Project title: **Evaluating the ecological and cost effectiveness of constructed wetlands at reducing nutrient export in tile-drained subwatersheds of the Mackinaw River, Illinois**

Agreement #: AG-3151-P-12-0113

Project duration: 28 September, 2012 – 25 March, 2016

Grant funding: $96,516

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Purpose of grant funding: Provide funding to The Nature Conservancy to support (a) water quality analyses that will be used to quantify and document nutrient removal effectiveness of CP39 wetlands at the site-specific and watershed-scale, and (b) economic analyses of the cost effectiveness of CP39 wetlands that have been or will be constructed in Bray Creek, a 10,000-acre subwatershed of the Mackinaw River, Illinois.

Project Summary

The overarching goals of the Mackinaw River Program are to (1) improve hydrology and water quality of the Mackinaw River watershed for mussels, fishes, and people who depend on it for water supply and recreation, (2) reduce nutrient export from the Mackinaw River to downstream river systems, and (3) develop a model for hydrologic and water quality improvements that is economically viable, compatible with agricultural production, and scalable across the Upper Mississippi River Basin (UMRB). Funding to The Nature Conservancy was provided by USDA-FSA to (a) monitor nutrient concentrations and water flow at the inlet and outlet of a one newly constructed CP39 wetland in Bray Creek, (b) monitor nutrient concentrations and flow in the entire Bray Creek watershed, and (c) evaluate cost effectiveness of CP39 wetlands at the wetland-site and the watershed scale. During the project period three CP39 wetlands were constructed in Bray Creek, as well as three CP39 wetlands in Money Creek – both subwatersheds of the Mackinaw River, Illinois. A fourth privately funded wetland was constructed in Money Creek as well. Nutrients and flow were monitored in Bray Creek, as well as at the inlets and outlets of the newly constructed wetlands. Estimates for the new Bray Creek wetland showed total reductions in nitrate-nitrogen (NO_3-N) loadings of 36% during the first 6-months and reductions as high as 56% in March, 2016. Regression analyses did not reveal any significant changes in the treatment watershed relative to the reference watershed for biweekly NO_3-N or total phosphorus concentrations at long term monitoring sites. The average cost acre^{-1} of the CP39 wetlands constructed in Bray and Money creeks was between $15,037.66 and $17,374.55 acre^{-1} of wetland. Annual removal estimates from these CP39 wetlands were

multiplied by 10 years to calculate an average CP39 wetland cost per kg NO_3-N removed of \$18.85 NO_3-N kg^{-1} over a 10-year period.

This project has served as an important step towards implementing and measuring watershed-scale effectiveness of wetlands for reducing agricultural runoff from subsurface tiles. Over the next several years, we plan to develop watershed maps that highlight areas of Money Creek watershed where edge-of-field practices best fit into the landscape and would be most effective at treating tile drainage waters. Next steps also include increasing acres of infield practices such as winter cover crops and spring nitrogen application in both Bray Creek and Money Creek subswatersheds. Parallel economic analyses are incorporating cost benefit analyses of these practices into a financial model that includes nutrient reduction potential from mapping scenarios. Development of a stakeholder feasibility study is currently underway to identify stakeholder interests and their potential investment in water resource protection. Results from all of these ongoing pieces of the larger Mackinaw River Watershed Program will be replicable in tile-drained watershed across the Midwest in an effort to move towards water quality improvement in the UMRB.

Introduction

As highlighted in the Upper Mississippi Conservation Effects Assessment Program report, conservation practices used in the Mississippi River Basin have focused on intercepting surface water runoff, neglecting to address nitrogen losses from tile drainage. Addressing this challenge is essential given that nutrient fluxes into the basin are transported primarily from areas within five Midwestern states that correspond closely to highest densities of tile drained farmland [(1, 2)]. This is especially critical in Illinois, which has the highest estimated total area of subsurface drainage of any state in the basin [(2)] and is among the highest of contributors for total nitrogen (16.8%) and phosphorus (12.9%) flux to the Gulf of Mexico [(3)].

Research in the Mackinaw River watershed in central Illinois indicates that surface water practices are not solving water quality problems and that increasing adoption of practices to reduce leaching of nitrogen and capture nutrient export from tiles is an essential next step[(4)]. Constructed wetlands efficiently reduce nutrient export from tiles, with potential to remove 46-90% of nitrate-nitrogen that would otherwise enter adjacent streams and rivers [(5, 6, 7)]. In Illinois, cumulative 9-year data from ongoing research by Dr. David Kovacic at the University of Illinois (UIUC) and The Nature Conservancy (TNC) show that wetlands representing 3-9% of tile-drained areas removed 12-48% and 31-93% of nitrate and dissolved phosphorus loadings, respectively. Models and demonstration practices have shown that targeted installation of these constructed wetlands in heavily tile-drained, high nitrogen contributing watersheds throughout the Upper Mississippi River Basin (UMRB) and Ohio River Valley watershed could significantly reduce nitrogen loading to the Mississippi River and the Gulf of Mexico [5, 6, 7].

As part of the Mackinaw River Program in Illinois, constructed wetlands are being, placed in the watershed such that they intercept and treat tile runoff before the water is discharged into the stream. These small wetlands generally require excavation of 3-4 feet to intercept the drainage tile; however, are constructed to maintain a depth of 1.5 to 2 feet in most of the wetland pool area. Tile drainage flows through the wetland and is discharged back into the tile system using control gates and/or risers to maintain desired water depth. Berms are constructed around the wetlands to prevent surface water runoff into the wetland pool, so that the wetlands are only treating tile drainage runoff. Berms are generally seeded with cool season grasses to control erosion, and warm season grasses and forbs are seeded in the remaining buffer area to provide wildlife benefits.

The Mackinaw River Watershed Program consists of three related projects, each an evolutionary step in TNC's 25-year history in the watershed. The overarching goals of the Program are to: (1) Improve hydrology and water quality of the Mackinaw River watershed for mussels, fishes, and people who depend on it for water supply and recreation, (2) Reduce nutrient export from the Mackinaw River to downstream river systems, and (3) Develop a model for hydrologic and water quality improvements that is economically viable, compatible with agricultural production, and scalable across the UMRB. The Paired Watershed Project is an ongoing 16-year project that uses a reference and treatment subwatershed design to measure the (a) effectiveness of outreach efforts on implementation, and (b) ecological effectiveness of conservation practices at the watershed scale of 10,000 acres. Research at the Franklin Family Research and Demonstration Farm (Farm) tests the effectiveness and optimal design of constructed wetlands at removing nutrients from tile drainage systems. TNC and UIUC have 9 years of monitoring data regarding N and P reductions from the inlets and outlets of wetlands located at the Farm that borders the Mackinaw River in Lexington, IL. These two projects are informing The Mackinaw River Drinking Watersheds Project (i.e., Bloomington Project), that integrates research, multiple conservation programs, government agencies, university researchers, municipalities and non-profit organizations to deploy constructed wetlands across reasonably large watersheds to reduce nutrient pollution.

Objectives and project deliverables

(1) Monitor nutrient concentrations and water flow at the inlet and outlet of a one newly constructed CP39 wetland in Bray Creek to confirm that performance is consistent with N and P efficiency data from wetlands located at the Research and Demonstration Farm;

(2) Continue to monitor nutrient concentrations and flow in the entire Bray Creek watershed;

(3) Evaluate cost effectiveness of CP39 wetlands at the wetland-site scale and at the watershed-scale levels

(a) Incorporate nutrient concentration and flow data from Bray Creek CP39 wetland with additional data into an economic analysis of the cost effectiveness of wetlands for N and P reductions from tile drainage water at the wetland site scale

(b) Incorporate nutrient concentration and flow data from Bray Creek watershed monitoring into an economic analysis of the cost effectiveness of CP39 wetlands for reducing instream nutrient loads measured at the 10,000-acre watershed scale of Bray Creek

Methods

Site description

Wetland effectiveness was quantified at the wetland and watershed scale using an existing paired watershed research design implemented in the headwaters of the Mackinaw River watershed (HUC 07130004) in McLean Co., Illinois (Figure 1A). This experimental design included two adjacent 10,000-acre subwatersheds of the Mackinaw River: Bray Creek (treatment) and Frog Alley (reference). Stream lengths were similar in Bray Creek (19.8 km) and Frog Alley (19.6 km) and landuse in both watersheds was extensively agricultural with 80-93% of the land used for corn and soybean row crop production. Outreach efforts to landowners during the project focused on increasing the number of wetlands that were constructed in the treatment subwatershed and enrolled in the CP39 program within the Farm Bill's Conservation Reserve Program. During the project, additional CP39 wetlands were constructed in a second tributary to the Mackinaw River called Money Creek (Figure 1A). Similar to Bray Creek and Frog Alley, Money Creek is 90% agricultural for row crop production.

Water quality

Stream sampling. - Water samples were collected biweekly from instream and representative tile outlet monitoring sites throughout the extent of Bray Creek and Frog Alley (Fig. 1B). Samples were analyzed at Illinois State University for nitrate-nitrogen, ammonium, total phosphorus, dissolved reactive phosphorus, and total suspended solids (TSS) using standard methods (American Public Health Association, 1998). In addition to biweekly sampling, water samples were also collected at 45-min intervals during storm events at 3 locations in the treatment subwatershed (downstream, midstream and upstream) and at 2 locations in the reference subwatershed (downstream, upstream) using ISCO programmable water samplers (Teledyne ISCO Inc., 6712 Compact Sampler, Lincoln, Nebraska) fitted with pressure transducers (Teledyne ISCO Inc., 720 Submerged Probe Module, Lincoln, Nebraska). Water levels were recorded every 15 minutes at downstream stations using Campbell data loggers (Model CR510, Campbell Scientific Inc., Logan, Utah) connected to CS420-L pressure transducers (Model PDCR 1830-8388, Druck Inc., Houston, Texas) that were installed in stilling wells. Discharge rating curves developed at the downstream sites converted water level readings to discharge. Water levels were also measured continuously at all of the ISCO monitoring sites.

Wetland sampling. – During this study, inlet and outlet structures (*Inline Water Level Control Structures*™ Agri Drain Corporation, Adair, Iowa) were installed to monitor flow through four constructed wetlands. Each stoplog structure was instrumented with an ISCO programmable water sampler fitted with a pressure transducer that recorded water levels in the stoplog structure at 15 minute intervals. Automatic water samplers were used to collect flow proportional samples when the tiles were running. Tile discharge inlet, outlet and seepage estimates were used to determine water budgets for each wetland. Seepage was determined as the difference in water volume coming into the wetland and leaving each wetland.

Wetland construction

Three wetlands were constructed in the treatment watershed prior to the beginning of this project and three additional CP39 wetlands were constructed during the time frame of this project (Figure 2). With the Farm Bill expiring at the end of September, 2012, we were not able to actively enroll any landowners into the CP39 Farmable Wetlands Program until mid-May, 2013. Between May 13 and 30 September, 2013, we completed the Conservation Reserve

Program (CRP) paperwork for 2 landowners to construct three wetlands and received approval from Farm Service Agency (FSA) for a waiver request to place the two Arrowsmith wetlands in existing CRP stream filter strips. Construction of the first wetland (Martin) was completed in 2013.

A meeting between NRCS, TNC, and the contractor for the two Arrowsmith wetlands was held on 28 October, 2013. From that meeting, it was determined that NRCS needed to modify their engineering design for the North wetland because (a) their design did not allow for the installation of monitoring equipment and (b) they were allowing surface water runoff into the wetland which would interfere with our ability to determine the effectiveness of the wetland to treat tile water. Final designs and revisions were completed and approved by state NRCS engineers for the Arrowsmith wetlands in March 2014. A second meeting between NRCS, TNC, and the contractors for these two wetlands was held on 14 March, 2014 where it was determined that construction will begin in June 2014 for the North wetland and after harvest for the South wetland. Although construction on the North wetland was scheduled for June (2014), it did not begin until August (2014), primarily because of the contractor's scheduling. Wetland construction was completed for the first Arrowsmith wetland in December 2014. The extended time to construct the wetland (August-December) was primarily due to frequent rain events and the discovery of gravel lenses at the site that needed to be packed with clay. Installation of monitoring equipment was postponed until the fall of 2015 because NRCS would not allow the control gates to be lowered to fill up the wetland until wetland plants had been established. We seeded the wetland in December, 2014, with cattails and water plantain seeds collected from our existing wetlands at the Research and Demonstration Farm. The plants were well established by July 2015, and monitoring equipment was installed in the Arrowsmith North wetland in August 2015. Construction of the Arrowsmith South wetland was completed in December of 2015.

Sample analyses

On each sampling date, grab samples were collected from a single point in the center of the stream at 50% depth using a 1-liter bottle. All stream and wetland samples were stored on ice prior to transport to the laboratory. Stream and Moga North wetland samples were analyzed at Illinois State University, whereas, all other wetland samples were analyzed at University of Illinois. All samples were filtered immediately upon arrival to the laboratory using Whatman

0.7-µm glass microfiber filters for nitrate-nitrogen (NO_3^--N) analyses and 0.45-µm membrane filters for dissolved reactive phosphorus (DRP) analyses. Filters from these samples were retained and used for total suspended sediment (TSS) analyses; whereas, unfiltered water was retained for total phosphorus (TP) analyses (TP analyses were conducted at ISU only). Refrigerated samples were then either analyzed within 24 hours upon arrival to the laboratory or frozen for future analyses. Nitrate analyses for stream and wetland samples were conducted using ion chromatography with a minimum detection limit of 0.01 mg/L as NO_3^--N (Dionex DX-120, Sunnyvale, CA). Phosphorus and TSS analyses were conducted using a Perkin Elmer Lambda 35 dual beam spectrophotometer (Waltham, MA) with a minimum detection limit of 0.005 mg/L. Ascorbic acid colorimetric method was used to determine DRP of filtered water samples (Method 4500-P, APHA). Unfiltered water samples were digested using the persulfate oxidation technique and subsequently analyzed using the ascorbic acid colorimetric method to determine TP. Total suspended solids were analyzed using standard methods (American Public Health Association, 1998).

Data analyses

Biweekly stream nutrient and TSS data were analyzed using standard paired watershed methods designed to decrease variability due to annual or seasonal effects [(9, 10)]. Regression analyses were used to test for significant trends over time in the relationship between the treatment and reference watersheds for nutrients and TSS concentrations. In these analyses, biweekly concentrations of nutrients and TSS estimated for the reference watershed stations was subtracted from those of the corresponding treatment stations and fitted to a linear regression model similar to previously published analyses from these watersheds[(4)].

Economic analyses

All costs associated with wetland construction in Bray Creek were documented and used to estimate construction costs per acre of wetland the cost effectiveness of CP39 wetlands in terms of $ per kg NO_3-N removed. Wetland site data from the Research and Demonstration Farm wetlands in McLean County, Illinois were also used in the analyses as well as additional wetland data from four CP39 wetlands that were installed in Money Creek, a subwatershed of the Mackinaw River in McLean County, Illinois. Information on the breakdown of total installation costs were calculated by NatureVest using data from these wetlands, which is the impact investment unit of The Nature Conservancy.

Results

Wetland efficiencies

Data collection began at the Arrowsmith North wetland mid-November, 2015. During the first six months of data collection, there was approximately 50% more water leaving the wetland through the outlet stoplog structure than entering the wetland through the inlet structure (Figure 3A). A seep was detected near the inlet structure early after construction was completed that could account for some of the additional water inputs into the wetland. Adjusting for this seepage in our estimates for nutrient reductions, we estimated that NO_3-N loadings during this 6-month period were reduced by 36%, TP by -31%, and TSS by 68% (Figure 3B). Estimated NO_3-N loadings ranged from 3.8 kg in the last two weeks of November, 2015, to 39.3 kg the following month (Figure 4, top). The highest inputs to the wetland were in December and January after 7 inches of rainfall in December; however, highest reductions occurred February through May when mean daily temperatures ranged between 54°F and 70°F (Figure 4). High NO_3-N reductions also occurred in December when mean daily temperatures were 60°F. Estimated NO_3-N loadings during the first 6 months at the Arrowsmith North wetland were lower than the six-month loadings in Money Creek North wetland, but higher than the 16-month loadings for a CP39 wetland in Towanda (Figure 5, top). Estimated NO_3-N reductions for the Arrowsmith North wetland were within range of the several other CP39 wetlands constructed in Money Creek (Figure 5, bottom).

Nitrate concentrations at downstream sites of Bray Creek and Frog Alley varied with season, ranging from <1 to 30 mg L^{-1} (Figure 6, top). Minimum NO_3-N levels typically occurred during the summer months of August and September. Nitrate concentrations increased during the fall and remained high throughout the winter and spring, with maximum NO_3-N levels typically occurring from April through June. Biweekly concentrations for total P ranged from <0.01 to 0.62 mg P L^{-1} (Figure 6, bottom) and were generally low except during high discharge events. Similar nutrient concentration patterns were observed for NO_3-N and total P at the upstream sites (Figure 7), although total P concentrations reached higher levels (<1.0 mg L^{-1}) during several storm events (Figure 7, bottom). Regression analyses did not reveal any significant changes in the treatment watershed relative to the reference watershed for biweekly NO_3-N (r^2=0.003, df=400, p-0.13) or total P (r^2=-0.003, df=316, p=0.93) at the downstream monitoring sites (Figure 8). Neither were significant changes observed for NO_3-N (r^2=-0.002, df=271, p=0.50) or total P (r^2=-0.004, df=266, p=0.97) at the upstream sites (Figure 9).

Economic analyses

Total cost of wetland installation ranged from $15,012.59 to $49,260.74 for wetlands ranging from 1.0 acres to 4.5 acres (wetland pond + buffer) (Table 1). Total cost per acre ($ $acre^{-1}$) of CP39 wetland construction ranged from $5,005.16 to $36,445.17 $acre^{-1}$. Two of the costs for wetland construction shown on Table 1 are the estimated costs for two CP39 wetland that will be installed this summer in Money Creek (Blue Mound #1 and #2). If these are included in the economic analysis, then the average cost $acre^{-1}$ of CP39 wetlands constructed in Bray and Money creeks was $15,037.66 $acre^{-1}$ wetland. If these two estimated costs are not included in the analysis, then the average cost per acre of CP39 wetlands constructed in Bray and Money creeks was $17, 374.55 $acre^{-1}$ wetland (Table 1). The majority of the wetland construction costs was excavation (Figure 10), followed by design costs and tiling expenditures. Wetland data from the Research and Demonstration Farm were included to calculate construction costs per kg NO_3-N removed estimated over a 10-year period, which is generally the length of a CP39 contract (Table 2). Using the annual removal estimates multiplied by 10 years, the CP39 wetland costs per kg NO_3-N removed averaged $18.85, ranging from $9.15 to $41.80 over a 10-year period (Table 2).

Discussion

Well-designed wetlands can effectively intercept and retain tile drainage to remove 46% to 90% of inflowing NO_3-N concentrations(1,5,6,8). Three of the four CP39 wetlands that were monitoring during this study were also very effective at reducing nitrate at the farm scale, showing total NO_3-N reductions ranging from 30% to 37% over the course of their existence in the watershed. Lower overall reduction estimates for the Towanda wetland (13%) may be a reflection of several very large flood events in which Money Creek overflowed into the wetland. Efficiencies of tile-treatment wetlands vary by season, and thus is one way to evaluate their overall contribution to larger watershed nitrate reductions. For instance, analyses of NO_3-N reductions for the three Money Creek wetlands from July to December 2015 estimated reductions ranging from 37% to 53% (Technical Report, University of Illinois). Similarly, the CP39 wetland in Bray Creek showed NO_3-N reductions ranging from 40% to 58% in the spring when nitrate loadings to the watershed are generally highest. These small wetlands are very effective at the farm scale; however, wetland research conducted in central Illinois indicate that to effect N retention within the ranges needed to reduce Gulf Hypoxia, a 5% wetland to drainage area ratio would be required(6). To-date, the estimated wetland to drainage area ratio in upper Bray Creek is approximately 0.2%, thus no significant reductions in stream NO_3-N was detected. In order to reach that 5% ratio in upper Bray Creek, we would need approximately 50 acres of constructed wetlands in order to reduce nitrate loadings by 40-50%. Further data analyses will be conducted that focus on possible reductions in stream NO_3-N loadings in the spring and in phosphorus export during storm events.

Estimated wetland construction costs per kg NO_3-N removed are higher for the wetlands in our study ($18.85) than those that are included in the Illinois Nutrient Loss Reduction Plan of $11.13 per kg N removed (11). The sample size for our calculations is very small, based on 5 wetland sites. There are other wetland sites that can likely be added to our analysis as we proceed with the project that include several of our partners' wetland research projects in central Illinois that would create a more robust analysis. In addition, monitoring data are now being collected from a fourth CP39 wetland in Money Creek and three more CP39 wetlands will be constructed in Money Creek this summer. Careful documentation of wetland construction costs has provided information on possible ways to reduce expenses associated with design and installation. We are currently working with partners from Conservation Strategies Consulting to examine line item costs and to strategize ways to reduce expenses as we plan to scale up implementation in the watershed. As we proceed with this project over the next couple of years, we will continue to update economic analyses with regard to landowner out-of-pocket expenses. The overall goal is to develop a financial model focused on implementing multiple conservation practices at the larger watershed scale.

Next steps

It is apparent that a multi-practice approach will be needed that combines both infield and edge of field practices in order to achieve nitrogen reduction goals for Illinois and the larger Gulf of Mexico. As part of the Bloomington project, researchers from University of Illinois are developing watershed maps that highlight areas of Money Creek watershed where edge-of-field practices (wetlands, saturated buffers, water control management, bioreactors) best fit into the landscape and would be most effective at treating tile drainage waters. Next steps also include increasing acres of infield practices that include winter cover crops and of spring nitrogen application (versus fall) in both Bray and Money creeks. Parallel economic analyses by Illinois State University are incorporating cost benefit analyses of these practices into a financial model that includes nutrient reduction potential from mapping scenarios. A critical component to scaling up watershed implementation is integrating the stakeholders in the process. Lack of stakeholder involvement is one of the major limiting factors to improving water quality in agricultural watersheds where implementation of conservation practices is strictly voluntary. Development of a stakeholder feasibility study is currently underway in which our partners at Conservation Strategies Consulting, LLC, are identifying stakeholder interests in Money Creek watershed and their potential investment in water resource protection. Results from all of these ongoing pieces of the larger Mackinaw River Watershed Program will be replicable in tile-drained watershed across the Midwest in an effort to move towards water quality improvement in the Upper Mississippi River Basin.

Acknowledgements

Funding was provided from USDA-FSA, Agreement # AG-3151-P-12-0113. We would like to thank Kent Bohnhoff (District Conservationist, McLean County NRCS) and Jackie Kraft (Watershed Specialist, SWCD) for their role in working with landowners, contractors, and engineers to design and install CP39 wetlands in Bray and Money creeks, McLean County, Illinois. We also acknowledge the partnerships with Dr. David Kovacic and Mike Wallace (University of Illinois) who conducted much of the installation of monitoring equipment and laboratory analyses of wetland samples. Krista Kirkham and Ashley Maybanks (TNC) also conducted a substantial portion of the fieldwork. We also would like to thank Terry Noto and Mike Linsenbigler (Conservation Strategies Consulting, LLC) and Rick Twait (City of Bloomington) for their active participation and major contributions to the project. Wayne Kinney (Midwest Streams, LLC) designed the wetlands in Money Creek and NRCS designed the wetlands in Bray Creek.

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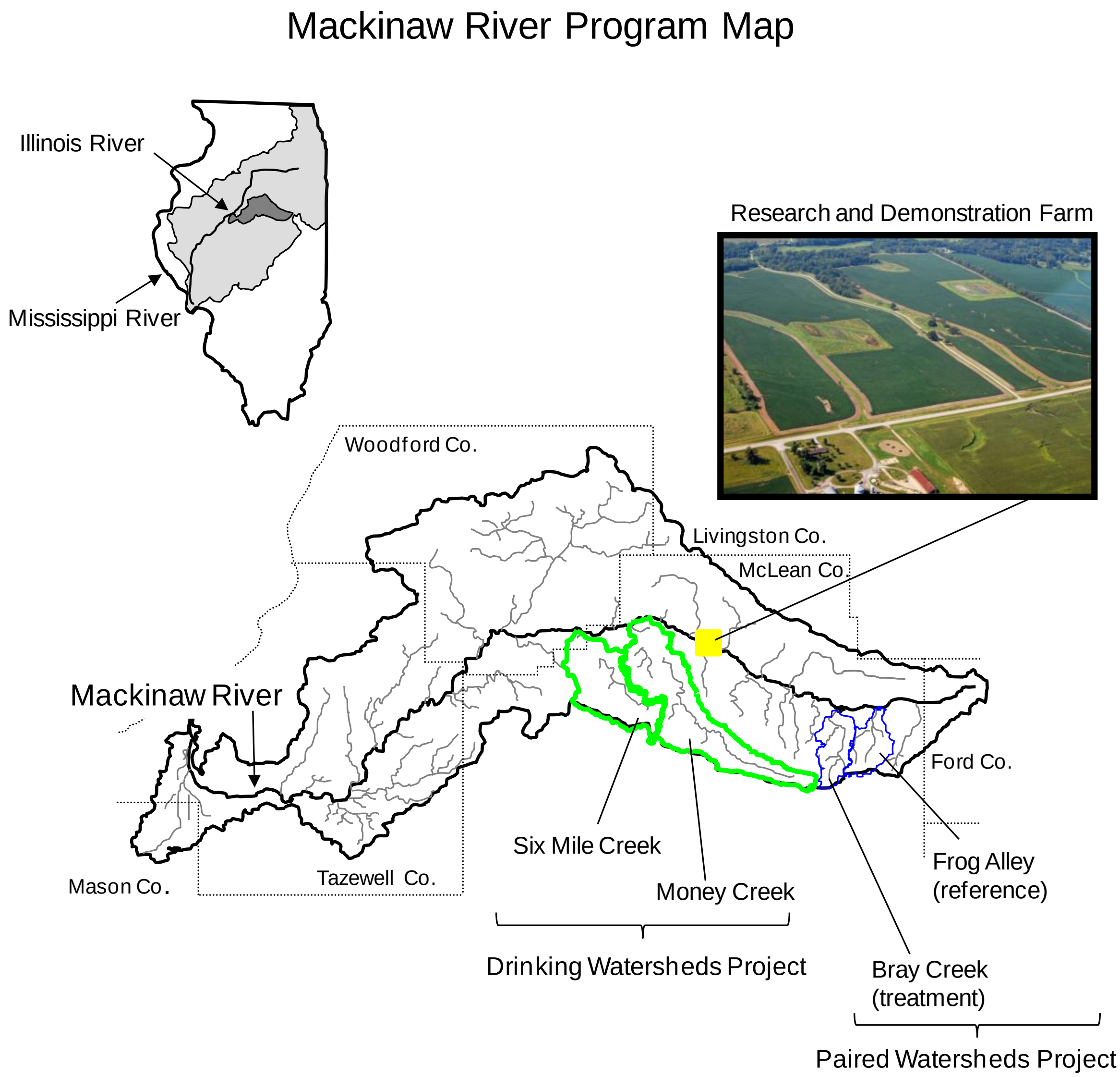


Figure 1A. Overview of the Mackinaw River Program project sites in the Mackinaw River watershed.

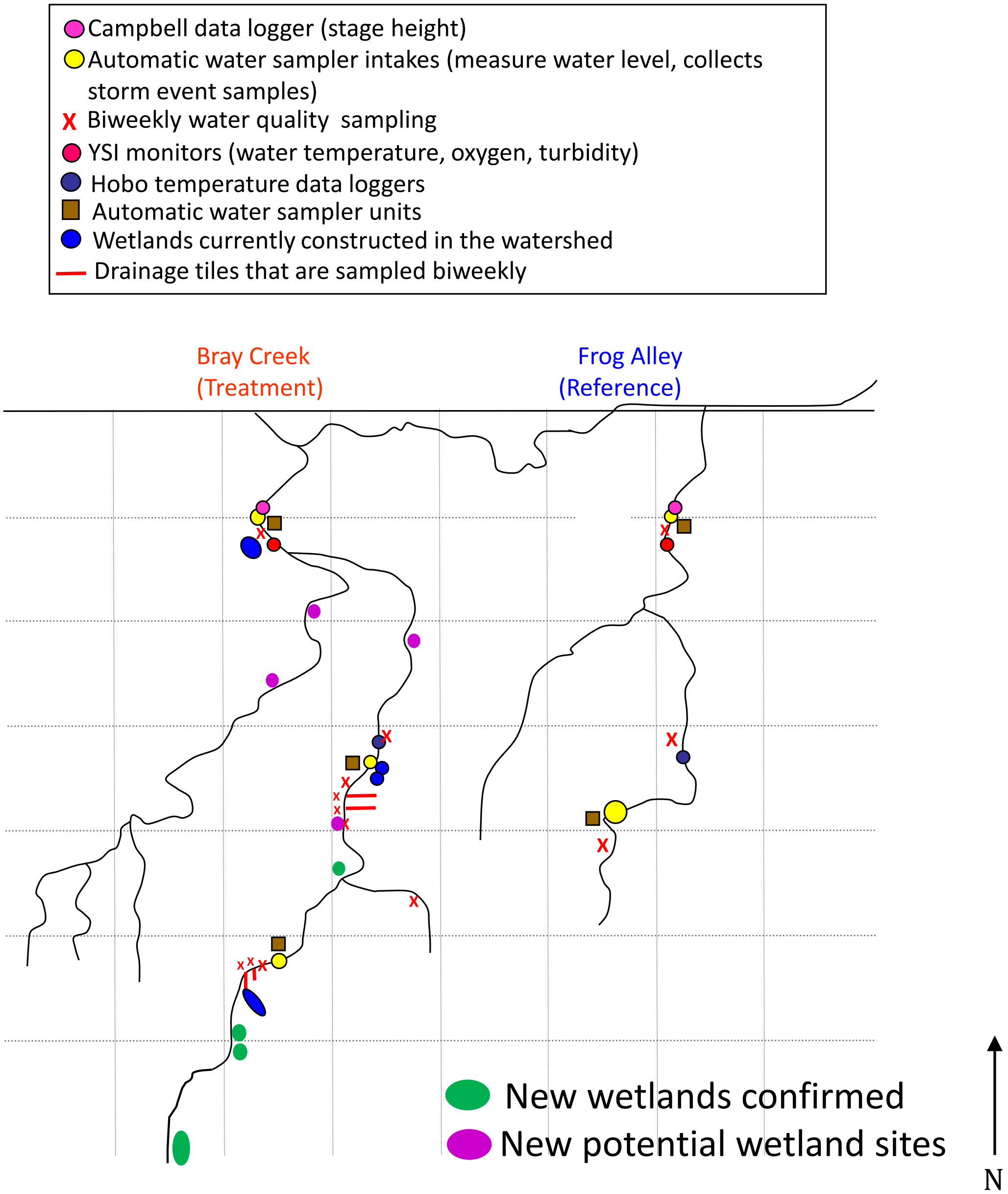
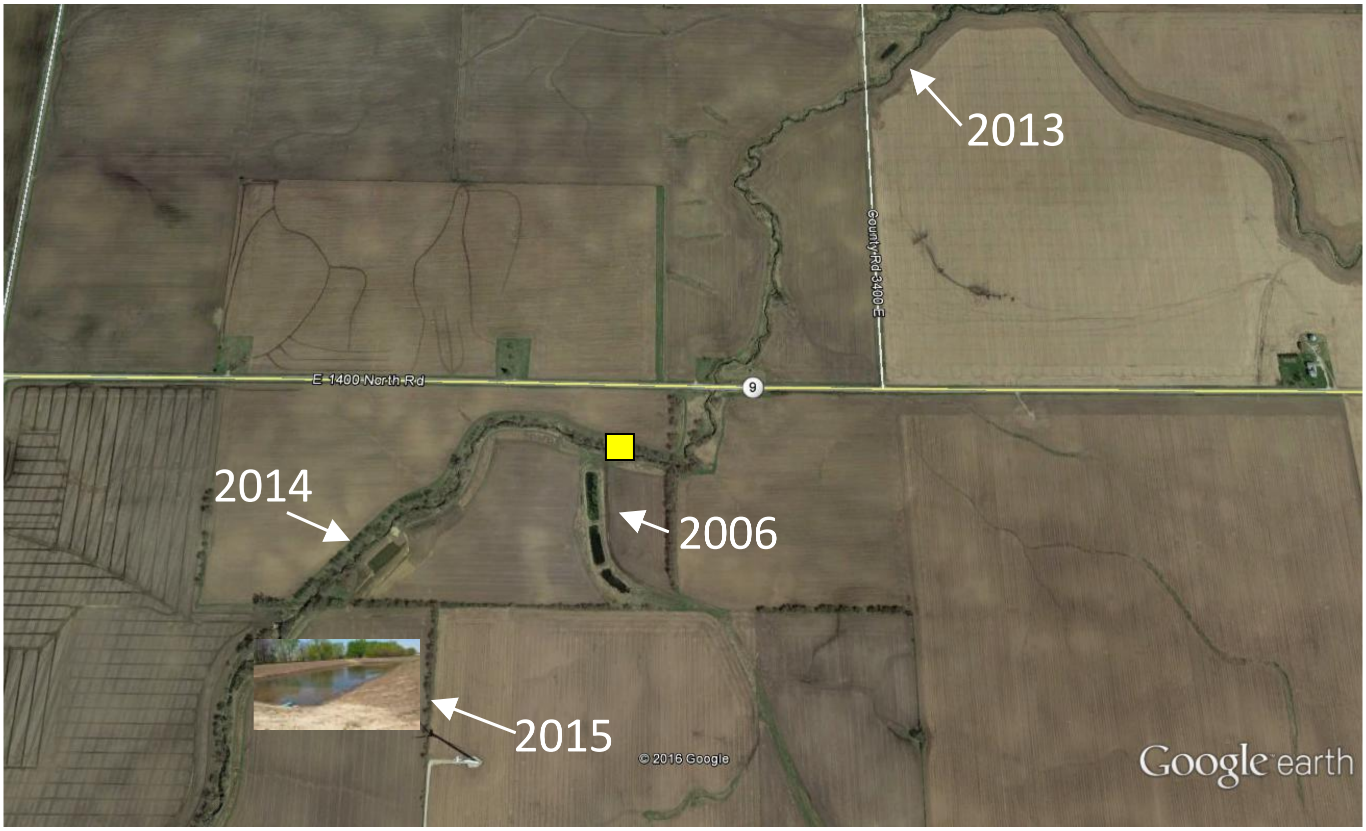


Figure 1B. Monitoring locations, current wetlands, confirmed new wetland sites, and potential additional wetland sites in Bray Creek (treatment) and Frog Alley (reference) subwatersheds of the Paired Watershed Project site, located in the headwaters of the Mackinaw River watershed.



Constructed wetlands in Upper Bray Creek

Figure 2. Aerial view of new CP39 wetlands constructed in upper Bray Creek (treatment) between 2013 and 2015. Upstream long term monitoring site is designated by the yellow square.

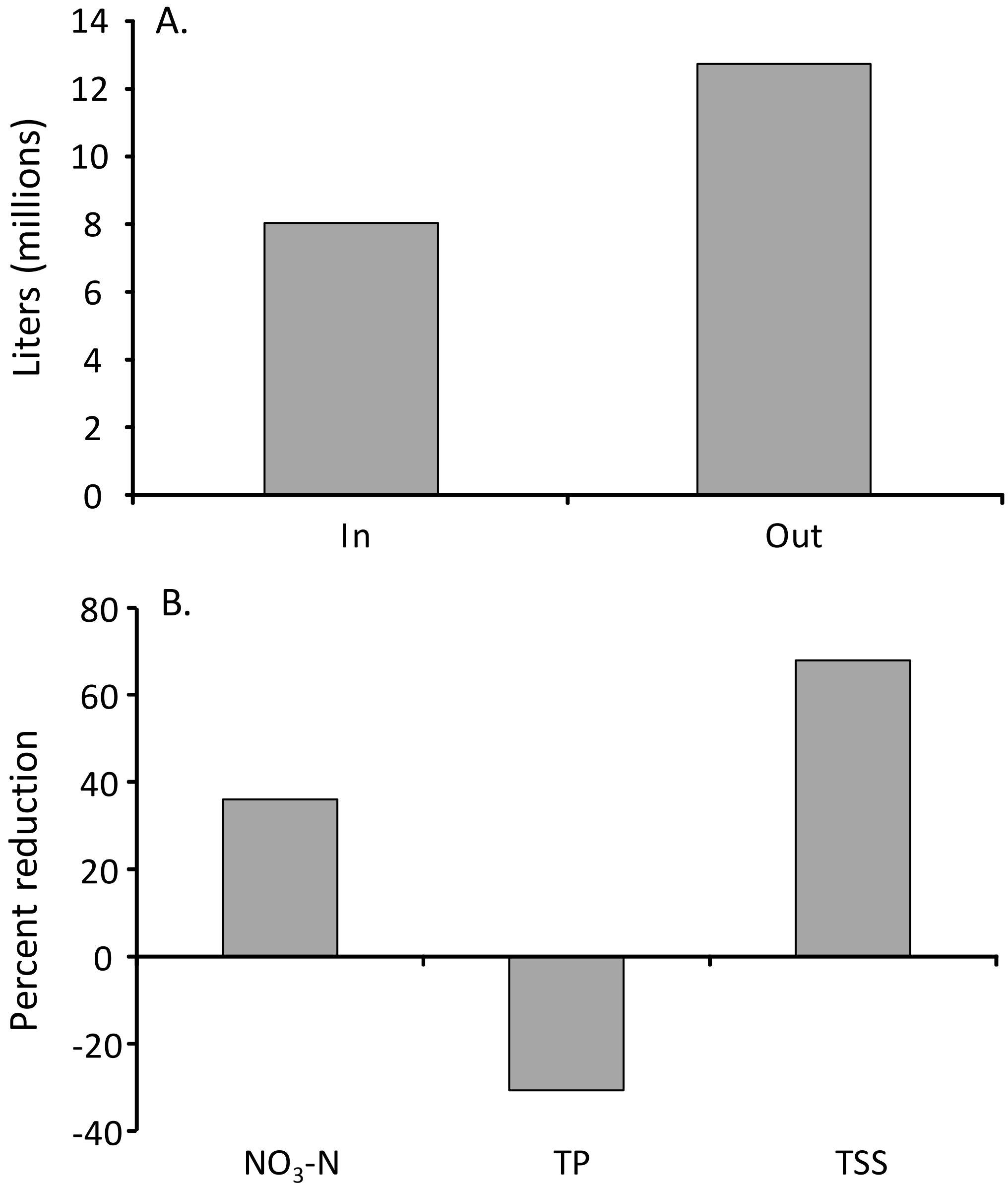


Figure 3. Total water inputs and outputs into Arrowsmith North wetland (A), and percent reductions in nitrate-nitrogen (NO_3-N), total phosphorus (TP), and total suspended solids (TSS) loadings (kg) (B) between November 17, 2015 and May 16, 2016.

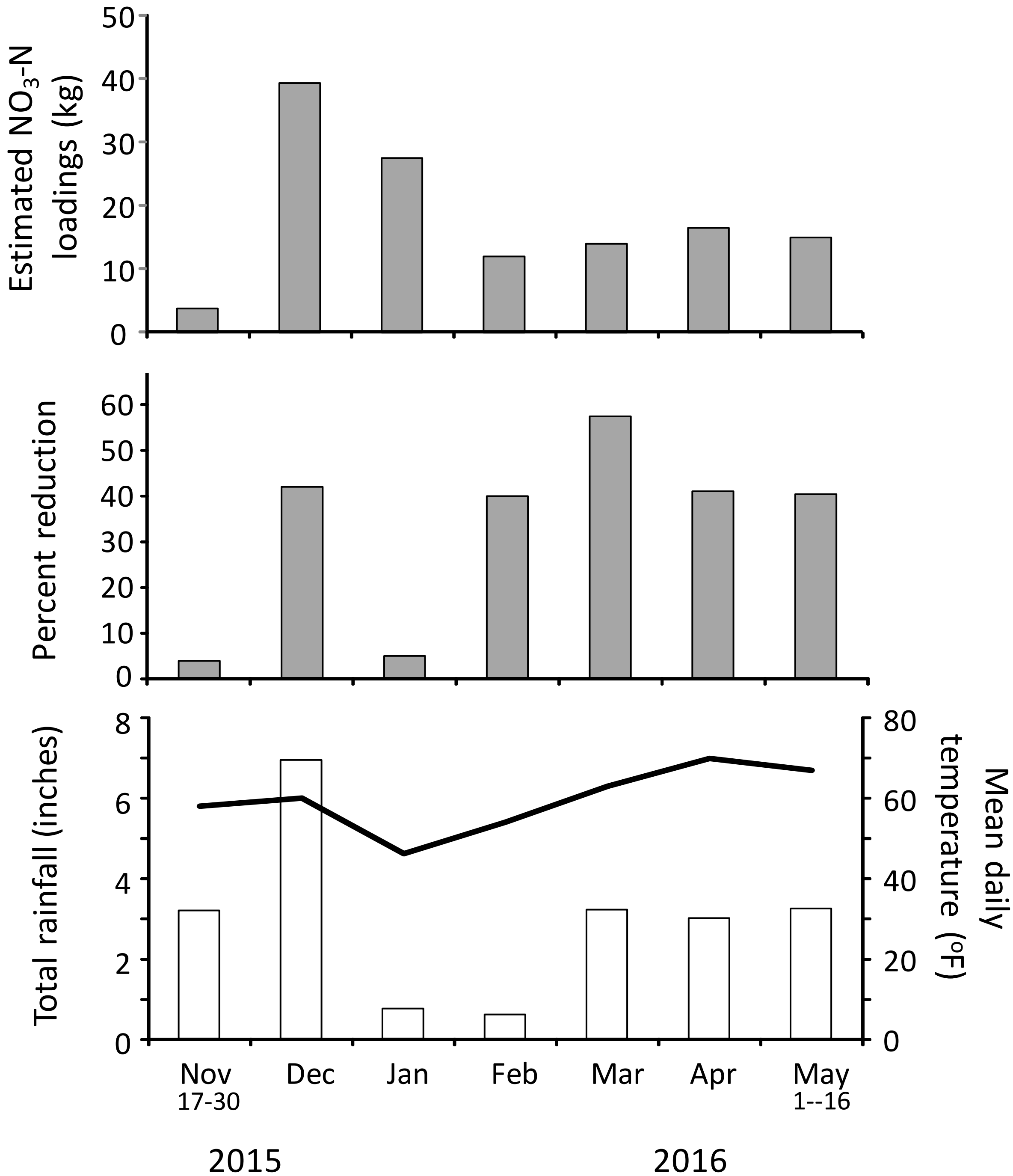


Figure 4. Estimated nitrate-nitrogen (NO_3-N) loadings (top), percent reduction of NO_3-N (middle), total rainfall (columns) and mean daily temperatures (line) (bottom) by month for the Arrowsmith North wetland constructed in Bray Creek watershed (treatment).

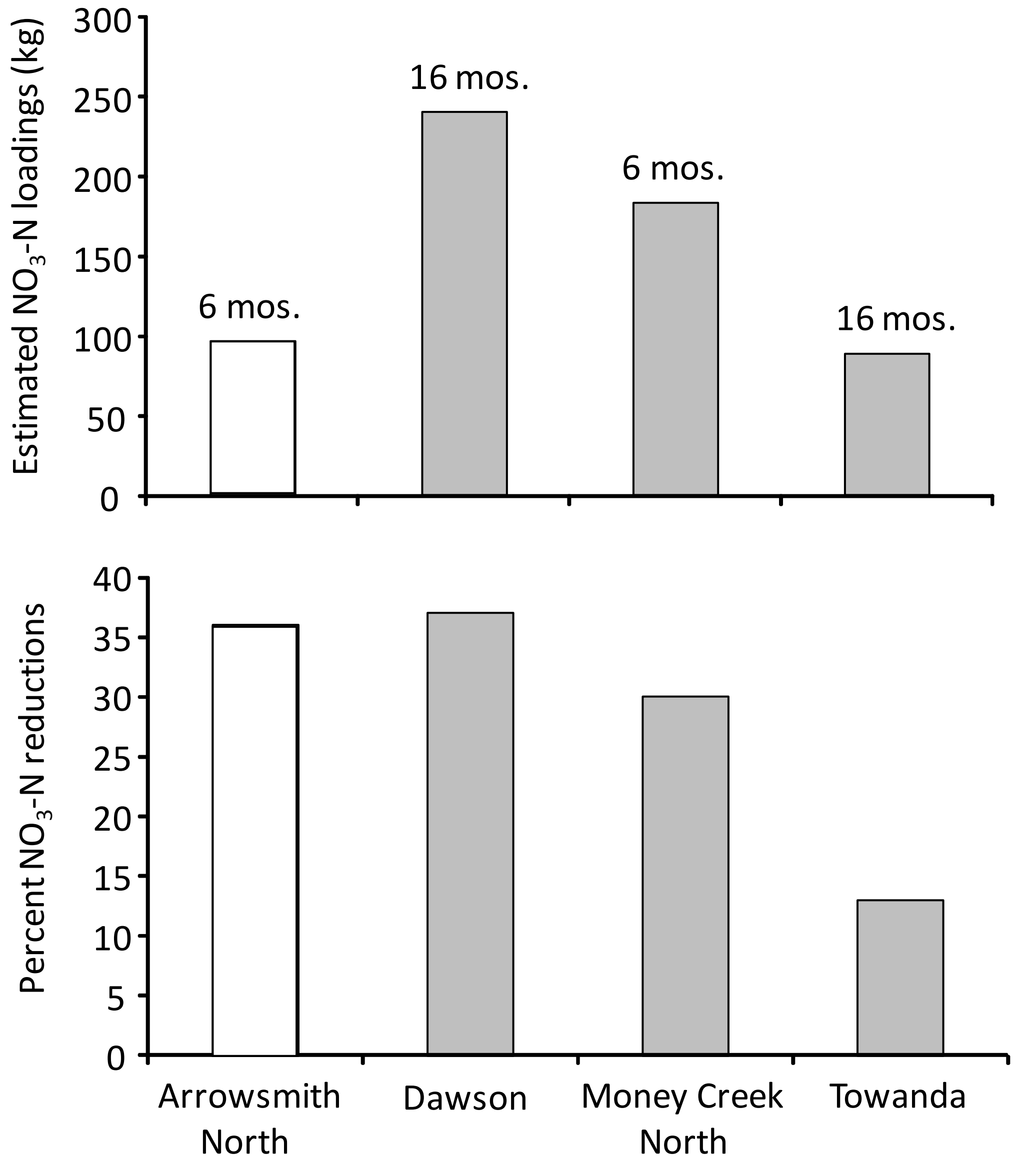


Figure 5. Estimated nitrate-nitrogen (NO_3-N) loadings (top) and percent reductions (bottom) for the CP39 wetland constructed in Bray Creek watershed (Arrowsmith North) and for CP39 wetlands constructed in Money Creek watershed (Dawson, Money Creek North, Towanda). Both watersheds are tributary watersheds to the Mackinaw River, Illinois.

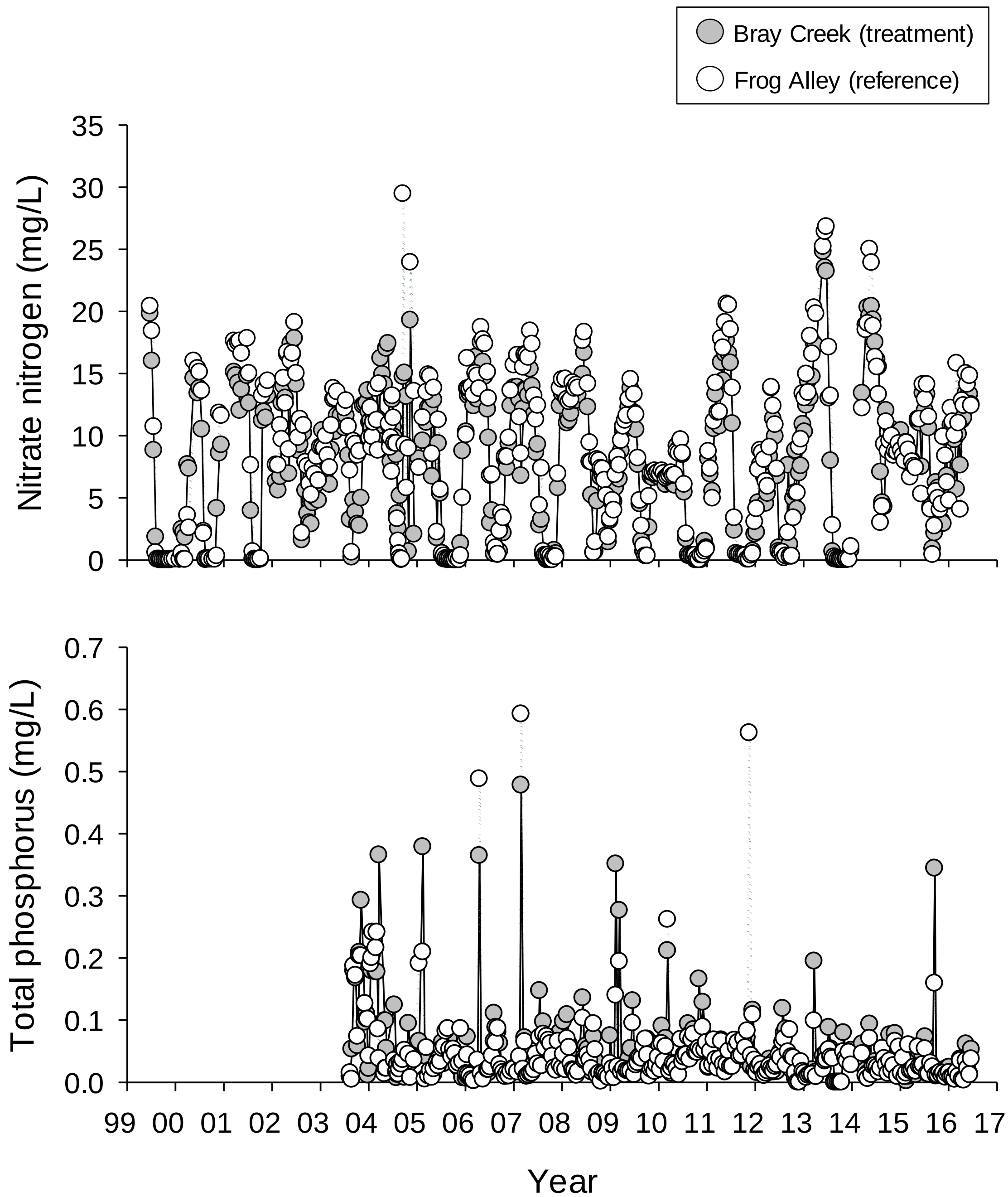


Figure 6. Nutrient concentrations for nitrate-nitrogen (NO_3-N) (top) and total phosphorus (TP) (bottom) from downstream monitoring sites in Bray Creek (treatment) and Frog Alley (reference) watersheds. Concentrations are based on biweekly samples collected between June 1999 and June 2016.

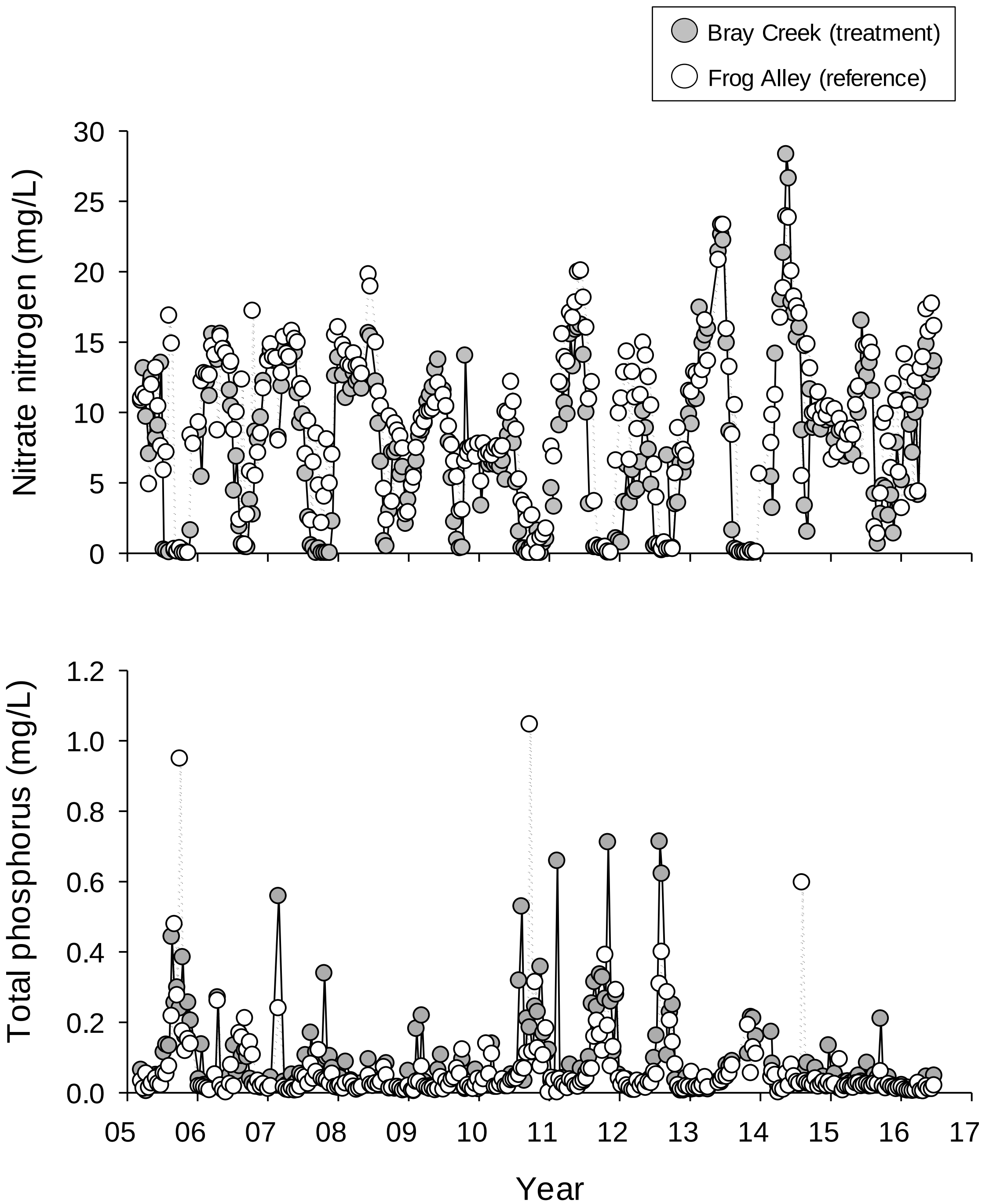


Figure 7. Nutrient concentrations for nitrate-nitrogen (NO_3-N) (top) and total phosphorus (TP) (bottom) from upstream monitoring sites in Bray Creek (treatment) and Frog Alley (reference) watersheds. Concentrations are based on biweekly samples collected between June 1999 and June 2016.

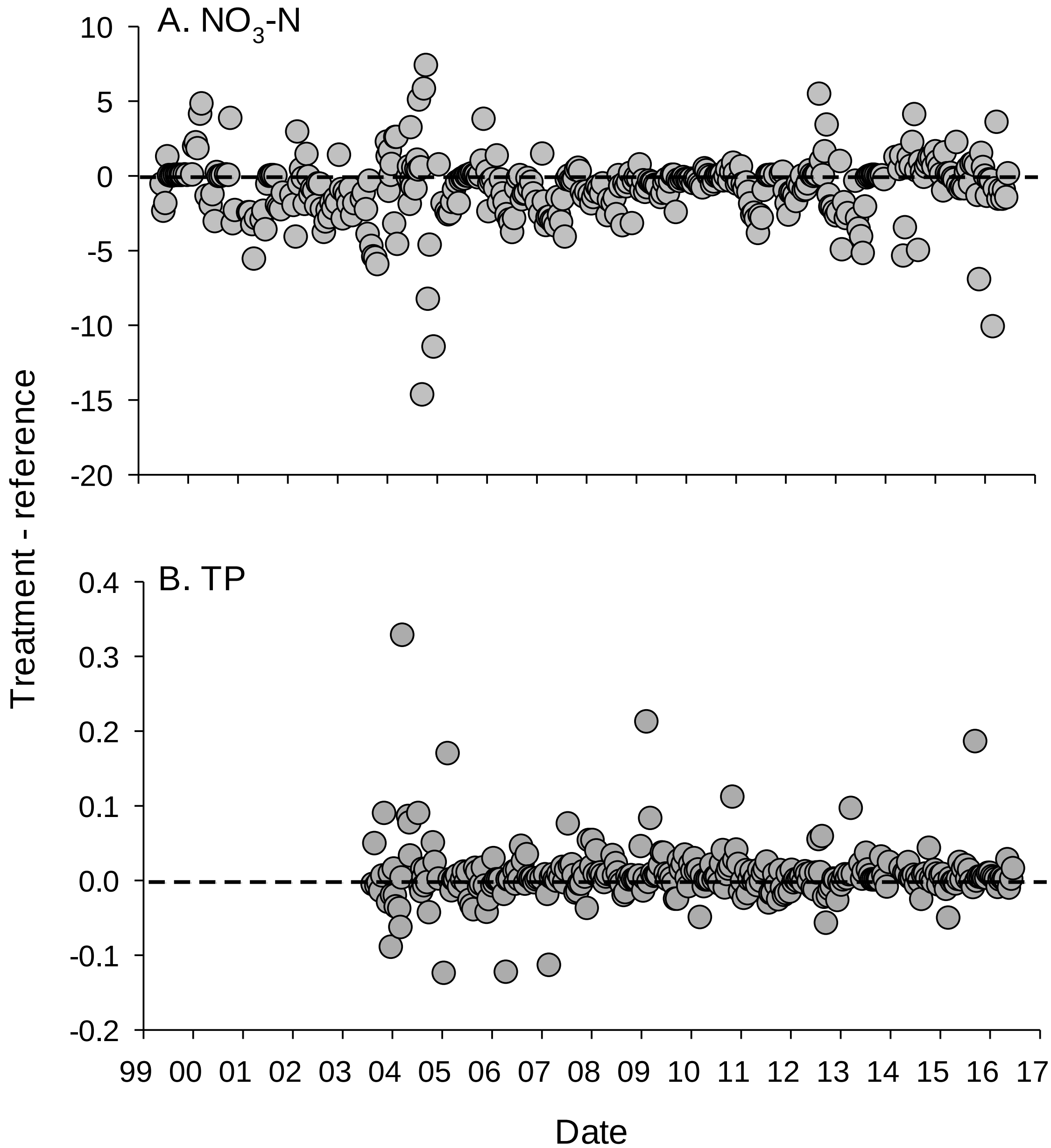


Figure 8. Differences between concentrations of nitrate-nitrogen (NO3-N) (A), and total phosphorus (TP) (B) in water samples collected at downstream monitoring sites in Bray Creek (treatment) and Frog Alley (reference) watersheds.

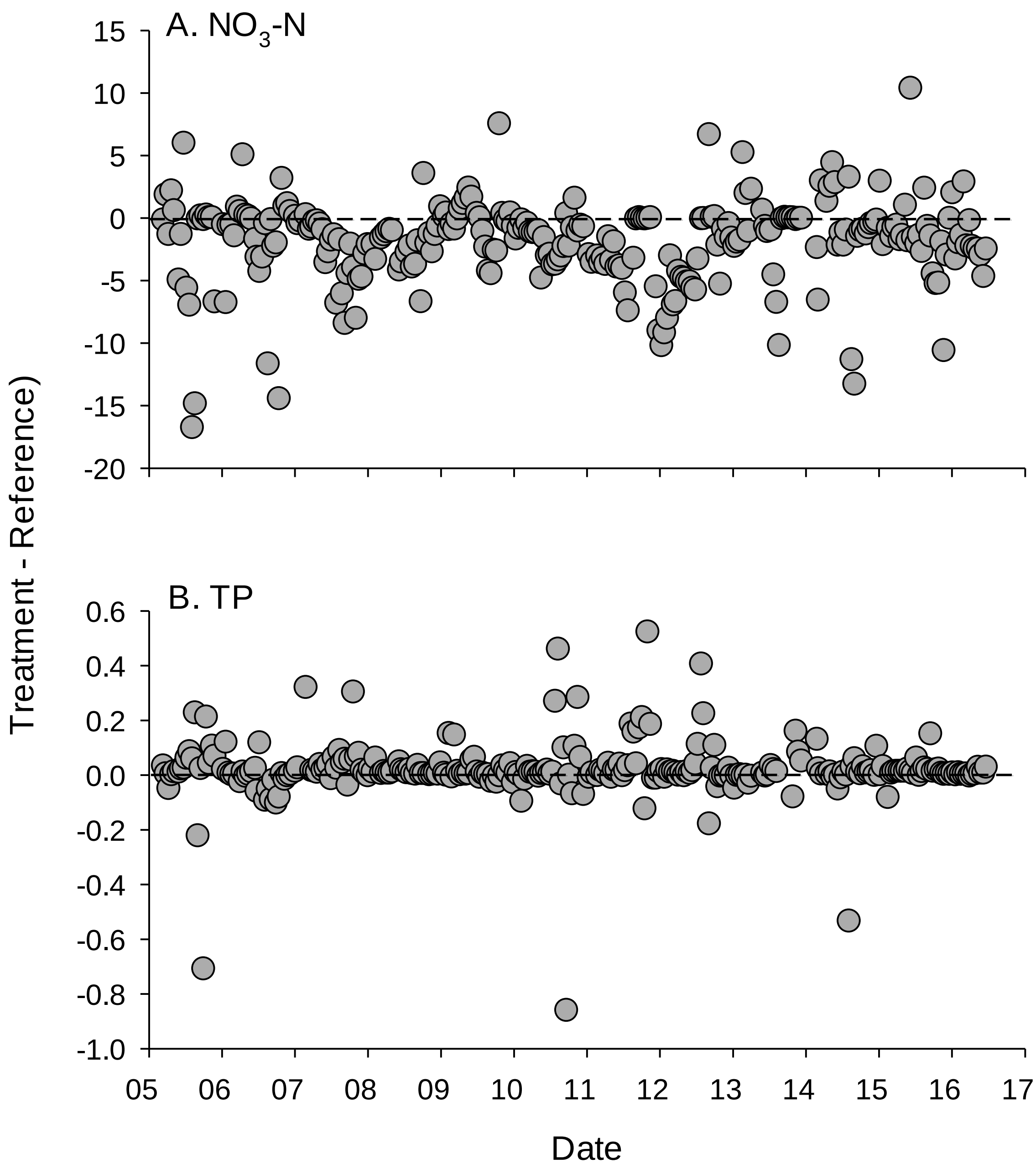


Figure 9. Differences between concentrations of nitrate-nitrogen (NO3-N) (A), and total phosphorus (TP) (B) in water samples collected at upstream monitoring sites in Bray Creek (treatment) and Frog Alley (reference) watersheds.

Table 1. Total construction costs of Conservation Reserve Program CP39 wetlands built between 2012 and 2015 in two agricultural tile-drained subwatersheds of the Mackinaw River, Illinois. The wetland names indicate the township that each wetland is located in McLean County, Illinois. Estimates designated by † indicate calculations that did not included estimated costs of wetlands that are not yet constructed.

Wetland site	Total Cost ($)	Total acres (wetland pond + buffer)	Cost per acre ($)
Martin	15,012.59	3.0	5,004.16
Blue Mound #1	29,474.00*	3.8	7,756.32
Blue Mound #2	27,304.00*	2.4	11,376.67
Money Creek North	33,680.80	2.4	14,033.67
Towanda	27,899.23	1.8	15,499.57
Arrowsmith South	70,899.23	4.5	15,755.38
Arrowsmith North	49,260.74	1.7	28,976.91
Dawson	37,845.36	1.2	31,537.80
Money Creek South	36,445.17	1.0	36,445.17
Total $	327,821.02		
Total acres		21.8	
Average $ $acre^{-1}$			15,037.66
Total $†	271,043.02		
Total acres†		15.6	
Average $ $acre^{-1}$			17,374.55†

*Estimated costs for two CP39 wetlands that will be built in 2016

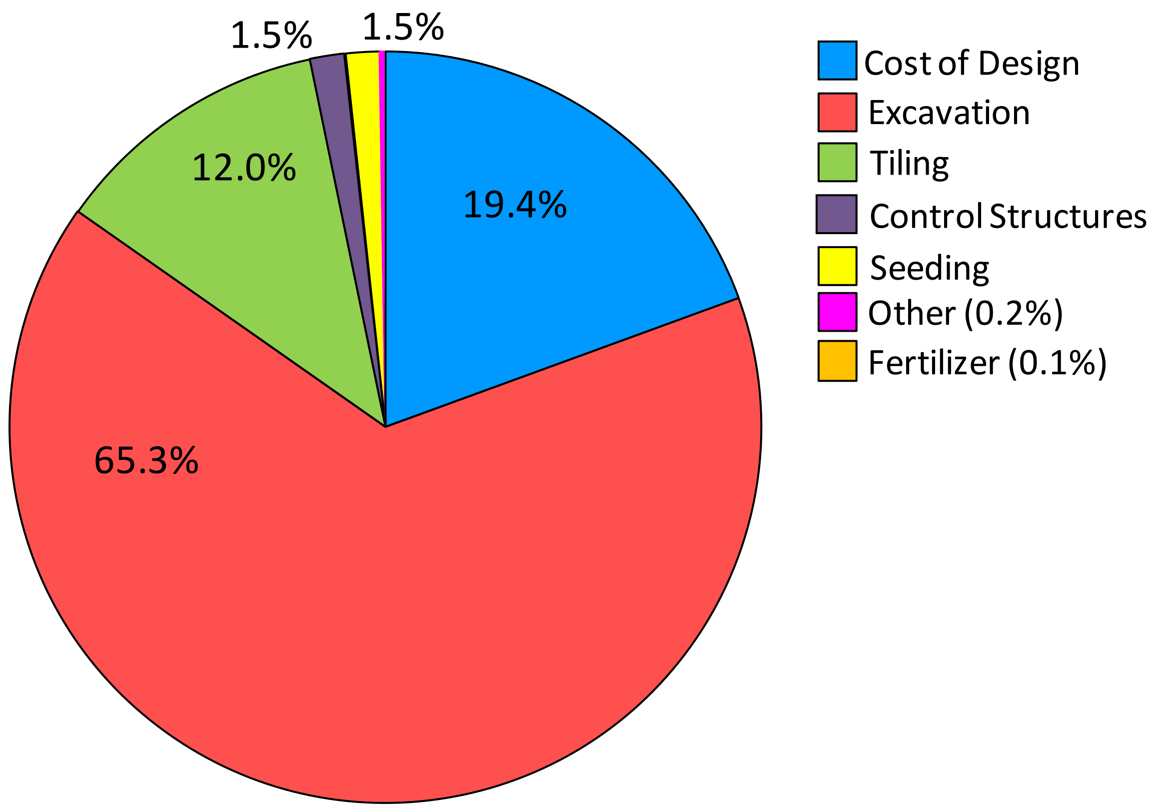


Figure 10. Breakdown of total installation costs for CP39 wetlands constructed in two subwatersheds of the Mackinaw River, Illinois. Total costs include actual expenditures from 7 wetlands constructed between 2012 and 2015, and estimated expenditures for 3 new wetlands that will be constructed in 2016. This figure was developed by The Nature Conservancy's NatureVest team.

Table 2. Cost ($) per kg nitrate-nitrogen (NO3-N) removed per year for constructed wetlands at the Research and Demonstration Farm (Farm) and new CP39 wetlands in two subwatersheds of the Mackinaw River, IL and estimated NO_3-N removal (kg) and removal costs ($/kg NO_3-N) over a 10-year Conservation Reserve Program contractual period.

Wetland Site	Total cost ($)	Wetland age (years)	Total acres (pond + buffer)	NO_3-N removed (kg)	NO_3-N removed year^{-1} (kg/y)	NO_3-N removed 10 year^{-1} (kg)	$/kg NO_3-N 10 year^{-1}
Money Ck. North	33,680.80	0.5	2.4	184	368.00	3,680.00	9.15
Farm	45,919.80	9.0	14.0	2008	223.11	2,231.11	20.58
Dawson	37,845.36	1.3	1.2	241	180.75	1,807.50	20.94
Arrowsmith North	49,260.74	0.5	1.7	97	194.00	1,940.00	25.39
Towanda	27,899.23	1.3	1.8	89	66.75	667.50	41.80
Combined sites	194,605.93					10,326.11	18.85