Nutrient removal by constructed and restored wetlands in the Maumee River basin of northwest Ohio

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Abstract

Three wetlands in in the Maumee River basin within Defiance County, one created (Blanchard) and two restored (Hoffman and St. Michael's),were monitored in 2016 to assess their effectiveness at reducing outflow and removing phosphorus and nitrogen which contribute to algae blooms in downstream rivers and Lake Erie. The two restored wetlands took farmland out of production to restore native plant cover over their drainage areas of 27.5 (St. Michael's) and 6.7 acres (Hoffman) while the created wetland treated runoff from about 7.4 acres of cropland. The St. Michael's wetland had the lowest nitrate concentrations near the wetland outlet averaging 0.34 mg/l. Nitrate outflow averaged 1.22 m/g from the Hoffman wetland and 1.56 mg/l from Blanchard with a maximum of 12.01 mg/l measured on April 12, 2016. Overall phosphorus concentration was not significantly reduced by the wetlands. However at high flows the Blanchard wetland did reduce total phosphorus (TP) concentrations which are disproportionately important for total load. In contrast, the TP total load was reduced by all 3 wetlands since 88-100% of the total rainfall volume over the basins was retained. Modeling of the pre-restoration hydrology and nitrate loading using DRAINMOD indicated that the two restored wetlands reduced annual nitrate loading from the former farmland by 97-100% since very little water flowed out of the wetlands in 2016. The Blanchard wetland reduced nitrate load by 88% compared to the pre-restoration condition. Vegetation quality was assessed using the vegetative index of biotic integrity (VIBI) with scores of 4 at Blanchard, 7 at Hoffman and 32 at St. Michael's. The Blanchard wetland had very poor vegetative quality and a lack of plant coverage that likely reduced its phosphorus and sediment removal efficiency. The St. Michaels' wetland had a higher VIBI score because it had been seeded with native plant mix and managed over many years while the other two sites were allowed to revegetate by natural colonization. The findings of this study help to inform current watershed management efforts to improve Lake Erie water quality in several ways. First the wetlands were shown to greatly reduce the total outflow of water, thus reducing the downstream load of nitrate and phosphorus. The concentrations of nitrate near the wetland outlets were much lower relative to the water quality standard (10 mg/l) than phosphorus (0.007 – 0.040 mg/l for states with phosphorus standards). Secondly the project demonstrated that while constructed wetlands placed at the edge-of-field can be effective, optimally wetland basins should be sited to receive more sub-surface tile drainage and treat larger drainage areas for nitrate removal. Wetlands designed to remove phosphorus may require a

smaller watershed-to-wetland ratio and be located higher in the landscape. Ideally a variety of different wetland basin types restored across the Maumee River basin in combination with farm management to reduce nutrient loading would provide the best mixture of nutrient removal and ecosystem services.

Project purpose: To monitor and assess the hydrologic and nutrient removal benefits of 3 restored and constructed wetlands within the Maumee River watershed both for nitrate-nitrogen and phosphorus. A secondary goal was to assess vegetative quality in treatment wetlands

Background: There is a strong need to reduce phosphorus (P) loading to Lake Erie to reduce algal blooms and wetlands can contribute by storing water and filtering out nutrients. The majority of wetlands were drained in the Maumee River basin over a century ago including most of the Great Black Swamp which covered northwest Ohio and parts of northeastern Indiana (Kaatz 1955). While large forested wetlands cannot be feasibly re-established in most cases, smaller wetlands that store and treat flow from farmland can contribute to nutrient load reductions to Lake Erie, both for phosphorus and nitrogen (Lenhart and Lenhart 2014).

Nitrogen has contributed to algae blooms in Lake Erie as well in particular the toxic strain of *Mycrocystin* that caused the problems with Toledo's was supply in 2014. So while the focus of overall watershed management should be on phosphorus, the nitrogen load is important to manage as well.

Study area: Three wetlands were selected for the study including the St. Michael's, Blanchard and Hoffman sites in Defiance County, Ohio. See Table 1 for a list of physical properties related to nutrient removal effectiveness and Figure 1 for their location. All sites drain to the Maumee River which eventually flows to Lake Erie approximately 50 miles downstream (Figure 1).

Table 1. Properties of study wetland sites and watersheds draining to them.

	St. Michael's Ridge	Blanchard Rd.	Hoffman Rd.
Wetland type	75% wet prairie, 25% marsh –	90% open water to deep marsh, 10% grass -, wet prairie fringe,	80% cattail marsh, 20% wet prairie –
Restored or constructed	Restored in former forested swamp with hydric soils	Constructed in a non-wetland area receiving farm runoff	Restored in area that was likely forested swamp on hydric soils
Sub-watershed of Maumee	Barnes Creek	Powell Creek	Powell Creek
Wetland Size (acres)	20.7	0.26	1.65
Watershed area (acres)	27.5	7.4	6.7
Watershed to wetland area ratio	1.3 : 1	30.3 : 1	4.0 : 1
Watershed Soil types	70% Hoytville clay, 30% loamy soils (Haskins and Mermill loam; Ottokee loamy fine sand)	Roselms silty clay (in farmland draining to it)	Roselms silty clay
Photo	Figure 2	Figure 3	Figure 4

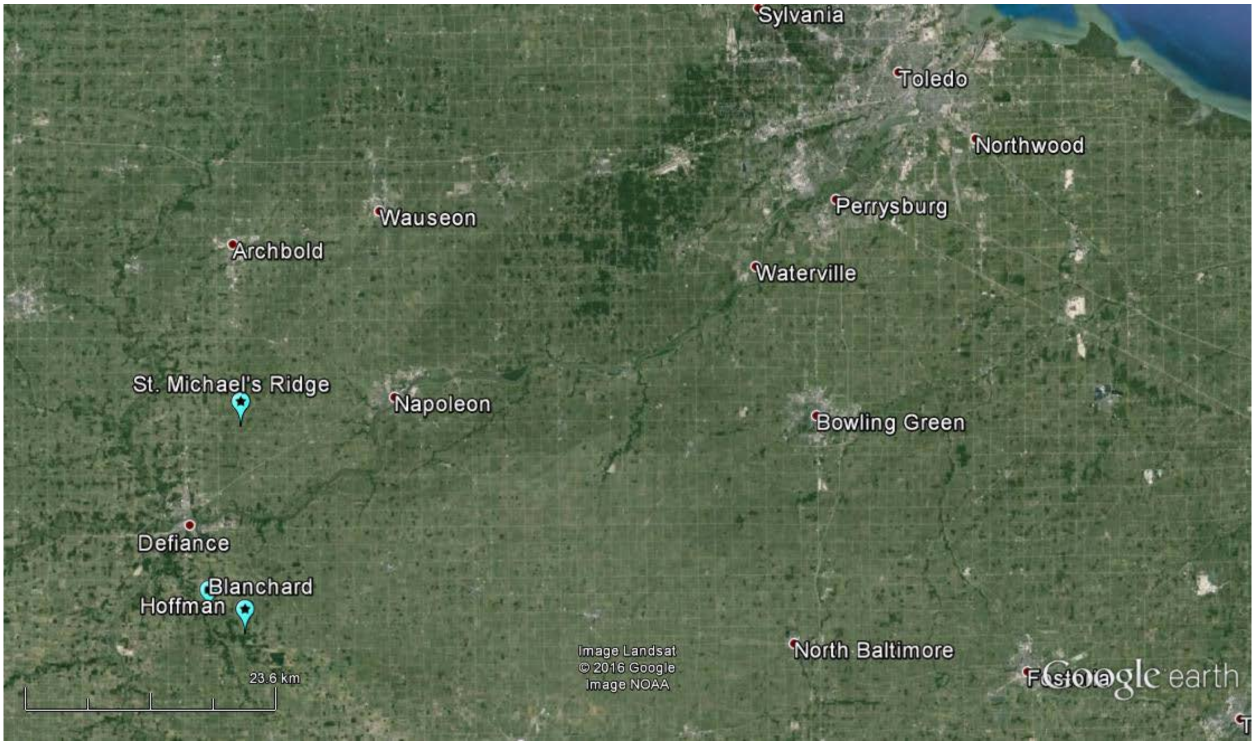

Figure 1. Location of wetland study sites within the Maumee River basin; St. Michael's Ridge, Blanchard and Hoffman. The study area is approximately 80 km southwest of Lake Erie within Defiance County.

The wetlands vary considerably in size, drainage area and plant community types as can be seen in Figures 2-4 and Table 1. The St. Michael's Ridge wetland was restored about ten years ago as a large 30 acre basin with native plant communities established via seed mix. The Hoffman and Blanchard Road sites were established in 2014-2015 by the Defiance SWCD to improve water quality by reducing nutrient loading to Powell Creek, a tributary of the Maumee River southeast of Defiance. While the Hoffman site functions as a restored wetland without row crop agriculture draining to it, the Blanchard wetland has 7.4 acres of row crop agriculture routed through it.

Soil and landscape characteristics:

The two Powell Creek watershed sites lie on Roselms Silty clay loam, a hydric soil which has a thin (0-9 inches) of silty clay on top of a clay subsoil. On eroded sites the topsoil depth may be just a few inches which creates a setting very prone to surface runoff. Both sites are located within a half mile of Powell Creek and drain through tributary ravines or grass swales.

The St. Michael's site lies along a relict beach ridge of a post-glacial lake of Lake Erie. It is underlain by Hoytville clay, a hydric soil in the main wetland area, although 40% of the contributing drainage area is either sandy non-hydric soil (Ottokee series) or loam (Haskins and Mermill series) contributing to greater infiltration rates in the surrounding uplands and greater water retention within the basin. Currently the wetland outlets through a berm into a public ditch which drains to Barnes Creek and then to the Maumee River south of Napoleon, Ohio.

Figure 2: St. Michael's wetland at St. Michael's Ridge part of a large natural restored wetland-prairie. It is located in the Barnes Creek sub-watershed of the Maumee River. (Photo Summer 2013).

Figure 3. Blanchard Road wetland in the Powell Creek watershed installed by Defiance SWCD. This is the upper pool of a two-cell flow-through wetland system which treats runoff and drainage from about 7 acres of farmland (photo March 2016)

Figure 4. Hoffman Road wetland in the Powell Creek watershed, installed by Defiance SWCD in 2014. Photo: March 2016

Methods

Hydrology methods

Water level monitoring was done by placing *Solinst* water level loggers within or near the outlet of each wetland with data recorded every 30 minutes for the time period of Jan. 29-October 10, 2016. At the Blanchard Road and St. Michael's sites, the loggers were placed within water control structures with known equations relating water height to discharge (Table 2). At the Hoffman Road wetland outlet, there was a rip-rap lined channel and grass swale. Discharge was calculated using the continuity equation for the grass swale as it poured out (Equation 1)

> Equation 1: Q= V*A, where Q=discharge in cubic feet/second (cfs), V= velocity in feet/second (ft/s), and A= cross sectional area of the channel in square feet (ft^2)

Channel cross sectional Area was calculated from survey data while velocity was estimated using Manning's equation (Equation 2).

> Equation 2: $V = (1.49/n)A*R^{2/3}S^{1/2}$, Where, V= velocity in feet/second (ft/s), 1.49 is a constant, n= Manning's roughness coefficient, A = cross sectional area of flow, R=hydraulic radius, s= water surface slope

Staff gauges were mounted in each of the three wetland sites on March 17, 2016 to visually record water level and provide a check on the *Solinst* water leveloggers. The gauges were installed with the zero near ground surface so they provide an estimate of water depth in the wetland near the outlet.

Table 2: Sampling locations and characteristics			
Site	Inflow sample location	Outflow / Outlet type	Discharge equation(s)
Blanchard Road	At edge of farm field	Agri-drain weir, 14 inches	(Chun and Cooke 2008, weir equation)
Hoffman Road	Upper part of wetland	Grass swale with riprap	Equations 1-2: Continuity + Manning's
St. Michael's	In an adjacent ditch*	Agri-drain weir, 14 inches	(Chun and Cooke 2008, weir equation)
*There was no farmland draining to St. Michael's wetland so an adjacent ditch was sampled for comparison			

Two *Solinst* barologgers were installed in each sub-watershed area; one near Powell Creek for both the Blanchard Road and Hoffman sites since they are located within one mile of each other and one near St. Michael's Ridge. Baroloogers are used to correct the water level data for variation in barometric pressure in the *Solinst* software program. The Blanchard Road water level logger was damaged by a large sediment influx to the outlet in late March. During the time period of late March to late May, an empirical estimation of flow was made using the record at the nearby Hoffman wetland and the previous flow record at Blanchard. Outflow did not occur from June until October, the remainder of the monitoring period.

Rainfall data was collected from the nearby weather station at the Defiance, Ohio airport. It was used to calculate the total volume of rainfall over the wetlands' drainage area in m^3 and to calculate the rainfall-runoff response at the three different sites. Rainfall-runoff was calculated as the ratio of rainfall volume to wetland discharge volume.

Nutrient sampling

Nutrient sampling was done by grabbing samples at each wetland outlet and one location either upstream from the wetland or at the inflow point on nine dates in 2016 (Table 3). At St. Michael's water was collected from an untreated farm drainage ditch for comparison as there was no farmland draining to the wetland after restoration. The Blanchard Road wetland had a clearly defined inlet from the farmland while the other two sites did not. In effort to minimize contamination, all sampling gear was rinsed with hydrochloric acid and then rinsed with distilled water twice before every sample collection. Sample bottles were prepared ahead of time by filling with distilled water. Upon reaching the site, samples were collected from the same spot on all dates for all locations. The distilled water was poured out of the container and the sample water was used to rinse the bottle, prior to filling. After collection, the samples were stored in a cooler on ice to prevent breakdown of nutrients. Immediately upon returning to the lab, all of the samples were measured for the amount collected and then filtered using a manifold to remove solid materials for analysis using the Hach nutrient kits (Models NI-11 for nitrate and PO-23 for phosphorus) which provide N and P concentrations based on a color disc. The filtered water was then tested for nutrients using Hach test kits for Ammonia, Nitrates, Phosphates and chlorophyll a in ug/L. Cyanobacteria was measured in in cells/mL using an AquaFluor machine. Typically, the water was tested within 24 hours of collection.

Table 3: Dates of water sample collection by Defiance College staff and notes on flow; yes/no indicates whether flow was occurring into and out of the Blanchard wetland. The St. Michael's and Hoffman wetlands had no well-defined inlets so only notes on outflow were recorded.				
Date	St. Michael's Outflow (flow present; stage)	Blanchard Outflow flow present; stage	Blanchard Inflow (flow present)	Hoffman Outflow flow present; stage on staff gauge*
2/3/2016	No	No	No	Yes
2/21/2016	No	No	No	No
3/17/2016	No- 10.5 inches	No- 10 inches	Yes	No- 4.25 inches
3/28/2016	No- 13.5 inches	Yes- 12 inches	Yes	No- 5 inches
4/12/2016	No-16 inches	Yes 14 inches	Yes	Yes- 7 inches
5/3/2016	No- 14 inches	Yes- 12 inches	Yes	No- 5.5 inches
5/12/2016	No- 9 inches	No- 9 inches	No	No- 4 inches
6/15/2016	No- 0 inches	No- 7 inches	No	No- 3 inches
6/23/2016	No- 0 inches	No- 5 inches	No	No- 2 inches
*Stage was taken from staff gauges mounted in each wetland showing the depth of water in the basin near the outlet. Staff gauges were mounted on March 17, 2016. The St. Michael's and Hoffman wetlands did not have a distinct inflow channel as the Blanchard wetland was the only site receiving flow from active cropland.				

Samples were frozen and sent to the Heidelberg National Center for Water Quality Research (NCWQR) lab in Tiffin, Ohio for comparison to the Hach kits. In addition to nitrate (NO_3) + nitrite (NO_2), soluble reactive phosphorus (SRP) and total phosphorus (TP), the lab provided chloride, sulfate, silicon dioxide and fluoride data at no additional cost.

An YSI water chemistry probe was also used to collect data on temperature, pH, dissolved oxygen, oxidation-reduction potential, and specific conductivity by placing the probe in a bucket of water collected from the wetland(s). In addition to the physical data, algae populations were measured from the wetland water at the DC lab. Chlorophyll A was used as an indicator of green algae measured in ug/l while blue-green algae was counted as # of cells/ml. The water chemistry and algal indicators were collected on six of the nine sampling trips between Feb. 21 and June 15, 2016. It wat not possible to collect during the earliest February dates due to frozen conditions nor at the end of the summer due to low water levels or dry conditions.

Analysis of nutrient removal rates

The percentage of nutrient removal was calculated by comparing inflow to outflow for an overall nutrient removal rate. A median was used to summarize the nutrient removal efficiency for each nutrient (nitrate, TP and SRP) and for each wetland site. Due to the small sample size and variability, the average values were highly affected by individual large values either negative or positive. Total loads were calculated by applying an average value for nutrient concentration from each site to low, average and high flows.

Modeling of pre- wetland restoration hydrology

In order to estimate the hydrologic benefit of the wetland projects it was necessary to simulate the flow and nitrogen loading into the wetlands prior to restoration since no monitoring data existed prior to restoration. DRAINMOD was used to simulate tile drain flow at the Blanchard, Hoffman and St. Michael's sites prior to wetland restoration. Nitrate losses were simulated as well, however DRAINMOD did not have the ability to model phosphorus loss at the time of our study. Input parameters were determined including soil physical properties, tile-drain spacing and depth, and weather data for input to the model. We used 40-ft tile drain spacing based on aerial photo observations and depth of 1 meter (3.28 feet). A clay soil profile similar to the Hoytville and Roselms series was used for the soil properties data. Weather data was obtained from the Defiance airport and the model run for a 25 year time period, 1991-2005.

VIBI survey methods

Vegetation surveys were conducted in July and August, 2016. The Vegetation Index of Biotic Integrity (VIBI) Procedure outlined by Mack (2004) was followed. A study module of 1000 m^2 was surveyed in ten separate quadrats in two adjacent rows of 50 meters. Each quadrat or sub-module was 10 x 10 meters. A walk through survey was done recording plant species presence and percent coverage in each quadrat. A spreadsheet provided by Ohio EPA was used to convert the raw data to VIBI scores which range from 0 – 100.

Outreach and public education activities

Two class presentations on wetlands ecology and water quality techniques were done at the Holy Cross Elementary School in Defiance, Ohio in October 2016 by the Maumee River Basin Center for Ecological Restoration. The in-class presentations described the functions and values of wetlands and demonstrated water quality test kits and turbidity tubes. Two additional field trips were done to the St. Michael's wetland site, part of the natural area managed by the MRBCER. 16 elementary students in grades 4-5 were engaged in the project, collecting seeds and learning about native plant identification. This work is summarized in the appendix.

Results

Hydrology data

Flow into the wetlands occurred as snow-melt runoff during parts of February after which flow into the wetlands occurred in the form of surface water runoff. All three wetlands receded and did not overflow after June through the end of the monitoring period on October 10. Rainfall was close to average for the 9 month monitoring period but was very dry for the summer months (Table 4).

The St. Michael's wetland did not overflow during the entire monitoring period of January-October 2016 (Figure 5). Fluctuation of water levels within the wetland occurred, varying by 2.1 feet within the outlet structure but not overtopping the outlet elevation. Maximum water levels were reached in April within the wetland and then declined to zero on the staff gauge for most of the summer, indicating the wetland bed was dry

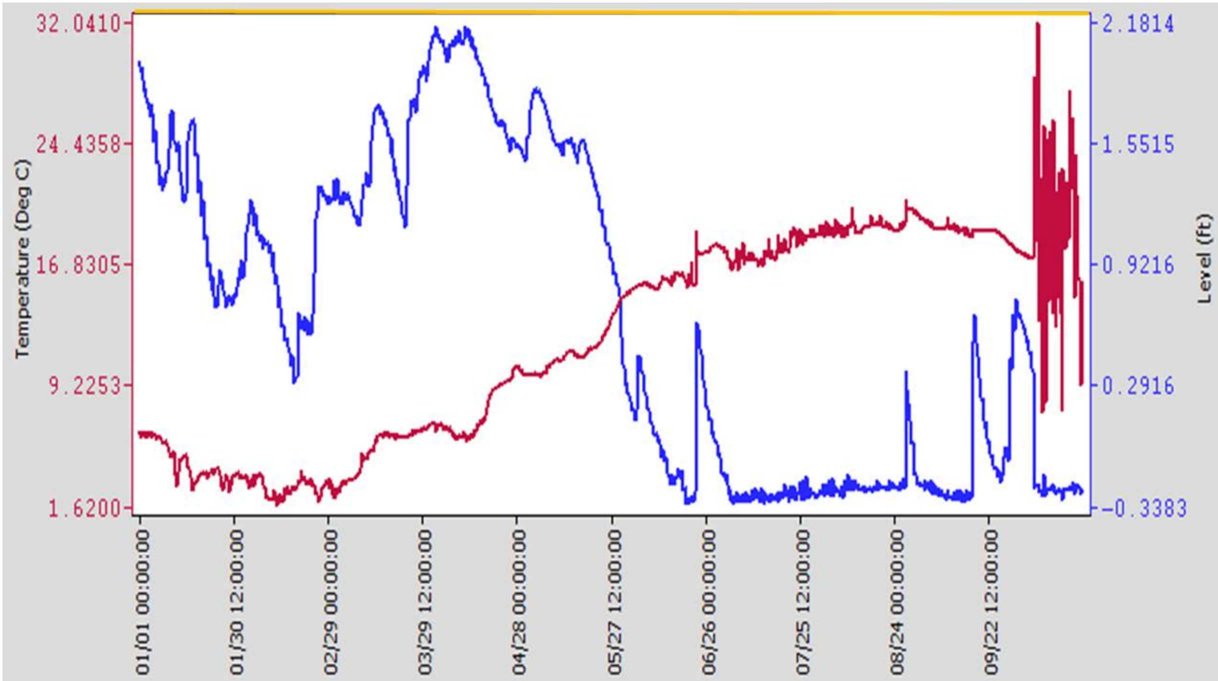

Figure 5. Water level within the St. Michael's wetland, 2016 monitoring season. Temperature is shown in red on the left side of the y-axis while water level is on the right side of the y-axis. The blue line indicates the water level within the structure. The date is on the x-axis The orange line is the elevation (2.25 ft) within the water outlet structure at which water flows out of the structure and into a ditch. While water levels fluctuated within the basin they did not reach sufficient levels to flow out over the top board within the Agri-Drain outlet. Therefore there was no discharge from the outlet in the 2016 monitoring season. The data loggers was installed January 29, 2016 and removed October 10, 2016.

The Blanchard Road wetland, overflowed the most frequently (Figure 6). Maximum water levels were observed from late March to early May. During the March period, the wetland overflowed continuously for a period of about 1 week. From June to October there were no outflow events.

The Hoffman wetland overflowed frequently during the ten month monitoring period during the time frame of late March to May (Figure 7). Outflow was in the form of gradual flow through the grass swale limiting the velocity and discharge. In total 7% of the total rainfall volume flowed out of the wetland during the monitoring period (Table 4).

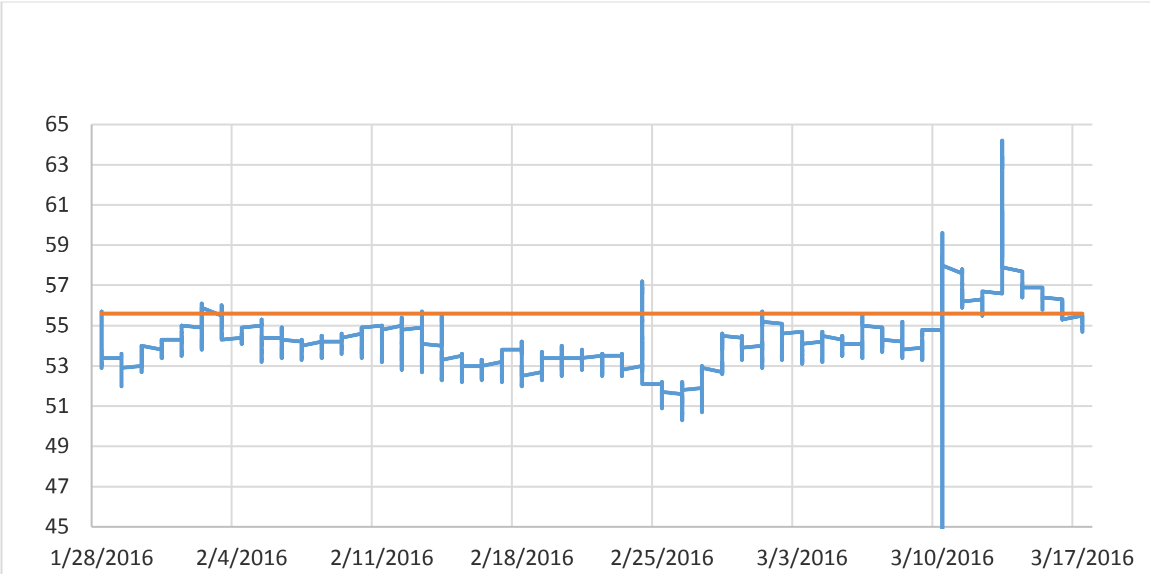

Figure 6. Outflow hydrograph for the Blanchard wetland. The y-axis shows water depth in cm behind the outlet structure. The orange line is the elevation (55.6 cm) at which water flows over the top of the water control structure. The blue line indicates the water level at the outlet structure. The datalogger was damaged by a large sediment influx in late March at which point an empirical estimation of flow was made for the period of March-May. No outflow occurred from June-October.

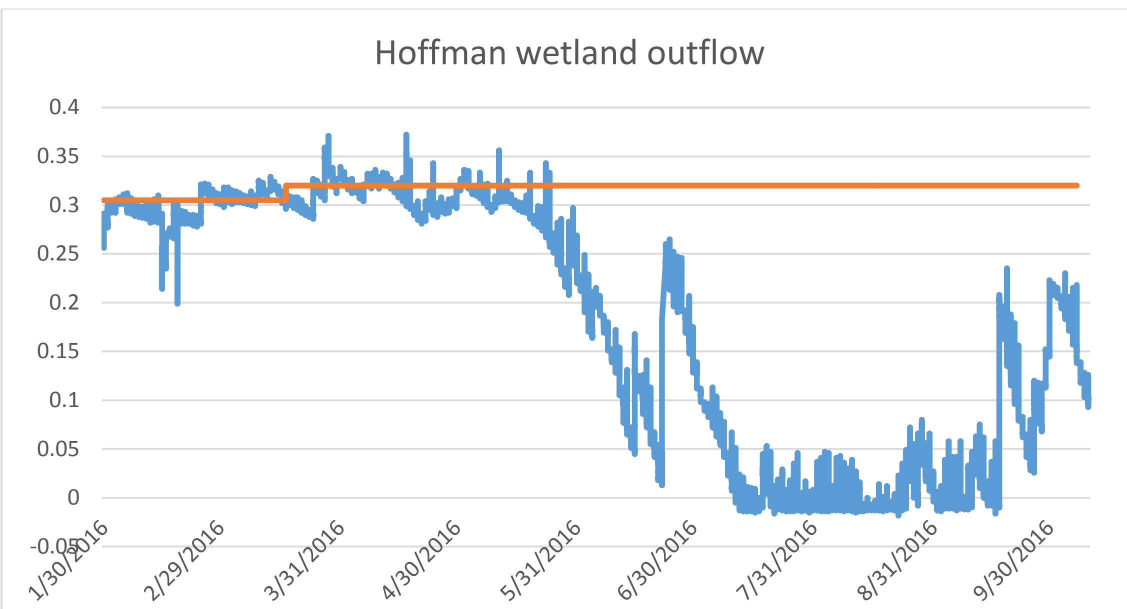

Figure 7. Outflow hydrograph for the Hoffman wetland for the time period 1/28/16 to 10/10/16. The y-axis shows water depth in meters. The orange line is the elevation (2.25 ft) at which water flows out of the outlet channel. No discharge occurs below the orange line. The blue line indicates the water level in the channel behind the outflow point.

Table 4. Flow statistics summary for 2016 monitoring season			
Site	Inflow characteristics for the three basins	Total rainfall* for period Feb. 1 to Sept. 30, 2016	Flow reduction as % of rainfall over wetland drainage area
Blanchard	Direct runoff from farmland	63.8 cm	84%
Hoffman	Diffuse flow from restored wetland and vegetated watershed	63.8 cm	93%
St. Michael’s	Diffuse flow from restored wetland and vegetated watershed with infiltration on adjacent sand ridge	63.8 cm	100%
*total rainfall as reported from the Defiance, Ohio regional airport			

Water Quality data

Water collected from within the wetlands or at the overflow was very low in nitrate and phosphorus. Using the Hach kits, nitrate averaged 0.03 mg/l at the outlet of the St. Michael’s, 0.12 mg/l at the Hoffman wetland and 1.00 mg/l at the Blanchard outlet (Table 5). Phosphate levels were measured as zero from most wetland water samples using the Hach kits, apparently below the detection level for the kit at low levels. A couple of higher samples raised the averages, with values ranging from 0.02 to 0.10 mg/l.

Table 5. Summary of water quality data measured using Hach water chemistry test kits and algae sampling at Defiance College lab								
Parameter	Units	Stat.	St. Michael's Ditch	St. Michael's - Outflow	Blanchard-Inflow	Blanchard-Outflow	Hoffman-Inflow	Hoffman-Outflow
Ammonia (NH_3)	mg/L	n	9	9	8	9	9	9
		Mean	0.14	0.19	0.18	0.13	0.12	0.10
		St.dev	0.11	0.17	0.13	0.09	0.08	0.11
Nitrate (NO_3^-)	mg/L	n	9	9	9	9	9	9
		Mean	29.82	0.03	6.62	1.00	0.03	0.12
		St.dev	14.62	0.08	10.27	2.92	0.08	0.27
Phosphate (PO_4^{3-})	mg/L	n	9	9	9	9	9	9
		Mean	0.02	0.06	0.04	0.02	0.05	0.10
		St. dev	0.04	0.13	0.11	0.04	0.11	0.26
Chlorophyll *a*	ug/L	n	9	9	9	9	9	9
		Mean	212.60	128.16	142.18	147.61	100.80	103.98
		St. dev	99.07	63.92	39.48	51.38	91.02	73.80
Bluegreen Algae	cells/ mL	n	9	9	9	9	9	9
		Mean	407.16	128.16	142.18	147.61	432.84	103.98
		St. dev	149.03	63.92	39.48	51.38	65.70	73.80
Sampling dates: see table 3								

The NCWQR water quality lab data showed that there were low levels of SRP and TP within the wetlands and/or flowing out during the infrequent overflow events (Table 6). SRP averages ranged from 0.006 mg/l at St. Michael's to 0.015 at the Hoffman wetland outflow. There was mixed results with phosphorus removal in the wetlands with no apparent trend in phosphorus concentration change between the inflow and outflow samples, although total loads were reduced because of flow retention.

Concentration reduction

Nitrate levels were at or near the wetland outlets with averages for Blanchard 1.56, Hoffman 1.22 and St. Michael's 0.34 mg/l. 93% of the outflow samples were < 1.5 mg/l. However one April storm event produced outflows from the Blanchard and Hoffman wetlands of 12.0 and 9.8 mg/l, respectively, indicating there reduced treatment capacity at high flow levels.

In comparing the Hach kits values from Table 5 with the NCWQR lab data in Table 6, the NCWQR levels were lower than that measured by the Hach kits though both indicated low levels within and flowing out of the wetlands. The highest nitrate values were observed in the St. Michael's ditch with the maximum 22.6 mg/l.

Table 6. Water quality data from wetland samples sent to Heidelberg NCWQR (all units in mg/l)

SITE	SUMMARY STATS	NH3	CL	S04	NO2	NO3	SIO2	SRP	TP	F
Blanchard inlet	avg.	0.050	9.600	70.600	0.006	1.419	2.040	0.009	0.315	0.186
	median	0.040	11.100	78.000	0.000	0.190	2.190	0.008	0.149	0.120
Blanchard outlet	avg.	0.054	7.378	45.611	0.004	1.559	2.114	0.012	0.193	0.174
	median	0.049	8.500	42.900	0.000	0.180	2.290	0.014	0.107	0.100
Hoffman upstream	avg.	0.070	10.044	52.633	0.001	1.169	1.102	0.012	0.114	0.163
	median	0.053	7.400	11.300	0.000	0.020	0.940	0.013	0.093	0.130
Hoffman downstream	avg.	0.048	16.889	34.867	0.231	1.223	0.999	0.014	0.101	0.249
	median	0.041	4.700	10.500	0.000	0.010	0.390	0.009	0.083	0.160
St. Michael's ditch	avg.	0.082	10.711	17.767	0.008	7.331	4.219	0.006	0.078	0.089
	median	0.082	13.400	9.200	0.010	8.240	4.940	0.004	0.059	0.140
St. Michael's outlet	avg.	0.139	4.856	35.211	0.009	0.340	1.081	0.025	0.130	0.130
	median	0.055	2.950	14.250	0.000	0.010	1.040	0.014	0.095	0.100
Notes: Sample size, n=9										

Nutrient concentration reductions are summarized in Table 7. There were not significant differences for inlet and outlet values for nitrate at the Blanchard and Hoffman wetlands, likely due to high variability and small sample size. Nitrate samples from the St. Michael's wetland were significantly lower than the nitrate levels in the adjacent ditch. For total phosphorus (TP) there were no significant differences between the inlets and outlet sample concentrations at any of the three sites. However at two high flow events the Blanchard wetland did reduce TP concentration by 38 to 54%. For SRP the wetland outlet samples at Blanchard and St. Michael's were significantly higher than the inlet values, indicating the

Blanchard wetland was serving as a source of SRP at times. The St. Michael's wetland did not overflow the entire 2016 season so no discharge of SRP actually occurred from the wetland during the monitoring period.

Table 7. Summary of % nutrient difference in wetlands by concentration at inlets and outlets (n=9)						
Site	% NO_3 removal median (min, max)	Significant difference, α= 0.1	% TP removal median (min, max)	Significant difference, α= 0.1	% SRP removal median (min, max)	Significant difference, α= 0.1
Blanchard	0 (-1066, 91)	no	36(-123, 54)	no	-50(-133 , 26)	Yes (increase)
Hoffman*	0 (-100, 100)	no	10 (-239, 71)	no	18(-187, 71	no
St. Michael's**	90% (-822, 100)	Yes (decrease)	-84(-650, 47)	no	-160(-6500, 44)	Yes (increase)
* The Hoffman wetland nutrient differences are comparing values from the upstream end of the wetland to the downstream end since there was no concentrated inflow to the wetland. **The St. Michael's wetland compared untreated ditch water from an adjacent ditch to the outflow of the wetland since there was no concentrated flow into the restored wetland.						

Estimates of the reduction in total flow from the wetland drainage area are shown in Table 8 along with nitrate loading estimates for the 2016 monitoring season.

Table 8. Estimates of total flow reductions and total nitrate-nitrogen load discharging from wetlands, 2016 monitoring season				
Wetland site	Inflow	Flow reduction as % of rainfall over basin	Nitrate discharging from wetland	
			Mass	Mass/area
Blanchard	Runoff from farmland	84%	8.4 kg	1.13 kg/ha
Hoffman	Diffuse flow from restored wetland and vegetated watershed	93%	2.14 kg	0.79 kg/ha
St. Michael's	Diffuse flow from restored wetland and vegetated watershed	100%	0	0.0 kg/ha

Water chemistry data collected from within the wetlands using the YSI probe data is summarized in Table 7. Temperature values were similar for the three wetlands, while the ditch at St. Michael's (representative of untreated farm drainage water) was slightly lower on average (14.7 ^{o} C) since much of the flow was from sub-surface tile drainage. Similarly the specific conductivity was higher in the ditch (average 353 µs/cm) and the Blanchard site (average 389 and 313 µs/cm above and below the wetland) which received direct runoff and drainage from farmland containing suspended sediment and pollutants. Salinity was generally low at all the sites while pH values ranged from 7.97 – 9.13.

Table 9. Water Chemistry probe data, Summary of values at each site								
	Temperature		**Specific Conductivity**		**Salinity**		**pH**	
	mean	median	mean	median	mean	median	mean	median
Site	C°	C°	µs/cm	µs/cm	ppm	ppm	-log([H+]	-log([H+]
Blanchard Inflow	16.9	16.9	389	423	0.19	0.20	8.89	8.90
Blanchard Outflow	16.7	16.5	313	358	0.15	0.17	8.87	9.13
Hoffman Inflow	17.3	16.2	155	154	0.07	0.08	8.35	8.33
Hoffman Outflow	17.1	14.0	120	118	0.06	0.06	8.52	8.24
Ditch (St. Michael's)	14.7	13.3	353	453	0.17	0.22	7.97	8.12
St. Michael's	16.2	15.0	189	183	0.09	0.09	8.18	8.13
Sample size (n)=6, sample dates; there was insufficient standing water at most of the sites in late summer for placing the YSI probe so data was not collected from each of the 9 sampling trips								

Vegetation data collected in July-August of 2016 from the VIBI survey is summarized in Table 10. The three wetlands varied greatly by wetland plant community type and coverage. The St. Michael's site was covered mostly by dense native wet prairie vegetation with about 35% shallow vegetated marsh (Figure 2 and Figure 8A). The predominant species was big bluestem (*Andropogon gerardii*) with other warm-season grasses such as Indian grass (*Sorghastrum nutans*) and switch grass (*Panicum virgatum*), sedges (*Carex, Scirpus* and *Schoenoplectus spp*.) and composite family plants including goldenrods (*Solidago spp*.), sunflower (*Helianthus spp*.), daisy fleabane (*Erigeron spp*.) and aster species (*Symphyotrichum spp*.). The Hoffman wetland was covered by 90% cattail marsh, with broadleaf (*Typha latifolia*) and hybrid (*Typha x glauca*) cattail, a few scattered pioneer species such as the floating duckweed (*Lemna minor*) and green algae in the deeper water areas (Figure 4). Sixteen native species were recorded in the plant survey with greater diversity on the wetland edges outside of the standing water. The Blanchard site was primarily open water with bare sediment un-stabilized by vegetation and a small grass fringe with a few native wetland species and mostly non-native weeds (Figure 3 and 8.C). In total 8 native species were found, primarily along the pond fringe.

The Vegetative Index of Biotic Integrity scores (VIBI) weighted by the Coefficient of Conservation varied from 32 at St. Michael's, to 4 at Blanchard and 7 at Hoffman. The St. Michael's site score was raised by a number of sedge species (*Carex spp*.) and native wet prairie forbs such as (*Silphium* spp.) while the Hoffman site was lower in VIBI due to dominance by cattail (Figure 8.B).

Table 10: Vegetation characteristics: Vegetation Index of Biotic Integrity (VIBI) data for the three study sites.				
Site	**Type and overall coverage**	**# native species**	**Avg. Native species per quadrat**	**VIBI-FQA**
St. Michael's	75% Wet prairie / 25% marsh	35	10	32

Hoffman Rd.	Marsh 90%/ wet prairie 10%	16	4	7
Blanchard Rd.	Open water 90% / grass-wetland fringe 10%	8	2	4

Figure 8. Characteristic vegetation types from each of the basins (July-August, 2016). A)St. Michael's wet prairie basin with abundant bergamot (*Monarda fistulosa*), ashy sunflower (*Helianthus mollis*), big bluestem (*Andropogon gerardii*) and other prairie plants. Past studies have found over 80 herbaceous species in the wetland. B) Hoffman wetland with mostly broad-leaf cattail (*Typha latifolia* and hybrid cattail (*Typha x glauca*). C)Blanchard wetland

A) St. Michael's wet prairie

B) Hoffman wetland cattail marsh

C) Blanchard wetland, shallow marsh basin

DRAINMOD modeling results

Modeling of the pre-restoration hydrology at the three sites using DRAINMOD showed that the majority of flow volume occurred as sub-surface drainage (indicated by the blue line in Figures 9 and 10) for the 1991-2005 monitoring period. Modeled outflow of nitrate-nitrogen showed a peak in April with high discharge levels occurring from March – June. During late summer and fall nitrate loading rates are small due to increase plant growth in cropland and greater losses to evapotranspiration (Figure 9).

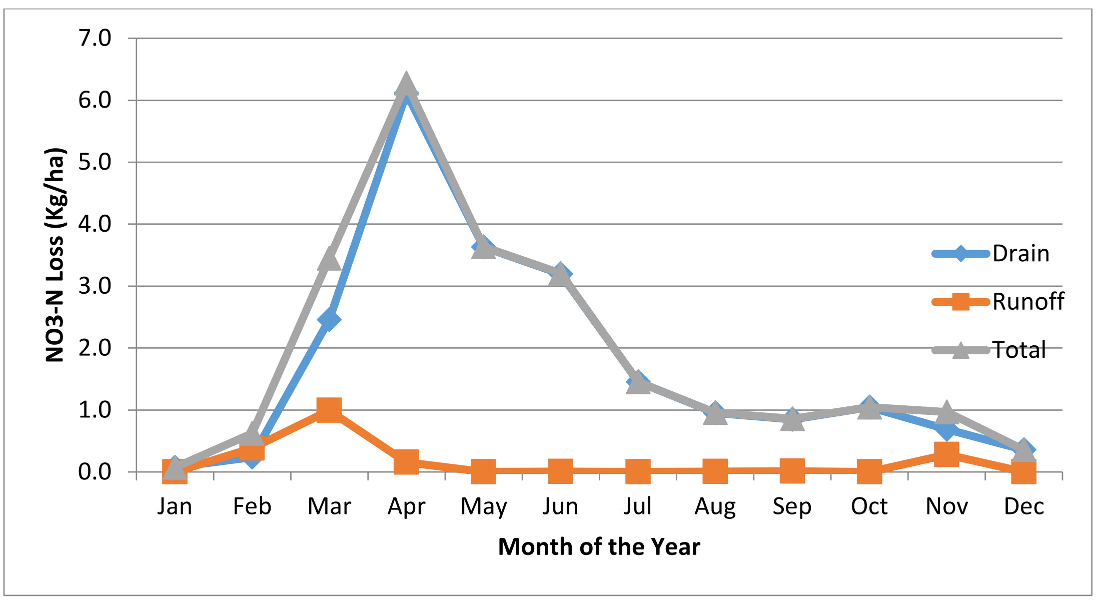

Figure 9. Modeled monthly loss of nitrate from tile drained farmland in Defiance County at wetland sites prior to restoration / construction using DRAINMOD. The modeling indicates the peak nitrate loading period is March to June with the peak in April for the 1991-2005 time period.

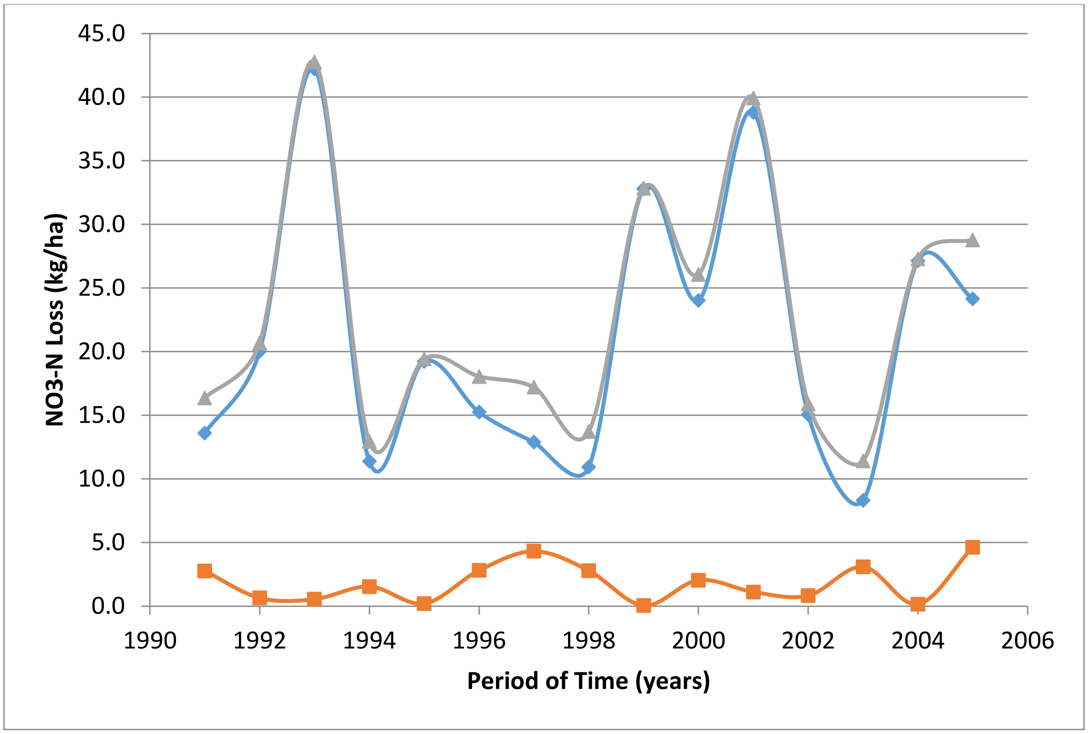

Figure 10. Annual loss of nitrate-nitrogen modeled by DRAINMOD from tile drained farmland at the three wetland sites prior to restoration or construction during the 1991-2005 time period. Tile drainage is indicated by the blue line, total flow in gray and surface runoff in orange. In all years, tile drainage flow dominates by volume although during high rainfall years such as 1997 surface runoff increases relative to tile drainage flow.

In comparing DRAINMOD pre-restoration modeling results to the 2016 monitoring data, large reductions in nitrate load from wetland restoration or creation were found, ranging from 88-100% (Table 9). The model assumed an annual nitrate loading rate of 22.9 kg/ha, which is high but typical for farmland in the region.

Table 11. Nitrate-nitrogen loading: modeled pre-restoration condition vs. 2016 monitoring data*

Site	Pre-restoration Modeled (in DRAINMOD) nitrate load from wetland drainage area(kg)	Total nitrate load calculated from 2016 monitoring data (kg)	% reduction in nitrate load from wetland restoration/ construction	Notes
St. Michael's	255.0	0	100%	No outflow in 2016
Blanchard	68.6	8.4	88%	
Hoffman	62.1	2.1	97%	Very little outflow in 2016
*2016 was very dry from May through the summer months with below-average rainfall				

Discussion

Hydrology

The two restored basins were very effective at storing water and reducing the outflow from their drainage basins with 100% and 93% of rainfall volume over the basins retained by the St. Michael's and Hoffman wetlands, respectively. The Blanchard wetland was less effective, with 88% retained, since it had a bigger watershed relative to its wetland area and flow discharging to it from active cropland. There was likely much infiltration of rainfall and local runoff particularly at the St. Michael's site which has a sandy ridge on its upstream end. Evapotranspiration was likely the major loss of water once plant growth and temperatures start to elevate in late May to June through the summer and early fall. In 2016 the wetlands did not outflow during or after the summer drawdown.

Nutrients

Although there were low levels of nitrate-nitrogen discharging from the wetlands (93% of samples from the wetlands were < 1.5 mg/l) and high overall total load reductions when compared to the modeled pre-restoration conditions there were occasional high outflow events. Nitrate outflow during the April 12 storm event from the Hoffman and Blanchard wetlands, reached 9.8 and 12.01 m/l, respectively at their outflows. Overall the majority of the nitrate discharge from the wetlands occurred in April to May with outflow ceasing in June for 2016.

Soluble reactive phosphorus concentrations at or near the wetland outlets were low with SRP averaging 0.012 to 0.025 mg/l. Since there was little concentration change within the wetlands it appears that the retention of water and uptake by plants is very important for phosphorus removal by wetlands. TP was very high coming into the Blanchard wetland from the untreated farm runoff reaching 1.45 mg/l on 6/23/16. Higher levels discharged from this wetland than the others reaching a maximum of 0.66 mg/l possibly because of the un-stabilized pond bottom. Sediment appeared to be mobilized from the un-vegetated wetland bed and a small gully at the edge of the farm field draining to it.

More data was needed at high flow levels coming into and out of the wetland as that is when the majority of loading occurs. This study was limited to grab sample collection at certain high flow events so there was a relatively small sample size (n=9). Future studies would benefit from more intensive sampling and/or automatic sampling particularly during high flow events when the majority of loading occurs.

Water chemistry

The water chemistry data showed higher specific conductivity values for the areas receiving sub-surface tile drainage and farm runoff with high levels of suspended sediment and/or dissolved pollutants (the St. Michael's ditch and the Blanchard wetland) averaging 318-354µs/cm. The SC values in water within the St. Michael's and Hoffman wetlands were much lower averaging 118-189 us/cm. The lower SC values suggest the water source was primarily rainfall and localized runoff or shallow sub-surface flow.

The pH values found in the wetlands ranging from 7.97 to 9.13 could influence phosphorus adsorption and release from wetland soils. Higher pH values, > 8.0 or 9.0 tends to increase the release of phosphorus from bottom sediments. Although this was not documented in this study it could be a potential issue for the use of wetlands in phosphorus management.

Vegetation data

The VIBI data shows that there are trade-offs between water quality treatment and plant diversity with very low VIBI scores in the two wetlands (Blanchard and Hoffman) that weren't actively seeded with native plants and managed. Wetlands such as the Blanchard site that lack plant coverage allow for re-suspension and mobilization of sediment and nutrients from the pond bottom, which was an issue at this site. Seeding the sites prior to their first use as treatment basins would benefit biological diversity and water quality by reducing sediment and particulate phosphorus outflow.

Modeling simulations vs. monitoring data

The DRAINMOD exercise indicated very high nitrate loading rates from the subsurface tile-drained wetlands at 22.9 kg/ha. This may have elevated the nitrate removal rates of the wetlands over what was actually occurring as indicated by the average inlet and outlet values for nitrate at the Blanchard wetland outlet. The benefit of the modeling was that it showed over years the reduction of nitrate is likely to be 80% or more, although there will be time periods when it is much lower as occurred in April 2016. However since no water discharged from the wetlands for most of the summer and fall, this raised the removal rates.

Management applications:

<u>Water storage</u> is a key factor in reducing phosphorus and nitrogen loading to Lake Erie especially in the late winter to early spring, when the majority of loading occurs. The findings of this study help to inform current watershed management efforts to improve Lake Erie water quality in several ways. First the wetlands were shown to greatly reduce the outflow of water reducing the downstream loading of both nitrate and phosphorus. The concentrations of nitrate were low relative to the pre-restoration agricultural levels observed elsewhere and predicted by the DRAINMOD simulations. While phosphorus concentrations were not significantly different between the inlets and outlets in this study, there are ways to improve phosphorus removal in wetlands and treatment basins as discussed below.

<u>Size and placement</u>

The study demonstrated that constructed wetlands placed at farm edge can be an effective management practice for Lake Erie water quality. However, wetlands that treat larger drainage areas than the ones in this study would be more cost effective at achieving nutrient reduction goals particularly for nitrogen (Crumpton 2008). Optimally wetland basins would be placed lower in the landscape to receive more sub-surface drainage and treat larger drainage areas, > 50 to 100 acres. Our study sites had watershed: wetland ratios ranging from 1.3: 1 to 30:1. The drainage areas should be larger to get the most nutrient removal benefit per dollar spent. For example in Iowa, their state treatment wetland program uses a watershed: wetland ratio of 50:1 to 200:1.

Wetlands designed to remove phosphorus may require a smaller watershed-to- wetland ratio and be located higher in the landscape than those designed to maximize nitrogen removal, which require slightly different conditions for promoting denitrification. Phosphorus is often released under anaerobic conditions, unlike nitrogen, which is removed most efficiently by denitrification at higher temperatures at low oxygen levels. Ideally a variety of different wetland basin types restored across the Maumee basin in combination with agricultural BMPs to reduce nutrient loading would provide the best mixture of ecosystem services and functions such as phosphorus and nitrogen removal

Vegetative diversity and function

VIBI was highest at St. Michael's (32) which demonstrated the benefit of seeding restored wetlands, particularly wet prairies, rather than allowing natural revegetation to occur. The diversity of plants, rare plant species (Lenhart and Lenhart 2014) and high infiltration rates indicate the value of wetland and prairie restoration alongside the relict glacial beach ridges which are found in the former Great Black Swamp area. The Hoffman wetland grew in by natural succession and was predominantly covered by cattail with duckweed and a lower VIBI score (7) and fewer native species. In contrast the Blanchard wetland had very little plant cover consisting of primarily weedy species along the pond fringe and had a VIBI of 2. The lack of plant cover allowed for mobilization of sediment and phosphorus from the pond bottom during periods of high flow.

Summary of Project Outcomes

Through installation, monitoring and outreach involving the three wetlands the following key points were learned and outcomes achieved:

- The utility of constructed and restored wetlands for flow reduction and nutrient removal, particularly for nitrogen, in the western Lake Erie Basin was demonstrated
- It was shown that plant diversity, quality and coverage can be very low in treatment wetlands which can reduce their value and effectiveness as the Blanchard wetland demonstrated.
- Based on the study findings and related studies in other Midwestern states, recommendations to optimize wetland basin design for nitrogen vs. phosphorus removal were made
- Public outreach and education were done including two class presentations and two field trips with Holy Cross Elementary School in Defiance, Ohio involving 16 students. The project provided education on local wetland, water quality and agricultural issues to the students.
- Two presentations of the study were made; 1) Doug Kane, professor at Defiance College presented at the Water Management Association of Ohio (WMAO) in November, 2016; 2) Chris Lenhart, professor at the University of Minnesota, presented at the Minnesota Wetlands conference on January 13, 2017 about this study and related treatment wetlands studies in Minnesota

Acknowledgements

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Addenda:

Public Outreach/Education Activities

In an effort to enhance public awareness of the importance of water quality, we decided to focus our efforts on a class at a local elementary school. We taught a group of around twenty 5th-8th grade students during four sessions. Two of these sessions were in a classroom setting and two were on the St. Michael's Ridge restored wetland site. Our focus was defining and learning about ecology and wetlands, with an emphasis on water quality in Northwest Ohio.

Our first session focused on the basics with an interactive presentation in the classroom. We thought it would be interesting to do a compare and contrast of the students' knowledge before and after the session. The students were asked to write down what came to mind when they heard the word "wetland". We posted their notes on the board and had them do the same activity at the close of the hour. We created an interactive presentation to introduce topics like characteristics of wetlands, interactions in ecosystems, water quality in Lake Erie and the local rivers, and native/invasive species. Students were also engaged with a variety of seed samples including rare native seeds such as Rattlesnake Master and Compass Plant. With the abundance of Swamp Milkweed on our prairie site, we often see Monarch caterpillars, two of which were brought along to illustrate an example of a relationship in an ecosystem (ecology).

The presentation briefly touched on the impact various soil types have on water quality and erosion. As we began our second session on site at the St Michael's Ridge wetland we contrasted the sand on the relic beach ridge, to the heavy clay and plants in the adjacent wetland. The students were given some time to explore the wetland habitat. After this, a scavenger hunt for native species was conducted. The students were given laminated sheets with photos of 16 different native plants with larger populations on the property. They were asked to locate as many as possible with the winners earning small prizes.

Water quality was the focus of the third session back at the school. The kids were grouped into teams of 3 or 4 and worked with a *Lamotte Water Monitoring Kit* for a hands-on experience. Our water sources were the Auglaize and Maumee Rivers, an agricultural ditch, and a wetland pool. The students tested for nitrogen, phosphorus, pH, and dissolved oxygen and contrasted the results from the various water sources. The nitrogen and phosphorus were particularly important to the project, as the school is in a rural area where large amounts of fertilizer is used. The students then compared the turbidity of the same samples using a 120 cm turbidity tube.

Our fourth session was again at the wetland with the students engaged in native seed collection.

The four weekly hands-on sessions seemed to be effective in generating interest on wetlands and water quality among the students and staff at the school.