NC STATE UNIVERSITY

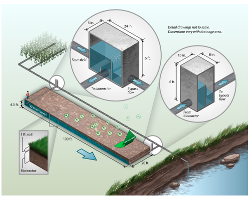
Biological and Agricultural Engineering Department

Modeling Flow-Driven Nitrate Removal Rates and Prototyping Electrical-Augmentation for Woodchip Bioreactors

Samuel Blackman, Chen Cheng, and Dr. Francois Birgand

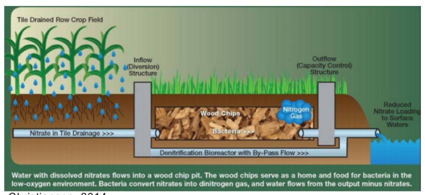
Background:

Excess nutrients draining from agricultural lands, particularly nitrate (NO_3^-), often enter the water column and can have detrimental effects on aquatic ecosystems and can lead to degraded aquatic life. Woodchip bioreactors are an agricultural best management practice used as buffers between agricultural fields and surface waters to reduce nutrient loading. Nitrate loading is reduced through agricultural runoff entering anaerobic woodchip pits, which provide an environment for denitrification to convert nitrate to dinitrogen, an inert gas. Although a promising practice, it has been shown that denitrification rates in these woodchip pits drop off after 2-3 years of use.



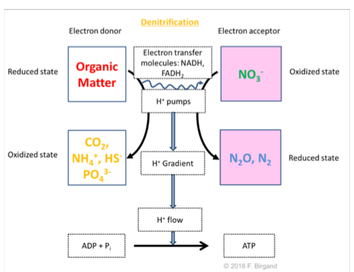
Christianson and Helmers, 2011

Middle Fork Crow River Watershed District (WI)



Christianson, 2014

Biogeochemical Process:



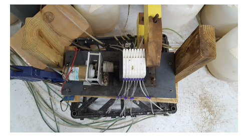
Objective:

1. Systematically quantify the impact of flow rates through bioreactor media on volumetric removal rates.
2. Design an efficient and cost-effective electrical stimulation setup.

It has been shown that electrical stimulation can significantly improve denitrification rates, and we theorize that increased mixing due to varying flow rates may synergize with the positive effects electricity has on denitrification rates.

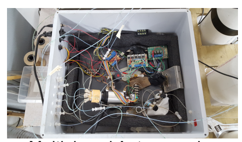
Varying Flow Rate Experiment:

A lab column experiment lasting ~90 continuous days (Jan. 11th, 2019 – present) is underway in the BAE Weaver Labs. There are eight PVC columns (height =95 cm, diameter=15.2 cm), each filled with 6 cm of gravel for flow disbursement, then 50 cm of woodchips, leaving 39 cm of head space. The columns were divided into two groups based on their flowrates after two weeks of flushing. Nitrate concentrated carbon filtered water was pumped through a peristaltic pump and flow rates were changed based on the pump tubing size (1mm, 2mm, 3mm), however the standard flow rate of ~.2 mL/s was maintained at all times in at least one group as a control. Nitrate concentration is mixed in a separate tank that the pump pulls from, and is kept at ~25 mg/L $N - NO_3^-$.



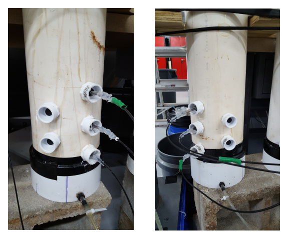
Peristaltic Pump (Above), Filter (Below)

Water outflow from the columns and tank are sampled every two hours with a sequential multiplexed auto-sampler coupled with a high-frequency nitrate probe. Probe data is logged on a desktop, which controls the probe and other sensors (Dissolved Oxygen & Temperature sensors for monitoring purposes).



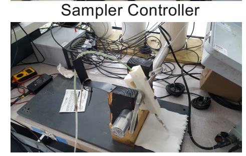
Multiplexed Auto-sampler

Pump Controller



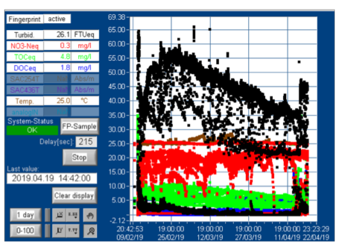
Dissolved Oxygen Sensors

Sampler Controller

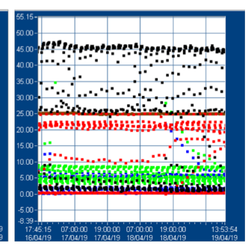


Nitrate Probe

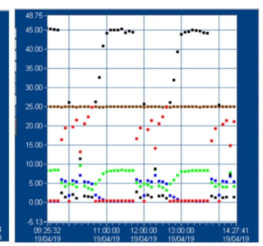
Raw N-Nitrate Concentration Data:



~90 Day Timeseries



~3 Day Timeseries



~4 Hour Timeseries

Red = $N - NO_3^-$ Black = Turbidity Green = Total Organic Carbon (TOC)
Blue = Dissolved Organic Carbon (DOC) Brown = Temperature

Prototype Design:

Key design decisions for the electrical augmentation prototype include (1) placement of anodes and cathodes in the reactor (configuration/order) and (2) anode and cathode material. These decisions are influenced by the consequential reactions, durability, and the cost-effectiveness as a result of electrode materials. Specifically, pH stabilization is an important factor to maintain an efficient reaction.

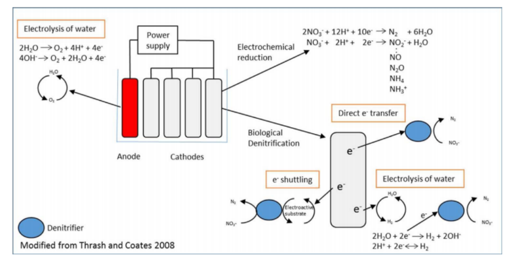
Choosing Electrodes:

- Anode – Graphite: Cheap (+), pH Buffer, (+), the oxidation reaction quickly deteriorates the rod, making it not practical for long usage (-).
- Anode - Stainless Steel: Cheap (+), slow corrosion (+), No pH buffer (-).
- Cathodes – Graphite: Cheapest (+) and will not deteriorate quickly (+)

Choosing Configuration:

- Configuration can balance pH, when there is no buffer.
- J.Y. Law (2018) saw that after the SS anode, pH did not inc. due to better mixing.

Chosen Configuration: SS → G → G



J.Y. Law, 2018

Results & Conclusion:

Currently, we are still synthesizing the data collected over the last 3 months, so there are no definite conclusions on the varying flow rate data as of yet. On the other hand, prototype construction is complete and is awaiting testing. On a broader context, woodchip bioreactor research is crucial to improve a promising best management practice that could lower nutrient loading in surface waters. Less nutrient loading potentially means less frequent harmful algal blooms, which are often cited for their detrimental effects on aquatic life (i.e. fish kills).

Future Work:

Our first step is to model and analyze the varying water flow rate data, to verify our theory that increased mixing has a positive impact on denitrification rates. Our second step is to do proof-of-concept testing on the electrical-augmentation prototype (e.g. running nitrate concentrated flow through the column and recording denitrification efficiencies). If successful, we plan on scaling the electrical-augmentation design up to the 8 column experiment and then running another 3 month data collection series.