2021 Final Report Summary Sheet

Grantee Information

Project Title: Modelling and Designing Saturated Buffers for Nitrogen and Phosphorus Mitigation in Illinois

Institution: Southern Illinois University

Primary Investigator: Jon Schoonover

NREC Project # NREC-2019-5-206333-436

Is your project on target from an IMPLEMENTATION standpoint? ☒ **Yes** ☐ **No**

If you answered "no" please explain:

Is your project on target from a BUDGET standpoint? ☒ **Yes** ☐ **No**

If you answered "no" please explain:

Based on what you know today, will you meet the objectives of your project on-time and on-budget? ☒ **Yes** ☐ **No**

If you answered "no" please explain:

Have you encountered any issues related to this project? ☐ **Yes** ☒ **No**

If you answered "yes" please explain:

The ISCO 6712ci LTE telemetry device stopped working, so storm event sampling was scaled back to one per season in August of 2021.

Have you reached any conclusions related to this project that you would like to highlight? ☒ **Yes** ☐ **No**

If you answered "yes" please explain:

Our data suggest that Saturated buffers are effective at nutrient attenuation during base flow conditions but are much less effective during high flows. The Moultrie county site experiences elevated water tables and has relatively low saturated hydraulic conductivity, which resulted in high backflow from dispersion lines during significant storm events on the standard saturated buffer. Furthermore, this site was on the lower end of the spectrum for acceptable levels of soil organic carbon, which could potentially further inhibit nitrate removal. Future designs should focus on areas with lower water tables or have backflow valves installed to minimize water contribution from the dispersion lines.

Have you completed any outreach activities related this project? Or do you have any activities planned? ☒ **Yes** ☐ **No**

If you answered "yes" please explain and provide details for any upcoming outreach:

This project was highlighted virtually in the form of a poster at a conference hosted by University Council of Water Resources (UCOWR) in June 2021.

Research was presented to local farmers and stakeholders at an NREC Field Day July 9, 2021 hosted at SIU.

Please write a detailed summary report that includes: Details of each objective and the progress made towards its competition, planned research activities for 2022, major accomplishments, any preliminary findings or data relevant to the project, relevant budgeting, and any publications or outreach accomplished from the research. Please **include a one page summary with relevant data tables or graphs and pictures related to the project that you would like included in the NREC end of the year report.**

Summary

The past year was an active year for data collection and analyses at the saturated buffer site in Moultrie County. During 2021, 240 groundwater samples were collected from the monitoring wells throughout the year and there were 11 storm events sampled by the ISCOs. Based on analysis of ISCO data, in-field observations, and stage data from the control structures, we determined that high flow events created high turbulence in both control boxes that interfered with the calibration and accuracy of the pressure transducers. For that reason, water level readings were unreliable during high flows, which resulted in erroneous discharge estimates that were not representative of actual flows. The stormflow data from the ISCO samples was used to calculate loads input to the buffer, and outflows were estimated based on the percentage of flow diverted in each buffer at baseflow. In 2021 the pitchfork buffer outperformed the standard in by reducing discharge and nutrient loading by 17% (Table 2). The standard buffer consistently had more backflow events and higher nutrient loading to the stream, contributing and contributed 82% greater flows and nutrients to the stream (Table 2).

Volume and nutrient loads flowing into and out of each buffer when the outlet is discharging in 2021.

Treatment	Volume in (gallon/ac)	Volume out (gallon/ac)	Nitrate-N in (lb/ac)	Nitrate-N out (lb/ac)	DRP in (lb/ac)	DRP out (lb/ac)
Pitchfork	26,638.16	22,108.67	1.14	0.95	0.02	0.02
Standard	56,231.17	102,340.72	2.62	4.78	0.05	0.09

The results of the denitrification potential experiment suggest denitrifying bacteria are present in the soil of both buffers. For the pitchfork buffer conditions are most favorable for denitrification in the first 12-inches of soil, which does become saturated during high flows, while in the standard buffer denitrification was highest at 1-2 feet (Table 3). The overall rates of denitrification are within range of other saturated buffers, which span from 0.004 mg N_2O kg^{-1} hr^{-1} to 70.83 mg N_2O kg^{-1} hr^{-1} where denitrification was present, but this is likely due to lower soil organic carbon content at this site and the smaller sample size for this study (Groh *et al*., 2018).

Denitrification rates of standard and pitchfork buffers.

Average Denitrification Rate (mg N_2O kg^{-1} soil hr^{-1})		
Depth (feet)	Standard	Pitchfork
0-1	1.65	4.64
1-2	2.50	0.08
2-3	0.03	0.07

Objective 1. Design, install, and monitor a saturated buffer implementing a new pitchfork design equipped with backflow check valves to test the impact on water quality (nitrogen and phosphorus) and quantity reaching the tile outlet and compare results to a standard buffer in the same field.

A summary of events to date related to the saturated buffer project (Table 1).

Table 1: Timeline of accomplishments.

Date	Activity
4/23/18	Saturated buffer partnership formed.
1/4/2019	Deep soil cores collected.
3/19/19	Saturated buffer installation.
3/20/19	Saturated buffer field day.
6/4/19	Corn planted.
6/4/19	Broadcast sprayed (DiFlexx, RoundUp, Atrazine with 15 gallons of 32% (53 lbs of N).
5/2/19	Spring soil sampling completed.
6/6/19	Platforms constructed for ISCO samplers and solar panels installed.
7/2/19	Side-dressed 40 gal/ac of 32% (142 lbs of N).
7/3/19	Teledyne ISCO 6712 autosamplers arrive and taken to field site.
7/31/19	Teledyne ISCO 720P Pressure Transducers installed and initial Programming of ISCOs complete.
9/4/19	Remote Telemetry on ISCO autosampler installed and running.
10/3/19	Cover crops planted in the standard and pitchfork buffers.
1/29/2020	Monitoring well elevations surveyed.
6/5/20	Soybeans planted.
10/14/20	Soybeans harvested.
10/15/21	Strip tilling with Zn and gypsum application.
10/22/20	Fall 2020 soil sampling completed.
4/6/21	Deep soil cores collected.
4/27/21	Corn planted. Applied 70 lbs of N.
4/28/21	Applied herbicides Gramaxone, Atrazine, and Acuron.
5/30/21	Side-dressed 140 lbs of N.
6/3/2021	Applied herbicides RoundUp and Capreno.
8/5/2021	Applied fungicide Delaro.
11/4/21	Corn harvested.
11/16/21	Fall 2021 soil sampling completed.

Groundwater Quality

In 2021, 240 samples were collected from the monitoring wells. The routine groundwater sampling shows an overall decrease in NO_3-N concentration from the field edge to the final well closest to the stream (Figure 1). While some middle wells in the pitchfork buffer that are in proximity to the lateral dispersion lines show increases in NO_3-N concentration there is an overall reduction by the last well (Figure 1B). All samples were below the USEPA drinking water standards of 10 mg L^{-1} for nitrate-N. Further, nitrate-N concentrations were consistently

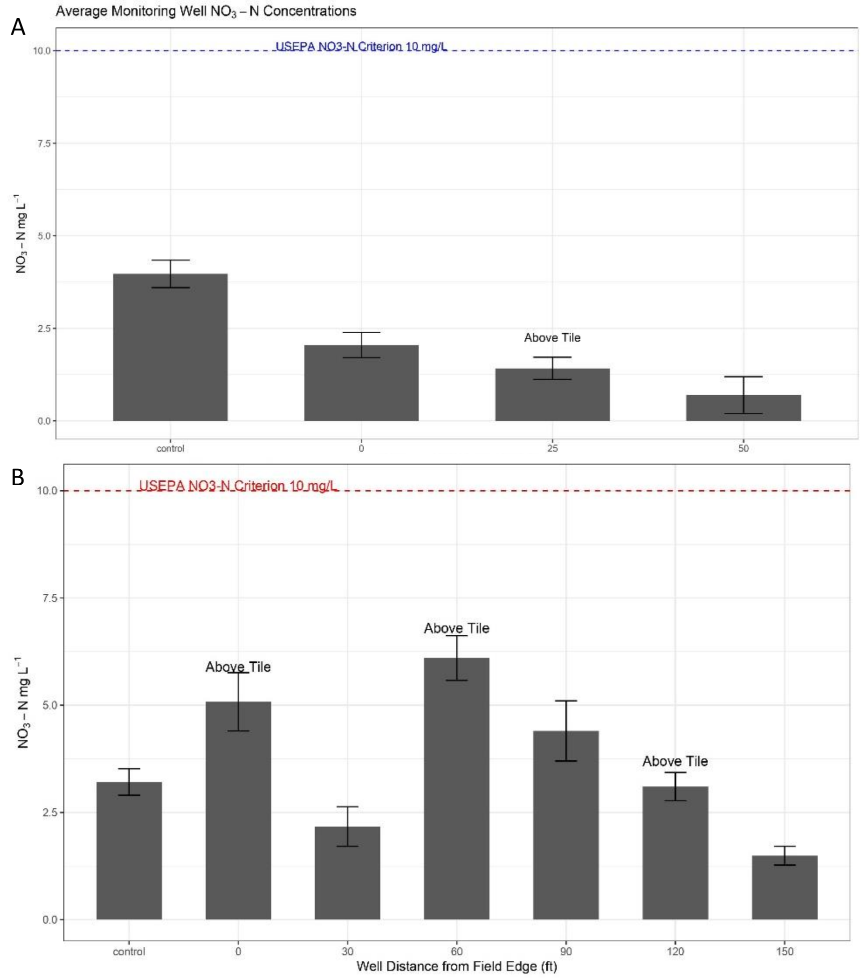

Figure 1: Standard Buffer (A) and Pitchfork Buffer (B) average monitoring well NO_3-N concentrations in 2021.

lowest in the wells closest to the stream. This is likely due to plant assimilation by the buffer vegetation, or denitrification under the saturated conditions. Similarly, standard buffer NO_3-N concentrations also decrease with distance from the field. Both buffers showed an overall reduction in nitrate-N, although there were some increases mid-buffer in proximity to the dispersion lines (Figure 1B).

The results for DRP were less consistent. In the standard buffer some individual well samples exceeded the USEPA drinking water criterion of 0.10 mg L^{-1}, but on average the DRP levels fall below the USEPA limits. The well in the field and the well closest to the stream had the lowest DRP concentrations, while the two middle wells had the highest DRP concentrations (Figure 2A). In the pitchfork buffer, the DRP concentration of the wells in the field were higher than those in the buffer, more than double that of the next highest well. There was little variation

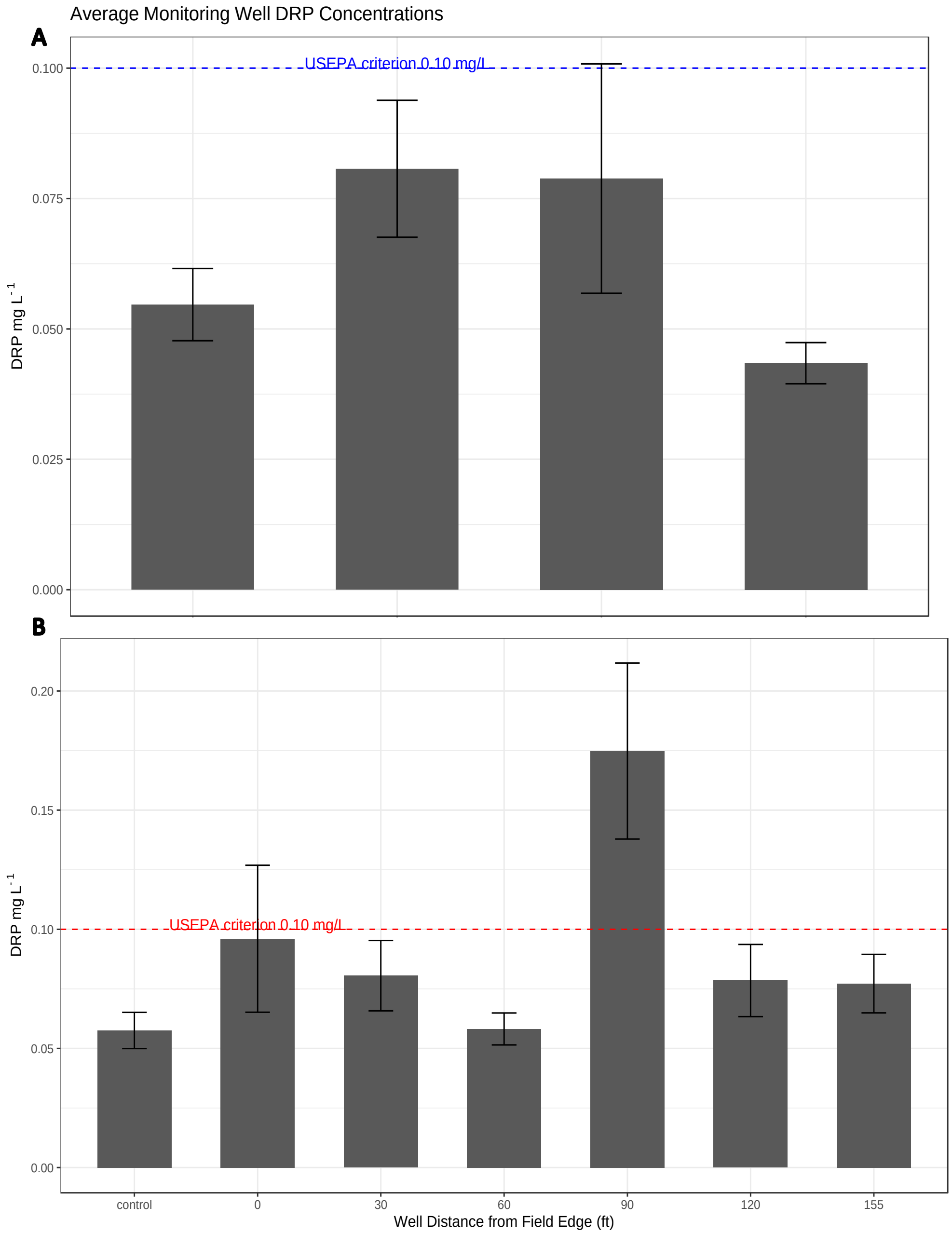

Figure 2: Standard Buffer (A) and Pitchfork Buffer (B) average monitoring well DRP concentrations in 2021.

in DRP concentrations within the buffer (Figure 2B).

Discharge and Nutrient Loading

Image 1: The pitchfork control structure during a high flow event on October 28, 2021. None of the v-notch weirs or chambers are visible due to the high volume of water.

Analysis of storm events throughout the year has yielded poor results, which was determined to be due to turbulence in the control structure during high flows (Image 1). During high flow events much of the water from the field tile completely bypasses the second chamber, and the turbulence interferes with the accuracy of the pressure transducer. For that reason, outflows for storm events were estimated using the percentage of flow diverted at baseflow. Flows were highest in winter and early spring, and both buffers dried up to near zero flows during the summer and early fall when precipitation was low, and antecedent soil moisture was relatively dry.

In 2021, the pitchfork buffer is outperforming the standard buffer in terms of outlet discharge and flow diverted during high flow events (Table 2). During storm events this year, the standard buffer has discharged about 49,110 more gallons to the stream than entered the field tile, indicating a considerable amount of backflow is occurring. At baseflow, the pitchfork buffer (equipped with a backflow valve) diverted about 17% of the volume coming into the field; conversely, the standard buffer (without a backflow valve) contributed more water than what was leaving the patterned tile in the fields due to dispersion line back flow (Table 2).

Table 2: Volume and nutrient loads flowing into and out of each buffer during high flow events in 2021.

Treatment	Volume in (gallon/ac)	Volume out (gallon/ac)	Nitrate-N In (lb/ac)	Nitrate-N out (lb/ac)	DRP In (lb/ac)	DRP out (lb/ac)
Pitchfork	26,638.16	22,108.67	1.14	0.95	0.02	0.02
Standard	56,231.17	102,340.72	2.62	4.78	0.05	0.09

Similar to the discharge results, the pitchfork buffer outperformed the standard buffer in terms of nutrient removal this year. The pitchfork buffer contributed nitrate-N to the stream at a rate of 0.95 pounds per acre, compared to the standard buffer that discharged more than five times the rate of the pitchfork at 4.78 pounds of nitrate-N per acre. About 0.19 pounds of NO_3-N per acre were diverted in the pitchfork buffer during storm events. Due to backflow events in the standard buffer, NO_3-N was lost from the buffer at a rate of 2.16 pounds per acre (Table 2). This trend continued for DRP loading. The pitchfork buffer discharged DRP to the stream at a rate of 0.02 pounds per acre. While the standard buffer discharged DRP to the stream at a greater rate of 0.09 pounds per and the buffer contributed 0.04 pounds of DRP per acre due to backflow (Table 2).

Objective 2. Assess the potential denitrification rates and the changes in deep soil carbon and nitrogen pools in the area surrounding the saturated buffers.

Fall 2021 soil samples were collected on November 16, 2021, following the harvest. Those samples have been dried and ground and were shipped to Brookside Laboratory for nutrient analysis. Three-foot long soil cores were collected in April 2021 for analysis of denitrification rates at 3 depths (i.e., 0-1 feet, 1-2 feet, and 2-3 feet). Samples were analyzed for N_2O in parts per million in the Fermentation Science Lab at SIU.

Denitrification rates in the pitchfork buffer ranged from 14.14 mg N_2O kg^{-1} soil hr^{-1} to 0.05 mg $N_2O kg^{-1}$ soil hr^{-1}, less than other buffers ranging from 70.83 mg N_2O kg^{-1} hr^{-1} to 0.004 mg N_2O kg^{-1} hr^{-1} (Groh *et al*., 2018). The highest rates of denitrification in the pitchfork buffer were in the first 12 inches of soil. The average rate for the first foot of soil was 4.64 mg N_2O kg^{-1} soil hr^{-1}, and average rates for depths 1-2 feet and 2-3 feet were substantially lower with both around 0.07 mg N_2O kg^{-1} soil hr^{-1}. In the standard buffer the rates varied 4.91 mg N_2O kg^{-1} soil hr^{-1} to 0.03 mg N_2O kg^{-1} soil hr^{-1}. The highest rates of denitrification were at 1-2 feet, with an average of 2.50 mg N_2O kg^{-1} soil hr^{-1}. The overall average denitrification rates were similar for the pitchfork and standard buffers at 1.60 mg N_2O kg^{-1} soil hr^{-1} and 1.39 mg N_2O kg^{-1} soil hr^{-1}, respectively (Table 3).

Table 3: Denitrification rates of standard and pitchfork buffers.

Average Denitrification Rate (mg N_2O kg^{-1} hr^{-1})		
Depth (feet)	Standard	Pitchfork
0-1	1.65	4.64
1-2	2.50	0.08
2-3	0.03	0.07

Objective 3. Develop design criteria to guide the installation of saturated buffers in tile-drained fields of Illinois.

Our preliminary results indicate that neither the pitchfork nor standard buffers are performing as well as expected, especially during higher flows. According to McEachran *et al*., the efficacy of saturated buffers is a function of the width of the buffer (L_x), saturated hydraulic conductivity (K), and difference in hydraulic head ($h_2 - h_1$) (2020). Based on our survey elevations, the estimated difference in hydraulic head for the pitchfork and standard buffers are similar, 3.1 and 2.8 respectively. K is the same across both buffers (9.17 μm s^{-1})

(NRCS Web Soil Survey). The pitchfork buffer has a greater width but has more dispersion lines than the buffers that were analyzed for hydrologic variation. Therefore, the reduced efficacy of wider buffers may be mitigated by the pitchfork design. Further analysis of hydrologic characteristics will help improve understanding of saturated buffer effectiveness.

Like other studies, our data suggest that saturated buffers perform well during low flows; however, these data suggest that saturated buffers perform poorly during higher flows. Backflow issues with the dispersion lines in areas of high-water tables and in soils with low saturated hydraulic conductivities lead to an overwhelmed saturated buffer system during storm conditions. Future designs should focus on areas with lower water tables, high soil organic carbon, and higher saturated hydraulic conductivity. This study hoped to expand the amount of land area beyond the site characteristic recommendations of the NRCS that saturated buffer designs could be applied to in Illinois. The next step is to evaluate the cost-benefit (installation vs attenuation) during low flows to ensure that various saturated buffers are cost-effective on sites with marginal suitability.

References

Groh, Tyler A., Davis, Morgan P., Isenhart, Thomas M., Jaynes, Dan B., and Parkin Timothy B. 2018. In situ denitrification in saturated riparian buffers. *Journal of Environmental Quality*. 48: 376-384.

McEachran, Andrea R., Dickey, Loulou C., Rehmann, Chris R., Groh, Tyler A., Isenhart, Thomas M., Perez, Michael A., and Rutherford, Cassandra A. Improving the effectiveness of saturated riparian buffers for removing nitrate from subsurface drainage. *Journal of Environmental Quality*. 49(6): 1624-1632.