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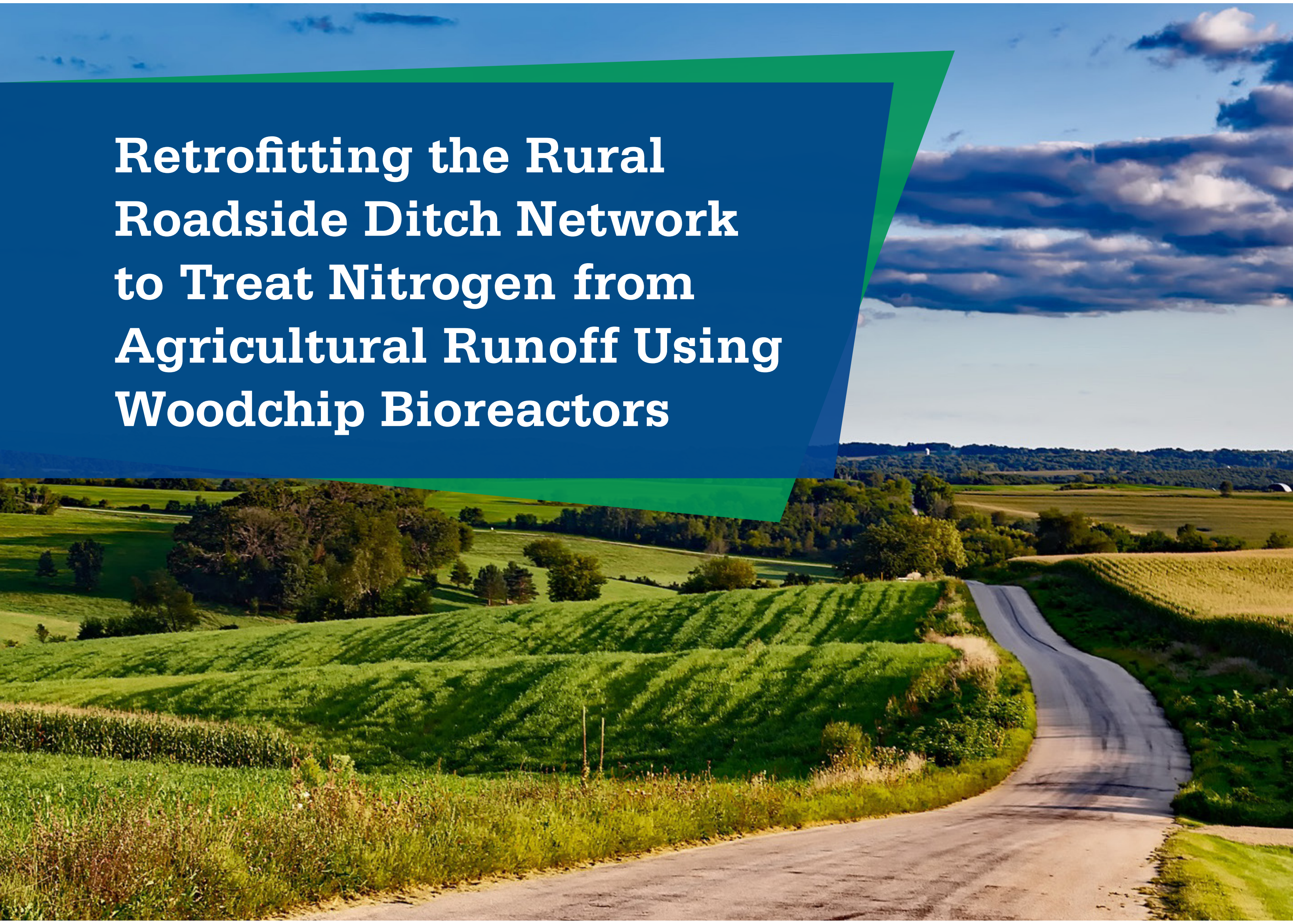
BRADFORD COUNTY CONSERVATION DISTRICT

PennState College of Engineering | CENTER FOR DIRT AND GRAVEL ROAD STUDIES

Cornell University

Retrofitting the Rural Roadside Ditch Network to Treat Nitrogen from Agricultural Runoff Using Woodchip Bioreactors



Project Summary

In 2018, Penn State and Cornell University partnered with the Bradford County Conservation District to demonstrate a novel method to treat agricultural nitrogen at the field edge. This two-year project—funded by the Natural Resources Conservation Service (NRCS) Conservation Innovation Grants (CIG) program—built on earlier successes utilizing the rural roadside ditch networks as the basis for a low-cost agricultural lands filtration system. This project specifically evaluated the effectiveness of using existing road ditches retrofitted with woodchip bioreactors to remove nitrogen from agricultural runoff and explored temporal and environmental changes on effectiveness. The results were used to determine nitrogen removal rates and limiting conditions for use of in-ditch woodchip bioreactors to improve water quality from farm field runoff and to enhance conservation practice standards.

Why is it important to treat agricultural nitrogen at the field edge?

Nitrogen movement across the landscape impacts local waterways, has been indicated as a key contributor to the growth of the hypoxic zone in marine estuaries, and is of national concern for watersheds such as the Chesapeake Bay. Rural roadside ditches play a very significant role in nitrogen movement because they efficiently transport agricultural runoff directly to streams and rivers with little to no treatment. Woodchip bioreactor technology has been in use for over two decades with a considerable amount of research conducted over the past 10 years, justifying the NRCS's adoption of Denitrifying Bioreactors, conservation practice 605. These woodchip bioreactors are large pits filled with woodchips used to treat nitrogen-laden water, flowing through sub-surface drain tiles associated with field crops. Large bioreactors can be up to 150-feet long, 50-feet wide, and up to 10-feet deep. Dissolved oxygen (DO) drops rapidly within the bioreactor, creating favorable conditions denitrifying bacteria that naturally grow in organic media, such as woodchips. The bacteria remove significant quantities of dissolved nitrogen compounds by converting the nitrate to nitrogen (N2) gas. However, these bioreactors have been primarily tested and used to capture large agricultural field runoff or in situations where there is a single point of discharge, such as a tile drain (Figure 1). In many agricultural settings, the topography and farm sizes do not lend themselves to treatment of agricultural runoff in large on-field pits or as point sources. To address these issues, this study evaluated the potential of installing scaled-down woodchip bioreactors into roadside ditches for removing dissolved nitrogen from agricultural activities. The specific objectives were to determine 1) the removal efficiency of individual bioreactors under differing environmental conditions of water flow and temperature, 2) whether two reactors placed in close proximity along a ditch would increase the total removal capacity as compared to a single reactor, and 3) whether dissolved organic carbon leaching from the woodchips could pose a threat to downstream waters.

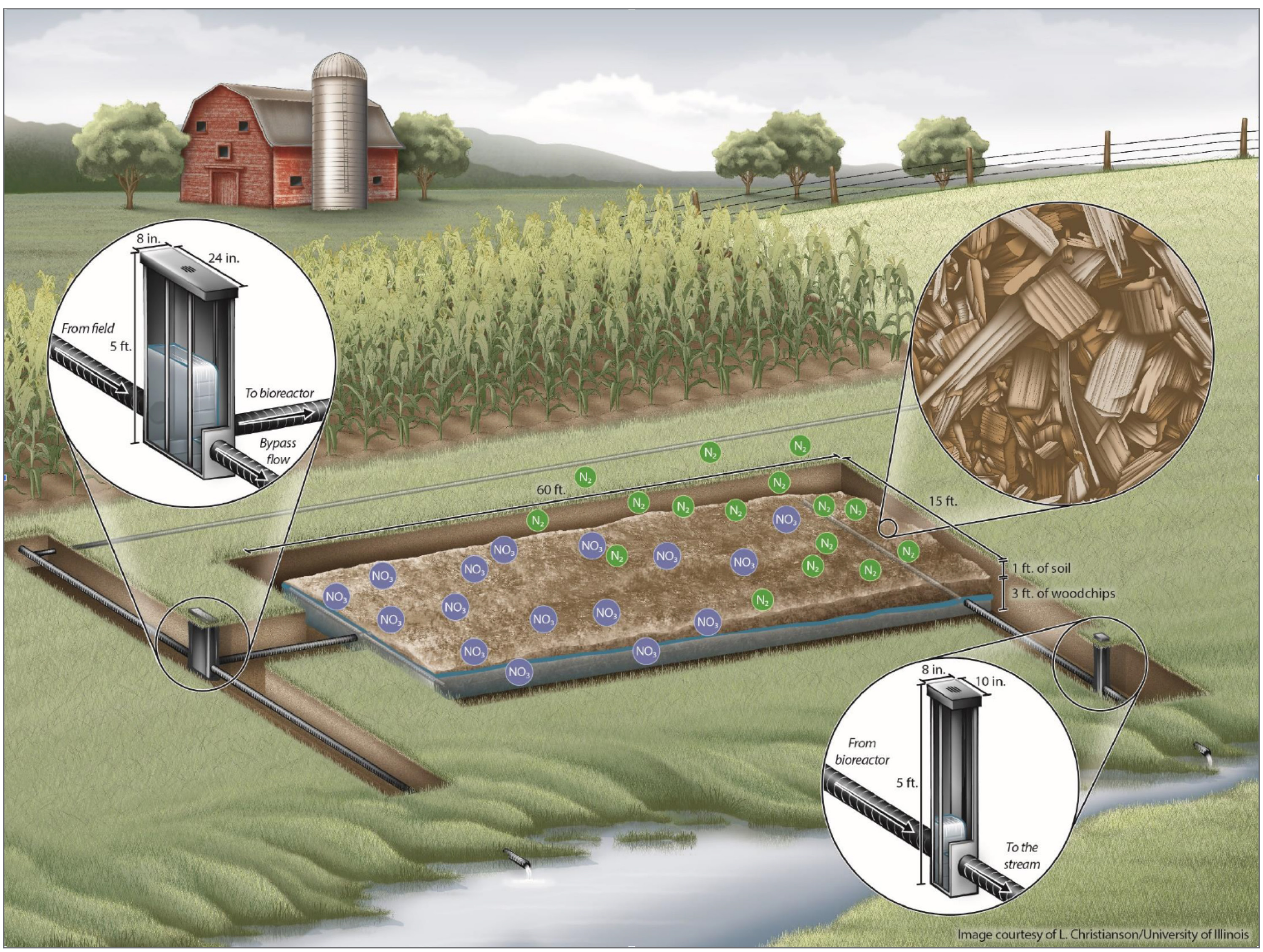


Figure 1. Large scale agricultural bioreactor design.

Study Sites

The bioreactors were installed and monitored at two roadside ditch sites in Bradford County, Pennsylvania (Figure 2). The primary site located east of Alba, Pennsylvania, had two bioreactors positioned in a gently sloping ditch that receives runoff from approximately 40 acres of mixed crop and hay farmland that had manure surface applied under a nutrient management plan at least twice during the study period. The two bioreactors were placed in series and separated by a one-foot gap that allowed for sampling above, between, and below the bioreactors. The second site was a single bioreactor installed north of Rome, Pennsylvania, in a ditch that borders approximately 12 acres of untilled hay fields that did not receive manure during the period of this study.

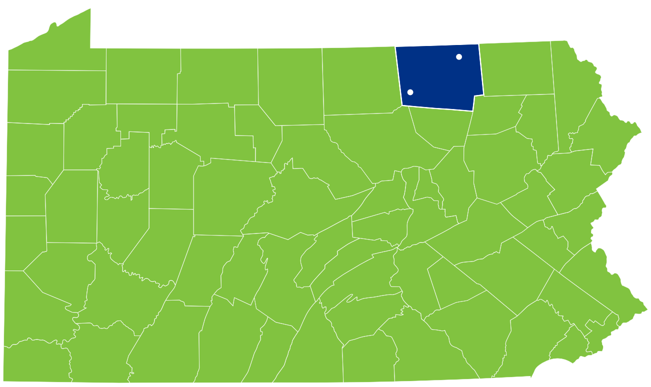


Figure 2. Bradford County, Pennsylvania. The white dots show the two areas included in the study: Alba (left) and Rome (right).

Methods

At the primary site, prior to the installation of the woodchip bioreactors, roadwork—consisting of additional cross pipe installations, farm field access upgrades, and road surfacing with high quality aggregate—was conducted to reduce sediment from the road entering the ditches. Additionally, a local spring was disconnected from the road ditch network to reduce overall flow volume entering the bioreactors. This preparatory work was performed in order to increase the overall efficiency and lifespan of the woodchip bioreactors.

The systems were installed in May 2018. Using a similar design to earlier work done by Cornell University, bioreactor "socks" were constructed for this study. A single sheet of polyester debris netting with quarter-inch openings was laid in the ditch bottom, extended completely across the ditch. The ditch was filled with woodchips approximately 20 centimeters deep. Then, the top layer of the netting was pulled over the woodchips, and the edges were secured with cable ties (Figure 3, Figure 4). Eight approximately 3-foot-long rebar stakes were pounded in straight through the bioreactor into the subsurface at equal spacing around the edges to hold it in place. The bioreactor media consists of a mixture of coarse hardwood woodchips (approximately one inch in length), half of which were sugar maple, aged in the open air for six months (*Acer saccharum*). The other half of the chips were white ash, (*Fraxinus americana*) freshly chipped one week prior to the start of the study. The completed bioreactors each measured approximately 15-feet long by 0.7-foot deep by 3-feet wide.

Figure 3. Installing woodchip bioreactor sock in ditch prior to securing the top netting.

After the installation of the bioreactors, three Teledyne ISCO automated water samplers were installed to collect samples above, between, and below the two woodchip bioreactors. Ditch flow was measured at the inlet and outlet of the bioreactors to create rating curves and water depth was continuously logged using capacitance style Hobo data loggers to create a continuous flow record (Figure 4). Field water sampling was conducted approximately every two

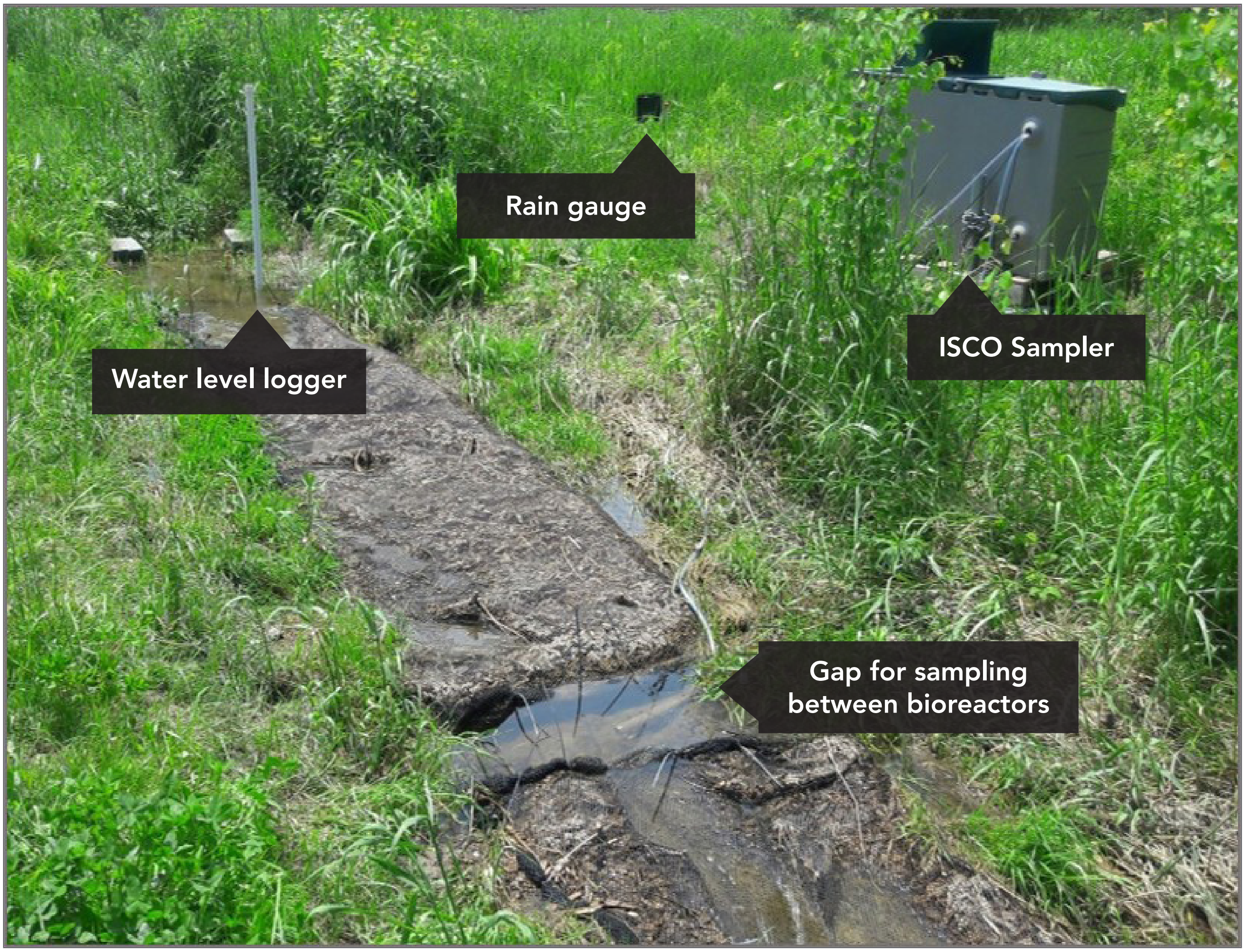


Figure 4. Woodchip bioreactor sock installed in ditch with ISCO sampler housing and rain gauge in the background.

weeks from May through October 2018 and from March through October 2019. Over the two-year study period, a total of 63 duplicate grab samples were collected at the Alba site on 22 separate dates including 12 dates in 2018 and 10 dates in 2019. In addition, 36 grab samples were taken from the Rome site during 18 sampling events over the two-year study. Several storm events were captured by the ISCO samplers.

Water samples were submitted to the Cornell University Nutrient Analysis Laboratory for analysis of dissolved nitrate and nitrite using a colorimetric method (hereafter reported as nitrate), total phosphorus, and metals using inductively coupled plasma (ICP) mass spectroscopy. At the time of each sampling event, electrical conductivity (EC), pH, and DO were measured on site. Readings were taken directly in front of the first bioreactor, in the gap between the two bioreactors, and directly below the second bioreactor.

Dissolved organic carbon concentration was measured on several different dates at the Alba study site.

In the second year of the project, the processes controlling the flow through the bioreactors were explored. Understanding the residence time of water within the bioreactor is critical as it determines the contact time available for denitrifying bacteria to process the dissolved nitrate. A modified tracer test was developed using deionized water as the tracer to monitor flow through the reactors under varying water depths, flow rates, and sediment loads in the bioreactor.

A laboratory study was also conducted to determine the amount of dissolved organic carbon (DOC) leaching from the woodchips, as a function of the tree species, time since cutting, and environmental conditions of storage. Eight species of tree were commercially chipped in December

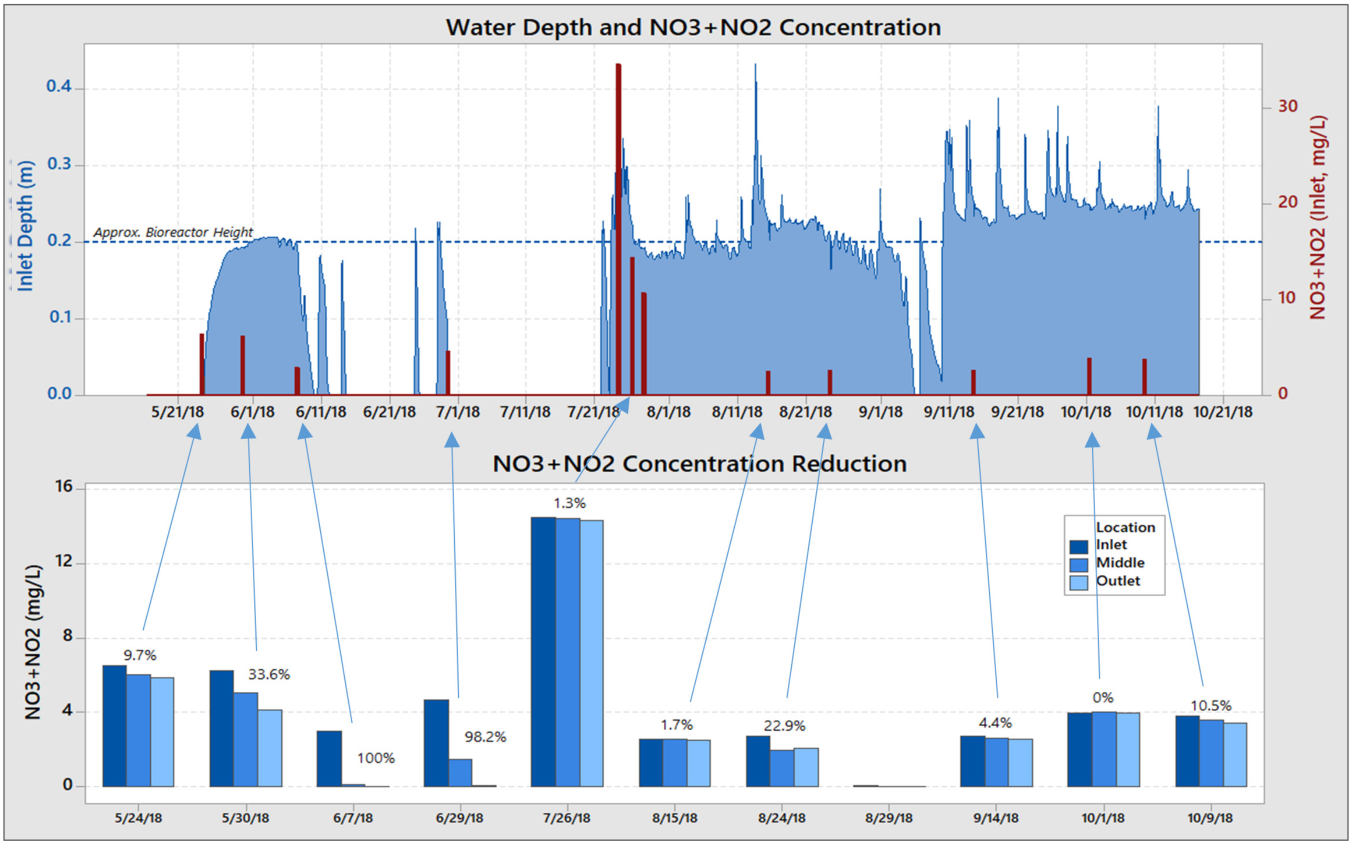


Figure 5. Top: Water depths in the Alba study site relative to the top of the bioreactors and nitrate concentrations in the incoming ditch water on 12 sampling dates. Bottom: Concentrations of nitrate above, between, and below the paired reactors with overall percentage removal efficiencies for each date.

2017, prior to the beginning of the project, and stored in porous, mesh bags. Half of the chips from each species were stored outside under ambient weather conditions and half were stored in the lab under constant temperature. At monthly intervals for the first six months, and less frequently thereafter, a sample was collected from each bag, sieved to one-cm size, and incubated in deionized water for six days at approximately 70 degrees farenheit. The leachate was collected and analyzed for pH, EC, and DOC.

Findings

The results show that scaled-down woodchip bioreactors installed directly within the roadside ditch can be a valuable new tool for removing dissolved nitrate. Relatively inexpensive, each bioreactor costs $150 in materials and is easy to install, taking about two hours of labor to construct. Removal efficiency over the two-year monitoring period ranged from 0% up to 100% and averaged approximately 30%, with greatest removal under low flow conditions.

Figure 5 from 2018 highlights that the paired bioreactors performed well in the spring and early summer when ditch flows were not overtopping the bioreactors. However, in the later summer and fall, high flows severely impacted removal efficiencies. The data also show, importantly, there was additional removal from the second bioreactor. Overall, the cost efficiency per pound of nitrogen saved over the two-year study was less than $3.50 per pound, not including annual maintenance checks. There was no detectable nitrogen moving through the reactor at the second study site, so it was used to evaluate hydraulic residence times.

DO levels of the inflowing water coming from the ag fields ranged from 4.5 to 11 mg/l over the two years (Figure 6). On 13 of the 15 dates when DO was measured, the DO content of the water decreased successively after passage through each bioreactor and frequently dropped the concentrations lower than 6 mg/l. These findings corroborate the hypothesis that woodchip bioreactors encourage microbial respiration, and that anaerobic conditions appropriate for denitrification are likely to exist at hotspots within the reactors.

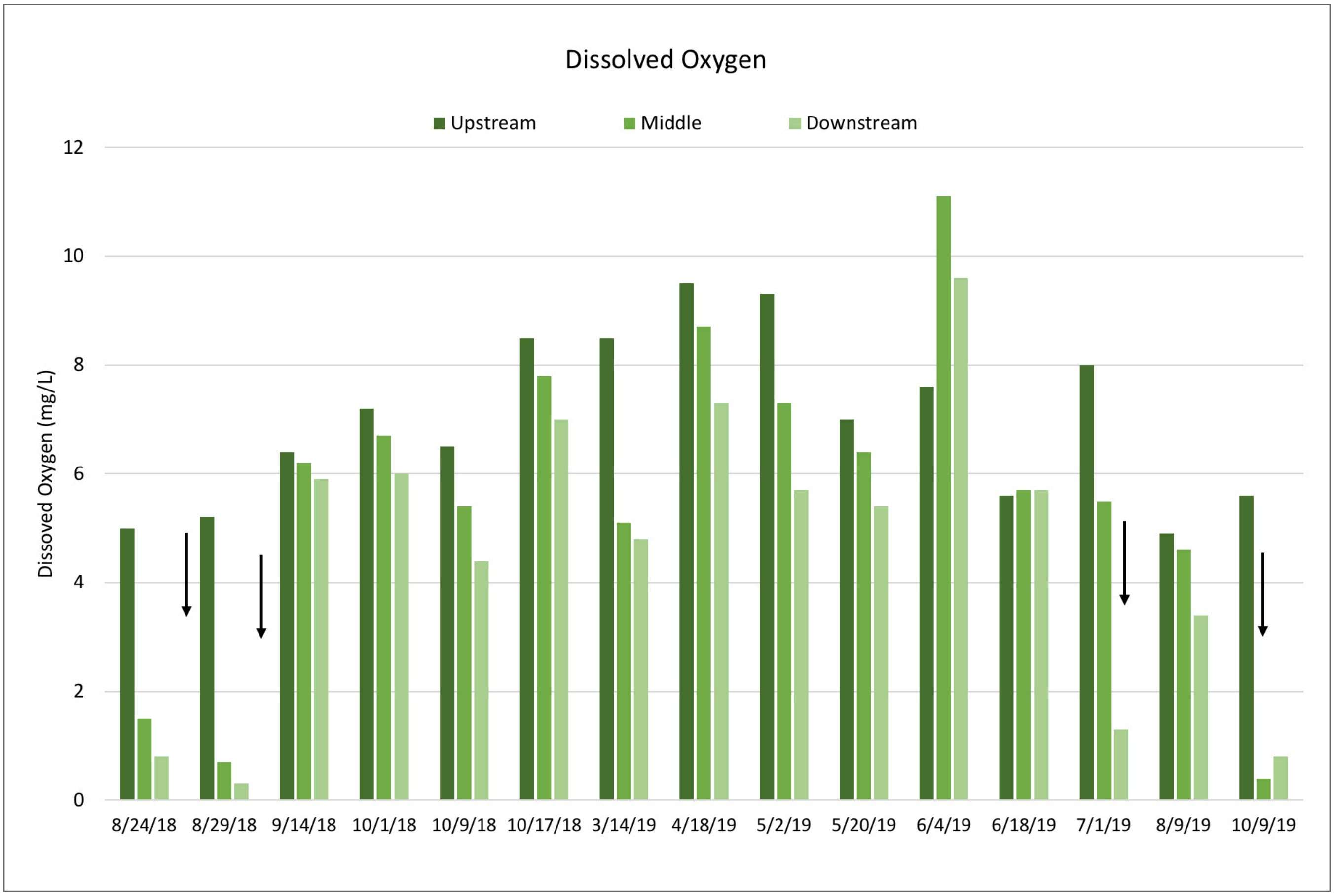


Figure 6. DO concentrations above, between, and below the paired reactors. Note that oxygen levels increased only on June 4 and 18 sample dates, immediately after reactor one was cleaned out of sediment, allowing a thick layer of algae to grow on top of the reactor.

Hydraulic residence time of the water in the bioreactors, an important driver of successful denitrification, ranged from 40 minutes to more than 1.5 hours, and measurements of DO declines supported the conclusion that the bioreactors were effective under low flow conditions. However, bioreactors were less effective in conditions of overtopping under high flow rates. The bioreactors also decreased their removal efficiencies after buildup of sediment had clogged the woodchip matrix resulting in partial bypassing of the reactors. Thoughtful site selection during the planning phase that emphasizes low slopes, vegetated landscapes or cover crops in farm fields to reduce sediment loads, and smaller basins to reduce the occurrence of overtopping ditch flows, can reduce the limitations.

The woodchip leachate experiment indicated that chips leach out dissolved organic carbon continuously, but in gradually decreasing amounts for up to two years following chipping. However, analysis of water samples from the Alba site on four separate dates in 2018 indicated that dissolved carbon from the woodchips in the reactor were not being released in significant quantities to be of concern to downstream water quality, again supporting that microbes are using the dissolved organic carbon for denitrification.

Challenges

Record breaking rainfall across Pennsylvania (> 100 cm in five months) in 2018 led to extended periods of bioreactor overtopping, which severely impacted removal efficiencies. Fine sediment from field runoff during the 2018 rains also impacted the bioreactors and in early 2019 overtopping began occurring at lower water levels than in 2018 due to clogging of the woodchip matrix (Figure 7). Samples were collected in May 2019 from the bioreactors and it was

Figure 7. Within hours of initial installation, a severe thunderstorm overtopped the bioreactors.

determined the woodchip matrix consisted of 43% sediment by weight. After cleaning the bioreactors by agitating the woodchips, the matrix consisted of 6% sediment. It is recommended that cleaning by agitation should be done if the matrix is greater than 25% sediment. The primary source of sediment was determined to be erosion from fields adjacent to the road ditch, indicating that having a buffer strip between the fields and the ditch or good cover cropping practices can reduce maintenance, increase nitrogen removal efficiency, and extend the life of the bioreactors.

Algae and vegetation growth were also noted on the bioreactors during this project and was manually removed to reduce any potential impact on the efficiency of the bioreactors. Based on this knowledge, it is anticipated that the bioreactors need to be monitored two to three times during the growing season to check for excessive vegetative growth or sediment buildup. In addition to manually removing vegetation, the bioreactors can be mowed over with careful attention to the mower height.

Outputs and Next Steps

As a result of this work and previous work by Cornell University, an in-ditch bioreactor fact sheet has been created to supplement this report. Preliminary results and findings have been presented at multiple workshops at the state level, such as the Pennsylvania Dirt, Gravel & Low-Volume Roads annual workshops, New York Federation of Lake Associations, Soil and Water Conservation Society conference, and the Transportation Research Board International Conference on Low Volume Roads.

The monitoring data are compiled in a comprehensive data set that is available from the NRCS and will be used to assess the feasibility and usefulness of in-ditch woodchip bioreactors for widespread adoption through an interim NRCS conservation practice or possibly enhancement of the current NRCS Denitrifying Bioreactor (605) Standard.

The bioreactors as installed are inexpensive, need little maintenance input other than seasonal inspection and cleaning to ensure water is not bypassing the bioreactor and that they are free of excessive sediment, and have a life expectancy of 5 to 10 years depending on environmental conditions. The data collected to date demonstrate that the use of the existing road ditch infrastructure that exists across Pennsylvania and the entire country can be used as a watershed-wide nutrient removal system. The bioreactors can be scaled up as needed depending on the nitrogen loads and field hydrology by simply adding more woodchip bioreactor reactors in sequence.

Extending the findings of this project, the team envisions this work going beyond just nitrogen reduction and leading to the utilization of the ditch networks as the basis for a low-cost, watershed-wide filtration system with multiple nutrient removal best management practices. Outside of the agricultural community, this technology has the potential to economically and environmentally benefit municipalities that need to reduce pollution under their Municipal Separate Storm Sewer Systems (MS4). The potential application of denitrifying storm water in the roadside ditch network should be of interest to not only agriculture, but both road and wastewater managers as well.

1. Christianson, L. E., A. Bhandari and M.J. Helmers. 2012. A practice-oriented review of woodchip bioreactors for subsurface agricultural drainage. Applied Eng. in Agric. 28(6): 861-874.

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