First-year performance of a pumped, cold-climate woodchip bioreactor

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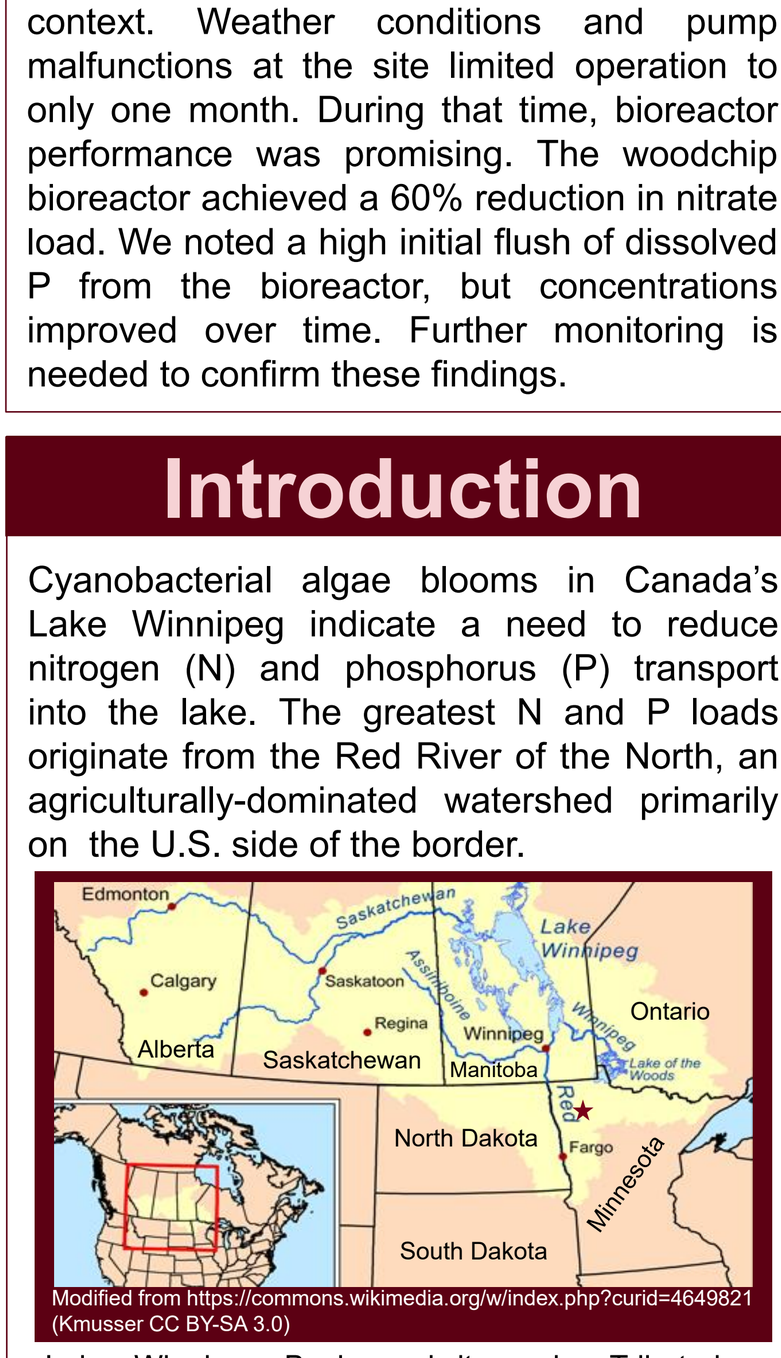
Abstract

Despite the urgent need to reduce nitrogen (N) and phosphorus (P) loss from agricultural land in North America's Red River Basin of the North, information on best management practice performance here is limited. Northwest Minnesota's first bioreactor was installed in November 2023 with an innovative design: water is pumped into the bioreactor from the subsurface drainage lift station. During its first year of operation (2024) site conditions presented challenges that may be difficult to overcome outside of a research context. Weather conditions and pump malfunctions at the site limited operation to only one month. During that time, bioreactor performance was promising. The woodchip bioreactor achieved a 60% reduction in nitrate load. We noted a high initial flush of dissolved P from the bioreactor, but concentrations improved over time. Further monitoring is needed to confirm these findings.

Introduction

Cyanobacterial algae blooms in Canada's Lake Winnipeg indicate a need to reduce nitrogen (N) and phosphorus (P) transport into the lake. The greatest N and P loads originate from the Red River of the North, an agriculturally-dominated watershed primarily on the U.S. side of the border.



Lake Winnipeg Basin and its major Tributaries. Bioreactor Location marked with a star.

Many strategies to reduce nutrient losses in agricultural discharge have received minimal or no testing in the Red River of the North Watershed. Woodchip bioreactors rely on microbially-driven denitrification to reduce nitrate concentrations in subsurface drainage discharge. This practice had not previously been tested in Northwest Minnesota partly due to concerns that the climate is too cold for the bioreactors to function properly.

Project objectives:

1. Design and install a bioreactor for the Red River Basin region of Minnesota
2. Evaluate how the region's climate (harsh winters and short growing season) impact practice performance.

Design & Methods

Site Description

- 42-ha field with a subsurface drainage system and a pivot irrigation system
- Sandy loam soil type
- Corn-soybean rotation

Bioreactor Design

- 12.2 m length x 4.6 m width x 0.6 m depth
- Plastic liner at bottom
- About 0.5 m woodchips capped with soil
- Four monitoring wells in the middle

The subsurface drainage system outlets into a lift station (shown). A secondary pump (not visible) was used to divert water above ground via a PVC pipe from the lift station well to the bioreactor at a rate of 38 L min^{-1}.

Discharge & Water Quality Monitoring

- Discharge measured using magnetic flow meters and HOBO pendant loggers
- Automated water samplers at lift station and bioreactor outlet collected N and P samples every 6 hour (composited every 24 hours)

Results

Weather-related challenges

Extreme winter temperatures (<-40C) require the site to be dismantled each year:

- Above-ground pipes linking the lift station and bioreactor removed
- Bioreactor drained to avoid water freezing in pipes

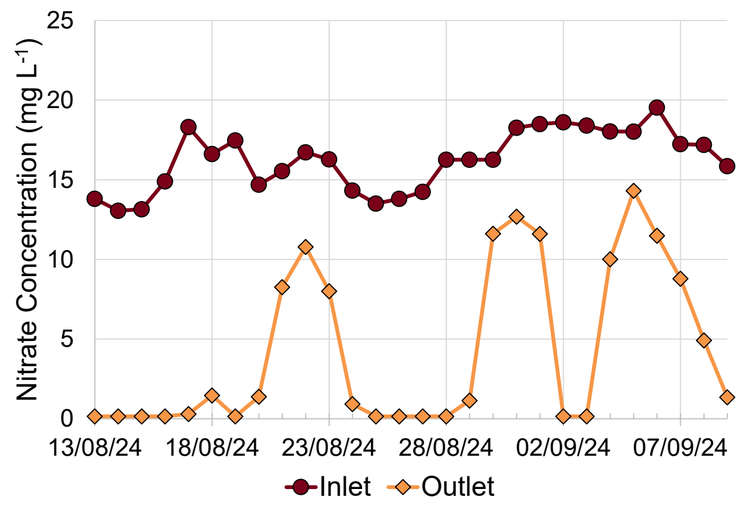
Snowmelt and heavy rainfall in Spring 2024 flooded the site and submerged the bioreactor making it inaccessible until mid-July.

Re-installation of bioreactor components and monitoring began in August 2024.

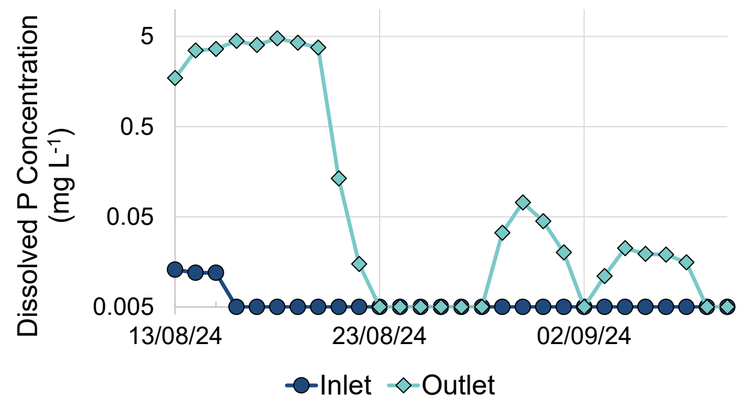
Results

Bioreactor Performance

- Nitrate concentration averaged 16.2 mg L^{-1} at the inlet and 4.3 mg L^{-1} at the outlet
- Overall nitrate load was 60% lower after passing through the bioreactor



- Dissolved P concentrations averaged 0.01 mg L^{-1} at the inlet and 1.09 mg L^{-1} at the outlet
- Concentrations peaked 4.75 mg L^{-1} but lessened after the first initial flush



Pump failure & seasonal site shut down

- Intermittent flow through the bioreactor resulted from the secondary pump shutting down between 3-5 days following our site visits. This was likely due to a power malfunction at the pump.
- At the end of the growing season and in anticipation of winter, the location was dismantled in early October 2024.

Conclusions

- Practice performance was limited by challenging conditions at the site (flooding, cold, pump failure)
- The bioreactor did not appear to be affected by site conditions and performed as expected (during hot, dry conditions)
- Initial release of P is concerning – further monitoring is needed to see if this is recurring or one-time
- We will continue monitoring the site during the 2025 growing season
- Practical consideration: Dismantling and reinstalling the site each year is labor-intensive and may not be practical for farmers and land managers

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