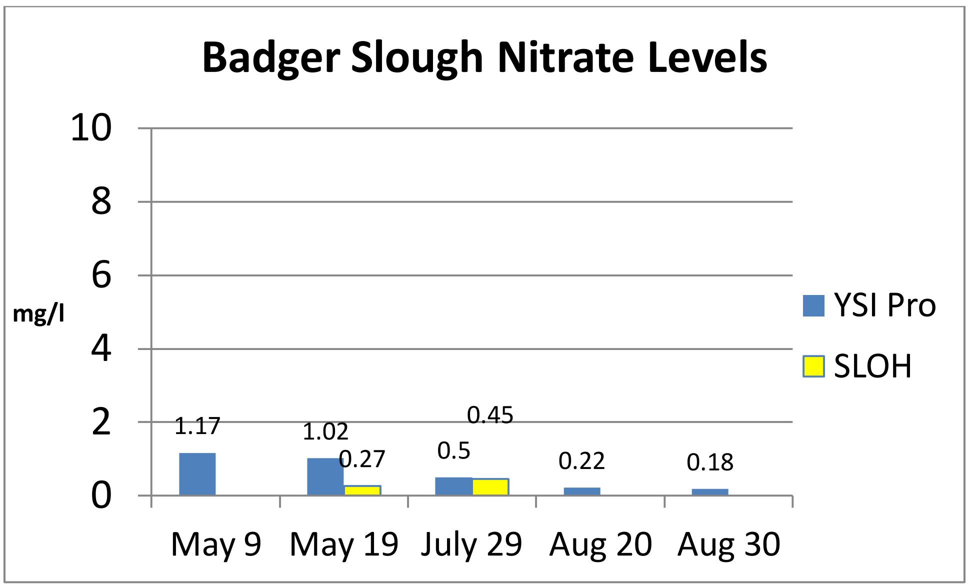


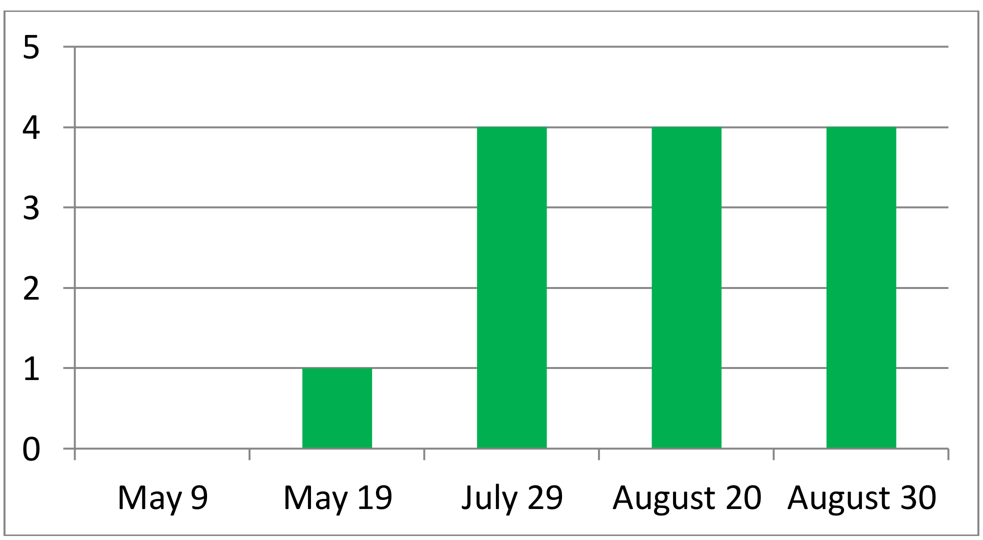
Figure 7: Jones Slough Metaphyton Cover



"Badger Valley" or unnamed (WBIC 1248000) is a Town of Troy cutoff channel oxbow lake that is sustained by both upland groundwater and a small tributary. The lake is about 5 acres in surface area with a maximum depth of about 5 feet. It lies much closer to the surrounding bluffs than the other lakes to the west and drains a very steep watershed. The 1404 acre watershed is about 22% agricultural and mostly wooded (~70%). The steep slopes have the potential to deliver significant sediment loads and nutrients. The tributary elevation change is very high at 125 ft/mile. Badger Slough contained relatively low nitrate concentrations in 2013 (Figure 8) compared with the floodplain lakes that lie adjacent to the broad Pleistocene terrace. Yet excessive metaphyton cover (Figure 9) was found late summer. While nitrogen levels were low in this slough and likely reflect wooded bluff groundwater discharge, phosphorus levels were high (81 ug/l and 77 ug/l). The high phosphorus concentrations may have reflected recent channel excavations for agricultural drainage in the steep watershed. On May 19th, the total kjeldahl nitrogen concentration was 1.1 mg/l and total nitrogen concentration was just 1.37 mg/l based on State Lab of Hygiene sample results. The N:P ratio was 17:1 and suggested a phosphorus limited ecosystem at the time. SHTM were collected the slough on August 20th and August 30th.

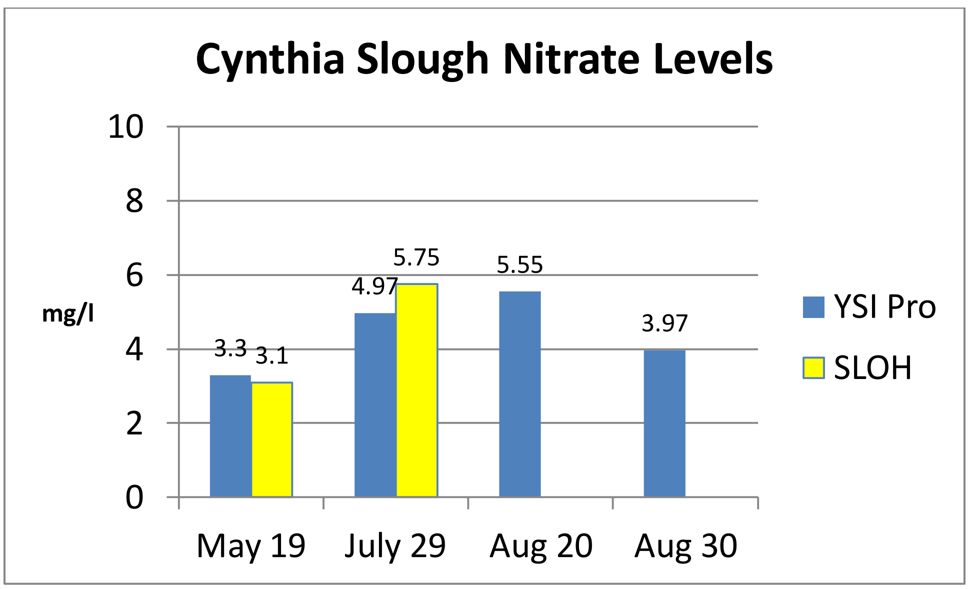
Figures 8 and 9: Badger Slough Nitrate Concentrations and Metaphyton Cover





Cynthia Slough (WBIC 5034625 – 14 acres) is located directly south of the Village of Spring Green and is surrounded by the Wisconsin Riverside Resort to the north. The floodplain lake outlet is directly connected to the river, accommodating frequent fish migrations. It shares the same elevation with the river and water levels fluctuate with river stages. The Pleistocene terrace and floodplain on the north side of the river is expansive. Surface watershed boundaries are unclear within this broad flat area. The estimated 708 acre watershed is considerably more developed than the other watersheds including about 80% moderate urban density and about 17% cropland. Cynthia Slough was sampled four times in 2013 with the nitrate data displayed in Figure 10. High levels were routinely found in Cynthia Slough but levels were somewhat lower compared to some of the other lakes in the area. A maximum concentration of 5.75 mg/l was significantly lower than a groundwater fed rivulet entering the slough with a concentration of 8.52 mg/l on August 30th. Metaphyton cover was typically low in Cynthia Slough and never exceeded a density level of 1. No STHM were collected in Cynthia Slough.

Figure 10: Cynthia Slough Nitrate Levels

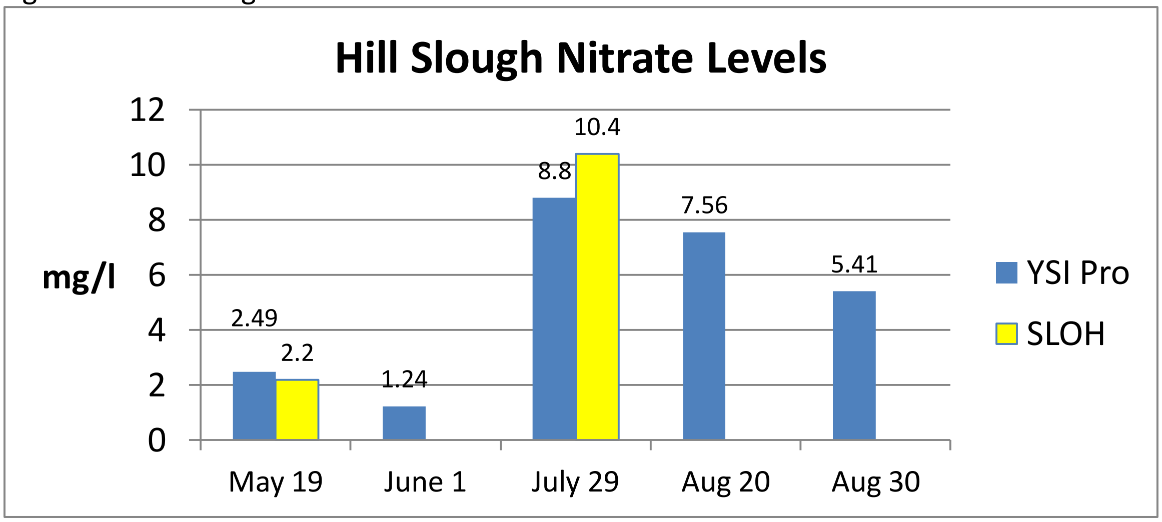


Hill Slough (WBIC 1241200 – 19 acres) is located about a mile west of Cynthia Slough and consists of a series of connected basins over 2 miles long. The far west basin drains into a river side channel. The lake drains an area of mostly sand terrace croplands of about 1220 acres. Hill Slough was sampled five times during the summer of 2013 with moderate levels of nitrates in the slough detected early in the season but increasing to very high levels by mid-summer (Figure 11). Total phosphorus concentrations exceeded the recommended criterion for drainage lakes concentration of 40 ug/l (68 ug/ and 47 ug/l$^{)}$. In spite of the very high nitrogen and phosphorus concentrations in Hill Slough, metaphyton densities never exceeded a cover value of 1. The sampling site was located on the eastern half of the slough where the hydrology and nutrient inputs are likely different from the west side. A flood control drainage ditch, that is highly polluted, discharges into the floodplain forest that lies adjacent to Hill Slough. The impacts of that ditch likely do not affect the water quality at the Hill Slough site monitored for this project since it is located (east) upstream of the ditch. SHTM were collected on June 1, July 29, August 20 and August 30.

Bakkens Pond (WBIC 1236700 – 14 acres) is a manipulated flowage system upstream of Long Lake with two earthen dams and tin-whistle discharge structures. It drains at least 660 acres of sand terrace cropland and is sustained by groundwater and a clear groundwater fed stream. Bakkens Pond is part of the Bakkens Pond State Natural and displays marshy habitat with abundant submersed, floating leaf and emergent plants. The flowage was sampled at two locations in 2013. Both sites displayed very poor water quality with excessive metaphyton cover (Figure 15). Bakkens Pond 1 (SWIMS 10017532 – cover photo) contained high nitrate concentrations in each of four sampling days (Figure 12). Phosphorus concentrations also exceeded criterion for drainage lakes (40 ug/l) at 41 ug/l and 71 ug/l. Nitrate concentrations were very high at Bakkens Pond 2 (SWIMS 10019775) ranging from 5.42 to 10.23 mg/l. Phosphorus concentrations at Bakkens Pond 2 were lower at 33 ug/l and 11 ug/l. No SHTM were found at Bakkens 1 but were found at Bakkens 2 on three sampling dates.

Jones Slough, July 29, 2013

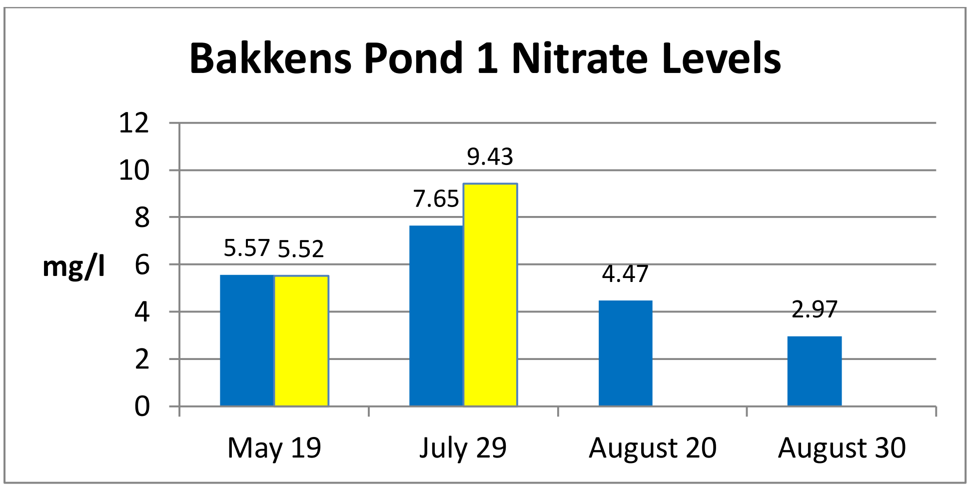
Figure 11: Hill Slough Nitrate Levels



Big Hollow Drainage Ditch (SWIMS 10037286)

Bakkens Pond drains into Long Lake (WBIC 1236600 – 37 acres). Long Lake is more typical of the long narrow cutoff channel oxbows. Long Lake is also more buffered from direct sources of contaminated groundwater than most of the lakes that lie directly adjacent to the Pleistocene terrace. The School Forest lies just to the north of the lake. The Long Lake watershed is at least 448 acres of mostly woods and low density residential. Nitrate levels in Long Lake revealed agricultural inputs with concentrations ranging from 2.54 – 4.23 mg/l but these levels were significantly lower than levels found upstream in Bakkens Pond. Phosphorus concentrations fluctuated from a high of 55 ug/l on May 19th to 33 ug/l on July 29th. Metaphyton levels, ranging from 0 to 1, were significantly lower in Long Lake compared to Bakkens Pond upstream. More sampling is needed to determine if Bakkens Pond is functioning as a nutrient sink. The primary production in Long Lake was primarily benthic algae that floated to the surface as opposed to the dense Cladophora filamentous algae and duckweed growths found in more severely degraded floodplain lakes including Bakkens Pond, Norton Slough and Jones Slough. SHTM were collected in Long Lake on July 29th and August 20th. Further monitoring is needed to determine if the elevated nitrogen and phosphorus concentrations were coming Bakkens Pond or upland groundwater.

Figure 12 and 13: Bakkens Pond Nitrate Concentrations



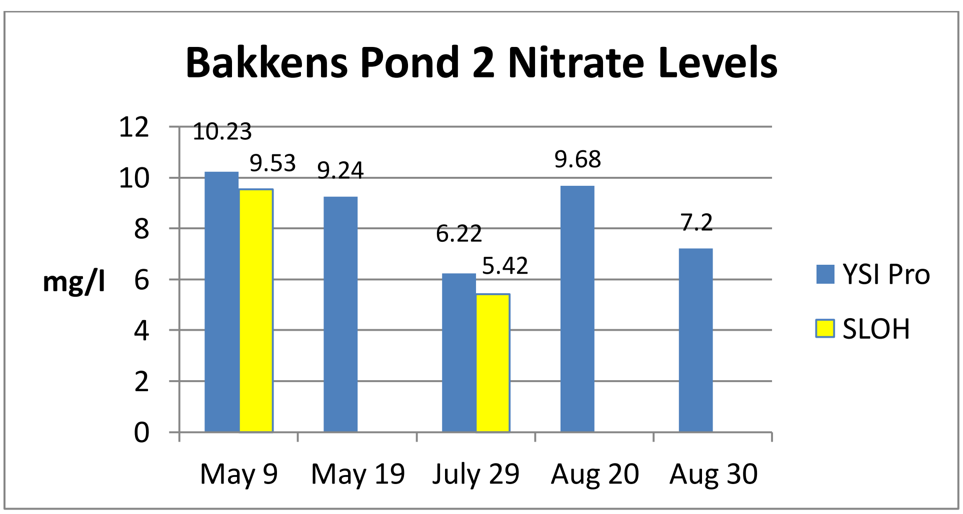


Figure 14: Bakkens Pond Metaphyton Cover

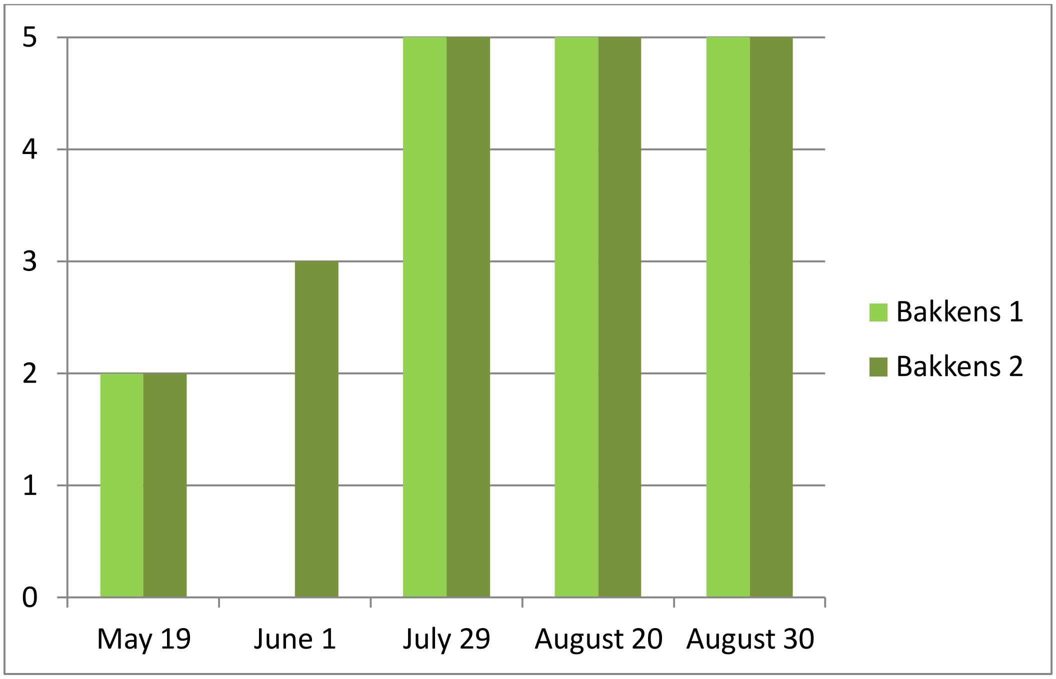
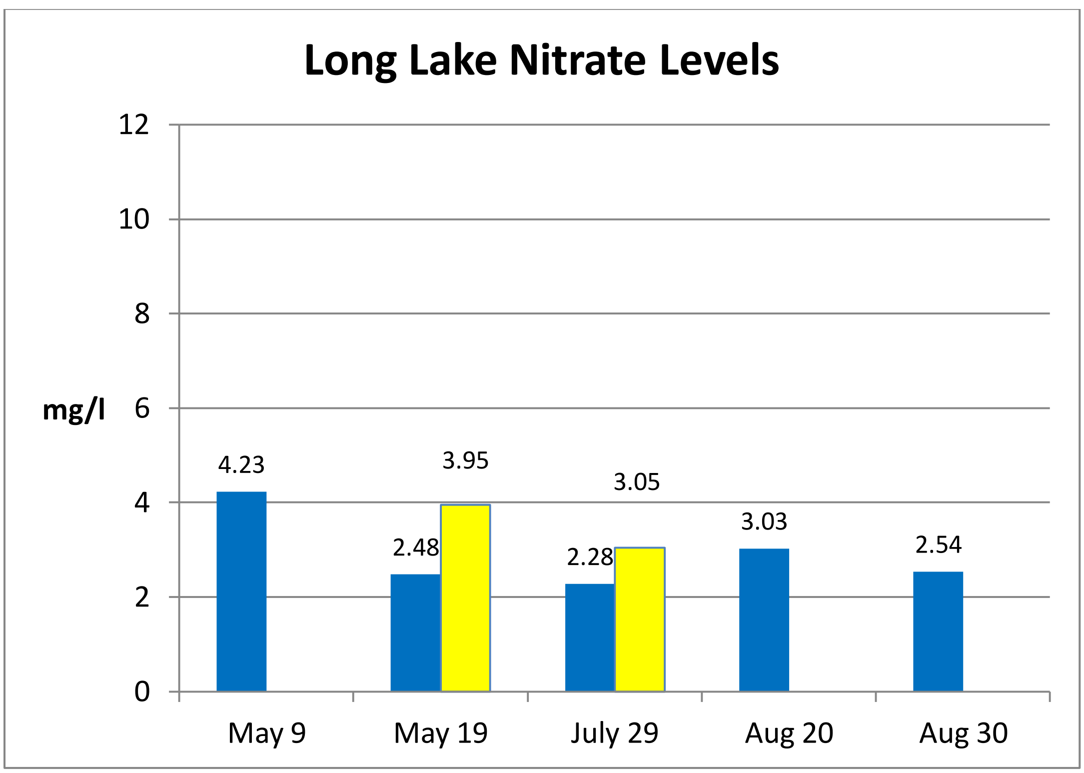


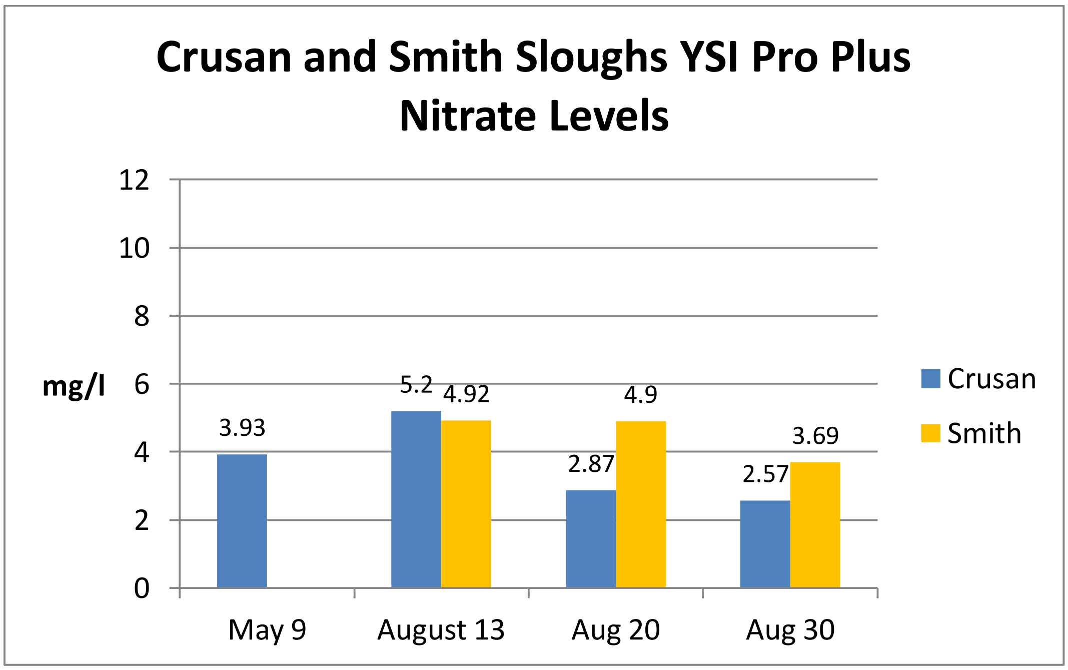
Figure 15: Long Lake Nitrate Levels



Additional Sampling Sites

West of Long Lake lie Smith (WBIC 1236400 – 17 acres) and Crusan (WBIC 5573731 – 20 acres) sloughs. These waterbodies were sampled several times using the YSI Pro nitrate meter to represent water quality conditions within the Richland County part of the Pleistocene terrace and floodplain. Both lakes contained elevated nitrate concentrations, reflecting anthropogenic pollution but the metaphyton cover was not as severe as conditions in Jones Slough, Norton Slough or Bakkens Pond. The nitrate results are presented in Figure 16. Consistent with Long Lake, the primary production in the Richland County lakes was primarily benthic algae (mostly Oscillatoria) that floated to the surface as opposed to Cladophora and duckweeds. Both sloughs had metaphyton cover of level 3 on August 20th and August 30th. SHTM were found in Crusan Slough on August 13th, August 20th and August 30th and in Smith Slough on August 20th.

Figure 16: Crusan Slough and Smith Slough Nitrate Levels



In an effort to sample reference sites, Wegner Borrow Pit (WBIC 5574197) was sampled on August 20th and August 30th. The pond is located at the Highway 23 Spring Green canoe launch and park and is well buffered by the floodplain forest. The Wisconsin River at the canoe launch was also sampled as a reference site and because comments at Town of Spring Green public meetings suggested that the river was the actual cause for water quality declines in the floodplain lakes. The results indicated that both waterbodies contained very low nitrate and total nitrogen concentrations (Figure 17). The sampling results are also consistent with the WDNR monthly monitoring data presented in Figure 18 at Muscoda. Metaphyton cover was nonexistent in Wegner Pond.

Figure 17: Reference YSI Pro Plus Nitrate Levels in Wagner Pond and Wisconsin River

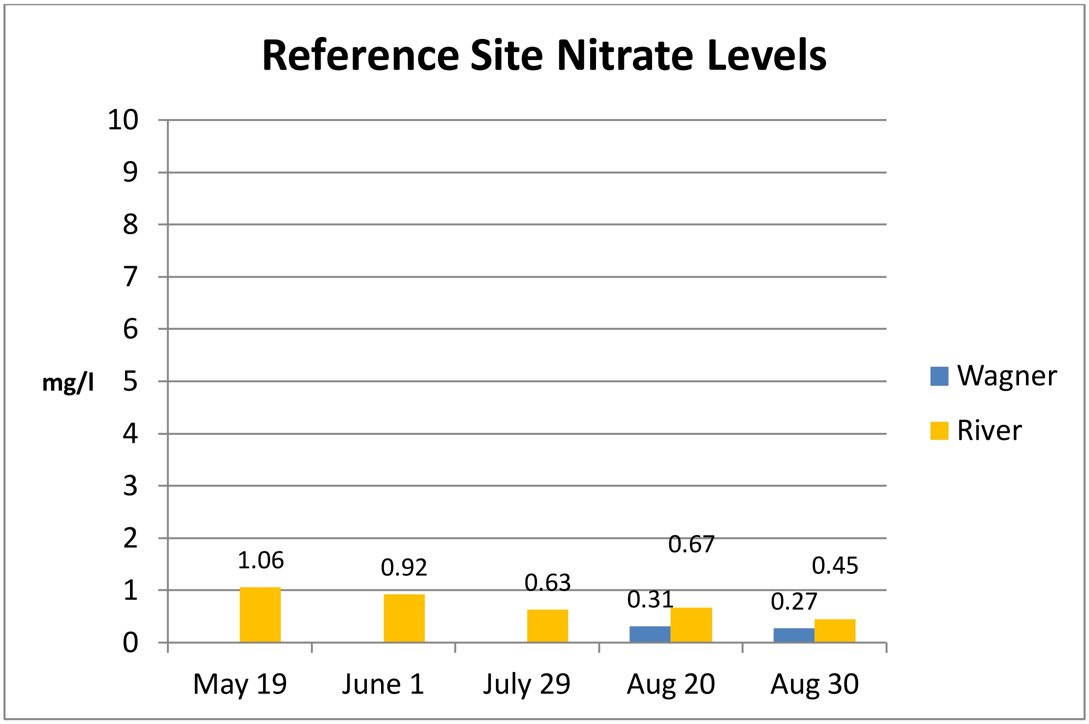
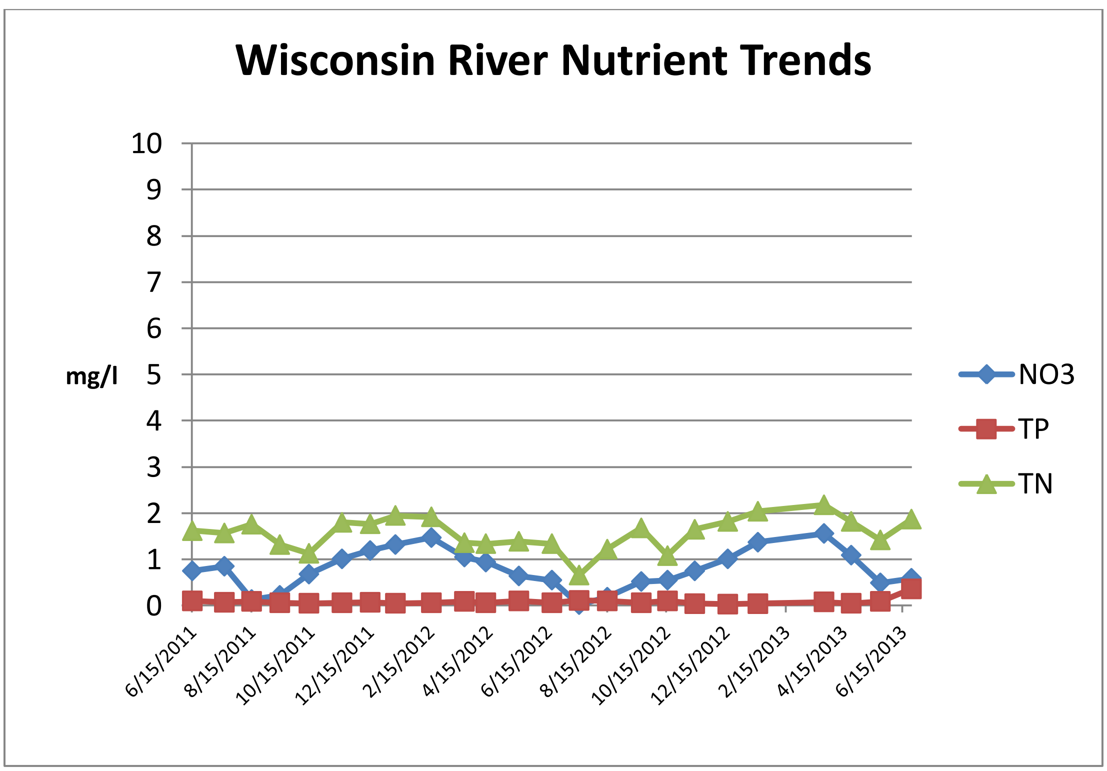
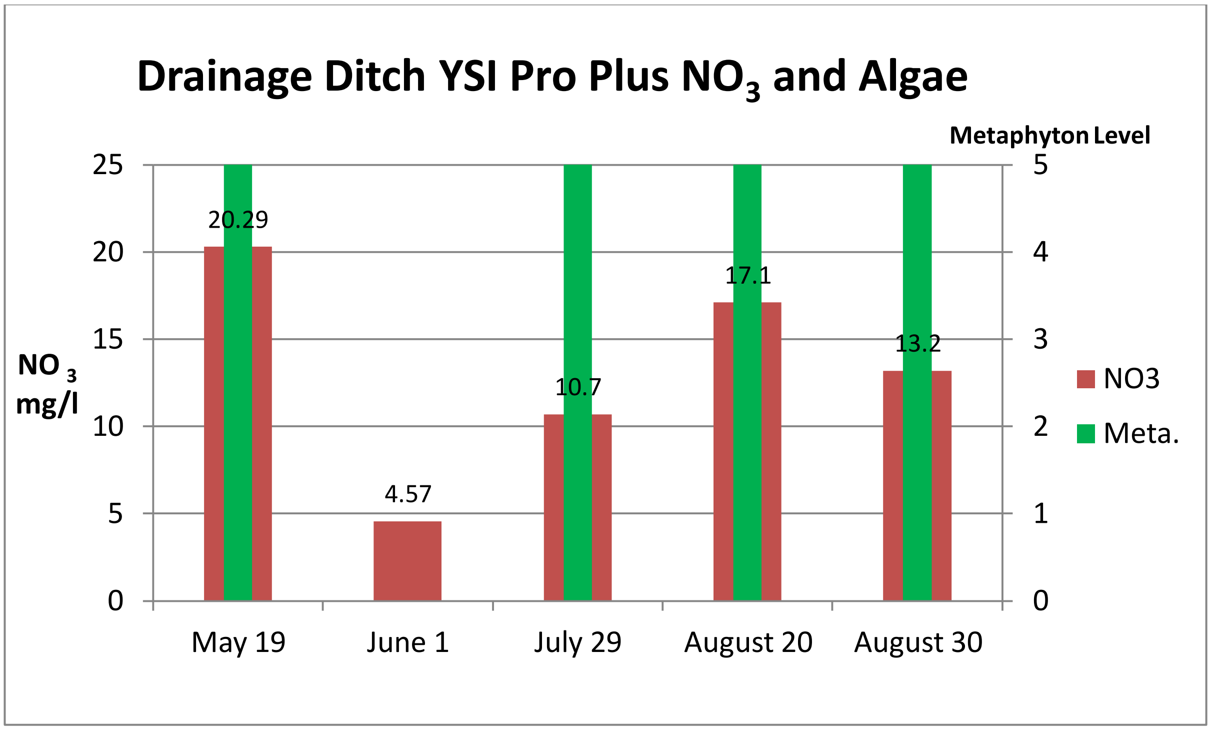


Figure 18: Wisconsin River Nutrient Concentrations at Muscoda



The flood control drainage ditch Big Hollow Drainage Ditch (SWIMS 10037286) was sampled five times in 2013 and displayed the highest nitrate concentrations found in the area. The high nitrate concentrations coincided with dry periods when groundwater dominated the ditch hydrology. The exception occurred on June 1st when the sample was collected during an extended period of precipitation. The nitrate and Cladophora levels were the lowest in the ditch after precipitation and flushing had occurred.

Figure 19: Flood Control Drainage Ditch Nitrate and Metaphyton Levels



YSI Pro Meter versus SLOH Nitrate Results

Using the recommended calibrations standards of 1 mg/l and 100 mg/l NO_3, the nitrate field measurements were in close agreement with the SLOH results ($R^2 = 0.948$). The means of 16 paired samples (meter 4.97 and SLOH 5.29) were not statistically different ($P = .05$). The greatest differences were found at the higher ranges (> 8 mg/l) where the meter measurements were lower than the SLOH in three of four samples (Figure 20).

Nutrient Management Implications

Phosphorus concentrations for Badger Valley, Jones Slough, Norton Slough, Cynthia Slough, Hill Slough, Bakkens Pond and Long Lake appear in Figure 21. 70.6 % of the samples exceeded the recommended phosphorus criterion of 40 ug/l for drainage lakes. These concentrations likely did not reflect phosphorus contained within surface and bottom metaphyton growths. All but one of the samples fell within the eutrophic TSI range, however the recommended criterion is more useful since floodplain lake eutrophication is typically expressed in different forms than in glacial lakes or impoundments where standard TSI metrics apply. Except for a few sampling dates early in the season, when river levels were high, the floodplain lakes were also very clear with minimal planktonic algae. The water clarity data were based on the 120 cm secchi transparency tube since water depths were too shallow for standard secchi measurements. As a result, water clarity data could not be transformed into TSI values. The use of WILMS to predict phosphorus loading is also of limited use given the nebulous watershed boundaries and undetermined groundwater levels of phosphorus. The WILMS predicted annual phosphorus loadings were 318 lbs./yr. for Badger Valley, 155 lbs./yr. for Bakkens Pond, 417 lbs./yr. for Cynthia Slough, 414 lbs./yr. for Hill Slough, 1061 lbs./yr. for the Jones – Norton flowage and 144 lbs./yr. for Long Lake. The use of this software is of limited value without assessing the levels of groundwater phosphorus loads and dynamics of fluctuating river stages. The effects of the fluctuating river levels were evident on dissolved oxygen levels in Figure 5 but how nutrients may change under these conditions requires further investigation. There is potential release of iron-bound phosphorus within the floodplain forest during high river stages (Loeb et al. 2008).

Figure 20: Comparing YSI Pro and SLOH Nitrate Concentrations

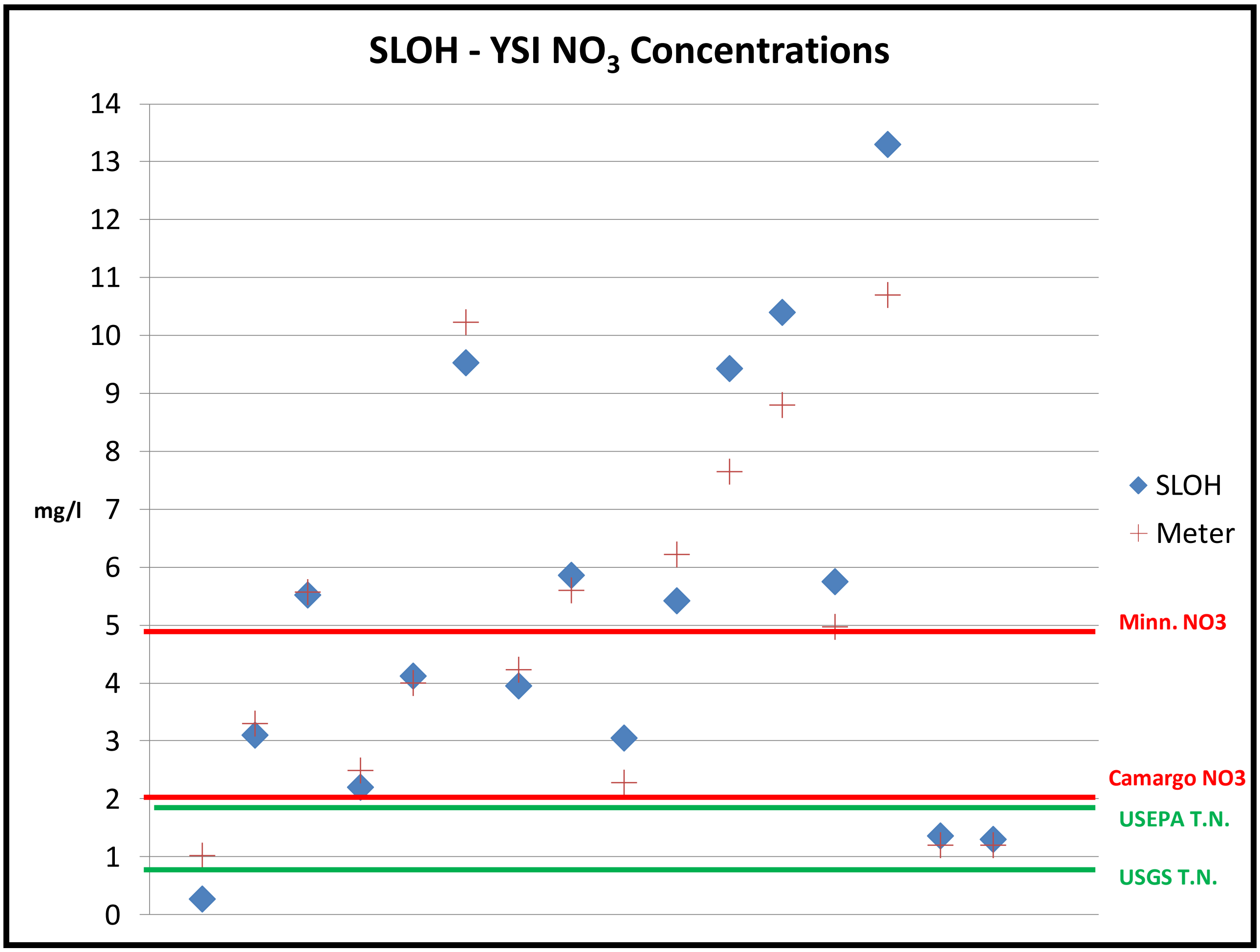
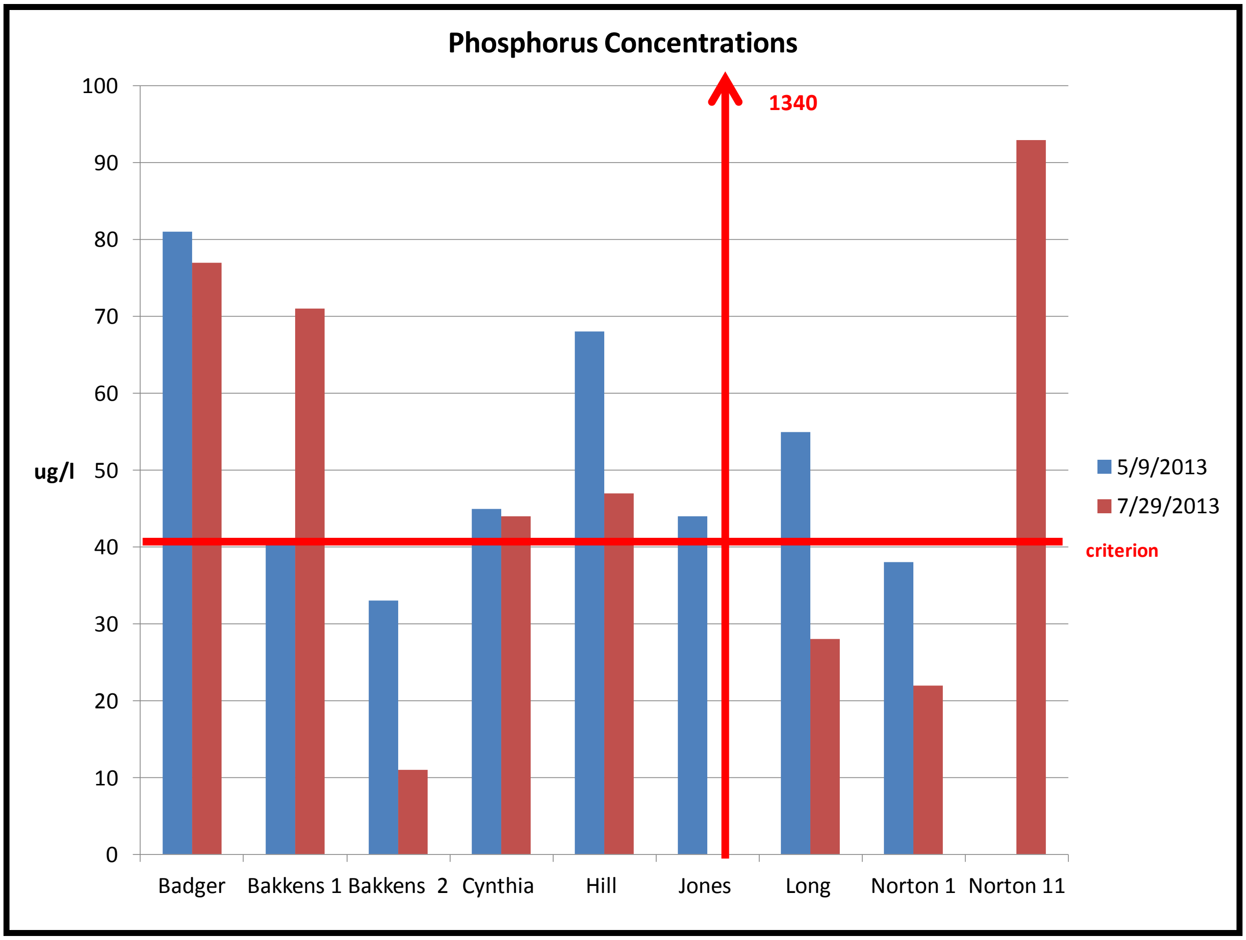
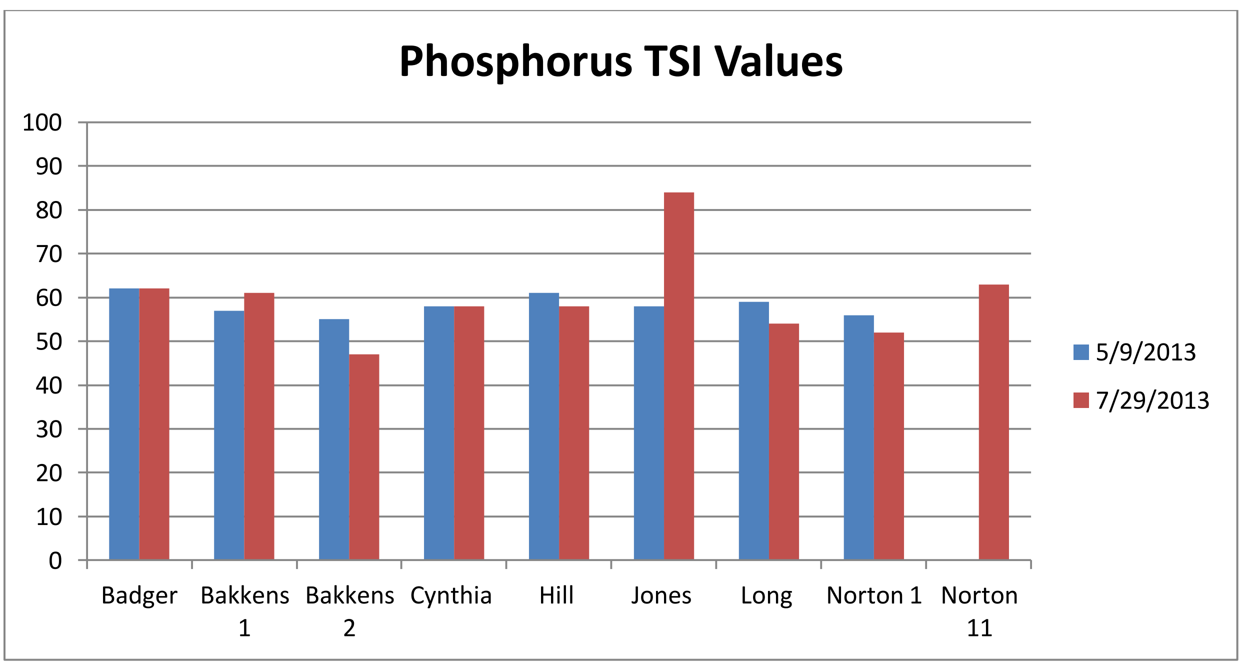


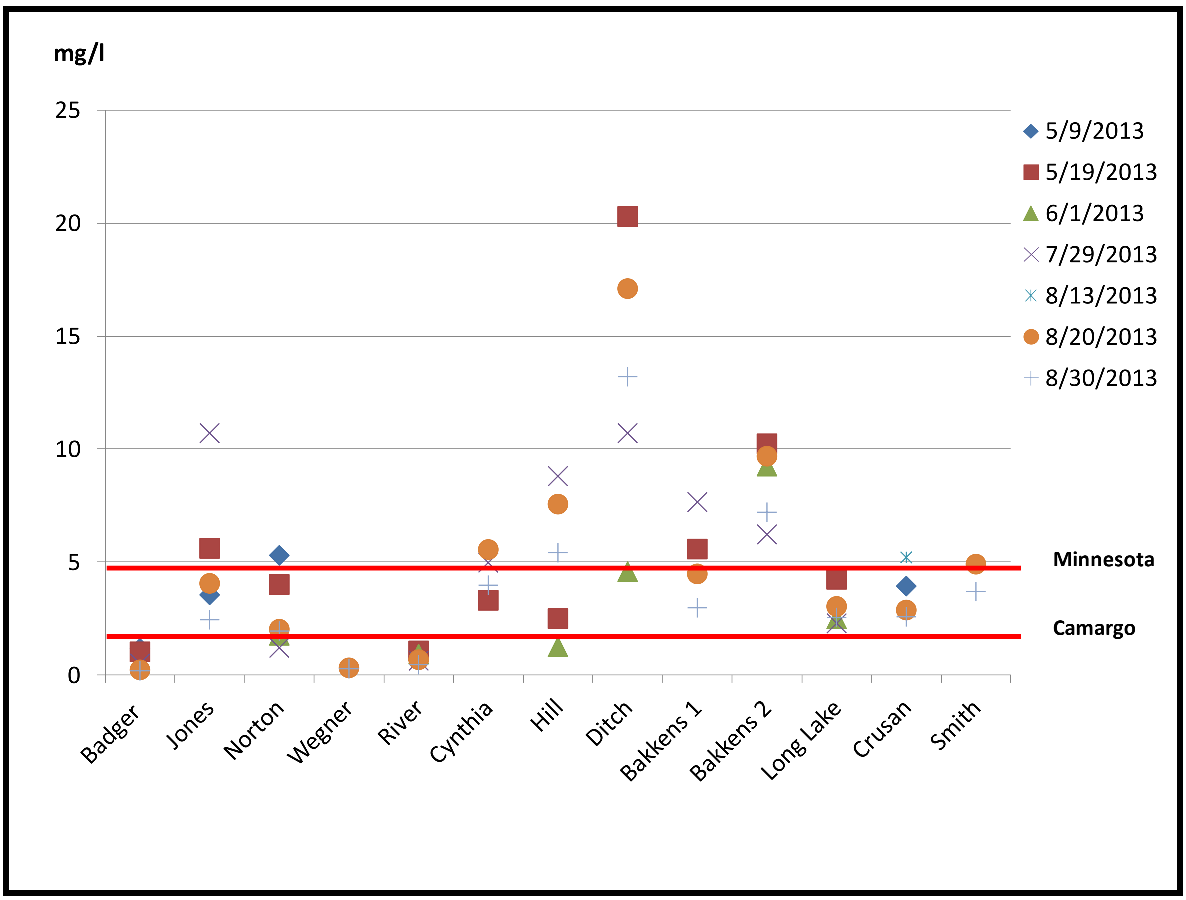
Figure 21: Phosphorus Concentrations in Lower Wisconsin River Floodplain Lakes





The focus on phosphorus in floodplain lakes must be balanced with the potential effects of nitrogen. Fried et al. (2003) and Sullivan (2008) correlated both phosphorus and nitrogen with algae and metaphyton growths. Sullivan found a slightly higher correlation between metaphyton and nitrogen. Penich et al. (2012) found a strong correlation between nitrates and Cladophora growth. Concentrations of total nitrogen exceeding 3 mg/l are considered hypersaturated and environmental pollution is clearly linked to high nitrates in groundwater and surface water (Stanley and Maxted 2008). In this study, most of the floodplain lakes had nitrate concentrations exceeding 3 mg/l at least part of the 2013 season. Robertson et al. (2006) identified 3.46 mg/l nitrates as a threshold or breakpoint concentration when fish and invertebrate communities reflected environmental degradation. Criteria and thresholds for both total nitrogen and nitrates have been proposed but none have been adopted in Wisconsin. The USEPA recommended criterion for total nitrogen is 1.88 mg/l to control eutrophication. Robertson et al. (2008) reported a total nitrogen background concentration of 0.7 mg/l as another possible criterion. Sullivan (2008) recommended a total nitrogen criterion 0.95 mg/l to prevent excessive metaphyton growths in Mississippi River sloughs. Figure 20 highlights two proposed criterion for total nitrogen (green lines).

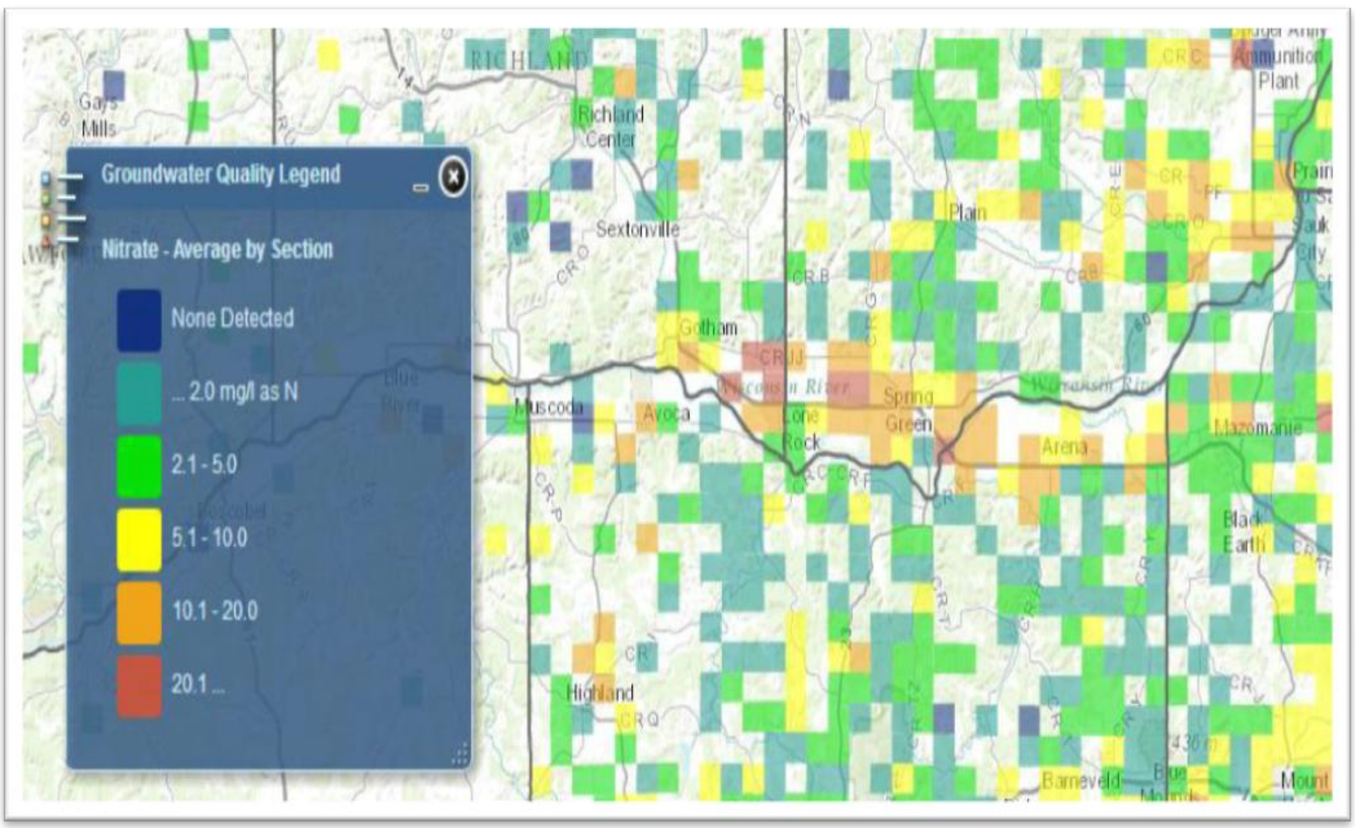
Figure 22: YSI Pro Meter Nitrate Levels Plotted with Two Proposed Thresholds for Toxicity Criterion



In addition to proposed total nitrogen criterion, nitrate criterion has been proposed due to the toxic effects on fish and other aquatic organisms. Camargo et al. (2005) recommended a criterion of 2 mg/l NO_3 to protect sensitive aquatic organisms. The Minnesota Pollution Control Agency is recommending a NO_3 limit of 3.1 mg/l for coldwater fisheries and 4.9 mg/l for other waterbodies. These proposed criteria are compared with Lower Wisconsin River floodplain lakes nitrate levels (red lines) in Figures 20 and 22. Even more conservative nitrate criterion had been proposed elsewhere. Hichen and Martin (2009) proposed 20 mg/l for acute toxic criterion, 1 mg/l chronic criterion for areas of high conservation value, 1.7 mg/l chronic criterion for waterbodies with slight to moderate environmental damage and 3.6 mg/l for degraded waterbodies. Even the proposed less conservative 4.9 mg/l NO_3-N Minnesota chronic nitrate criterion was often exceeded in Jones, Norton, Cynthia, Hill, Bakkens, Crusan and Smith lakes in 2013.

The high nitrate concentrations in Spring Green and Lone Rock area sloughs is linked to heavy nutrient applications on Pleistocene terrace coarse sandy soils. High nitrate levels in sand terrace groundwater were already identified by the UW Stevens Point Center for Watershed Science and Education in Figure 23. The higher level well concentrations are highlighted in yellow (5.1 – 10 mg/l), orange (10.1 – 20 mg/l) and red (20.1 + mg/l) and these areas lie in close proximity to the degraded floodplain lakes.

Figure 23: Nitrate Contamination in the Spring Green and Lone Rock Areas



The specific mechanism for the observed water quality declines in the Lower Wisconsin River floodplains lakes is unclear but may have mirrored modern agricultural changes including loss of CRP lands, increased corn production and increased numbers of animal units linked to larger scale farms. Large-scale farming on the Pleistocene terrace is environmentally risky due to nutrient leaching in the coarse sandy soils. Novak (2000) and Nair et al. (2004) reported substantial phosphorus buildup and ultimate leaching into a shallow aquifer beneath sandy soils. WDNR and UW Madison Extension had identified the sand terrace as highly susceptible to contaminated groundwater in 1989. Recent well testing has demonstrated that nitrate levels have been increasing well beyond the Drinking Water Standard (10 mg/l) and this trend has coincided with the floodplain lakes water quality declines.

Two options for reducing the pollution include effective nutrient management and establishing conservation buffers. The former is required if local governments adopt Farmland Preservation Zoning and tax credits are provided. However, the Town of Spring Green has not adopted the ordinance along with the required nutrient management plans. Another issue is the use of the Pleistocene terrace for liquid manure waste disposal and it is imported from outside the watershed and township. In early September 2013, at least 55 large ~ 8,000 gallon tankers hauled liquid manure from outside the township for application on 70 acres of recently harvested cropland close to Norton Slough and private wells. This situation has the potential to saturate sandy soils with phosphorus followed by leaching into the shallow groundwater table. USEPA (2003) recommends that nutrient management planning is needed if agriculture occurs in close proximity to surface waters (floodplain lakes), where well drained soils can result in leaching (Pleistocene terrace sands) and where the groundwater lies close to the surface (Pleistocene terrace). The other nutrient management option is to purchase conservation easements or fee title to establish buffers around environmentally sensitive floodplain lakes and private wells. Buffers can reduce nitrates in groundwater from 65 – 100% under the right conditions (Ranalli and Macalady 2010). Buffers often range from 7 - 100 meters in width (Mayer et al. 2006). But in the case of the Lower Wisconsin State Riverway, actual buffer widths should be based on predicted nitrate and phosphorus treatment. Wider buffers ($\geq$ 100 m) are likely needed due to the sandy soils where leaching is excessive and de-nitrification is minimal.

The goals for protecting the Lower Wisconsin State Riverway may be undermined by a clash of public policies. From 1995 to 2012, current farming practices in the Town of Spring Green had been heavily subsidized under the Farm Bill (nearly $18,000,000, Environmental Working Group 2013). Property taxes may also increase when floodplain lake riparian areas are managed as conservation buffer establishment.

The continued water quality decline in the Lower Wisconsin State Riverway cutoff channel lakes poses a significant threat to this unique large river ecosystem and the rare and popular sport fish populations that otherwise thrive in these habitats. Further declines could alter habitats more favorable for nuisance species such as common carp (Bajer and Sorenson 2010). Wisconsin's Public Trust Doctrine requires that these unique resources are restored and protected.

Liquid manure import to the Pleistocene terrace sands, September 2013

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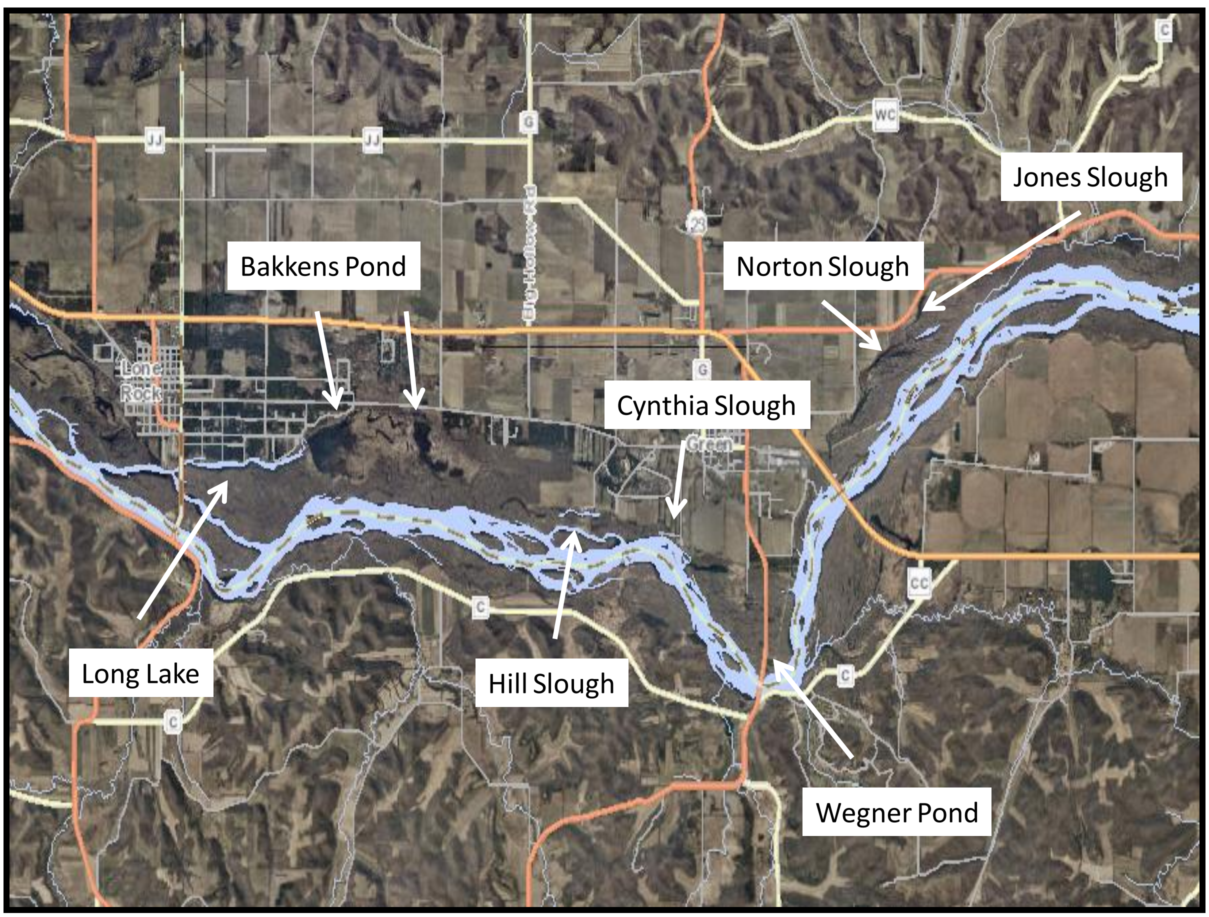

Field Temperature data (C):

Site	5/9/2013	5/19/2013	6/1/2013	7/29/2013	8/13/2013	8/20/2013	8/30/2013
Badger	17	19.5		19.8		20.9	22
Bakkens 1		21.2		19		21.6	24.9
Bakkens 2		16.2	21.1	17.3		16.3	17.7
Ditch		13.3	23.5	20.8		18.5	
Crusan					24.6	21.6	25.6
Cynthia		18.6		24.2		26.7	26.8
Hill		17.1	22	21.1		20.9	23.2
Jones	16.6	20.6		16.4		25.2	23.2
Long		19.4	24.2			21.4	24.4
Norton	18.2	21.3	24.4	18.3		22.5	22
Smith					20.4	21.3	25.3
"Wegner "						26	27.2
Wisconsin R		17.5	21.4	25.8		24.8	26.4

Field D.O. data (mg/l):

Site	5/9/2013	5/19/2013	6/1/2013	7/29/2013	8/13/2013	8/20/2013	8/30/2013
Badger	3.6	6.8		12.5		10	4.6
Bakkens 1		15.7		13.9		5.8	3.4
Bakkens 2		12.6	16.4	11.6		6.8	6.9
Ditch		4.1	10.7	12.4		5.8	
Crusan					5.2	6.4	4.7
Cynthia		7.5		11.04		18.1	10.8
Hill		9.3	10.9	13.6		9.7	7.1
Jones	5.3	15.5		4.6		12.6	6.3
Long		8.7	8.4	8.7		8.2	7.9
Norton	10.7	14.9	10.4	16.7		9.7	5.6
Smith					10.7	11.4	7.3
"Wegner "						7.8	7.5
Wisconsin R			10.3	8.6		8.8	8.2

Field pH (su):

Site	5/9/2013	5/19/2013	6/1/2013	7/29/2013	8/20/2013	8/30/2013
Badger	6.86			8.20	7.78	
Bakkens 1		10.07		9.03	7.59	6.71
Bakkens 2		8.82	8.70	8.52	7.75	8.14
Ditch		7.30		9.04	7.75	
Crusan					6.70	7.12
Cynthia		7.25		8.71	8.87	8.73
Hill		8.10	8.10	9.23	8.70	8.21
Jones	7.6	8.78		7.80	8.75	7.58
Long		8.40	8.21	8.10	7.86	8.15
Norton	7.68	9.08	8.20	9.10	8.10	7.70
Smith					8.60	8.30
"Wegner "					8.03	8.20
Wisconsin R		8.36	8.08	8.79	8.10	8.90

Field Specific Conductance (uS/cm):

Site	5/9/2013	5/19/2013	6/1/2013	7/29/2013	8/20/2013	8/30/2013
Badger	426	461		546	548	564
Bakkens 1		362		484	499	441
Bakkens 2		433	421	373	442	508
Ditch		569		408	540	
Crusan					335	324
Cynthia		342		422	501	448
Hill		220	189	372	354	344
Jones	345	441		473	410	406
Long		326	308	348	368	361
Norton	392	383	409	371	412	425
Smith					352	352
"Wegner "					249	245
Wisconsin R		190	163	214	255	241

Water clarity (cm):

Site	5/9/2013	5/19/2013	6/1/2013	7/29/2013	8/13/2013	8/20/2013	8/30/2013
Badger	120	120		120		120	120
Bakkens 1		120		120			120
Bakkens 2		120	103	120		120	120
Ditch				120		120	120
Crusan					120	120	120
Cynthia		64		88		120	120
Hill		65	90	110		120	120
Jones	120	83		92		120	120
Long		75	83	120		120	120
Norton	120	120	99	120		120	120
Smith					120	120	120
"Wegner "						120	120
Wisconsin R		57	56	56		47	45

Metaphyton Cover (0 – 5 max):

Site	5/9/2013	5/19/2013	6/1/2013	7/29/2013	8/13/2013	8/20/2013	8/30/2013
Badger	0	1		4		4	4
Bakkens 1		3		5		5	5
Bakkens 2		3	3	5		5	5
Ditch		5	0	5		5	5
Crusan					3	4	3
Cynthia		0		1		1	1
Hill		1	0	3		2	3
Jones	1	3		5		5	5
Long		0	1	1		2	2
Norton	1	4	3	4		5	4
Smith					2	3	2
"Wegner "						0	0

Starhead topminnow reports (presence/absence):

Site	5/9/2013	5/19/2013	6/1/2013	7/29/2013	8/13/2013	8/20/2013	8/30/2013
Badger						X	X
Bakkens 1							
Bakkens 2				X		X	X
Ditch							
Crusan					X	X	X
Cynthia							
Hill			X	X		X	X
Jones						X	X
Long				X		X	
Norton						X	
Smith						X	
"Wagner "						X	X