Quantifying the Effectiveness of Installing Saturated Buffers on Conservation Reserve Program to Reduce Nutrient Loading from Tile Drainage Waters

April 2017

PROJECT COLLABORATORS:

Agricultural Drainage Management Coalition Member Companies

Dr. Dan Jaynes, National Laboratory for Agricultural & the Environment

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September 1, 2016 – April 30, 2017

NUMBER OF SITES: 9

"Quantifying the Effectiveness of Installing Saturated Buffers on Conservation Reserve Program to Reduce Nutrient Loading from Tile Drainage Waters"

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FSA Order Number: AG-3151-P-16-0225

Project Duration: September 1, 2016 – April 30, 2017
Number of Sites: 8 (Additional site, MN4 added to this report)

Date of Submission: April 30, 2017

List of deliverables/products of project activities:

Deliverables:

This project will:
1) Measure and estimate nitrogen concentrations and flow data from the agricultural tile drains before being distributed along the buffer, monitor the flow data for water through tile drains and distributed to the buffers, and the nitrogen concentration in ground water as it moves through the buffers,
2) Incorporate this data with other monitoring data to conduct an analysis of the cost effectiveness of saturated buffers in reducing nitrogen loadings from tile drainage water,
3) Evaluate the use of saturated buffers within a farm operation, and
4) Develop outreach materials to increase awareness of the suitability and effectiveness of the saturated buffer practice.

Executive Summary

Nutrient loss through subsurface drainage systems is a major concern throughout the Midwest. This project sought to further demonstrate and evaluate the effectiveness of a new conservation practice commonly referred to as a Saturated Buffer (SB). By hydrologically reconnecting a subsurface drainage outlet with an edge-of-field buffer this practice takes advantage of both the denitrification and plant nutrient uptake opportunities that are known to exist in buffers with perennial vegetation to remove nutrients from the drainage water. The USDA-NRCS developed practice standard (604) for Saturated Buffers and released it in May 2016.

The objectives, or deliverables, of this project were 1) measure and estimate nitrogen concentrations and flow data from agricultural tile drains before being distributed along the buffer, monitor the flow data for water through tile drains and distributed to the buffers, and the nitrogen concentration in ground water as it moves through the buffers, 2) incorporate this data with other monitoring data to conduct an analysis of the cost effectiveness of saturated buffers in reducing nitrogen loadings from tile drainage water, 3) evaluate the use of saturated buffers within a farm operation, and 4) develop outreach materials to increase awareness of the suitability and effectiveness of the saturated buffer practice.

Deliverable 1: Measure and estimate nitrogen concentrations and flow data from the agricultural tile drains before being distributed along the buffer, monitor the flow data for water through tile drains and distributed to the buffers, and the nitrogen concentration in ground water as it moves through the buffers.

This project monitored 9 SB's in Iowa, Illinois, and Minnesota. These sites intentionally included a variety of soil types, buffer vegetation, surface topographies, and ditch/stream channel depths. This variety was included to evaluate the effectiveness of this practice if it were to be adopted on a regional scale. The monitoring timeline included a period from September 2016 through February 2017, yielding 6 months of flow and nutrient samples. Collected data included: flow and nitrogen samples within the structure, the before flow distribution to the buffer lines; nitrogen concentrations within the stream; monitored flow before and after SB tile distribution by comparing pre and post structure flow; and nitrogen concentrations of groundwater within the buffer via a series of monitoring wells.

There was flow diverted from the main tile system to the buffer in 7 out of the 9 sites (Fig. 2). The sites ranged from a low of 22% to a high of 95% with an average of 65% of the flow diverted.

All 9 sites were consistent in showing nitrate concentration reductions from the main line of the drainage system to the stream side test well. This reinforces data from the previous study where 27 out of 28 field years indicated the same reductions.

Of the 9 SB sites seven (IA-1, IA-3, MN-3, MN-4, IL-2, IL-4, and IL-5) showed substantial nitrate removal. IA-1 removed 17.7 lbs, IA-3 removed 342.3 lbs, MN-3 removed 82.1 lbs, MN-4 removed 148 lbs, IL-2 removed 13.5 lbs, IL-4 removed 11.4 lbs, and IL-5 removed 60.0 lbs of nitrate-N. The average nitrate load reductions of all sites for this period was 61% (Fig. 16).

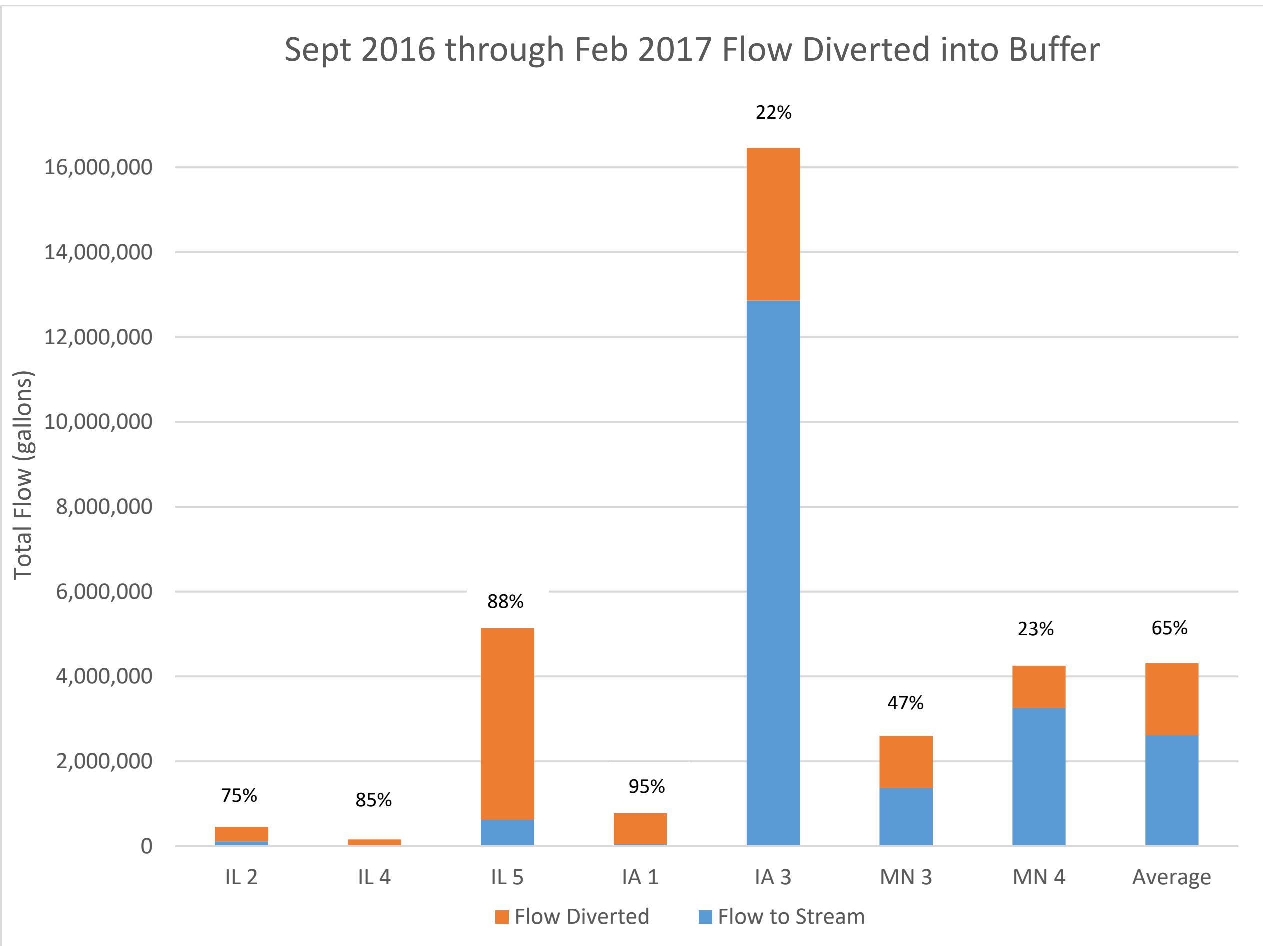

Figure 2: *Flow Reduction Summary*

Deliverable 2: Incorporate these data with other monitoring data to conduct an analysis of the cost effectiveness of the saturated buffers in reducing nitrogen loadings from tile drainage water.

Since loads were only monitored over a 6-month period, the total was doubled to receive the full year's data set with which we calculated the cost of reduction. Two (2) sites were eliminated in the computation due to flow monitoring problems encountered. The average installation cost was $3,700 per saturated buffer. Assuming a 50-year lifespan and 4% inflation rate, the cost of nitrate removal averaged $2.44/lb-N. This makes them competitive with other field-edge practices for nitrate load reduction. Comparing these numbers to the initial 2013-2015 report, the reduction cost per pound of N showed a slight increase from $2.13/lb-N removed. The increase in cost is likely due to the former project calculating flows over spring months, compared to this project, which only used data in the late fall and winter.

Deliverable 3: Evaluate the use of saturated buffers within a farm operation

This project has shown the importance of managing SB's efficiently within a farm operation. In an ideal scenario, the SB would be at a substantially lower elevation than the adjacent field. This would require no management of the water table underneath the buffer. The same board settings can be used throughout all times of the year and not impact the field condition. Often, the SB is at a similar elevation to the adjacent field. In this case, it is important to educate the producers on managing their SB according to season. Board settings will need to be lowered slightly during the growing season to ensure ideal field conditions and to not harm their crop. After harvest has taken place, boards need to be added back to the structure to ensure more water can be treated when adequate drainage in the field is not needed. Addressing the management schedule with producers will be a vital part to widespread implementation. The producers reported no yield losses due to the saturated buffer in this evaluation.

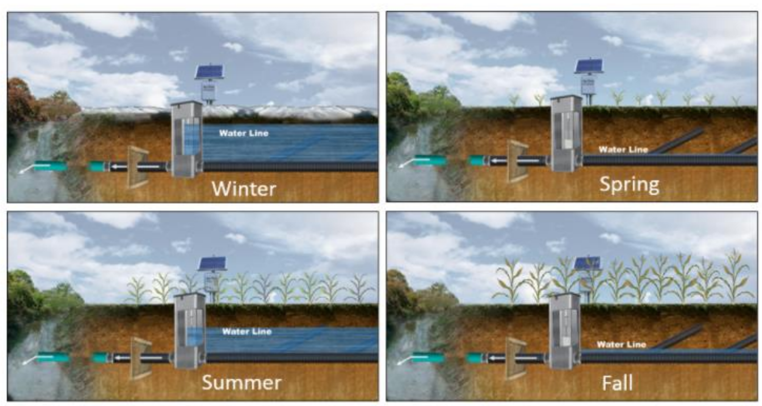

Figure 1: *Desirable water table control for water quality and yield*

Deliverable 4: Develop outreach materials to increase awareness of the suitability and effectiveness of the saturated buffer practice.

Outreach of the results of this demonstration will take on several forms. The first will be the distribution of the entire report in hard copy to the Farm Service Agency. There will be multiple copies available for distribution throughout the agency. It is critical that all necessary FSA personnel have access to the report given their jurisdictional responsibilities with CRP. Post card announcements will be created and mailed to over two hundred stakeholders. These stakeholders include NRCS officials from seven states, university academia from fifteen universities in the Midwest, State FSA officials from eight Midwestern states, major agricultural associations from all Midwestern states and EPA regional offices. This announcement will describe briefly the findings and a driver to the Saturated Buffer website (www.saturatedbufferstrips.com). The website will be updated with a copy of the report for review or download. There will also be a press release announcing the report and showing briefly the results. This press release will be distributed to all major agricultural media outlets. It is anticipated that this media release will generate commentary and interview requests for Dr. Dan Jaynes, Charlie Schafer, ADMC president, and Stephen Baker, ADMC project director. All of these individuals will be available for this. These individuals will also do presentations to stakeholders over an indefinite time period about the SB practice.

Conclusion

Data from this demonstration confirms that proper siting and design considerations have to be met for the SB to achieve Nitrogen transport reductions from subsurface drainage systems. This work confirms the details of those design considerations. The data also leads to the conclusion that SB are not just going to work in year one (1). Many of these sites have three-year data sets all with similar results. The significant geographical spread in locations of the sites gives a view of the sites with different weather patterns, soil types and agronomy practices. The SB continue to perform in a wide area of geography across the Midwest.

All of these SB were retrofits from existing CRP buffers. The SB in all cases have healed nicely and show no detriment to the original purpose of the buffer. Vegetation returned quickly and there seems to be no long-term harm to wildlife (Fig. 26 & 27).

Streambank stability was studied in detail in the pilot study of SB. This study confirms the conclusion that was reached in that work. Streambanks with stable banks will not have increased sloughing due to the SB condition. There was no streambank instability observed in any of these sites in our current work.

Introduction

Summary of the work performed:

Artificial subsurface drainage systems have been in use by farm producers for over 150 years in the Mississippi River Basin. These systems facilitate crop production in areas that would be otherwise unsuitable, and increase yield in others. Almost invariably, they were designed for the sole purpose of quickly removing excess water from the plant root zone to prevent wet stress and to improve crop yields. In the past, there was little consideration of their effects on water quality.

This project was intended to further evaluate and demonstrate diverting tile water through grass buffers along ditches and streams to reduce nutrient transport and improve water quality from agricultural subsurface drainage systems. This project further evaluated existing buffers to demonstrate the effectiveness of this practice and help develop additional criteria necessary for widespread adoption.

Saturated Buffers (SB) are constructed by installing tile lines under the buffered area perpendicular to the tile drainage outlet. A control structure is installed in the main close to the outlet. The control structure can be managed to raise the water table under the buffer to allow increased denitrification, which is the conversion of nitrate (NO_3^-) to atmospheric nitrogen (N_2), and allow perennial vegetation to utilize the nutrient rich water. Under this system, the buffer can reduce overland flows and sedimentation, while reducing nutrient transport from subsurface outflows.

There were four areas of consideration in this project: (1) how to engage producers in demonstration of the multiple benefits of saturated buffers on farm economics, and water quality and quantity; (2) how to test the magnitude and cost effectiveness of the nutrient reduction benefits that can be achieved with saturated buffers; (3) how to improve the water and nutrient accounting for these systems; and (4) how to disseminate this information to the farming community.

Field evaluations:

In each of the three states, we monitored existing field drainage systems that had been retrofitted for the SB practice to evaluate the environmental effectiveness of saturated or intermittently saturated buffers. All field sites were planted with corn or soybean varieties and with normal pesticides and fertilizer application rates – allowing us to determine the impacts of saturated buffers on normal farming operations.

Flow, water quality, and water table:

Water flow rates from subsurface drainage systems were monitored, and water samples for nitrate analysis were taken approximately twice a month during periods of tile flow. Water flow measurements were combined with nitrate concentration measurements to calculate the reduction in nutrient loads resulting from the SB systems. Water quality sample analyses were performed by the National Laboratory for Agriculture and the Environment in Ames, Iowa.

Data summary and technology transfer:

A database of the different sites, with their soil, crop, drainage system, slope, climate, and other relevant factors was developed. Results from the different sites were analyzed to explain similarities and differences in effectiveness of the SB practice. One focus was to provide data to FSA and other stakeholders that will assist them in determining program priorities and payment dollars for SB practices. ADMC will post on its website where data is gathered and disseminated in a central location. The material will further support the efforts of these practices.

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Agri Drain Corp

Ecosystem Services Exchange

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Barker Lemar Engineering Consultants

USDA-ARS, National Laboratory for Agriculture and the Environment (NLAE)

FSA Funding **Total project cost:** $70,000

Background

Nutrient transport from agriculture lands is of major concern in the upper Midwest. Eutrophication of fresh water bodies, which is primarily attributed to phosphorus, raises concerns in both the urban and rural communities. The hypoxic zone in the Gulf of Mexico has also received national attention. Typically, in marine systems eutrophication is associated principally with nitrates.

Many of the row-crop agriculture fields in the Midwest are located adjacent to ditches, streams, rivers and lakes. Producers have used grassed buffers along many of the water systems to protect them from sediment due to overland flows. However, they provide limited protection from subsurface flows that may contain excess nitrates, especially in tile-drained landscapes.

While the first steps to reducing nutrient transport through the tile water are typically accomplished through agronomic-related practices, such as fertilizer rate and timing, in-field and edge-of-field conservation practices related specifically to subsurface drainage water have also been developed. These practices include Drainage Water Management (DWM), denitrifying bioreactors, and enhanced or created wetlands. While these conservation practices have proven to be effective for reducing nutrient loading from tile-drained fields, adoption has been limited due to the cost of implementation, grower knowledge of the practices, and grower confidence on how the practices will fit into their farm operation. Continued development of innovative, lower-cost practices is needed to meet the water quality issues facing the Midwest region. Continued demonstration of these practices will be critical in helping landowners and farm operators build the awareness of and confidence in these practices that will be needed for broad adoption.

The Agricultural Drainage Management Coalition (ADMC) is a nation-wide group of agricultural, industry, and environmental interests that have come together to promote drainage water conservation practices. The ADMC includes over 60 key stakeholders, including individual farmers, industry manufacturers, and environmental groups like The Sand County Foundation. The Agricultural Drainage Management Systems Task Force (ADMS-TF) is a multi-agency and university collaboration that has met regularly since 2003 to develop a national effort for implementing improved drainage water management practices and systems that will enhance crop production, conserve water, and reduce adverse off–site impacts on water quality and quantity. These two (2) groups have worked over the last thirteen (13) years in a collaborative effort to study, educate and demonstrate the benefits of edge of field practices in improving water quality in the agricultural areas.

Review of Materials and Methods

Riparian buffers have been shown to remove nitrates from subsurface flow with varying levels of efficiency (Mayer et al, 2005). Large areas of the Midwest are intensively tile drained and it is assumed that many of the vegetated buffers adjacent to waterways are being under-utilized because the tile outlets quickly move large amounts of subsurface flow past the buffer and into the receiving waterway without any opportunity for treatment by the buffer. The goal of a Saturated Buffer (SB) system is to hydrologically reconnect the buffer with the tile flow. By doing this, one can capitalize on the water treatment capacity of the buffer and use it to remove nutrients from the tile water, thereby improving the water quality in the receiving water bodies. This treatment method has not been used previously and is just now getting past the demonstration phase.

A SB system works by diverting tile water into the subsoil of the buffer and then letting it move horizontally as shallow groundwater through the buffer and into the receiving water body, such as a ditch or stream (Fig. 3 & 4). In a typical system, this is accomplished by intercepting the tile main as it enters the buffer. An additional tile, referred to as a distribution line, intercepts the main and runs underneath the buffer and parallel to the receiving water body. A control structure is used to create an elevated water table within the buffer, which brings the tile water into the more biologically rich area of the soil where nutrient removal is more likely to occur. This raised water table also creates the hydraulic gradient needed to move the water from the distribution area into the receiving water body. As the water moves into the soil in the buffer the nitrates are removed, it is

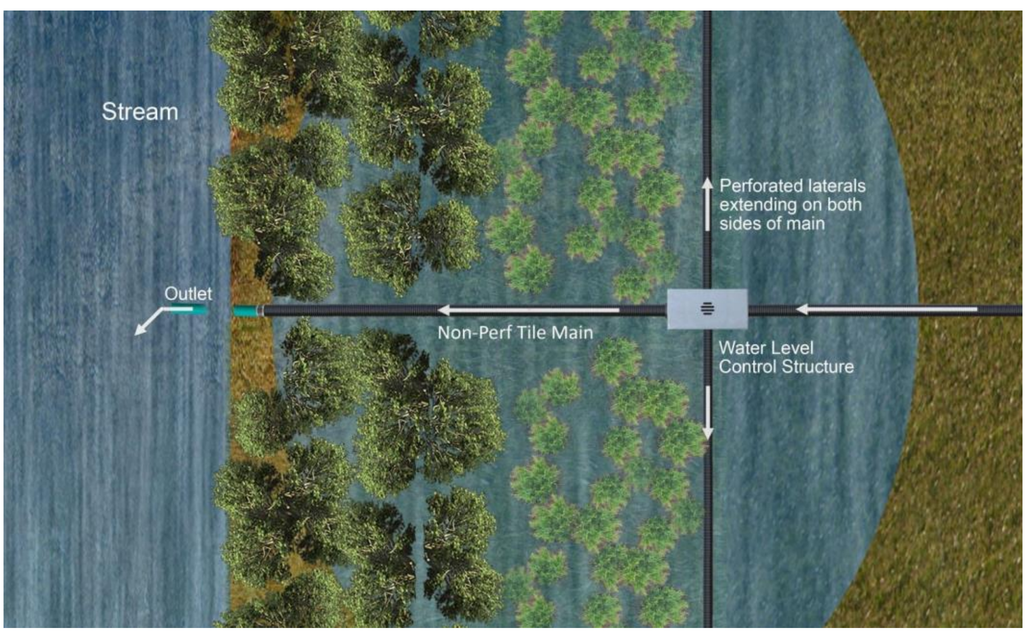


Figure 3: *An aerial view of a theoretical saturated buffer*

hypothesized, by both plant uptake and denitrification, with the latter being thought to be the more dominant pathway.

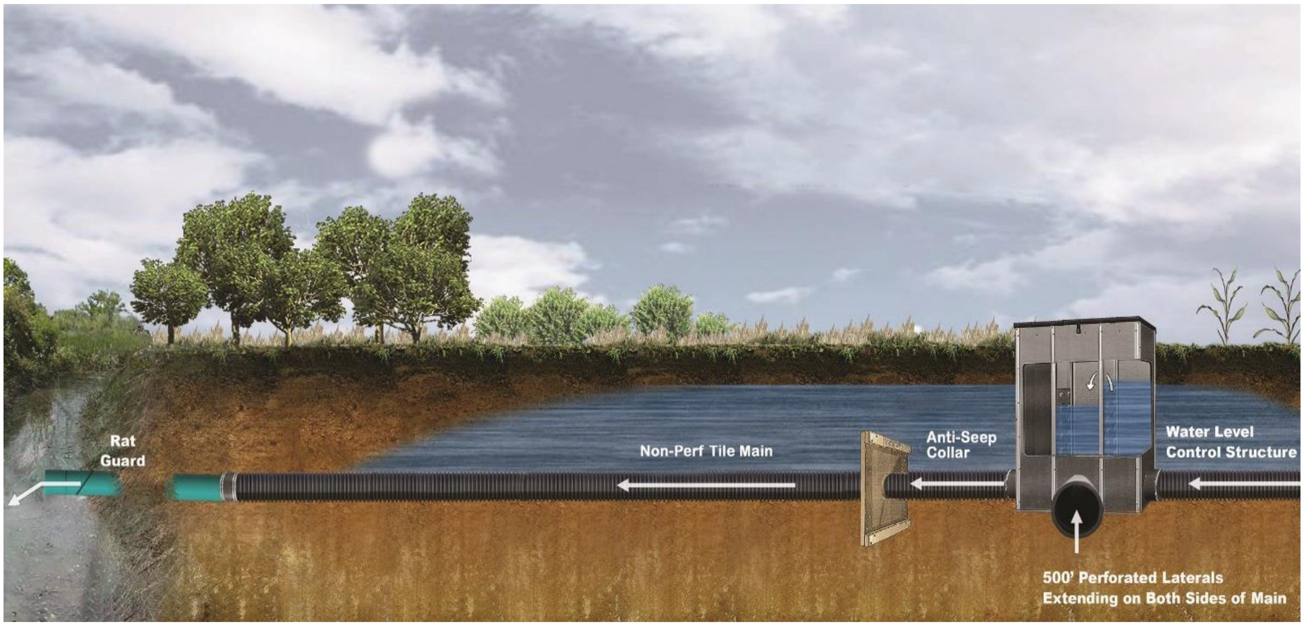


Figure 4: *A side view of a theoretical saturated buffer*

In terms of nitrate removal through denitrification, a SB operates under the same principles as denitrifying bioreactors (NRCS Practice 605). In both cases tile water is diverted through an area that will encourage denitrification and the speed or rate at which the water moves through the treatment area can be manipulated with water control structures. While a bioreactor utilizes a woodchip trench to provide a carbon food source for the denitrifying microbes a SB uses the carbon already present in the soil as the food source. This allows for potentially similar nutrient removal to occur without the cost of digging the large trench and filling with wood chips that are generally trucked in. The greatly reduced cost of implementation could prove to be significant in allowing this practice to receive widespread implementation.

Prior to beginning this regional SB demonstration project a pilot SB was installed and monitored near Story City, Iowa by USDA-ARS National Laboratory for Agriculture and the Environment (NLAE) and Iowa State University. Early results from this site looked very promising for the practice (Jaynes and Isenhart, 2014). Over a two-year period, they observed that over 50% of the tile flow was diverted through the buffer, with the remaining flow bypassing the treatment system and exiting through the traditional outlet. Of the water diverted through the buffer, all measurable nitrates were completely removed. The goal of this demonstration project was to test if similar results would be obtained at other locations with varying site and climate characteristics.

To accomplish the goals of this demonstration project nine monitoring sites were selected in three different states (IA, IL, and MN). Sites were chosen with a variety of site characteristics, recognizing that not all were "ideal". This allowed the project to demonstrate the effectiveness of the practice if implemented at a large scale. This also afforded the opportunity to explore why some sites had SB systems that were more effective at removing nutrients than others, which could lead to better site selection and design criteria for the FSA, NRCS and other agencies.

All SB sites used in this project were retrofits to existing tile and buffer systems. In situations where the field elevation at the site was sufficiently higher than the buffer elevation there was no need for the landowner to change any of the stop log elevations in the SB control structure. At these sites the landowners/operators saw no noticeable change in how they managed their land, except for being careful not to hit the control structure and monitoring equipment with a mower or other implement. Sites where the field and buffer elevations were more similar required slightly more management by the landowner/operator. In these conditions, the stop logs in the SB control structure had to be managed at time intervals similar to a Drainage Water Management system (NRCS Practice 554). Overall, time and management requirements for this practice were minimal.

The following table (Table 1) and map (Figure 5) show the locations for the 9 sites used in this project and summarize some key site characteristics, including the installation date of the SB.

Table 1: Site Descriptions

Site ID	County	Latitude (N)	Longitude (W)	Installation Date	Well Depth Avg. (ft)	Structure Height (ft)	Outlet Pipe Size (in)	Buffer Length	Drainage area (acres)	Soil Texture	Vegetation Type
IA-1	Hamilton	42.284949°	93.585772°	11/15/2012	8.29	6	8	1,000	11.6	Clay, Loam	Grass, Some Trees
IA-3	Benton	41.949545°	91.972652°	5/6/2013	6.22	8	6	1,000	35*	Silty, Clay, Loam	Grass, Some Trees
IL-1	Sangamon	39.585983°	89.777395°	7/16/2012	6.37	6	8	1,020	26.37	Silty, Clay, Loam	Grass Only
IL-2	Sangamon	39.566567°	89.814644°	7/2012	6.37	6	12	1,635	62.81	Silty, Clay, Loam	Grass Only
IL-3	Edgar	39.788653°	87.852870°	7/2012	6.88	8	12	585	38.36	Silty, Clay, Loam	Grass Only
IL-4	Piatt	40.054900°	88.740330°	6/2013	6.10	6	5	1,300	17.18	Silty, Clay, Loam	Grass Only
IL-5	Rock Island	41.367779°	90.689689°	3/26/2013	6.37	7	12	720	149.33	Silty, Clay, Loam, Complex	Grass Only
MN-3	Dodge	44.113780°	92.850176°	4/2013	5.68	8	6	1,000	28.26	Silty, Clay, Loam, Complex	Grass, Some Shrubs
MN-4	Dodge	44.014358°	92.793908°	6/2013	5.99	8	6	850	39.94	Silty, Clay, Loam	Grass Only

-All sites under soybean/corn or continuous corn rotation

*Drainage acres were estimated using main line size and review of topographical maps.

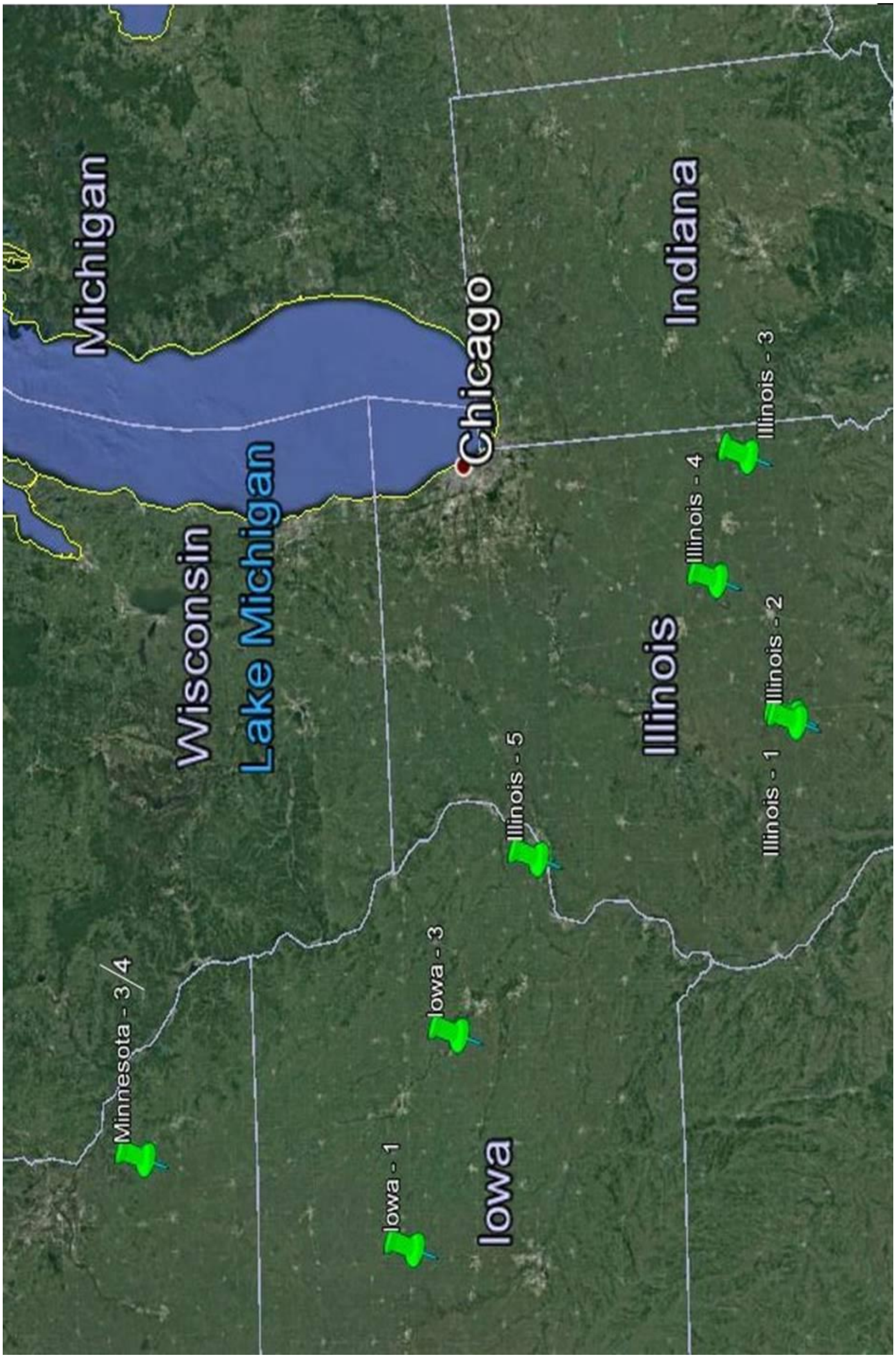


Figure 5: *Site Location Map*

Discussion of Quality Assurance

To determine the effectiveness of the Saturated Buffer (SB) practice it was essential to monitor the amount of tile water that was diverted into the SB treatment system and then determine the effectiveness of the SB at removing the nutrients (N) in the tile water as it moved through the SB and into the receiving waterway. Each site was equipped with monitoring equipment to measure both the amount of tile flow that left the field and the amount of tile flow that bypassed the SB system and discharged into the receiving waters through the existing tile outlet. The difference between these two values represented the amount of tile water that was treated by the SB system.

The effectiveness of the SB at removing the nutrients it received was quantified by first determining the nutrient concentration as it left the field but prior to it entering the saturated buffer. Additional measurements were taken at set locations within the buffer to measure the change in nutrient concentration as the tile water moved horizontally through the buffer.

Flow Monitoring:

Sampling Design

Tile flow was monitored using v-notch weirs that were installed inside the three-chambered (two sets of stop logs) water level control structures installed (see image below) as part of the SB practice. The exception to this was the site IL-2, which will be discussed later in this section. The special v-notch stop logs used were manufactured by Agri Drain Corp (ADC). The geometry and thickness of the ADC v-notch is slightly different than a standard 45° v-notch. A rating curve for that specific geometry was developed by Dr. Richard Cooke (University of Illinois Urbana-Champaign). Additional flat-weir rating curves had also been developed for the ADC control structures by Dr. Cooke. During periods when the water level was higher than the top of the v-notch the two equations were combined.

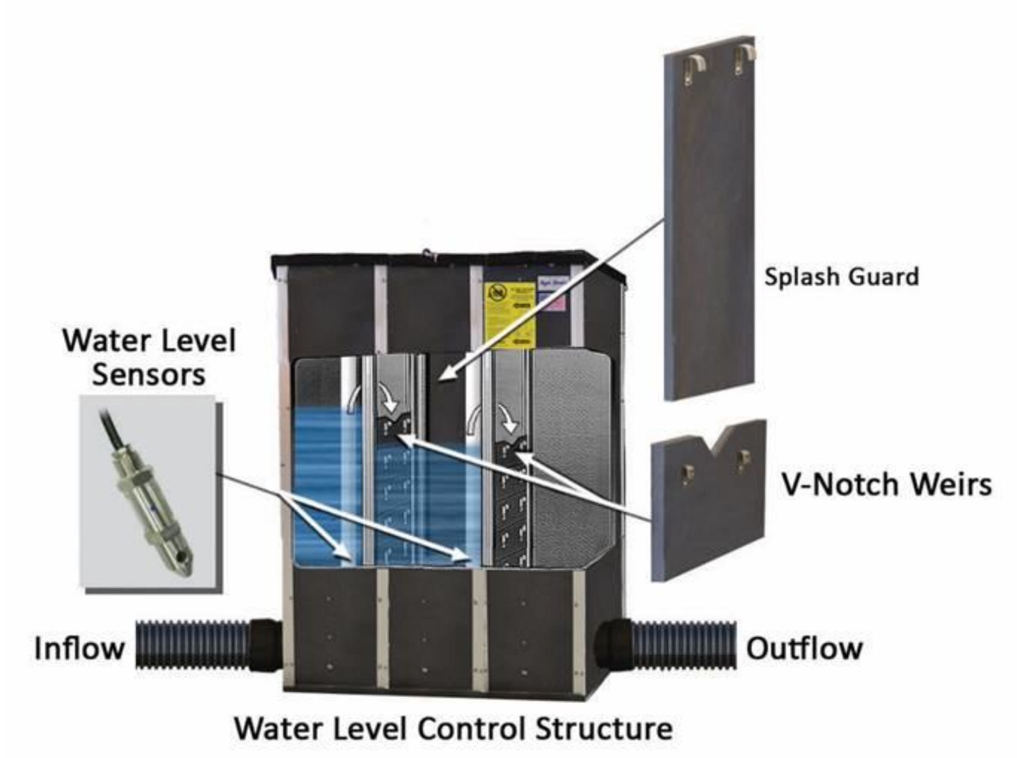


Figure 6: *A typical control structure, equipped with water level sensors, v-notch weirs, and splash guard between chambers*

The SB distribution line was connected to the chamber between the two sets of stop logs. Tile flow from the field was measured using the v-notch in the first set of stop logs. The v-notch in the second set of stop logs, which was always at least five inches lower the first v-notch, was used to measure the bypass flow. The difference in these two flow values is assumed to equal the amount of flow that was diverted into the SB treatment area. A splash guard was installed between the two sets of stop logs to prevent water from jumping over the middle chamber. It also helped reduce the turbulence in the middle chamber and allowed for more accurate measurements for the bypass flow.

The IL-2 site was set up differently than the other sites. In this field, the perforated 12-inch main ran underneath the buffer and was used as the distribution line. A regular two-compartment control structure was used to hold water in the main and encourage water to move through the buffer. While this system could work fine for a typical SB installation, it complicated the monitoring process. The two-compartment structure used for managing the SB was installed upstream of the final four laterals and used a v-notch stop log as described previously to measure the bypass. An additional structure was installed at the outlet of the tile system and the weir was set such that the bottom of the v-notch was about equal to the top invert of the main. The flow at the outlet structure would then equal the bypass flow from the first structure plus the flow from the final four laterals. It was assumed that all the laterals, which are approximately the same length, would flow the same amount and that the difference in flow between the two structures could be used to estimate the flow from the rest of the system.

Flow Measurement Procedures

In order to calculate the flow, it was important to accurately know the distance from the bottom of control structure to both the water surface (water level) and bottom of the v-notch weir (weir height). The weir height was measured to the nearest 1/16th of an inch using a standard tape measure. This distance was measured at the time of installation and whenever the weir height was modified by ESE staff. The weir height was periodically re-measured to ensure that it had not been unknowingly changed. The landowners and other non-ESE support staff were asked to report both the date/time and amount that the weir height changed if they ever adjusted their weirs. However, this guidance was not always followed. If a discrepancy was found between the recorded and current weir height, the water level data was reviewed to find abrupt changes in the level that were consistent with the change in weir height. If no clear point of change was found, the change in weir height was recorded for the date/time that it was observed by ESE. In cases where unreported weir management was observed, it was due to stop logs being removed from the structure. This means that any discrepancy between when the weir height actually changed compared to when ESE estimated it changed would result in underestimating flow values.

The water levels in the structures were measured to the nearest 0.1 inch and in-field calibration checks were periodically performed by ESE staff (every other week) to ensure they were reporting accurate data. The level sensors were connected to data loggers equipped with two-way telemetry. The water levels were recorded every six minutes and then transmitted to an ftp site every hour via a built-in cellular modem. The loggers also had adequate capacity to store data in case the transmission capabilities were temporarily lost.

Data Custody Procedures

The ftp site, hosted by Barker-Lemar Companies, was used to store all the data sent by the logger/telemetry units. The ftp site was connected to a website for real-time viewing of the data and there was a place built on the website for recording the weir height and other details related to the flow calculation. Additionally, data that were manually downloaded from the loggers (for periods when the telemetry portion was not operating properly) were also uploaded to the ftp site for storage and viewing.

Calibration

During periodic site visits the water level recorded by the sensors were compared to manual measurements to ensure that the sensors were recording properly. The pressure transducers were also able to be field-calibrated as needed.

Data Processing, Reduction, and Review

Data processing and reduction was performed by ESE. Automated filtering methods were attempted but not successful so a more manual approach was used. If the data was too noisy to confidently discern between false and real readings, then the data was discarded. After the initial data processing was complete ESE reduced the data to daily water levels and used this information to calculate the daily flow rates through the v-notch weirs. Barker-Lemar performed independent 3rd-party data review to verify quality.

Any data that appeared to be the result of either sensor malfunction or submerged outlet conditions was flagged. These judgements were based on site visit records, rainfall information, estimated maximum flowrates for the intercepted tile, and personal knowledge/experience with the site.

Water Quality Sampling

Sampling Design

Water samples were collected at all sites to determine the effectiveness of the practice and calculate nutrient load reductions. All sites were monitored for nitrate only. Local partners and employees were used to collect bi-monthly grab samples during periods of tile flow. A water sampling protocol was established by the ADMC and an instruction sheet was distributed to all sampling partners.

Water samples were collected as the tile left the cropped area to determine the pre-treatment nutrient concentration. This sample was collected from the upstream chamber of the control structures. Groundwater samples were collected to measure any changes in nutrient concentration as the water moved through the buffer and into the receiving ditch or stream. An additional sample was collected in the receiving ditch or stream to put the observed nutrient concentrations in context with the local watershed.

Groundwater monitoring wells

Groundwater sampling wells had been installed at each site to monitor the change in nutrient concentration as the water moved laterally underneath the buffer. Three well transects were installed at all sites except IA-3, which had four. The transects were equally spaced along the distribution line. Three monitoring wells were installed for each transect. One well was installed at the edge of the stream bank and the other two were installed at equal intervals between the stream bank and the distribution line. Maps with well locations for each site are included Appendix A.

The wells comprised of a 5’ section of slotted 2” PVC pipe that was wrapped in a knitted nylon fabric, as shown in the images below. A non-slotted 2’ section of pipe was used to bring the pipe above the ground surface for access. The wells were typically installed between 5.0 and 6.0 ft. deep. Some sites had shallower wells due to excessive stones or rock in the soil sublayers.

The wells were installed using a 4-inch auger. After the PVC pipe was inserted into the hole it was backfilled with sand within 4 – 6 inches of the surface. At this point bentonite was used to seal the top of the well and prevent surface water from flowing into the well. A ¼ inch diameter tube was installed inside each well for pulling the water samples.

Sampling Procedures

Samples were collected on a bi-monthly basis during periods of tile flow. Water samples were collected more frequently at IA-1 as it was close to Ames, IA and could be visited by NLAE staff more frequently. After the samples were collected they were placed in insulated containers with freezer packs and shipped next-day to the ARS lab in Ames, Iowa for analysis.

Custody Procedures

All water quality data was processed and stored by staff at the NLAE.

Calibration

No in-field calibration was performed for collecting samples. Laboratory equipment was properly maintained and calibrated using standard procedures.

Sample Analysis

When the water samples arrived at NLAE, the boxes were opened, logged in, and stored in a refrigerator before analysis. Water samples were analyzed for nitrite (NO_2) using a Lachat 8000/8500 (Formally the Zellweger Analytics. Lachat Instrument Division from Milwaukee, WI, now known as HACH from Loveland CO.) Wherein NO_3 was quantitatively reduced to NO_2 and its concentration determined colorimetrically (Kenney and Nelson, 1982). The method quantitation limit was 0.3 mg N L^{-1} as NO_3. NO_3 and NO_2 are reported together as NO_3.

Data reduction, analysis, and review

All water quality data was compiled and reviewed by NLAE staff.

Results/Findings

Nitrate concentration:

Water samples were generally collected bi-monthly at each site and analyzed for nitrate concentration. For this report, nutrient concentrations in the control box at the tile outlet were graphed and averaged over the 6-month project period. Average concentrations within the stream and wells are also calculated. The average concentrations for the observation wells in the buffer closest to the distribution pipe, the observation wells closest to the stream, and the observation wells in the middle of the buffer are graphed below.

Nitrate

In general, individual nitrate concentrations ranged from below our detection limit (<0.3 mg L^{-1}) to over 40 mg L^{-1} for some samples. When computing concentration averages, nitrate concentrations less than the detection limit of 0.3 mg L^{-1} were set to 0. For most of the sites, average nitrate concentrations followed the pattern of highest at the tile outlet, decreasing across the buffer, and then higher again in the stream. This decreasing trend in nitrate concentrations across the buffer is what was found at the first saturated buffer in Bear Creek (Jaynes and Isenhart, 2014) and what we would expect if nitrate was being denitrified or sequestered as it flows through the buffer towards the stream. Yearly results for each saturated buffer site are detailed below.

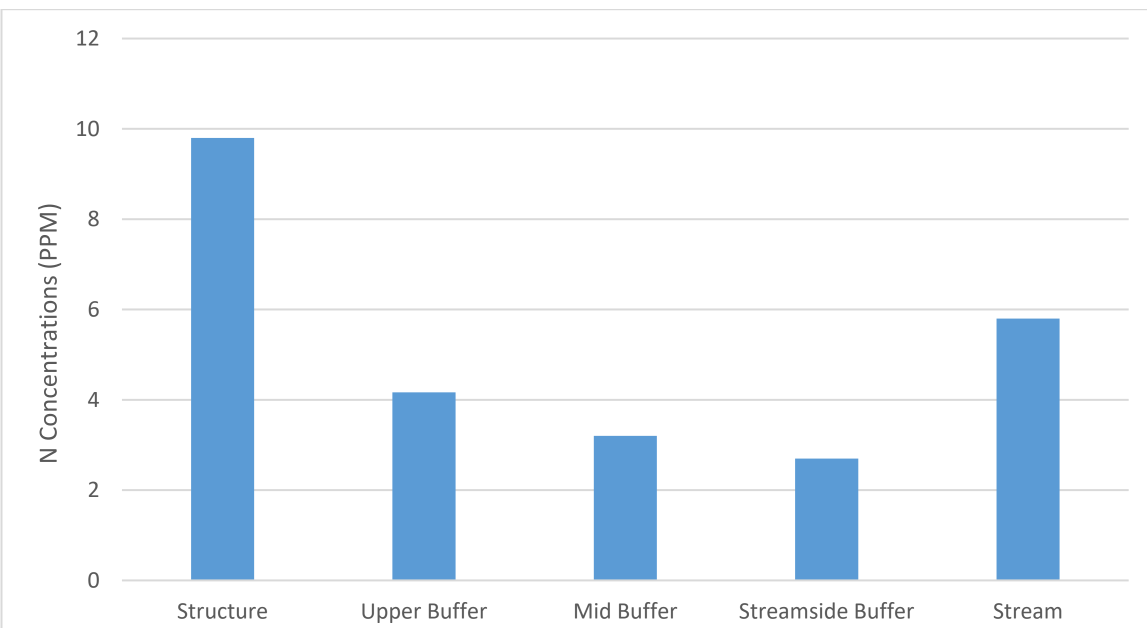


Figure 7: *Illinois 1 Buffer Concentrations*

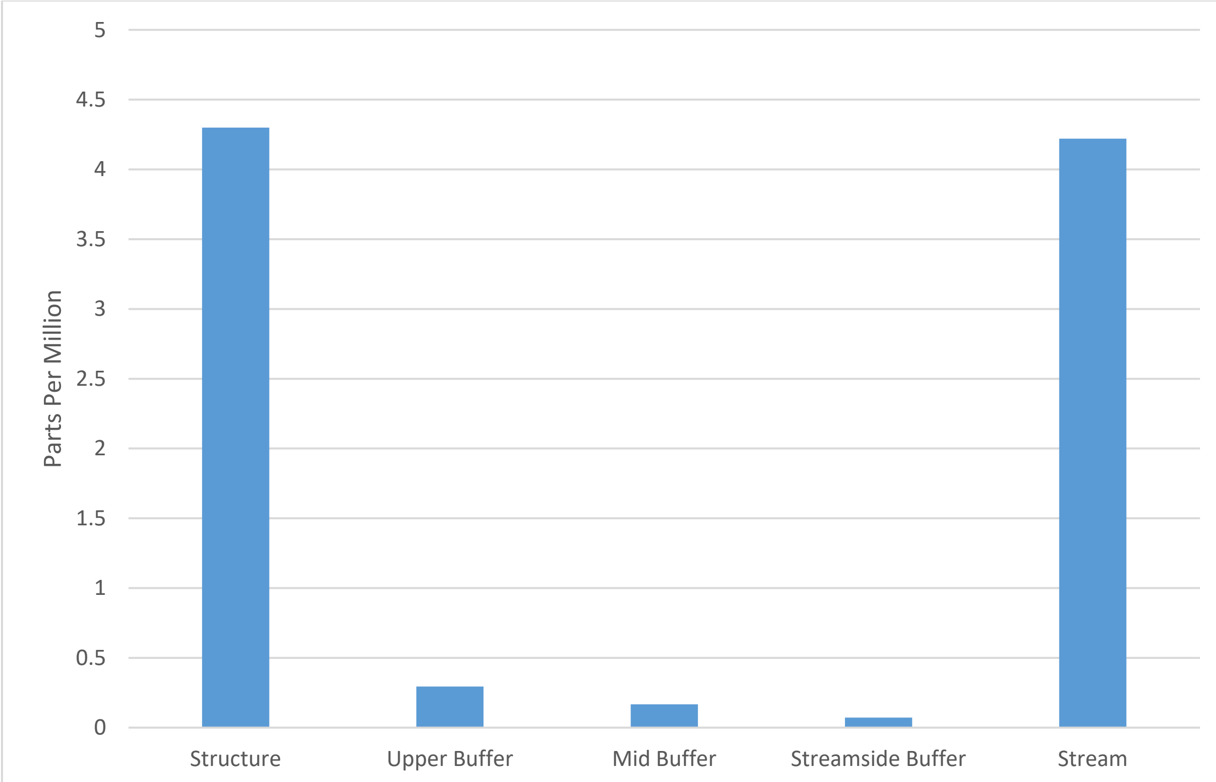


Figure 8: Illinois 2 Buffer Concentrations

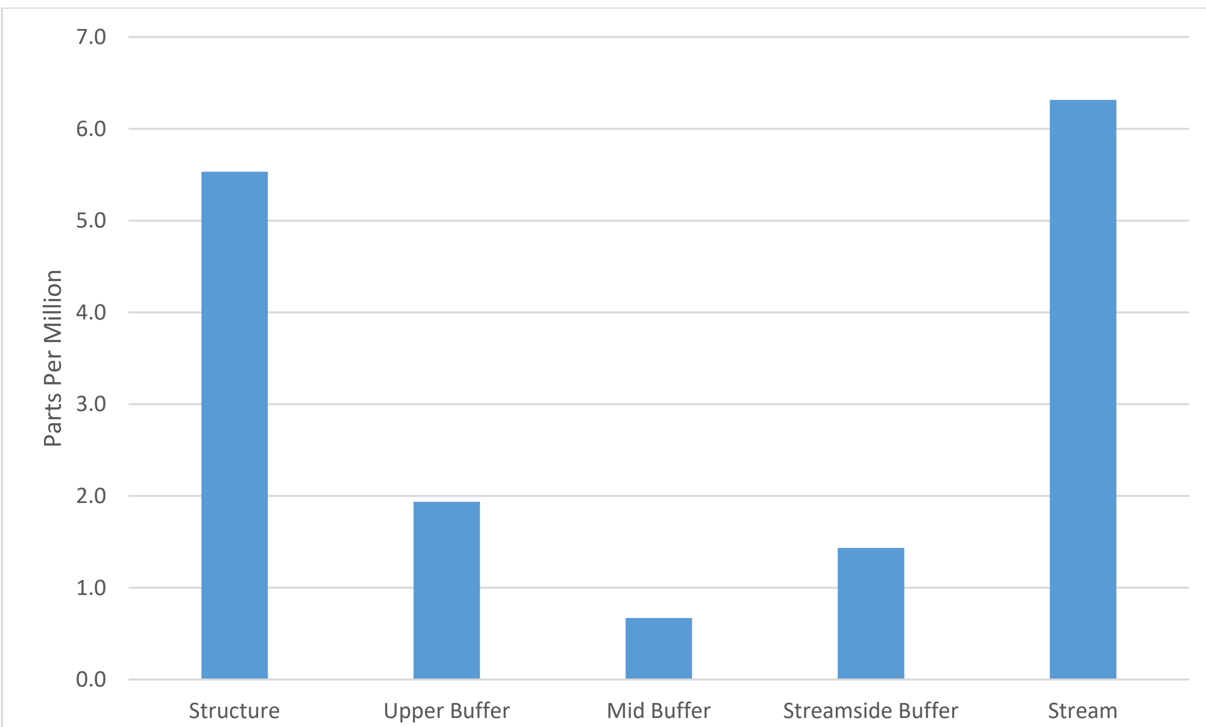


Figure 9: *Illinois 3 Buffer Concentrations*

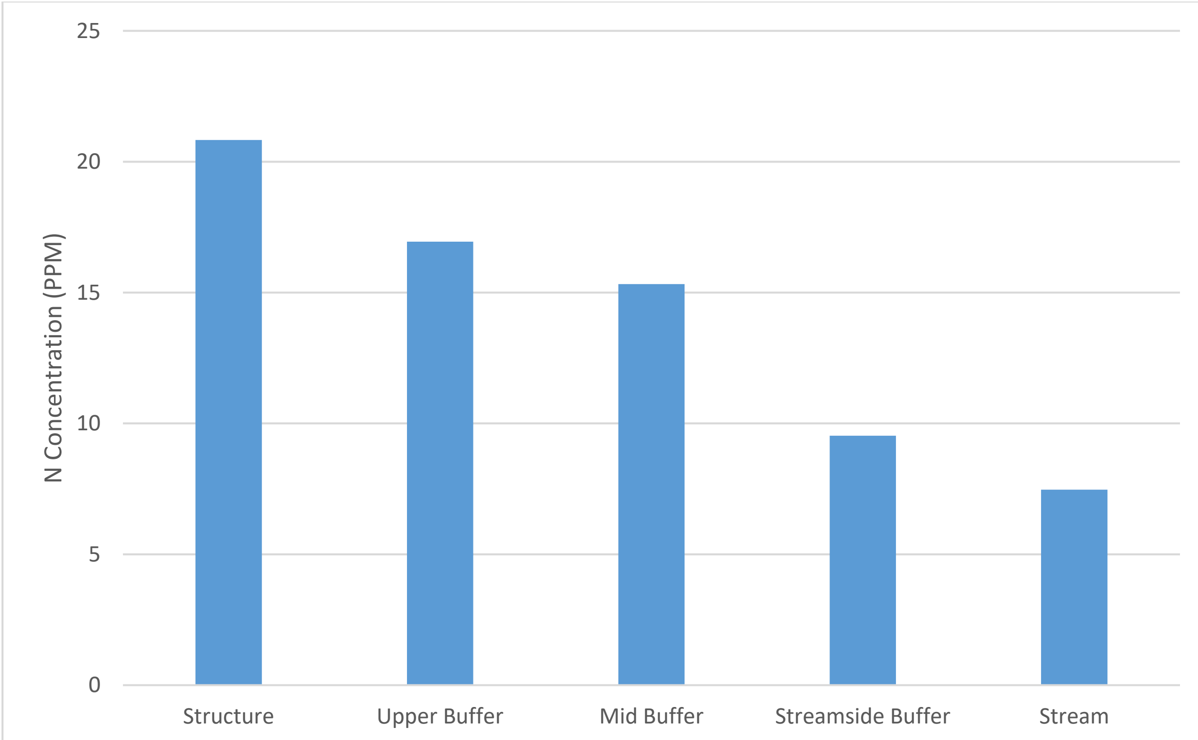


Figure 10: *Illinois 4 Buffer Concentrations*

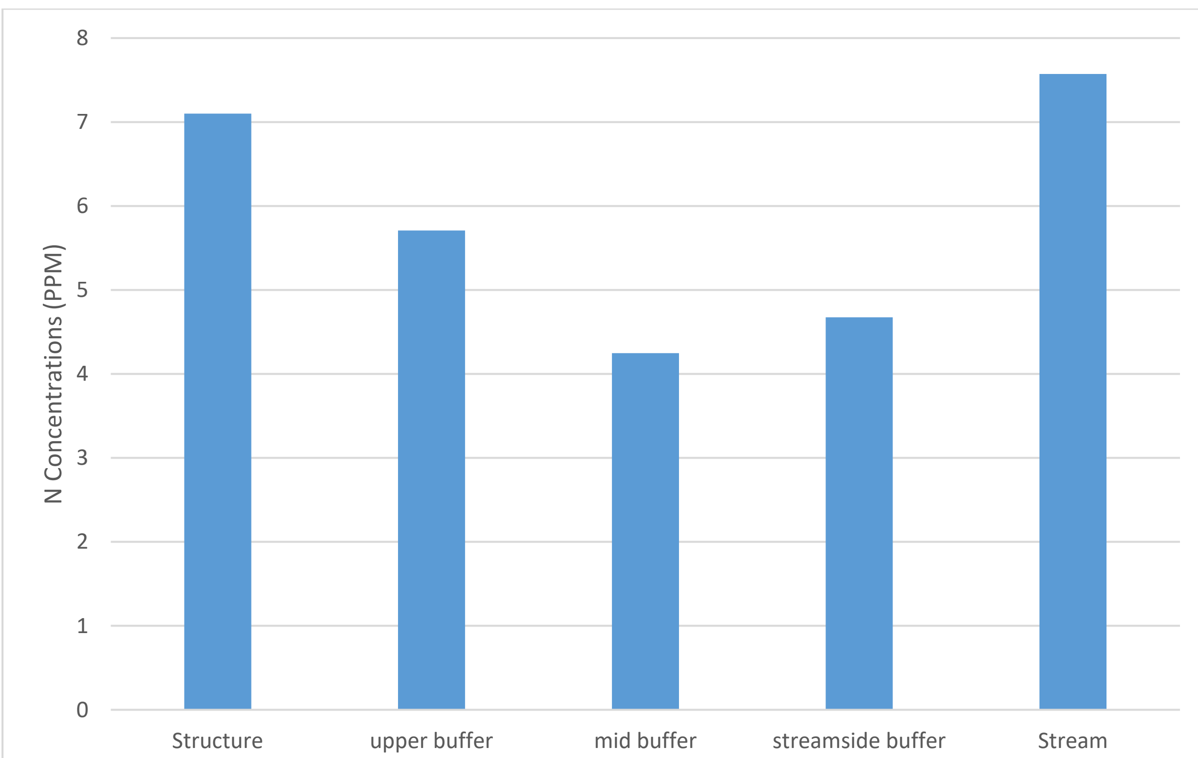


Figure 11: *Illinois 5 Buffer Concentrations*

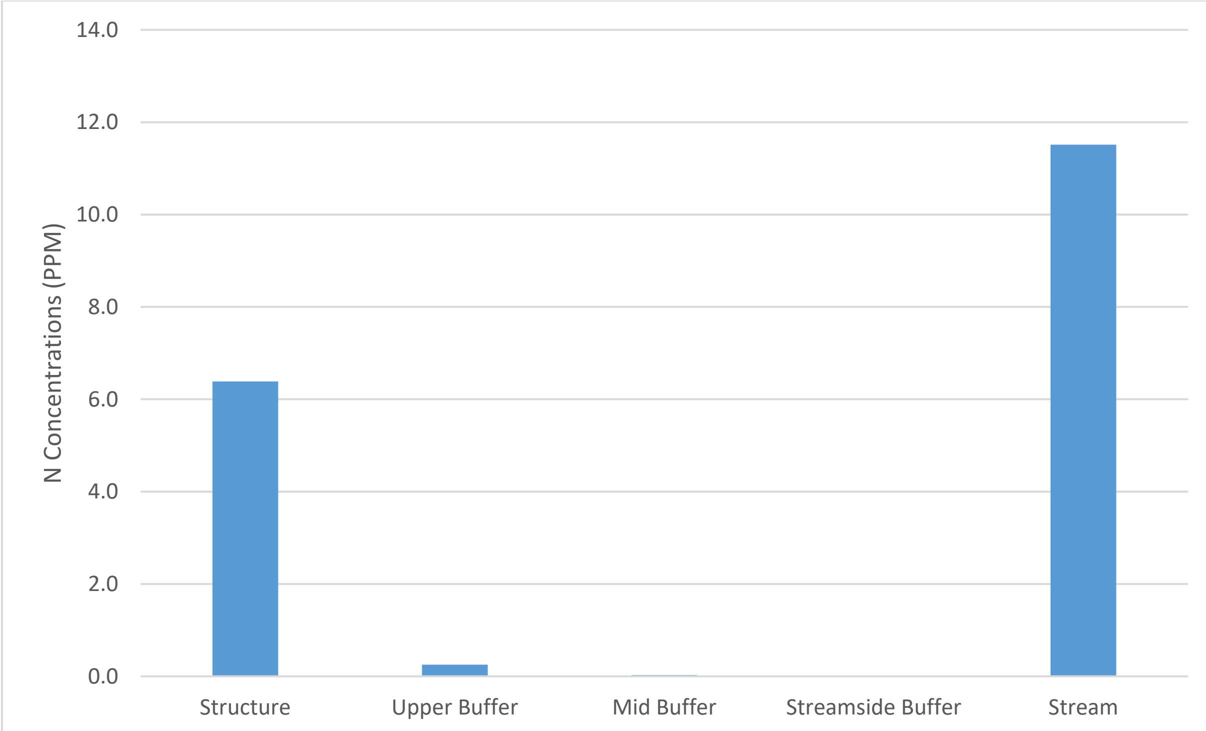


Figure 12: *Minnesota 3 Buffer Concentrations*

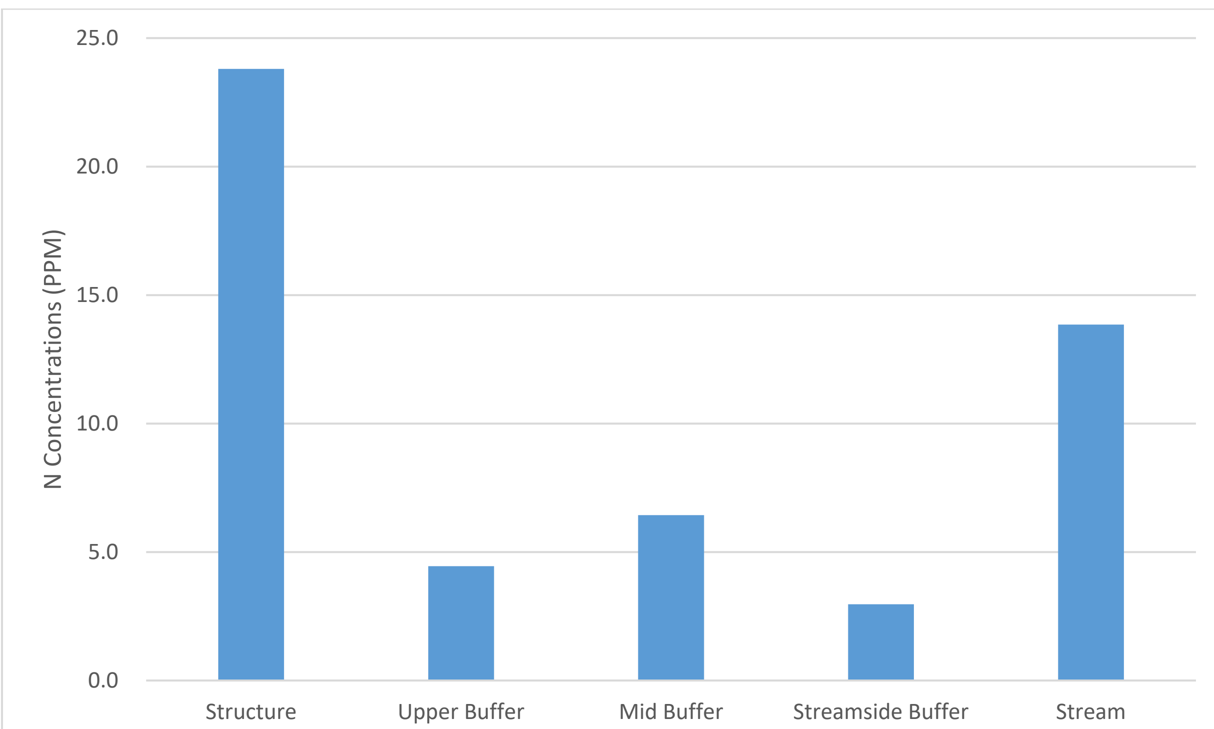


Figure 13: *Minnesota 4 Buffer Concentrations*

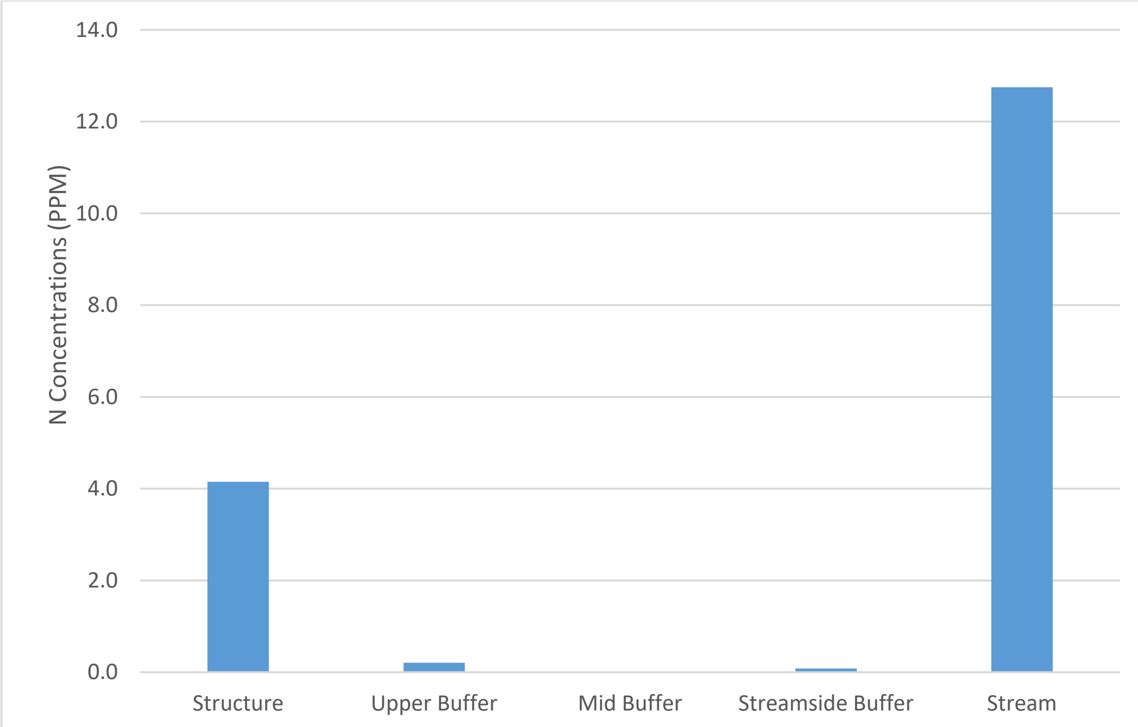


Figure 14: *Iowa 1 Buffer Concentrations*

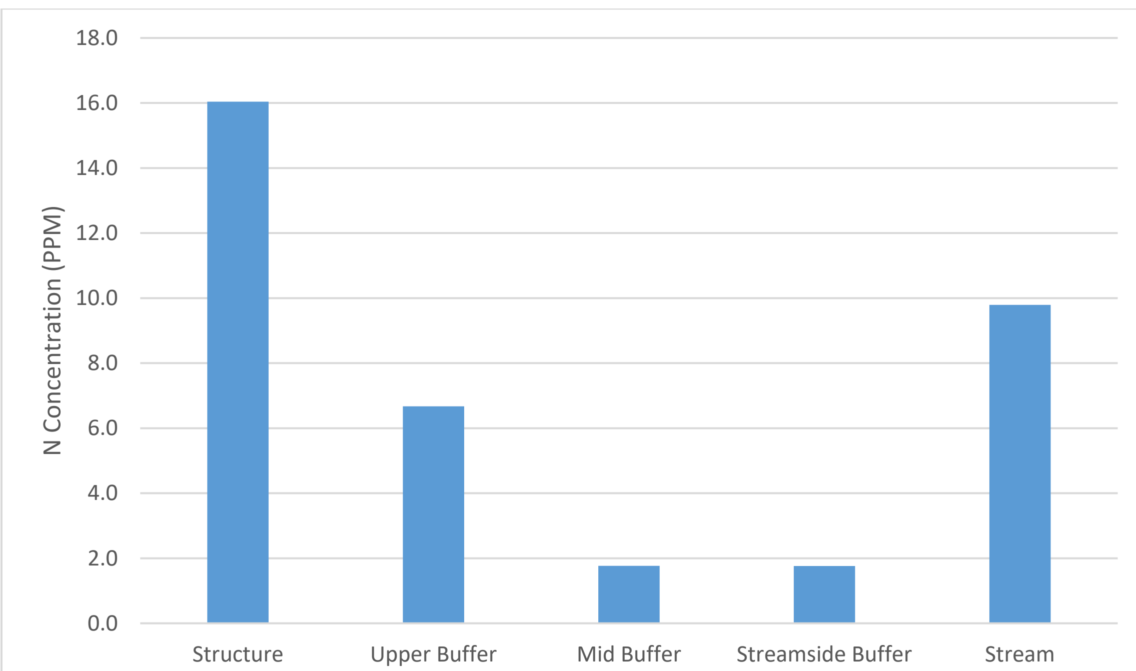


Figure 15: *Iowa 3 Buffer Concentrations*

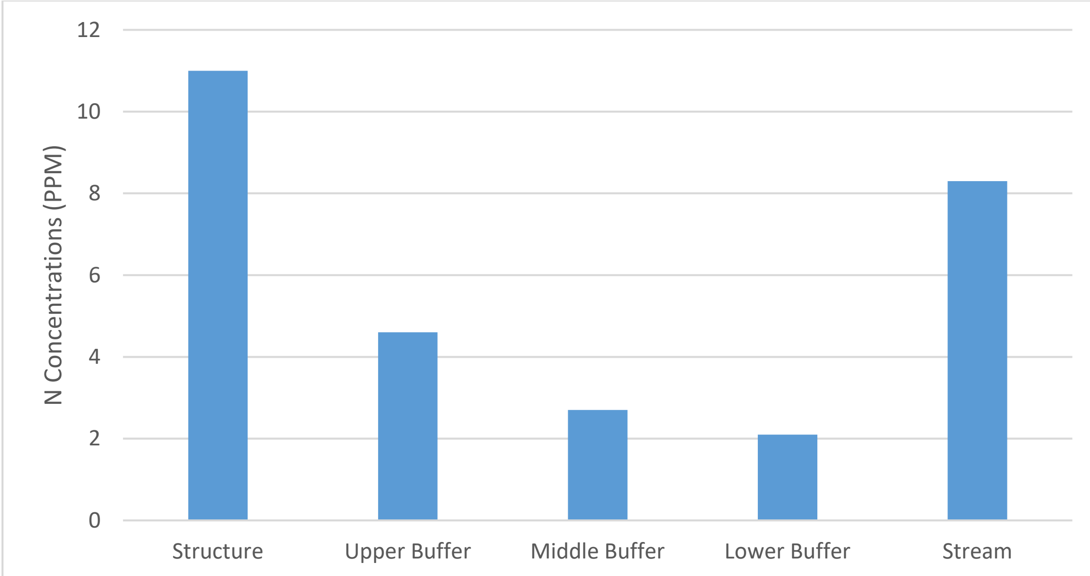


Figure 16: *Average Buffer Concentrations*

Summary of nitrate concentration data

Overall, the average nitrate concentrations across the buffers indicated substantial nitrate concentration reductions in 6 of the 9 sites (see above Figures 7-16). Nitrate may have been reduced from the other sites as well, or even in higher concentrations than measured, but the reduction was not consistent across the buffer as flow could not be accurately measured. Note that monitoring for nitrate removal with fully penetrating wells has its limitations. For example, the wells may be tapping into groundwater in the buffer that is more regional in nature and not being impacted by the saturated buffer infrastructure. Thus, these wells may be sampling water that is introduced by the saturated buffer infrastructure as well as water that in not impacted giving a mixed signal in the water sample. Also, as noted above, the wells closest to the stream may be sampling some of the stream bank storage of water. As the nitrate concentrations in the streams were greater than what was in the buffer in all sites except 1, this bank storage would serve to increase the average nitrate concentration being sampled by the well closest to the stream. A third possible complication is that flow paths in the shallow groundwater within riparian buffers can be quite complicated. While not part of this study, a tracer study at the saturated buffer in Bear Creek, IA showed that while tracer added through the distribution pipe showed up in all of the buffer observations wells, the travel times were variable with tracer arriving at some wells further from the distribution pipe sooner than wells closer to the pipe. This could impact the expected decreasing trend in nitrate concentrations across the buffer that we are using to determine nitrate removal in this project leading to misinterpretation of some of the well data. Thus, while we based our assessment on the presence of a decreasing trend in nitrate concentration across the buffer, nitrate removal may still be taking place at sites without this trend, we just could not measure it accurately.

Flow Measurements and Calculations

Flow to the buffer was determined at most sites by measuring tile flow leaving the field at the tile outlet where it was intercepted by the control box. This flow was calculated from the measured height of the water column above the flashboards separating the 1st from the 2nd chamber of the control box. Flow from the outlet that did not go to the buffer was discharged directly to the stream and this flow was calculated by measuring the height of the water column in the 2nd chamber as it flowed over the flashboards separating the 2nd from the 3rd chambers of the control box. Flow rates over both sets of flashboards were computed by using a rating equation that converted height above the flashboards to flow rate in gallons per minute. Flow to the buffer is computed as the difference between the flow from the field minus the flow to the stream. This difference method is a cost-effective method for determining flow both from the field and out to the buffer. However, any errors or inaccuracies in measuring flow within the control box would be magnified in the computed flow to the buffer. Given the design of the 3-chamber control box, computed negative flows to the buffer are not possible unless the stream is in flood stage or because of errors in the flow measurements over the two sets of flashboards. Thus, for this analysis, we set any negative flows to 0, and only computed nitrate removal when water was flowing from the control box out to the buffer.

Flow diversion totals are shown below in Table 2 for each site. In the following graphs (Figures 17-23), the flow rate out to the buffer is shown where we expect denitrification to remove some of the nitrate. Shown in these graphs is the cumulative mass of nitrate that is being diverted within the buffer. Within the 6-month study, IL-2 diverted 75% of flow (~350,000 gallons), IL-4 diverted 85% of flow (~135,000 gallons), IL-5 diverted 88% of flow (~4,700,000 gallons), MN-3 diverted 47% of flow (~1,225,000 gallons), IA-3 diverted 22% of flow (~3,600,000 gallons), and IA-1 diverted 95% of flow (~900,000 gallons)and MN-4, diverted 23% (~1,000,000 gallons). In totaling incoming and diverted flow between the seven of nine sites with flow reduction, approximately 40% of all flow was diverted (~12 of 30 million gallons).

Table 2: Preliminary Results*:

Site ID	Sept. Reduction (gal.)	Oct. Reduction (gal.)	Nov. Reduction (gal.)	Dec. Reduction (gal.)	Jan. Reduction (gal.)	Feb. Reduction (gal.)	Total Reduction (gal.)
IL 1							
IL 2					249,748	95,782	345,530
IL 3							
IL 4			31,357	29,586	63,820	10,175	134,938
IL 5	451,290	443,854	552,397	7,222	2,545,119	691,642	4,691,523
IA 1	560,988	129,546	15,051	30,062	0	155,308	890,955
IA 3	468,429	870,678	587,198	541,648	302,727	831,854	3,602,533
MN 3	979,460	215,900	32,177	**	**	**	1,227,538
MN 4	577,298	157,394	188,001	71,099**	**	1,185**	994,976

***Blank cells are representative of data missing due to faulty sensors. Numbers may not be representative of entire flow reduced.**
****Transducers pulled from boxes during coldest portions of winter months to prevent sensor freezing**

Nitrate Load Calculations

Nitrate load that went out to the buffer was determined by multiplying the flow to the buffer over a given time period by the nitrate concentration in the tile outlet for the same period. At sites where flow was measured for times when nitrate concentration was not measured, the nitrate concentration for the time closest to the flow measurement period was used. Thus, we can compute the total load of nitrate being delivered by the tile outlet for each year. To compute the nitrate reduction within the buffer, we took the average nitrate concentration in the tile outlet minus the average nitrate concentration within the wells closest to the stream. While simple, this method could be in error. For example, there two sites where the nitrate concentrations in the wells closest to the stream were higher than nitrate concentrations in the middle of the buffer. As noted in the nitrate concentration section above, the higher concentrations in streamside wells may have reflected stream bank storage where the high nitrate concentration stream water infiltrated the soil next to the stream raising the concentration in the streamside wells. In this case, our calculation of nitrate removal within the buffer may have been conservative. Throughout the 6-month study period, IA-1 removed 17.7 lbs, IA-3 removed 342.3 lbs, MN-4 removed 148 lbs of N, MN-3 removed 82.1 lbs, IL-2 removed 13.5 lbs, IL-4 removed 11.4 lbs, and IL-5 removed 60.0 lbs of nitrate-N.

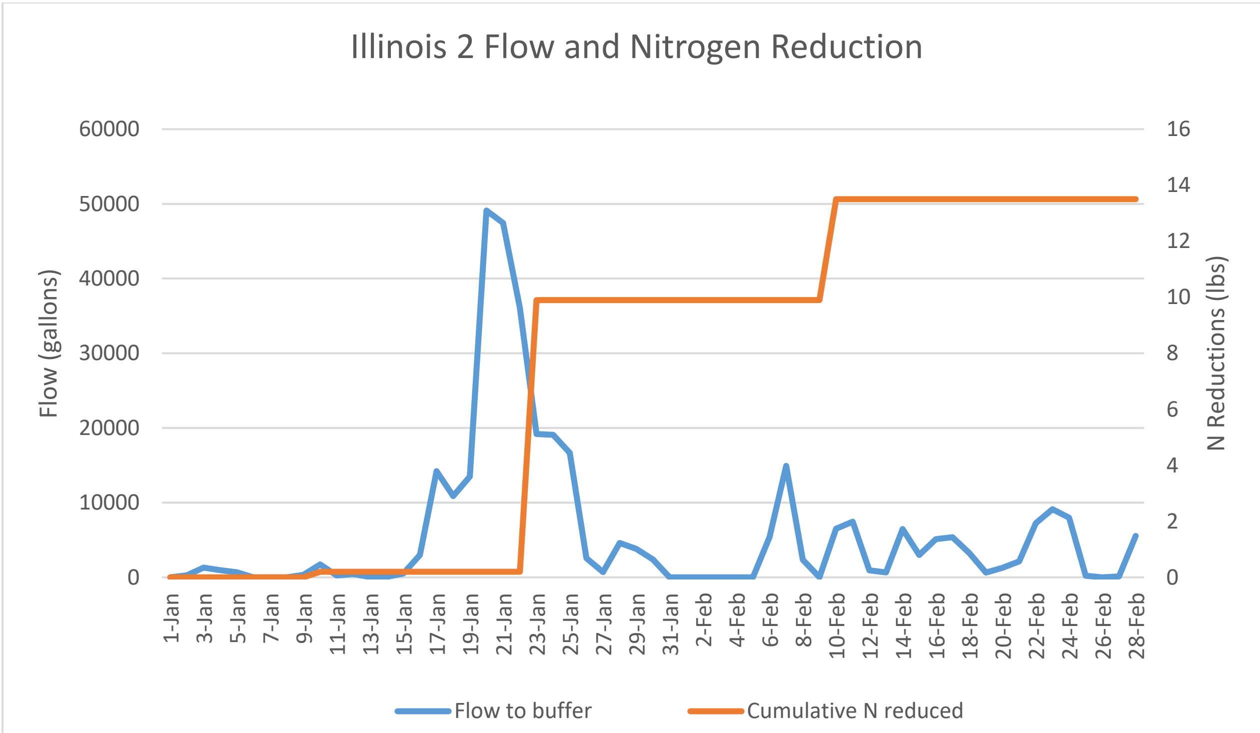


Figure 17: *IL-2 Reduction*

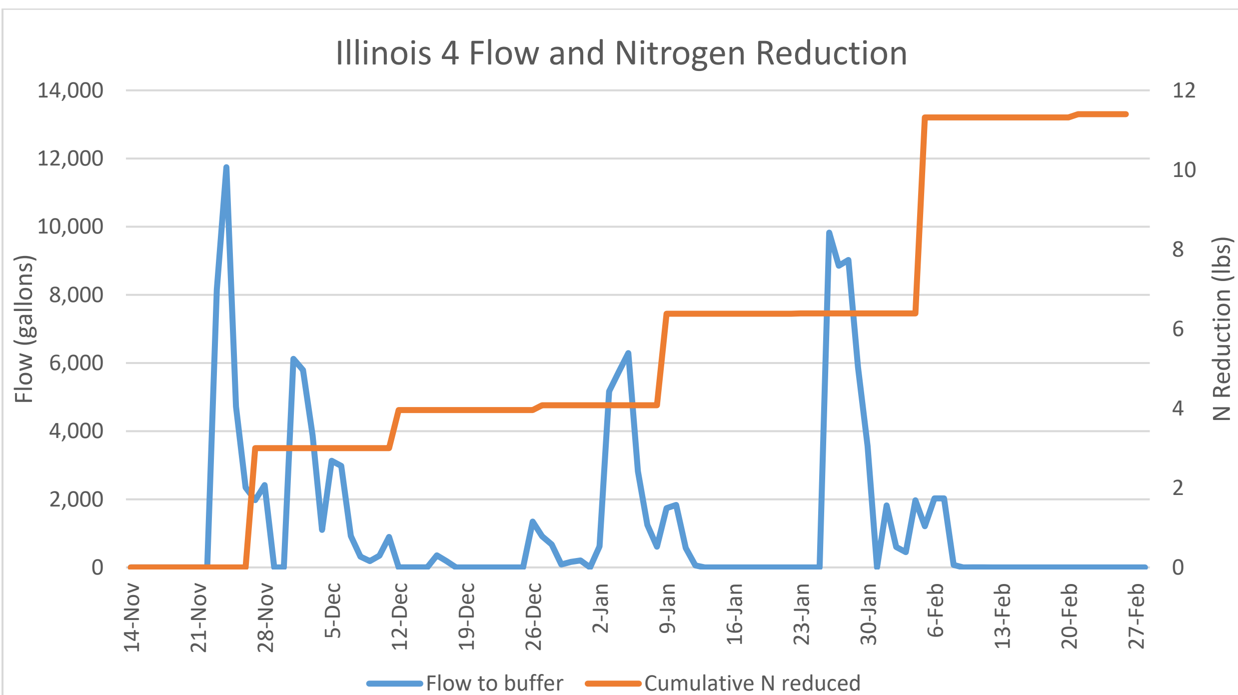


Figure 18: *IL-4 Reduction*

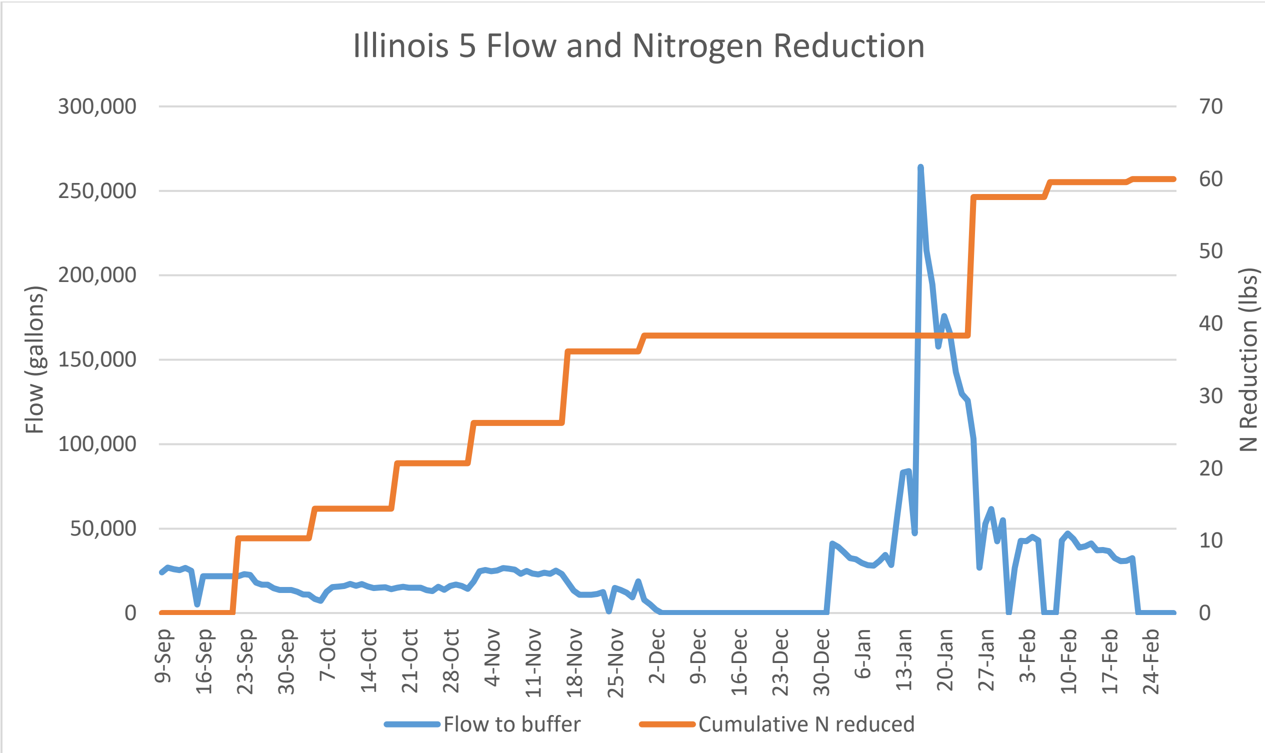


Figure 19: *IL-5 Reduction*

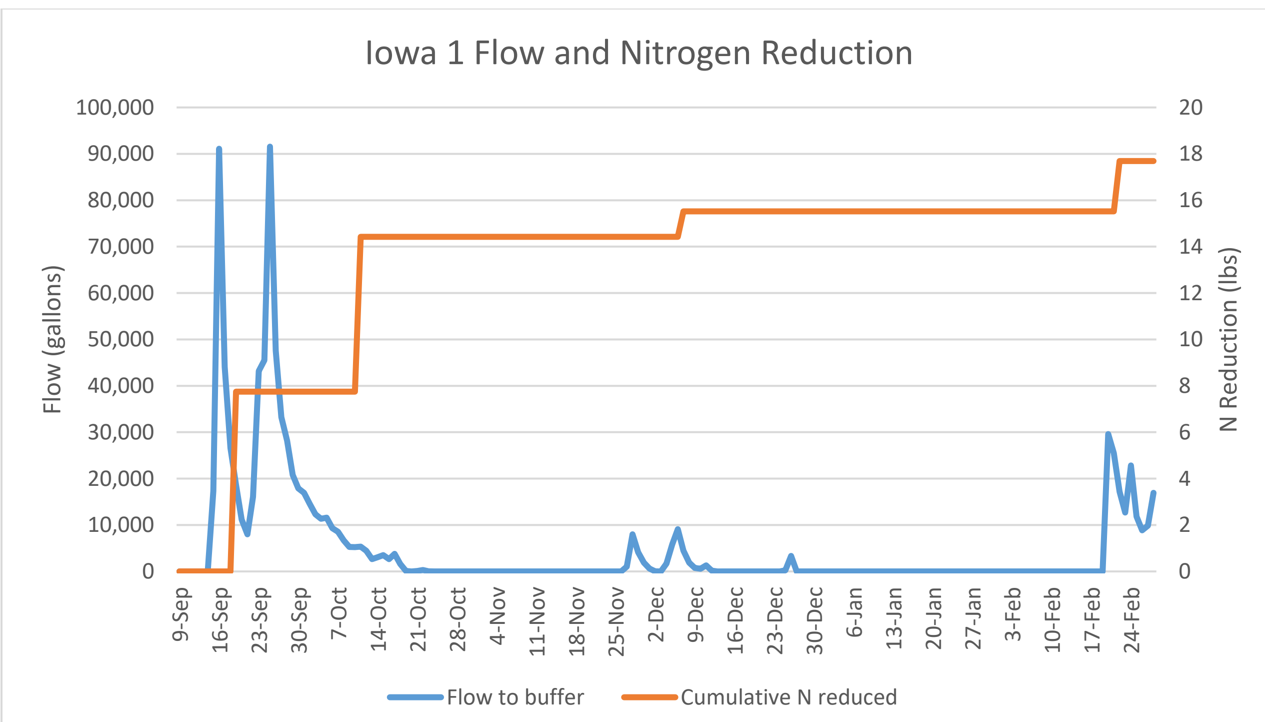


Figure 20: *IA-1 Reduction*

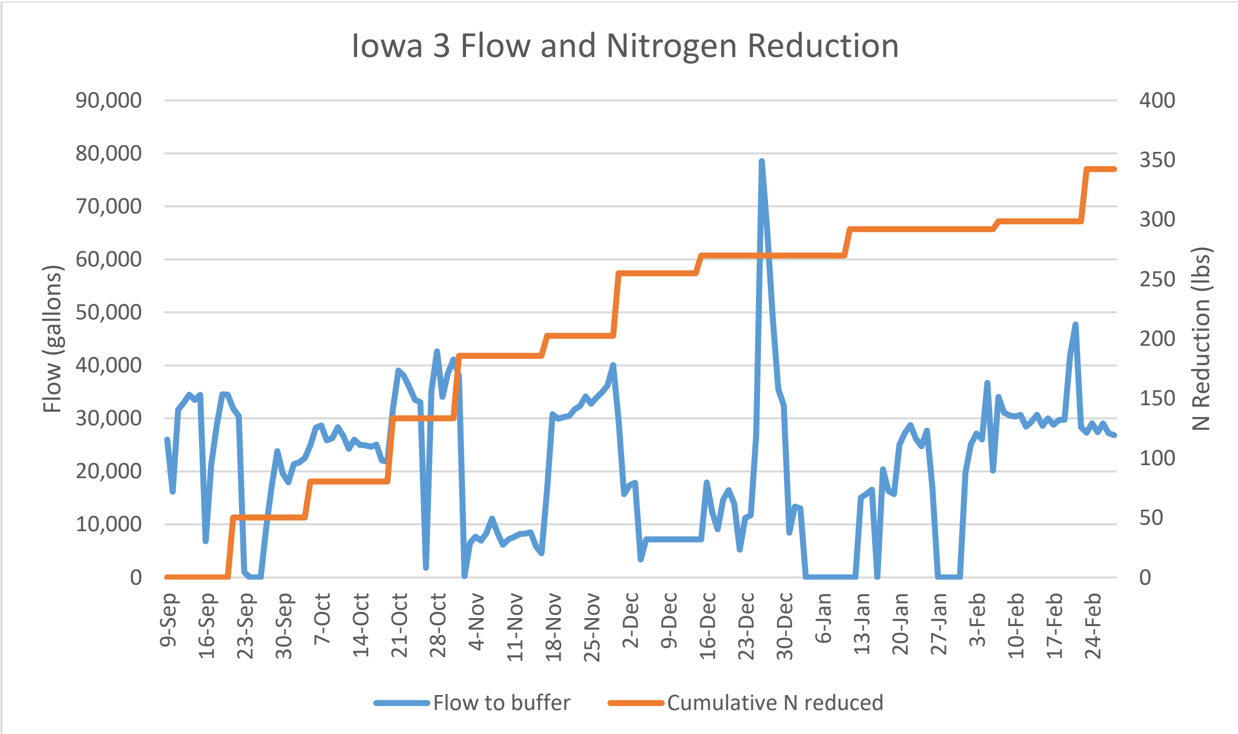


Figure 21: *IA-3 Reduction*

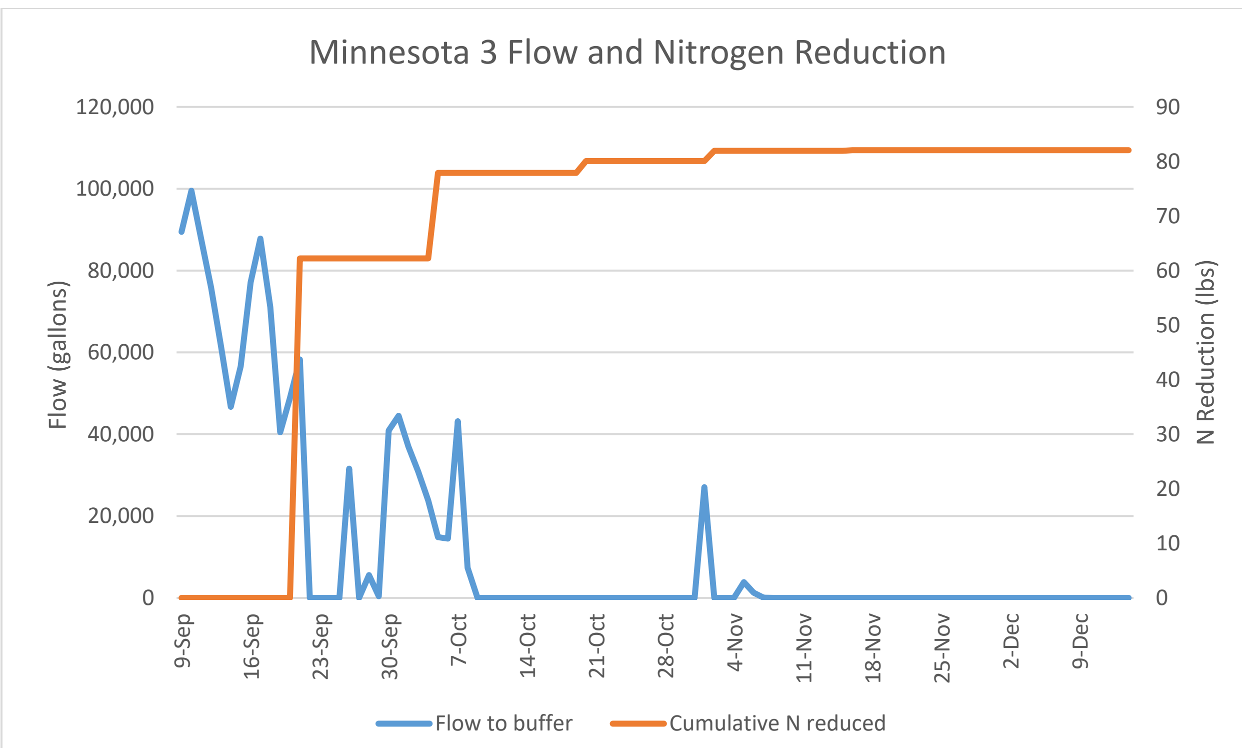


Figure 22: *MN-3 Reduction*

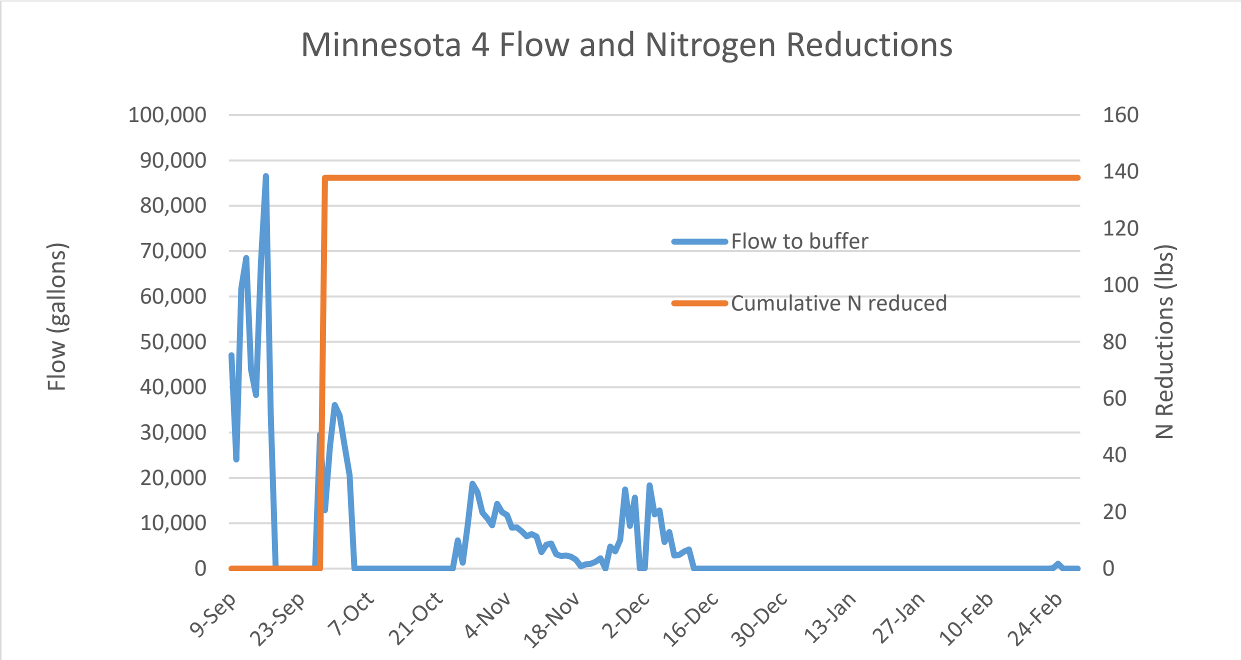


Figure 23: *MN-4 Reduction*

Conclusions, Recommendations and Lessons Learned

Saturated Buffer Performance: Nitrate Load Reductions

As documented in Jaynes and Isenhart (2014), at least two conditions are necessary for nitrate removal in a saturated buffer. First, the soil in the buffer must have a sufficient soil carbon content to serve as an energy source for the denitrifying bacteria. Burford and Bremner (1975), showed that soil with organic carbon contents of at least 2% can easily sustain denitrification. In selection of these sites in the preliminary project, a threshold of 1% organic carbon was present in the soil at 2.5 ft deep to support denitrification. The second criterion was that the water table in the buffer could be raised to submerge the high carbon soil layer, therefore restricting oxygen diffusion and leading to an anaerobic condition conducive for denitrification. Thus, for the currently used sites, there was evidence of either a historically high water table at the depth of the high soil carbon layer, or the presence of a hydraulically restricting layer in the buffer soil that would allow the water table to raise by re-directing tile drainage into the buffer.

In the current 9 sites, the nitrate removal performance of the installation was evaluated at each site based on several criteria. One method used was measuring nitrate removal due to redirecting tile flow into the buffer using a control structure. This was done by monitoring flow in and out of the structure. The difference between the flow in and out was the total flow diverted to the buffer. This flow data was used with concentration samples to calculate nitrogen load reductions. Sites IL1 and IL3 did not have adequate flow data with which to form a conclusion based on flows redirected into the buffer. Another method was taking water samples from wells within the buffer, between the distribution lines and streams. Six of the nine sites (including MN-4) showed decreasing trends in nitrate concentration from the field-side to the stream-side of the buffer which was considered an indicator of nitrate removal. IL3 and IL5 did not follow this trend, it appears that during high water events stream flows inundated the streamside buffer and its sampling wells. This phenomenon leads to higher concentrations in the streamside than mid buffer wells. The outlier in this grouping was MN4, which saw the highest N concentration in the mid buffer wells. Even with this odd spike, the streamside buffer concentration was substantially less, leading us to believe that treatment (in the form of N uptake and denitrification) was likely occurring. All nine sites did show the trend in which nitrate concentrations in the buffer wells were consistently lower than in the field outlet tile water samples taken in the structure.

In conclusion, current data collection techniques heavily support the use of saturated buffers as a credible nitrate load reduction practice. The cost per pound of nitrate removed is low compared to other nitrate removal practices.

For future projects and installations, sites with highly permeability soils below the buffer or distribution line and sites in which the stream flows are high enough that there is no room for the denitrification to occur, should be avoided. High stream flows will interfere with sampling wells when the topography of the site is not properly considered. In addition, well proximity to the streams may need to be evaluated to prevent seepage and interference.

Considerations in future design criteria of SB should also include available length of buffer and predict the amount of gallons diverted and the pounds of nitrate removed. Fig. 24 & 25 below show the results determined in this study of the amount of flow and nitrate reduction diverted per 100 feet of buffer. The average reduction of N load per 100 lineal feet of saturated buffer is 9.5 lbs. per 100 feet for the study period. Assuming this would be at least twice as much over a 12-month period, and the fact that the study occurred during the lower flow months or the year, one could project 19 lbs. of N reduction per 100 feet of saturated buffer per year.

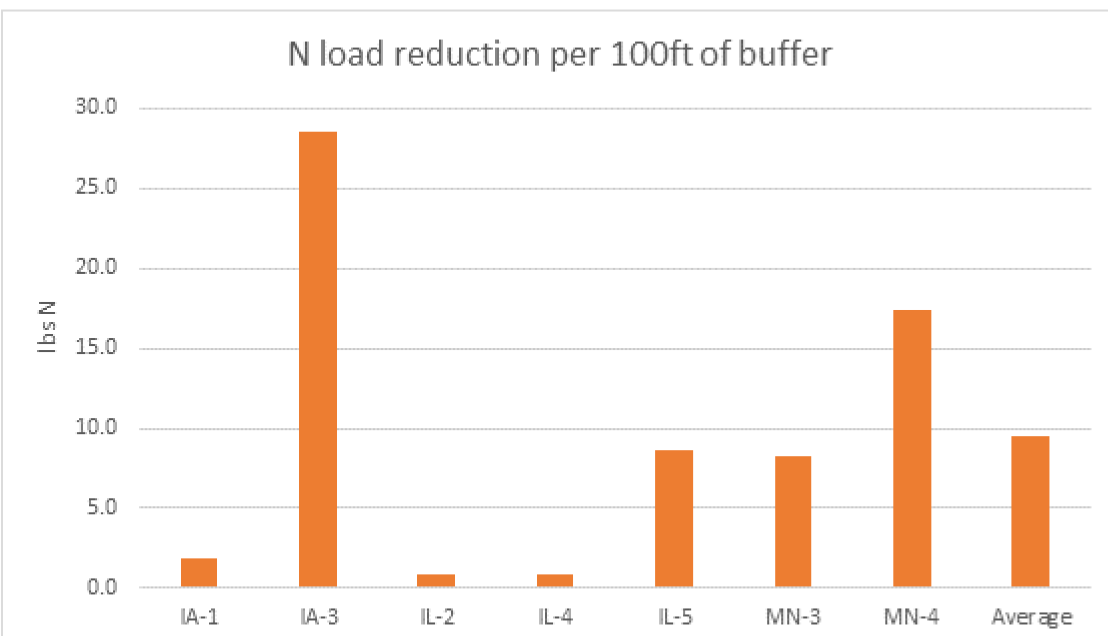


Figure 24: *Reduction per 100 ft. of buffer*

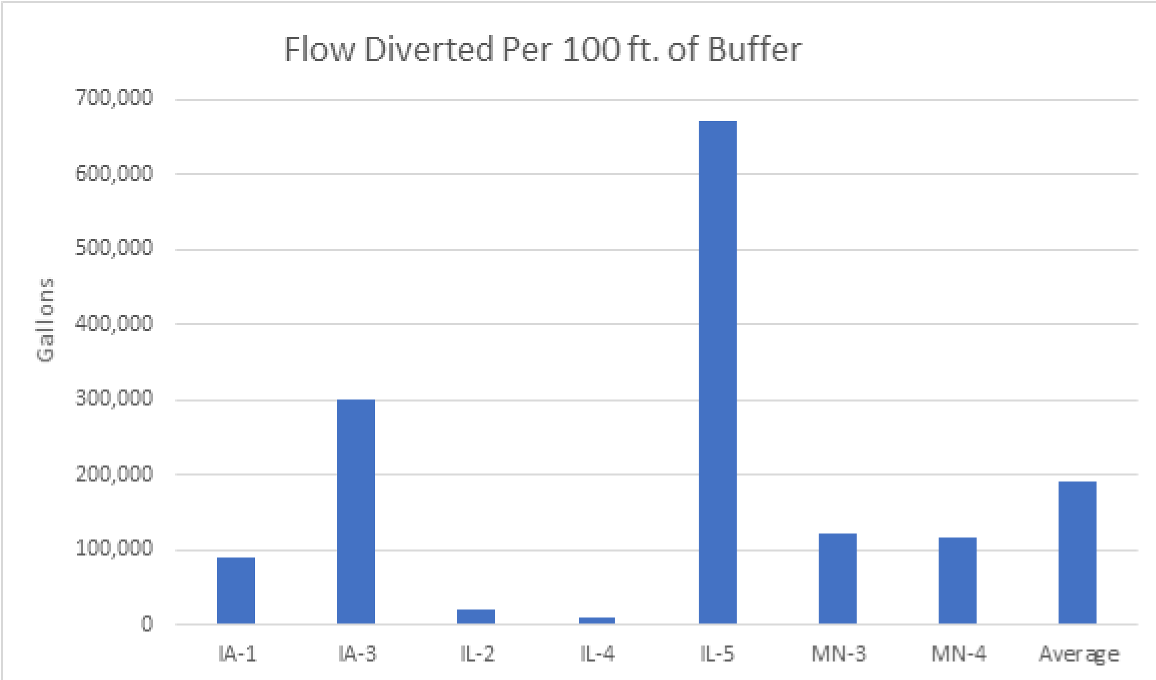


Figure 25: *Reduction per 100 ft. of buffer*

Saturated Buffer Performance: Health and Vitality of Buffer

There has been some concern about harming the health and vitality of the buffer. The buffer's original purpose was to reduce sediment loads to nearby streams and providing wildlife habitat. Examination of the sites in this study show no evidence of deviating from this purpose. The vegetation has healed very quickly and the wildlife doesn't appear disturbed (Fig. 26 & 27).

Figure 26: *IL -2 Small Mouth Salamander*

Figure 27: *IL-1 Bird Nesting*

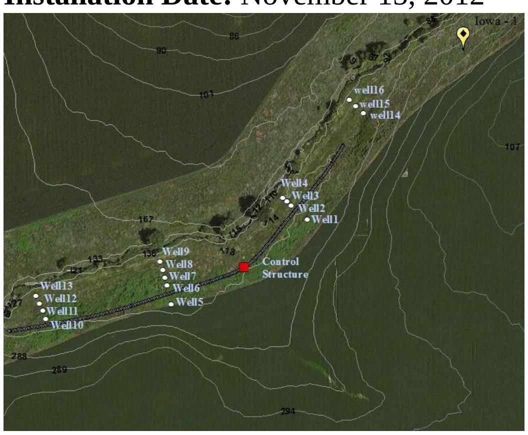
Appendix A – Well locations

IA – 1

Location: Hamilton Co. IA.
S1 T86N R24W 5th Meridian (Ellsworth Township)
42.284948°N 93.585772°W
Watershed HUC12 # 070801050402

Drained Area and Tile System:
The saturated buffer was installed on an existing 8” clay tile outlet. There was no tile map available for this site, but we estimated the drainage area to be approximately 4.7 ha or 11.6 acres based on local topography (right fig.). The field itself is gently sloping, with a gently sloping buffer. The field is in a corn-soybean rotation by the landowner.
Buffer Dimensions, and Characteristics:
The existing CRP buffer width is ~120 feet wide and was installed as a “Bird Buffer” in the mid 1990’s. The Buffer zone is mainly hardy perennial grasses with a few trees along the stream bank.

Installation Date: November 15, 2012



Installation Cost:
The overall cost for this project site was $3,802.32. The cost can easily be divided into three categories; Materials, tile pipe costs etc., Labor and Structure Costs. The total cost for materials and tile pipe was $2,145. Labor came to a total of $125 with approximately 4 hours of backhoe work, and 4 hours of labor. Finally, the structure cost was $1,532.32.
Installation and Management Information:
The saturated buffer was installed by NLAE staff using a back hoe and trencher by intercepting the 8” clay tile. Distribution pipe was ~1,000 feet long, with `600 feet of the tile going towards the West and another ~400 feet going to the East and was installed dead level. There is a riser placed every ~100 feet along the main tile line to help monitor the flow and observe any roots plugging the tile. The East end of the distribution pipe was wrapped in perforated fabric in attempt to exclude roots entering the pipe. The West end was not wrapped to serve as a check. Flow monitoring was via V-Notch weirs installed as the top flash boards of a three-chamber control structure. Flow calibration for these weirs was conducted by NLAE personnel. Water samples were collected approximately weekly when the tile was flowing by NLAE personal.

Well Setup and Management
Each site has one control structure set up which contains a control box, and a series of well transects. The 6-foot control box intercepted an 8-in. main. A 4-inch perforated field tile was connected at the flowline of the main and installed ~2 feet below the surface on a flat grade. The control box is designed to hold and retain water while diverting it from the field tile outlet and displacing it into the saturated buffer. Pressure transducers in the control structure box allow for continuous monitoring of the water flow

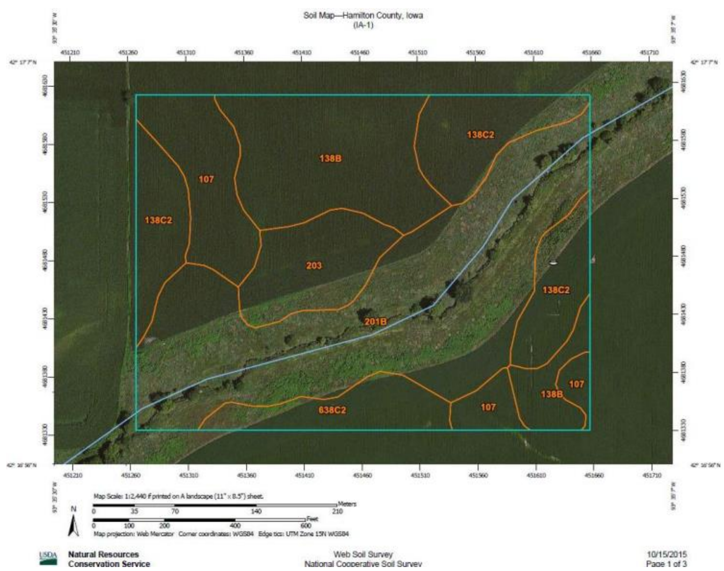
which get sent back to the NLAE building in Ames IA daily. A series of shallow, fully penetrating wells were installed at each location in the buffer zone. Currently, there are 16 observation wells on site to help monitor the nitrate concentrations as the drainage water leaves the field in the tile outlet, and enters the buffer zone on the way to the stream. The wells are set up so there is a group of four to make a transect. The well depths and ID's can be found in the table to the right, which also corresponds to the image on the previous page.

Well ID	**Depth (ft.)**
IA – 1	8.75
IA - 2	8.32
IA – 3	8.46
IA – 4	8.65
IA – 5	8.52
IA – 6	8.53
IA – 7	8.46
IA – 8	8.38
IA – 9	8.50
IA – 10	8.46
IA – 11	8.46
IA – 12	8.55
IA – 13	8.52
IA – 14	7.67
IA – 15	7.42
IA – 16	6.90

Ditch Characteristics:
This is an unnamed 1st – order stream about 72" below the bank top that flows directly into the South Skunk River.

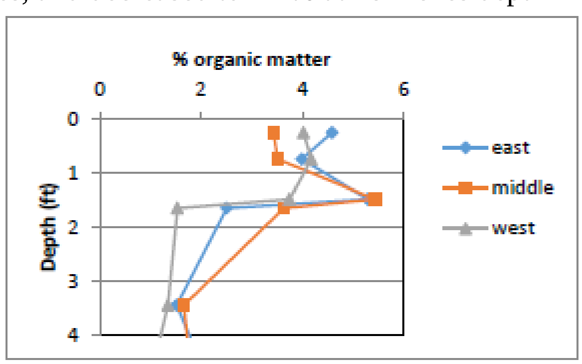
Soil Description (type, texture, etc.):
Soil map and soil series are below.

Map Symbol	Unit Name
107	Webster Clay Loam, 0-2 % slopes
138B	Clarion Loam, 2-6 % slopes
138C2	Clarion Loam, 6-10 % slopes, moderately eroded
201B	Coland-Terril Complex, 1-5 % slopes
203	Cylinder Loam, 32-40 inches to sand and gravel, 0-2 % slopes
638C2	Clarion-Storden Loams, 5-9 % slopes, moderately eroded



Soils in the buffer are mapped as Coland-Terril. Soil cores showed the soil to be loam or clay loam down to 80 cm (70 inches). Below this depth, the soil is loamy sand with frequent stones and pebbles with indications of reducing (saturated) conditions.

Soil Chemical Profiles
Soil organic matter was greater than 3% in the top 24 inches, and decreased to 1-2% at 48 inches depth and was below 0.5% below 60 inches (not shown). Soil pH was not measured at this site.

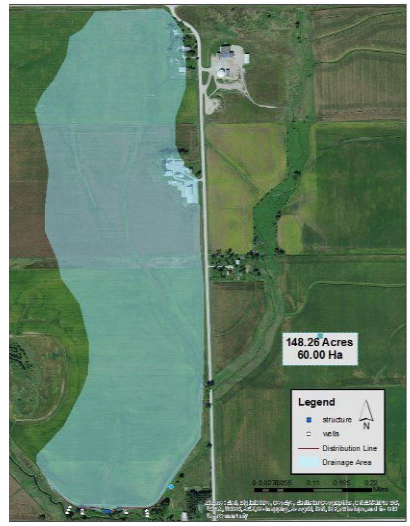


Other Important or notable site features: None.

Any Changes in Conditions During the Project?
A second transect of wells were added in 2014 (wells #14-#16) to serve as checks as these were placed within the riparian buffer but outside the area covered by the distribution pipe.

IA – 3

Location: Benton Co. IA.
S35 T83N R10W 5th Meridian (Eldorado Township)
41.949545°N 91.972652°W
Watershed HUC12 # 070802051403



Drained Area and Tile System:
The saturated buffer was installed on a 6” tile outlet. This outlet combined tile lines that drained two separate grassed waterways. There was not a tile map available for this site, but the estimated drainage area is 148 ac. or 60 ha. (right fig.). The field has a fair amount of slope to it and the buffer is fairly flat. The field was in a corn- soybean rotation for the duration of the project.

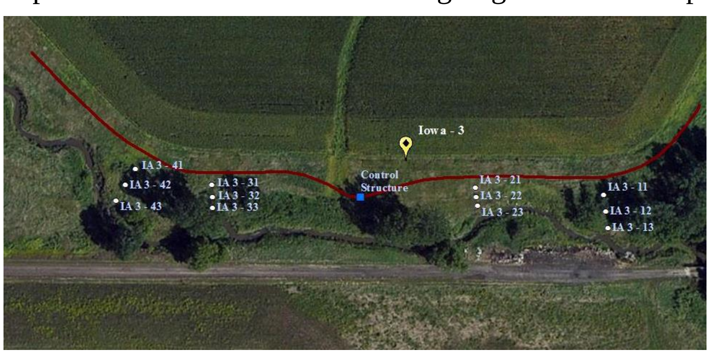
Buffer Dimensions, and Characteristics:
The CRP buffer is ~135 feet wide and is mainly hardy perennial grasses with some trees along the stream bank.

Installation Date: May 6, 2013

Installation Cost:
The overall cost for this project site was $5,019 with $1,778 attributed to the control structure.

Installation Management Information:
The saturated buffer was installed by a local contractor who used a backhoe and tile plow to do the work in less than one day. The work included replacing a section of the main with non-perforated pipe and installation of the control structure and distribution line. The distribution line was ~1,200 feet long, with ~600 feet of the tile going in either direction. Flow monitoring was via V-Notch weirs installed as the top stop logs in the control structure. Flow depth was measured using water level sensors. Water samples were collected approximately twice a month when the tile was flowing.

Ditch Characteristics:
The tile system outlet was into a natural, meandering stream. The channel is less than six feet deep and experiences considerable bank sloughing. This creek is prone to flooding with water commonly coming over the banks.



Other Important or Notable Site Features:
A grassed waterway enters the creek just west of the control structure. As a result, we used non-perforated pipe on the distribution line until past the waterway.

Any Changes in Conditions During the Project? No

Well Setup and Management:
A series of four groundwater monitoring well transects were installed at this site. Each transect contained three wells (one near the stream bank and the other two equally spaced between the stream and the distribution line) for sampling the groundwater in the buffer as it moved from the distribution line to the stream. The depth of each monitoring well is given in the table on the following page. The Well ID’s correspond to the locations indicated above.

Structure Management:

The stop logs were not moved for the duration of the project.

Date	Board Height (in)		Elevation (ft)	
	Field	Buffer	Field	Buffer
Ground	NA	NA	810.9	810.5
5/10/2013	29.53	24.53	809.2	808.7

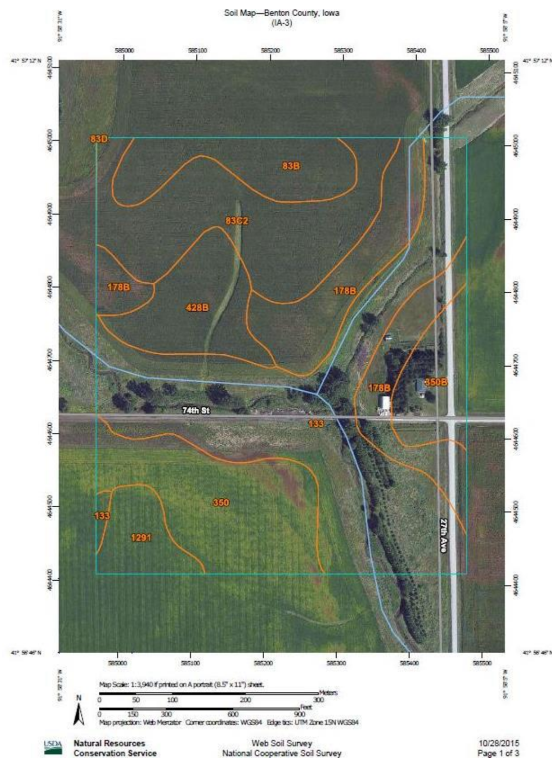
The "Board Height" refers to the height of stop logs within the structure and the corresponding "Elevation" of the top stop log.

Well ID	Depth (ft.)
IA – 3 - 11	5.88
IA – 3 - 12	6.46
IA – 3 - 13	5.58
IA – 3 - 21	6.43
IA – 3 - 22	6.30
IA – 3 - 23	6.33
IA – 3 - 31	6.38
IA – 3 - 32	6.25
IA – 3 - 33	6.82
IA – 3 - 41	5.93
IA – 3 – 42	6.13
IA – 3 - 43	6.10

Soil Description (type, texture, etc.):

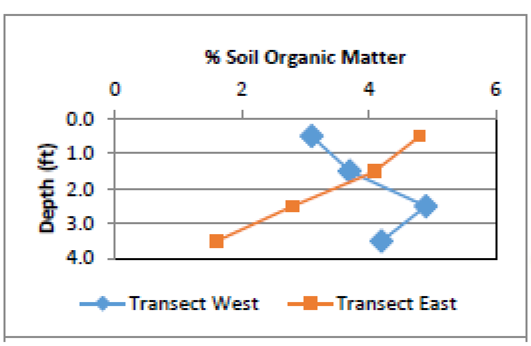
Soil map and soil series are below. Soils in the buffer are mapped as Colo silty clay loam. Soil cores showed the soil to be loam or clay loam down to 42 inches. Below this depth, the soil turns sandier with evidence of continuous saturation (gleying) at 85 inches.

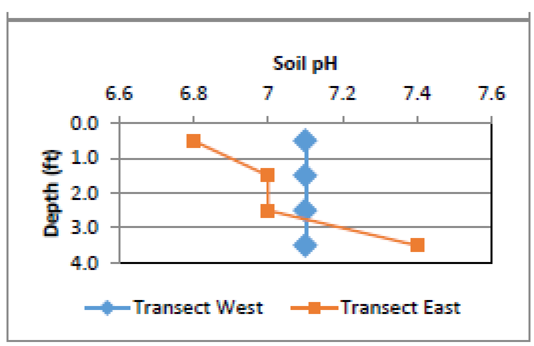
Map Symbol	Unit Name
83B	Kenyon Loam, 2-5% slopes
83C2	Kenyon Loam, 5-9% slopes
83D	Kenyon Loam 9-14% slopes
133	Colo Silty Clay Loam, 0-2% slopes
178B	Waukee Loam, 2-5% slopes
350	Waukegan Silt Loam, 0-2% slopes
350B	Waukegan Silt Loam 2-5% slopes
428B	Ely Silt Loam, 2-5% slopes
1291	Atterberry Silt Loam, Benches 0-2% slopes



Soil Chemical Profiles

Soil organic matter was greater than about 2% in the top 48 inches. Soil pH was neutral throughout the top 48 inches. Denitrification is maximum at a pH between 7 and 8.5 and decreases sharply for pH ≤ 5.





IL – 1

Location: Sangamon Co. IL
S9 T13N R6W 3rd Meridian (Auburn Township)
39.585983°N 89.777395° W
Watershed HUC12 # 071300070702

Drained Area and Tile System:
The saturated buffer was installed on an existing 8” tile outlet. This tile system drains approximately 26 ac. or 10.7 ha. The buffer is fairly flat and the field slopes upward from the buffer. This field was in a corn- soybean rotation for the duration of the project.

Buffer Dimensions, and Characteristics:
The existing CRP buffer width is ~70 feet wide. The Buffer zone is hardy perennial grasses along the stream bank.

Installation Date: July 16, 2012

Installation Cost:
The overall cost for this project site was $3,251 with $1,201 attributed to the structure.

Installation Information:
The saturated buffer was installed by a local contractor who used a backhoe and plow to do the work in less than one day. The work included replacing a section of the main with non-perforated pipe and installation of the control structure and distribution line. The distribution pipe was ~1,020 ft long, with ~740 ft of the tile going towards the South and ~280 ft going to the North. Flow monitoring was via V-Notch weirs installed as the top stop logs in the control structure. Flow depth was measured using water level sensors. Water samples were collected approximately twice a month when the tile was flowing.

Ditch Characteristics:
The ditch is less than six feet deep with well vegetated, relatively stable banks.

Other Important or Notable Site Features:
None.

Any Changes in Conditions During the Project?
None.

Well Setup and Management:
A series of three groundwater monitoring well transects were installed at this site. Each transect contained three wells (one near the ditch bank and the other two equally spaced between the ditch and the distribution line) for sampling the groundwater in the buffer as it moved from the distribution line to the ditch. The depth of each monitoring well is given in the table on the following page. The Well ID’s correspond to the locations indicated on the map to the left.

Structure Management:
The stop logs were not moved for the duration of the project.

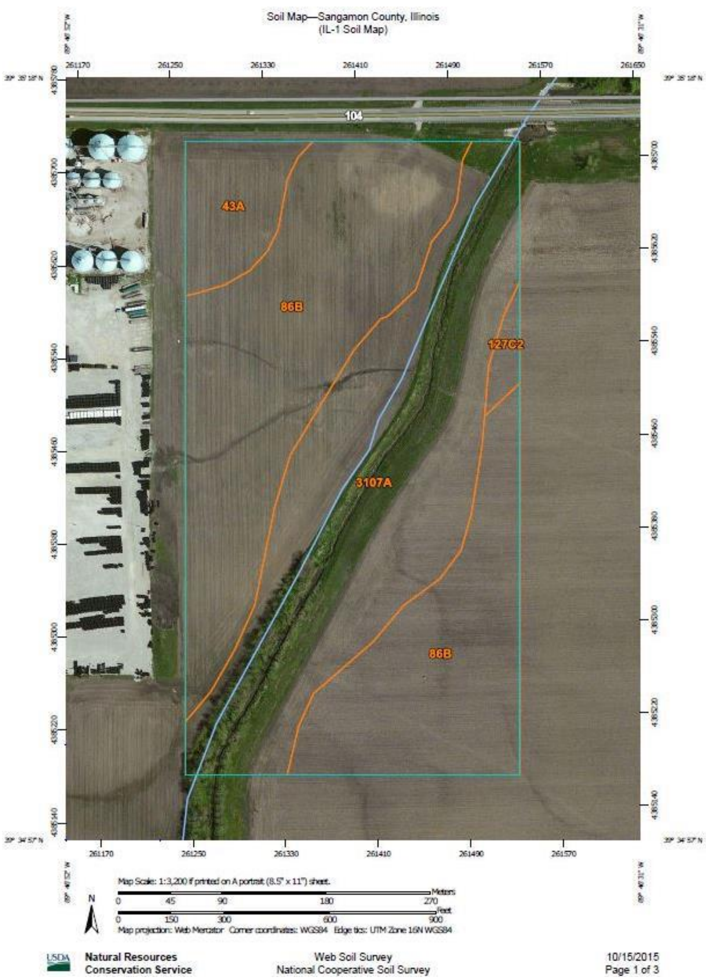
Date	Board Height (in)		Elevation (ft)	
	Field	Buffer	Field	Buffer
Ground	NA	NA	630.2	628.7
5/10/2013	41.32	36.32	626.9	626.5

The "Board Height refers to the height of stop logs within the structure and the corresponding "Elevation of the top stop log.

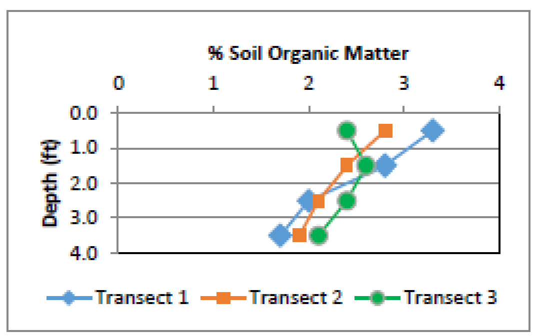
Well ID	Depth (ft.)
IL-1-11	6.33
IL-1-12	6.42
IL-1-13	6.58
IL-1-21	6.25
IL-1-22	6.67
IL-1-23	6.25
IL-1-31	6.75
IL-1-32	6.08
IL-1-33	6.00

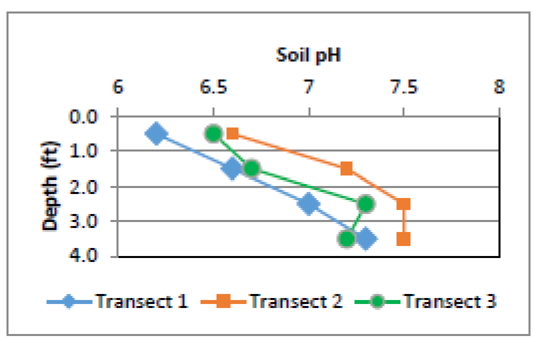
Soil Description (type, texture, etc.):
Soil map and soil series are below.
Soils in the buffer are mapped as Sawmill silty clay loam. Soil cores showed the soil to be silty loam to silty clay loam down to 42 inches. A gleyed soil layer with high chroma redoximorphic features indicative of saturated conditions was about 43 inches on the south side going to 67 of the north side. The south side was calcareous starting at 84 inches, but the rest of the buffer was non-calcareous. No sand layers were present.
Soil Chemical Profiles:

Soil organic matter was greater than about 2% in the top 48 inches. Soil pH was neutral throughout the top 48 inches. Denitrification is maximum at a pH between 7 and 8.5 and decreases sharply for pH ≤ 5.



Map Symbol	Unit Name
43A	Ipava Silt Loam, 0-2 % slopes
86B	Osco Silt Loam, 2-5 % slopes
127C2	Harrison Silt Loam, 5-10% slopes, eroded
3107A	Sawmill Silty Clay Loam 0-2% slopes, frequently flooded





IL – 2

Location: Sangamon Co. IL
S24 T13N R7W 3rd Meridian (Talkington Township)
39.566567°N 89.814644°W
Watershed HUC12 # 071300070702

Drained Area and Tile System:
The saturated buffer was installed on an existing 12” tile outlet. The drained area treated by the buffer is 63 ac. or 25.4 ha. The field and buffer are at similar elevations and both are fairly flat. The field was in a corn-soybean rotation for the duration of the project.

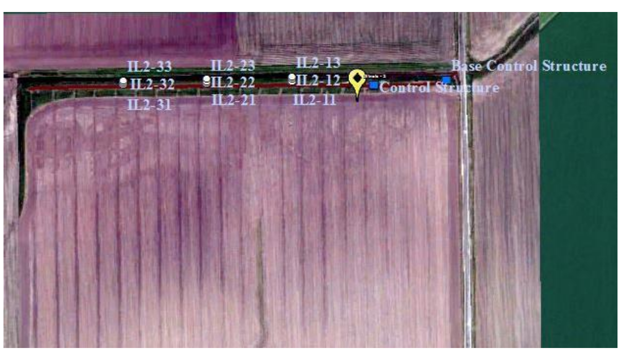
Buffer Dimensions, and Characteristics:
The existing CRP buffer width is ~80 feet wide and is planted to hardy perennial grasses along the stream bank.

Installation Date: July 2012

Installation Cost:
The overall cost for this project site was $2,440 with $1840 attributed to the structure cost.

Installation Management Information:
The saturated buffer was installed by a local contractor who used a backhoe to do the work in less than one day. The work included installing the control structures and replacing sections of the main near the structures with non-perforated pipe. The upper 1,635 ft of the perforated 12” main was used as the distribution line at this site. Flow monitoring was via V-Notch weirs installed as the top stop logs in the control structure. Flow depth was measured using water level sensors. Water samples were collected approximately twice a month when the tile was flowing.

Ditch Characteristics:
This ditch begins near the northwest corner of the field. It is fairly shallow, ranging from approximately 2.5 ft. – 4.5 ft. deep.



Other Important or Notable Site Features:
This site is different than the others in that the existing perforated main was used for the distribution line. While this simplified the installation process it did make flow monitoring more difficult.

Any Changes in conditions during the project?
None.

Well Setup and Management:
A series of three groundwater monitoring well transects were installed at this site. Each transect contained three wells (one near the ditch bank and the other two equally spaced between the ditch and the distribution line) for sampling the groundwater in the buffer as it moved from the distribution line to the ditch. The depth of each monitoring well is given in the table on the following page. The Well ID’s correspond to the locations indicated the map above.

Structure Management:
Because the buffer and cropped area are at similar elevations the stop logs needed to be managed to ensure adequate drainage needs for crop production were satisfied. Due to the conditions at this site there are only one set of stoplogs in the control structure, which managed both the buffer and the field.

Well ID	Depth (ft.)
IL-2-11	6.25
IL-2-12	6.25
IL-2-13	6.50
IL-2-21	6.42
IL-2-22	6.25
IL-2-23	6.42
IL-2-31	6.67
IL-2-32	6.50
IL-2-33	6.08

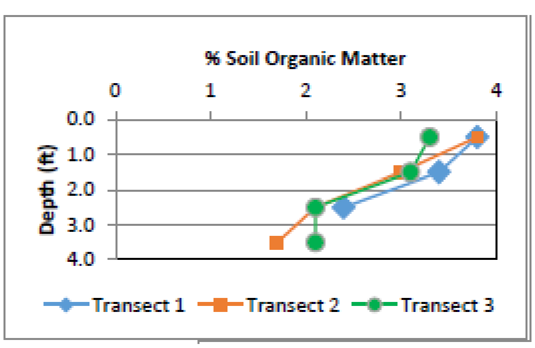
Date	Board Height (in)		Elevation (ft)	
	Field	Buffer	Field	Buffer
Ground	NA	NA	640.5	639.1
July 2012	NA	45.32	NA	639.9
6/6/2013	NA	24.38	NA	638.2
5/19/2014	NA	29.38	NA	638.6
6/8/2015	NA	17.38	NA	637.6

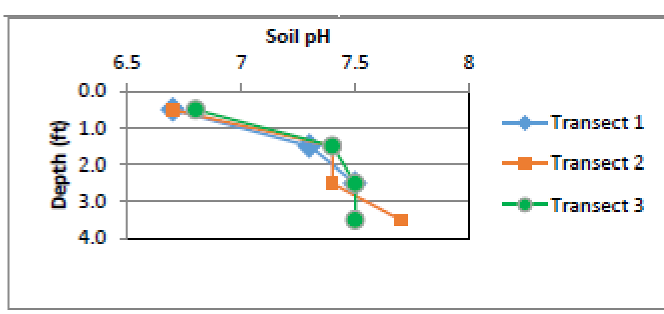
The "Board Height" refers to the height of stop logs within the structure and the corresponding "Elevation" of the top stop log.

Soil Description (type, texture, etc.):
The soil map and soil series are below. Soils in the buffer are mapped as Virden silty clay loam. Soil cores showed the soil to be a silty clay loam down to 42 inches. Below this depth, the soil showed evidence of saturation starting at 30 inches on the east side of the buffer grading to 67 inches on the west side. High chroma redoximorphic concentrations above these depths indicate periodic saturation.

Map Symbol	Unit Name
43A	Ipava Silt Loam, 0-2% slopes
50A	Virden Silty Clay Loam, 0-2% slopes

Soil Chemical Profiles
Soil organic matter was greater than about 2% in the top 48 inches. Soil pH was neutral grading to alkaline at 3½ feet. Denitrification is maximum at a pH between 7 and 8.5 and decreases sharply for pH ≤ 5.





IL - 3

Location: Edgar Co. IL
S3 T15N R13W 2nd Meridian (Shiloh Township)
39.788653°N 87.852870°W
Watershed HUC12 # 051201120301

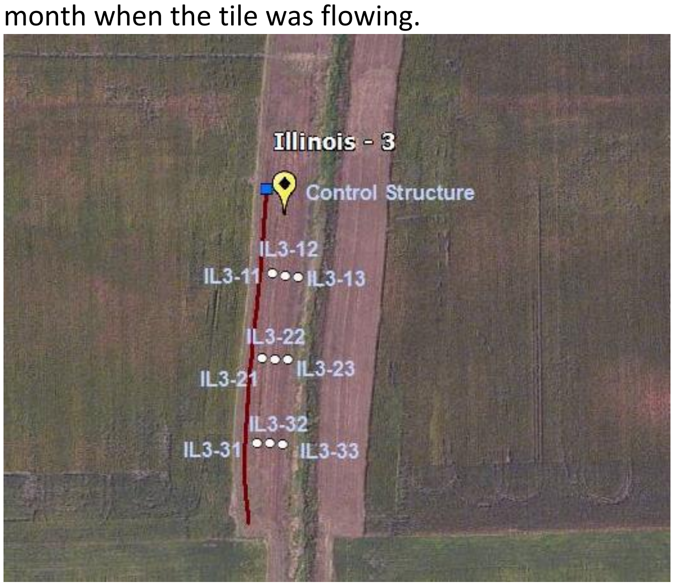
Drained Area and Tile System:
The saturated buffer was installed on an existing 12” outlet. The drainage area for this tile system is 38 ac. or 15.5 ha. The field and buffer are at a similar elevation and both are fairly flat. The field was in a corn-soybean rotation for the duration of the project.

Buffer Dimensions and Characteristics:
The existing CRP buffer width is ~75 feet wide and is planted to hardy perennial grasses.

Installation Date: July 2012

Installation Cost:
The overall cost for this project site was $3,680, with $1.755 attributed to the control structure.

Installation and Monitoring Information:
The saturated buffer was installed by a local contractor who used a backhoe and plow to do the work in less than one day. The work included replacing a section of the main with non-perforated pipe and installation of the control structure and distribution line. The distribution line is ~585 ft long and extends southward from the control structure. Flow monitoring was via V-Notch weirs installed as the top stop logs in the control structure. Flow depth was measured using water level sensors. Water samples were collected approximately twice a month when the tile was flowing.



Ditch Characteristics:
This ditch is about 10 ft deep with well-vegetated, sloped, stable banks.

Other Important or notable site features:
None.

Any Changes in conditions during the project?
None.

Well Setup and Management:
A series of three groundwater monitoring well transects were installed at this site. Each transect contained three wells (one near the ditch bank and the other two equally spaced between the ditch and the distribution line) for sampling the groundwater in the buffer as it moved from the distribution line to the ditch. The depth of each monitoring well is given in the table on the following page. The Well ID’s correspond to the locations indicated on the map above.

Structure Management:

Because the buffer and cropped area are at similar elevations the stop logs needed to be managed to ensure adequate drainage needs for crop production were satisfied.

Date	Board Height (in)		Elevation (ft)	
	Field	Buffer	Field	Buffer
Ground	NA	NA	647.5	647
July 2012	17.44	14.44	643.5	643.3
1/22/2013	65.38	46.32	647.5	645.9
6/6/2013	36.38	31.32	645.1	644.7
11/24/2013	46.38	41.32	645.9	645.5
4/5/2014	29.38	24.32	644.5	644.1
4/7/2013	17.38	12.32	643.5	643.1
6/21/2014	41.25	36.25	645.5	645.1
4/22/2015	5.44	5.44	642.5	642.5
5/13/2015	12.44	17.44	643.1	643.5
5/18/2015	17.44	12.44	643.5	643.1

Well ID	Depth (ft.)
IL-3-11	6.92
IL-3-12	6.83
IL-3-13	6.00
IL-3-21	7.00
IL-3-22	7.00
IL-3-23	7.00
IL-3-31	6.83
IL-3-32	7.17
IL-3-33	7.17

The "Board Height" refers to the height of stop logs within the structure and the corresponding "Elevation" of the top stop log.

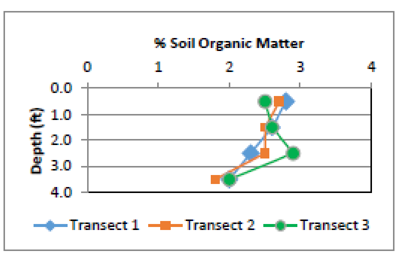
Soil Description (type, texture, etc.):

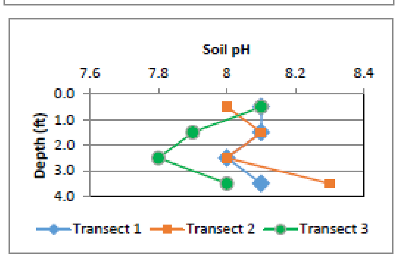
The soil map and soil series are below. Soils in the buffer are mapped as Drummer silty clay loam. Soil cores showed the soil to be loam to silty clay loam down to 42 inches. Starting at 57 to 81 inches the soil is gleyed with high chroma redoximorphic concentrations indicating periodic saturation. Soil is massive and calcareous starting at 90 inches. No coarse textured soil horizons were present.

Map Symbol	Unit Name
152A	Drummer Silty Clay Loam 0-2% slopes
154A	Flanagan Silt Loam, 0-2% slopes

Soil Chemical Profiles

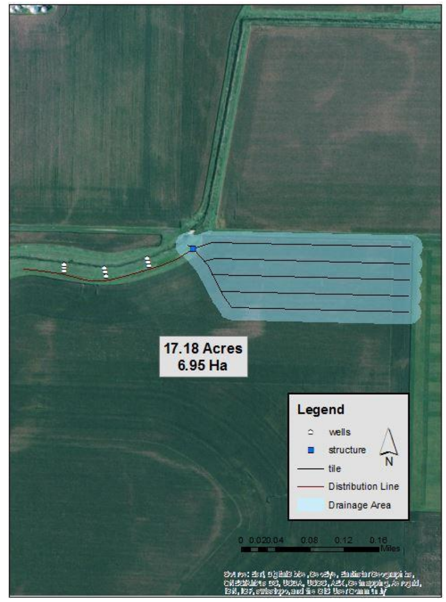
Soil organic matter was greater than about 2% in the top 48 inches. Soil pH was alkaline throughout the top 3½ feet reflecting the presence of calcareous soils below 75 inches. Denitrification is maximum at a pH between 7 and 8.5 and decreases sharply for pH ≤ 5.





IL – 4

Location: Piatt Co. IL
S3 T18N R4E 3rd Meridian (Willow Branch Township)
40.054900°N 88.740330°W
Watershed HUC12 # 071300060301



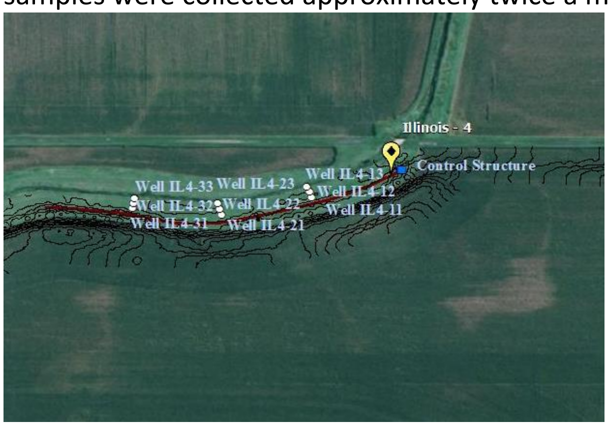
Drained Area and Tile System:
The saturated buffer was installed on an existing 5" outlet. The drainage area for this tile system is 18 ac. or 7 ha. The buffer has a small amount of slope and the distribution line was installed along a contour. The field has some slope to it as well. The field was in a corn-soybean rotation for the duration of the project.

Buffer Dimensions and Characteristics:
The existing CRP buffer width is ~105 feet wide and is planted to hardy perennial grasses.

Installation Date: June 2013

Installation Cost:
The overall cost for this project site was $4,215 with $1,495 attributed to the control structure.

Installation and Monitoring Information:
The saturated buffer was installed by a local contractor who used a backhoe and plow to do the work in less than one day. The work included replacing a section of the main with non-perforated pipe and installation of the control structure and distribution line. The distribution line is ~1,300 ft. long and runs roughly westward from the control structure. Flow monitoring was via V-Notch weirs installed as the top stop logs in the control structure. Flow depth was measured using water level sensors. Water samples were collected approximately twice a month when the tile was flowing.



Ditch Characteristics:
The ditch is about six feet deep with well-vegetated, sloped, and relatively stable banks.

Other Important or Notable Site Features:
None.

Any Changes in Conditions During the Project?
None.

Well setup and Management:
A series of three groundwater monitoring well transects were installed at this site. Each transect contained three wells (one near the ditch bank and the other two equally spaced between the ditch and the distribution line) for sampling the groundwater in the buffer as it moved from the distribution line to the ditch. The depth of each monitoring well is given in the table on the next page. The Well ID's correspond to the locations indicated on the map above.

Structure Management:
The stop logs were adjusted shortly after installation. Otherwise, they were not moved for the duration of the project.

Date	Board Height (in)		Elevation (ft)	
	Field	Buffer	Field	Buffer
Ground	NA	NA	674.0	671.1
June 2013	19.57	13.30	669.7	669.2
8/14/2013	22.57	17.57	670.0	669.5

The "Board Height" refers to the height of stop logs within the structure and the corresponding "Elevation" of the top stop log.

Well ID	Depth (ft.)
IL-4-11	6.08
IL-4-12	6.08
IL-4-13	5.58
IL-4-21	6.50
IL-4-22	*6.50*
IL-4-23	5.92
IL-4-31	6.08
IL-4-32	6.08
IL-4-33	6.08

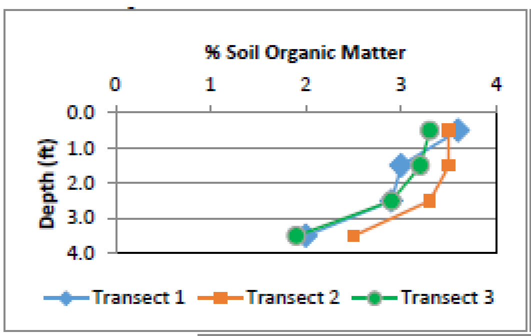
Soil Description (type, texture, etc.):

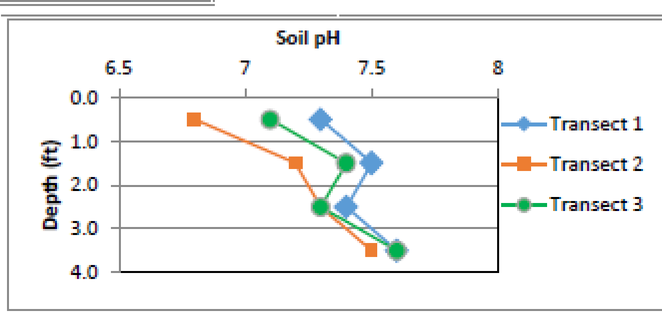
The soil map and soil series are below. Soils in the buffer are mapped as Radford silt loam. Soil cores showed the soil to be a silt loam to or clay loam down to 42 inches. Below 63 inches the soil was gleyed indicative of saturation. No coarse-textured layers were encountered.

Map Symbol	Unit Names
43A	Ipava Silt Loam, 0-2% slopes
56C2	Dana Silty Clay Loam, 5-10% slopes, eroded
68A	Sable Silty Clay Loam, 0-2% slopes
154A	Flanagan Silt Loam, 0-2% slopes
171B	Catlin Silt Loam, 2-5% slopes
171B2	Catlin Silt Loam, 2-5% slopes, eroded
3074A	Radford Silt Loam, 0-2% slopes, frequently flooded
3107A	Sawmill Silty Clay Loam, 0-2% slopes, frequently flooded

Soil Chemical Profiles:

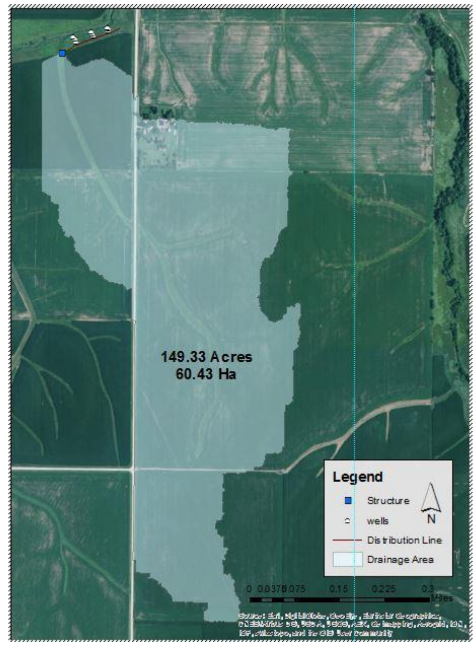
Soil organic matter was greater than about 2% in the top 48 inches. Soil pH was neutral trending alkaline with depth. Denitrification is maximum at a pH between 7 and 8.5 and decreases sharply for pH ≤ 5.





IL – 5

Location: Rock Island Co.
S23 T16N R3W 4th Meridian (Edgington Township)
41.36779°N 90.689689°W
Watershed HUC12 # 070900051201



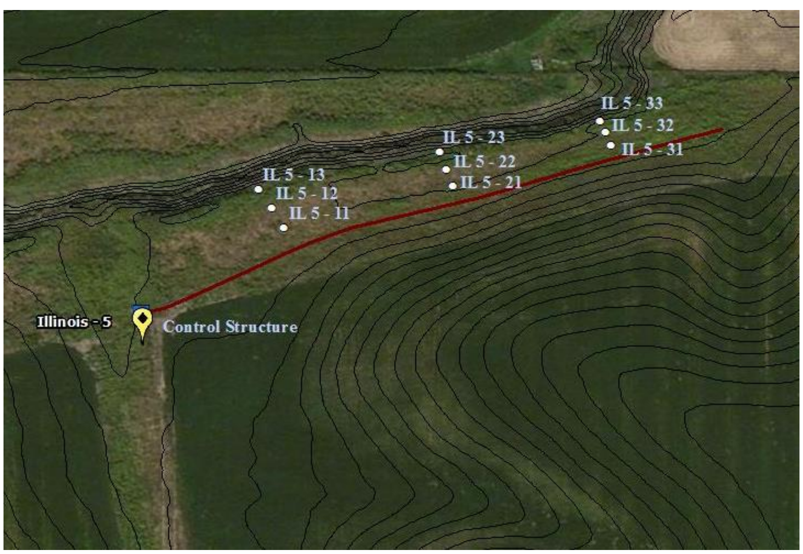
Drained Area and Tile System:
The saturated buffer was installed on an existing 12” outlet. There was not a tile map available for this site, but the estimated drainage area is 149 ac. or 60.4 ha. The buffer is sloped and the distribution line was installed along a contour. The field also has a relatively steep slope. The field was in a corn-soybean rotation for the duration of the project.

Buffer Dimensions and Characteristics:
The existing CRP buffer width is ~120 feet wide and is planted to native prairie grasses.

Installation Date: March 26, 2013

Installation Cost:
The overall cost for this project site was $3,205 with $2,079 attributed to the cost of the control structure.

Installation Management Information:
The saturated buffer was installed by a local contractor who used a backhoe and trencher to do the work in less than one day. The work included replacing a section of the main with non-perforated pipe and installation of the control structure and distribution line. The distribution line was ~720 ft long and runs roughly eastward from the control structure. Flow monitoring was via V-Notch weirs installed as the top stop logs in the control structure. Flow depth was measured using water level sensors. Water samples were collected approximately twice a month when the tile was flowing.



Ditch Characteristics:
The ditch is approximately eight feet deep with steep, almost vertical sides that are prone to sloughing. The channel has some minor meanders and the banks commonly have exposed soil.

Other Important Site Features:
None.

Any Changes in Conditions During the Project?
None.

Well Setup and Management:
A series of three groundwater monitoring well transects were installed at this site. Each transect contained three wells (one near the ditch bank and the other two equally spaced between the ditch and the distribution line) for sampling the groundwater in the buffer as it moved from the distribution line to the ditch. The depth of each monitoring well is given in the table on the following page. The Well ID’s correspond to the locations indicated on the map above.

Structure Management:
The stop logs were not moved for the duration of the project.

Date	Board Height (in)		Elevation (ft)	
	Field	Buffer	Field	Buffer
Ground	NA	NA	606.9	605.8
3/26/2013	57.25	50.32	604.4	603.8

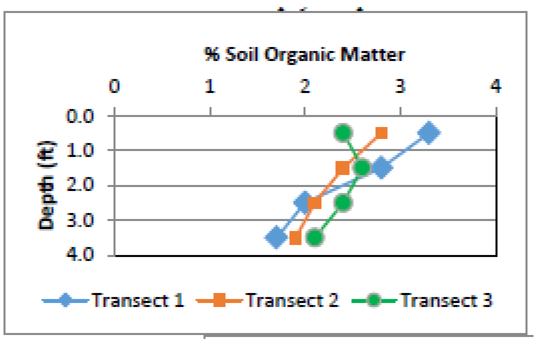
The "Board Height" refers to the height of stop logs within the structure and the corresponding "Elevation" of the top stop log.

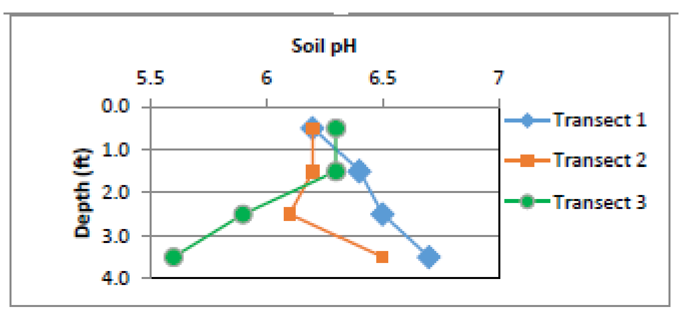
Well ID	Depth (ft.)
IL-5-11	6.33
IL-5-12	6.42
IL-5-13	6.67
IL-5-21	5.92
IL-5-22	6.50
IL-5-23	6.83
IL-5-31	5.67
IL-5-32	6.17
IL-5-33	6.83

Soil Description (type, texture, etc.):
The soil map and soil series are below. Soils in the buffer are mapped as Radford silt loam. Soil cores showed the soil to be silt loam to silty clay loam down to 42 inches. At about 59 inches the sandy soil was gleyed indicative of reducing (saturated) conditions.

Map Symbol	Unit Name
8F	Hickory Silt Loam, 18-35% slopes
19D	Sylvan Silt Loam, 10-18% slopes
86B	Osco Silt Loam, 2-5% slopes
946D3	Hickory-Atlas Complex,10-18% slopes, severely eroded
3074A	Radford Silt Loam,0-2% slopes, frequently flooded

Soil Chemical Profiles
Soil organic matter was greater than about 2% in the top 48 inches. Soil pH was neutral in the top 3 ½ feet with Transect 3 going more acid and the other two transects more alkaline with depth. Denitrification is maximum at a pH between 7 and 8.5 and decreases sharply for pH ≤ 5.





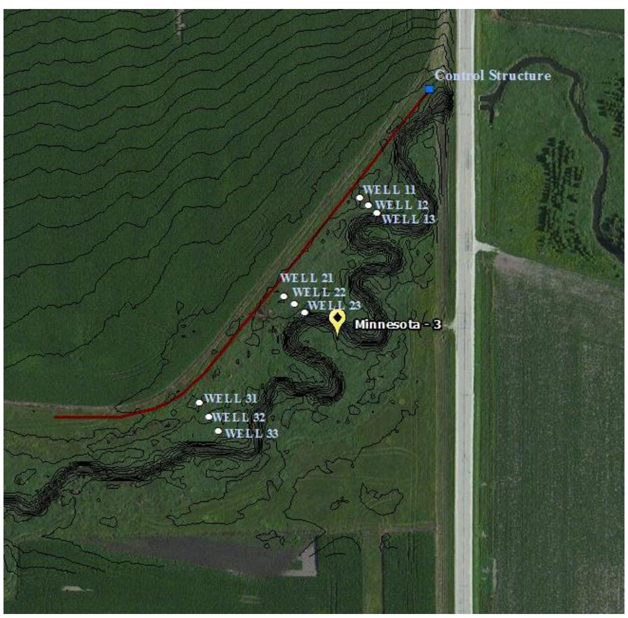
MN – 3

Location: Dodge Co. MN
S34 T108N R17W 5th Meridian (Concord Township)
44.113780°N 92.850176°W
Watershed HUC12 # 070400040304

Drained Area and Tile System:
The saturated buffer was installed on an existing 6" outlet. The drainage area for this tile system is 28 ac. or 11.4 ha. The buffer is fairly flat with some wet depressions. The field slopes uniformly to the north. The field was in a corn-soybean rotation for the duration of the project.

Buffer Dimensions and Characteristics:
The existing CRP buffer is ~35 to 150 ft wide and is planted to hardy perennial grasses. There are also some occasional shrubs.

Installation Date: April 2013
Installation Cost:
The overall cost for this project site was $3,670 with $1,400 attributed to the control structure.
Installation and Monitoring Information:
The saturated buffer was installed by a local contractor who used a backhoe and tile plow to do the work in less than one day. The work included replacing a section of the main with non-perforated pipe and installation of the control structure and distribution line. The distribution line is ~1,000 ft long and runs westward from the control structure. Flow depth was measured using water level sensors. Water samples were collected approximately twice a month when the tile was flowing.



Ditch Characteristics:
The stream is less than six feet deep and meanders extensively through the buffer.
Other Important or Notable Site Features:
None.
Any Changes in Conditions During the Project?
None.

Well Setup and Management:
A series of three groundwater monitoring well transects were installed at this site. Each transect contained three wells (one near the stream bank and the other two equally spaced between the stream and the distribution line) for sampling the groundwater in the buffer as it moved from the distribution line to the stream. The depth of each monitoring well is given in the table on the following page. The Well ID's correspond to the locations indicated on the map above.

Structure Management:
The stop logs were not moved for the duration of the project.

Date	Board Height (in)		Elevation (ft)	
	Field	Buffer	Field	Buffer
Ground	NA	NA	1214.8	1212.5
April 2013	30.19	17.57	1211.8	1210.7
2/25/2014	17.57	17.57	1210.7	1210.7
11/21/2014	30.19	17.58	1211.8	1210.7

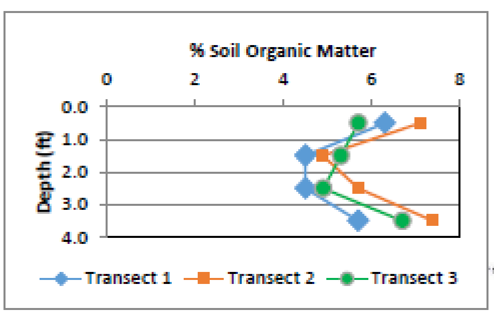
The "Board Height" refers to the height of stop logs within the structure and the corresponding "Elevation" of the top stop log.

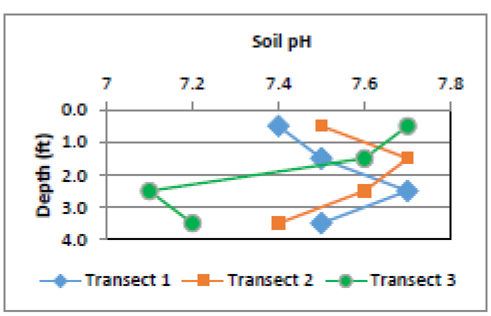
Well ID	Depth (ft.)
MN-3-11	5.83
MN-3-12	4.79
MN-3-13	5.67
MN-3-21	5.67
MN-3-22	5.67
MN-3-23	5.92
MN-3-31	6.13
MN-3-32	6.13
MN-3-33	5.29

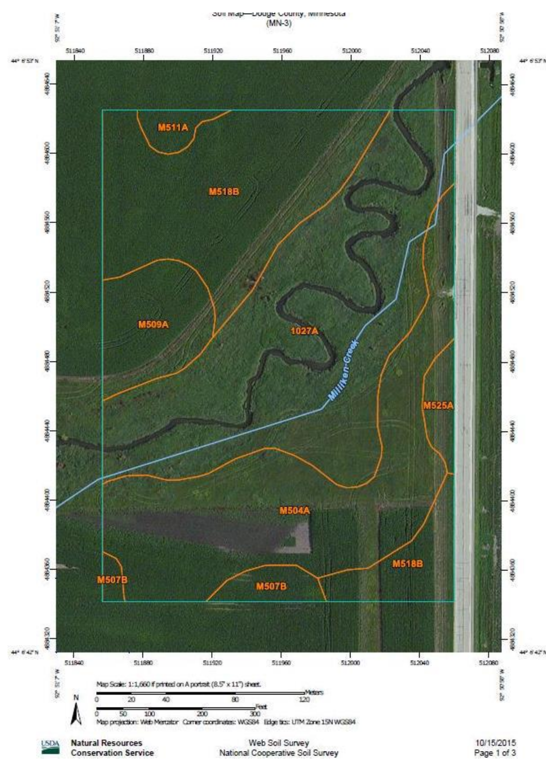
Soil Description (type, texture, etc.):
The soil map and soil series are below. Soils in the buffer are mapped as Coland-Spillville complex. Soil cores showed the soil to be loam to silt loam down to 42 inches. Starting at about 47 inches was a calcareous gleyed sandy material indicating reducing (saturated) conditions.

Map Symbol	Unit Name
1027A	Coland-Spillville Complex,0-2% slopes, flooded
M504A	Marshan Clay Loam, 0-2% slopes
M507B	Marquis Silt Loam, 2-6% slopes
M509A	Mantorville Loam, 0-2% slopes
M511A	Readlyn Silt Loam, 1-3% slopes
M518B	Clyde-Floyd complex, 1-4% slopes
M525A	Dakota Silt Loam, 0-3% slopes

Soil Chemical Profiles
Soil organic matter was very high at this site exceeding 4.5% everywhere in the top 48 inches. Soil pH was neutral throughout the top 3½ feet although the soil was calcareous at 65 inches depth. Denitrification is maximum at a pH between 7 and 8.5 and decreases sharply for pH ≤ 5.

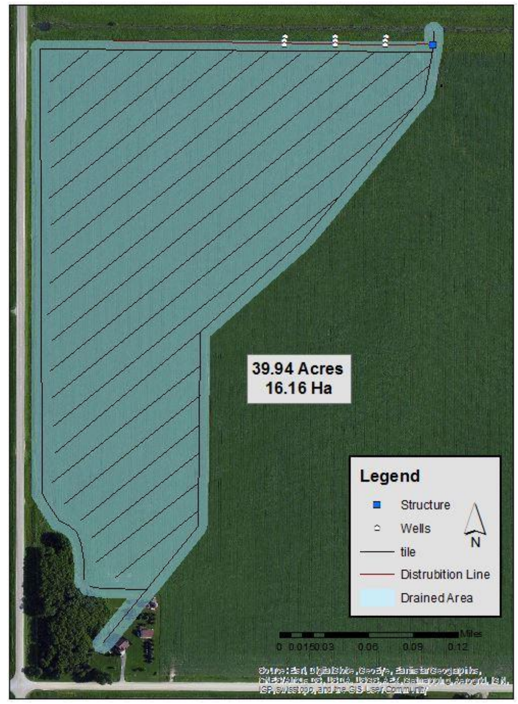






MN – 4

Location: Dodge Co. MN
S6 T106N R16W 5th Meridian (Canisteo Township)
44.014358°N 92.793908°W
Watershed HUC12 # 070400040204



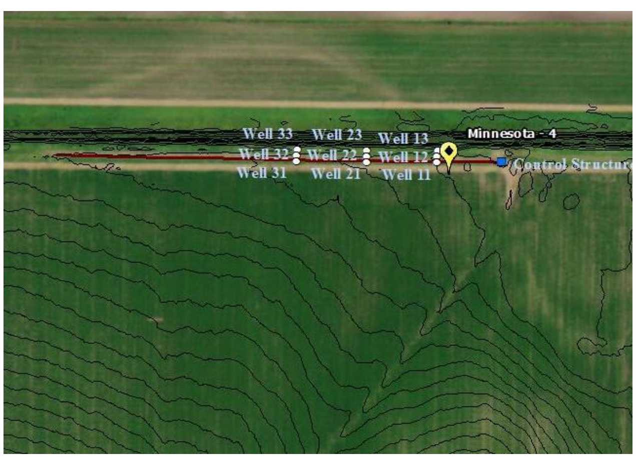
Drained Area and Tile System:
The saturated buffer was installed on an existing 6" outlet. The drainage area for this tile system is 40 ac. or 16.2 ha. The field has a fair amount of slope to it. However, the northeast corner (near the control structure) is relatively flat and at a similar elevation as the buffer. This field was in a corn-soybean rotation for the duration of the project.

Buffer Dimensions and Characteristics:
The existing CRP buffer is ~ 80 feet wide and is hardy perennial grasses.

Installation Date: June 2013

Installation Cost:
The overall cost for this project site was $2,453 with $1,117 being attributed to the control structure

Installation Information:
The saturated buffer was installed by a local contractor who used a backhoe and tile plow to do the work in less than one day. The work included replacing a section of the main with non-perforated pipe and installation of the control structure and distribution line. The distribution line is ~850 ft and runs due west from the control structure. Flow depth was measured using water level sensors. Water samples were collected approximately twice a month when the tile was flowing.



Ditch Characteristics:
The stream is less than six feet deep and is well-vegetated with relatively stable banks.

Other Important or Notable Site Features:
None.

Any Changes in Conditions During the Project?
None.

Well Setup and Management:
A series of three groundwater monitoring well transects were installed at this site. Each transect contained three wells (one near the ditch bank and the other two equally spaced between the ditch and the distribution line) for sampling the groundwater in the buffer as it moved from the distribution line to the ditch. The depth of each monitoring well is given in the table to the right. The Well ID's correspond to the locations indicated on the map above.

Well ID	Depth (ft.)
MN-4-11	4.79
MN-4-12	6.29
MN-4-13	6.71
MN-4-21	6.54
MN-4-22	6.21
MN-4-23	5.00
MN-4-31	5.21
MN-4-32	6.38
MN-4-33	6.75

Structure Management:
Because the buffer and cropped area are at similar elevations the stop logs needed to be managed to ensure adequate drainage needs for crop production were satisfied.

Date	Board Height (in)		Elevation (ft)	
	Field	Buffer	Field	Buffer
Ground	NA	NA	1265.0	1263.5
June 2013	32.44	27.44	1261.9	1261.5
7/24/2014	27.50	22.50	1261.5	1261.1
5/26/2015	32.50	27.42	1261.9	1261.5

The "Board Height" refers to the height of stop logs within the structure and the corresponding "Elevation" of the top stop log.

Soil Description (type, texture, etc.):

The soil map and soil series are below. Soils in the buffer are mapped as Clyde silty clay loam. Soil cores showed the soil to be loam or clay loam transitioning to sandy loam at 3½ feet. A narrow layer from about 26 to 41 was gleyed with high chroma redoximorphic concentrations indicating reducing (saturated) conditions. Under this layer was a sandy calcareous layer containing pebbles.

Map Symbol	Unit Name
M507A	Marquis Silt Loam, 1-3% slopes
M511A	Readlyn Silt Loam, 1-3% slopes
M515A	Tripoli Silty Clay Loam, 0-2% slopes
M517A	Clyde Silty Clay Loam, 0-3% slopes

Soil Chemical Profiles

Soil organic matter was very high at the surface and exceeded 1.3% in the top 42 inches. Soil pH was neutral at the surface trending alkaline at depth reflecting the presence of calcareous soil at 35 – 45 inches. Denitrification is maximum at a pH between 7 and 8.5 and decreases sharply for pH ≤ 5.