Use of bioremediation for *in situ* denitrification of nitrate in groundwater

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Introduction

- Nitrate contamination in groundwater is a byproduct of modern agriculture.
- Nitrate is highly mobile and can travel into municipal water supplies, posing health concerns (Critchley, K. et al., 2014).
- Best management practices (BMP) (e.g. efficient fertilizer use) take several years to lower nitrate levels (Shaw, J. et al., 2022).
- Past studies have sought to stimulate natural nitrate-reducing bacteria *in situ* as an economical short-term remediation alternative.
- Research at a study site in Woodstock, Ontario, Canada (Fig.1) was conducted to determine the success of denitrification in a local aquifer.

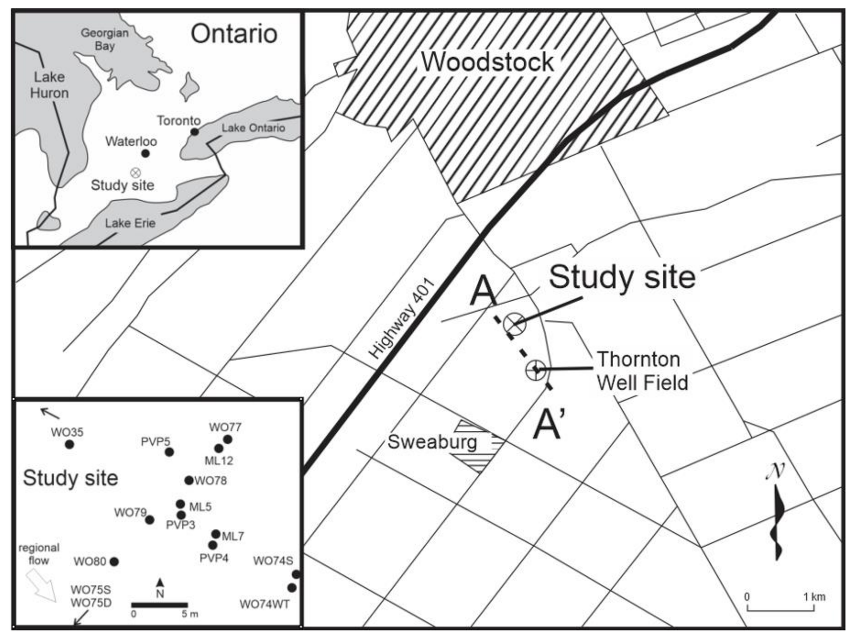


Figure 1. Study site location at Woodstock, Ontario, Canada. Taken from Shaw et al., 2022.


Figure 2. Field image of sediments thought to resemble the underlying aquifer layers. Image taken by Peter Schillig.

Methods

Cross-Injection System (CIS):

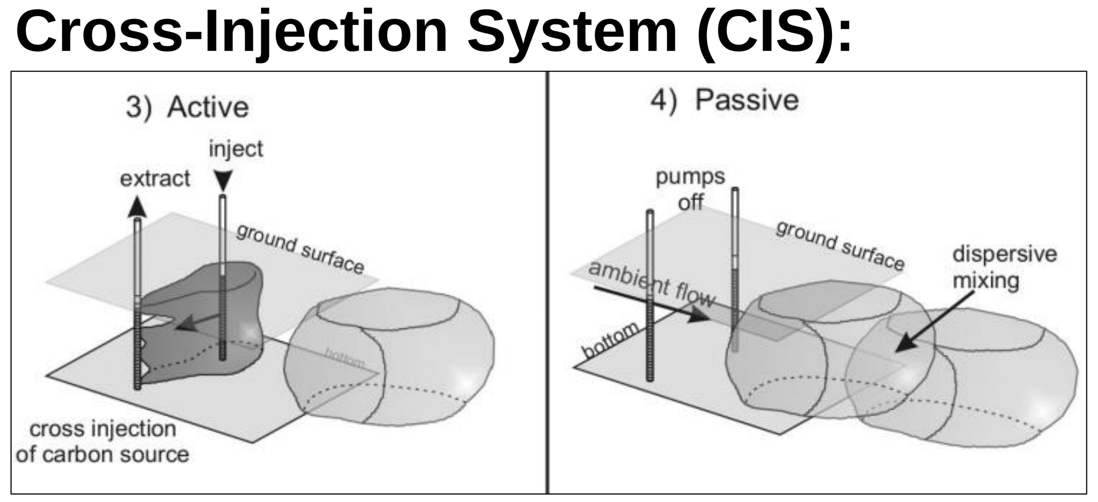


Figure 3. Schematic of the CIS. Acetate is injected into the ground perpendicular to ambient flow. Longitudinal dispersion mixes the pulses in the direction of ambient flow. Bacteria in the mixing zone receive a continuous supply of injected nutrients and develop a stable remediation zone.

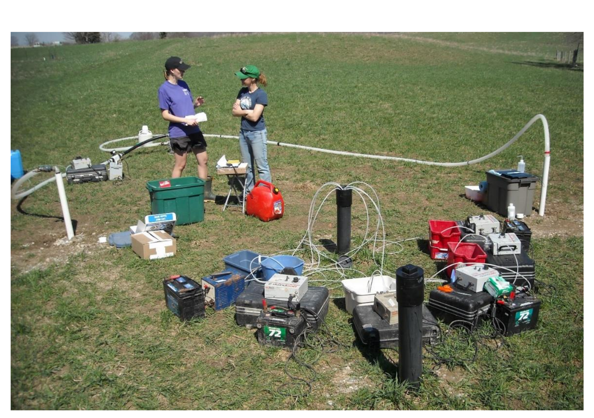


Figure 4. Field setup of the CIS. Collaborating students from the University of Waterloo are shown onsite.

Denitrification:

Denitrification is the process of converting nitrate into nitrogen gas. Several intermediate products are formed during this process as shown below:

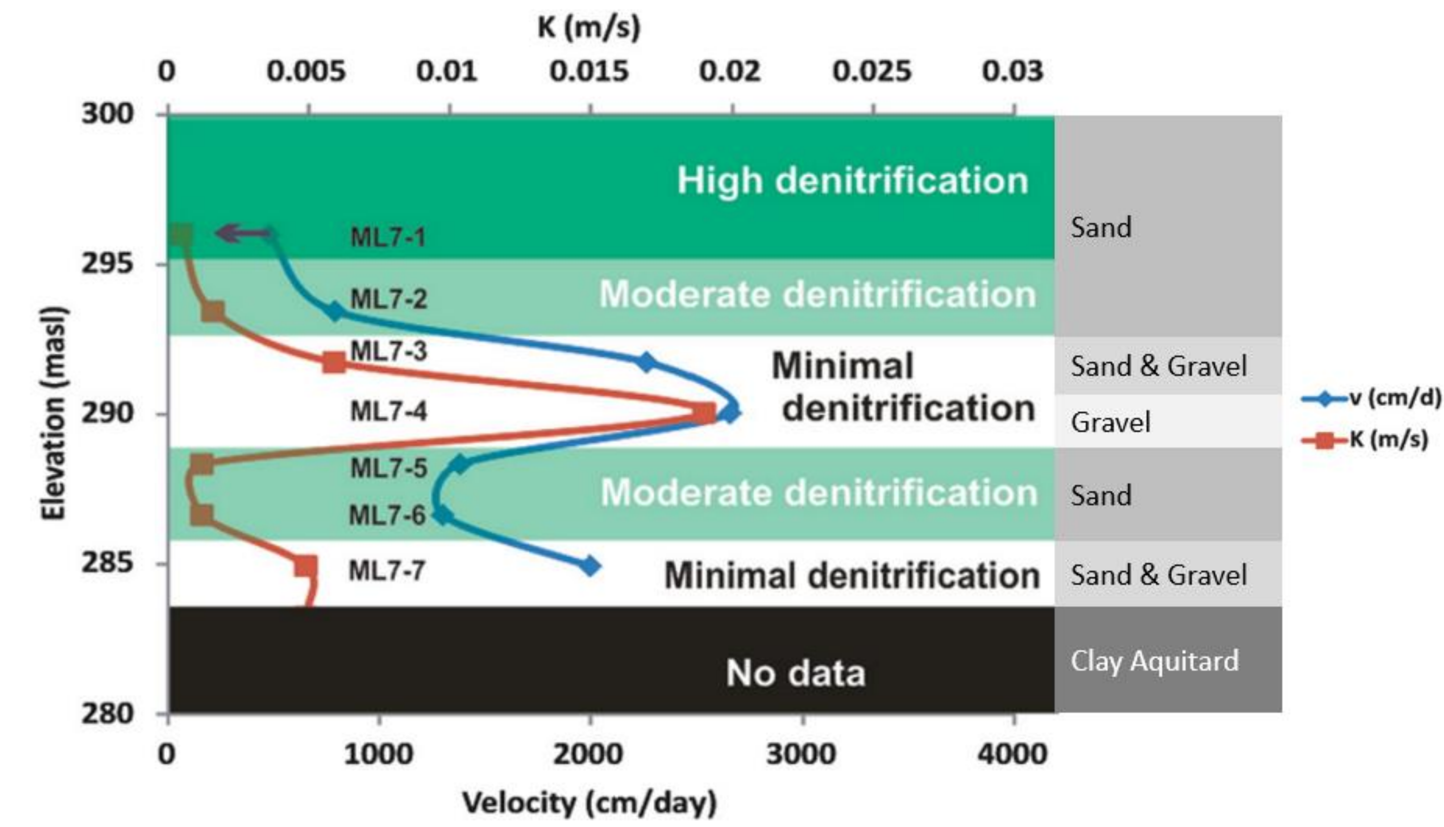
$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

To stimulate denitrification, acetate was introduced into the system as a carbon source. This electron donor triggers a series of reactions that ultimately lead to the production of N_2. The reaction can be summarized as (Shaw, J. et al, 2022):

$$5CH_3COO^-_{(aq)} + 8NO^-_{3(aq)} + 3H^+_{(aq)} \leftrightarrow 4N_{2(g)} + 10HCO^-_{3(aq)} + 4H_2O_{(l)}$$

Hydrogeology Results

Figure 5. Relation between K, tracer velocity, and denitrification in ML7. Modified from Critchley, K. et al. (2014).



The aquifer at Woodstock, Ontario is heterogenous and therefore the success of denitrification was dependent on six hydrogeologically different layers. These include sand, sand & gravel, gravel, and a clay aquitard (see Fig. 2). Velocity (v) was measured, while hydraulic conductivity (K) was back-calculated using a flow model.

Denitrification Results

Comparing the results of the studies conducted by Critchley, K. et al. (2014) and Shaw, J. et al. (2022), it can be seen that denitrification did occur when acetate was introduced into the system. It was generally found that:

1) Success of denitrification was directly correlated to the hydrogeology of the aquifer (Fig. 5).
2) Higher denitrification was seen in layers comprised of sand with modest v (Fig. 5).
3) Layers of high velocity and high K had minimal denitrification.
4) Layers of low velocity and low K had moderate to high denitrification.
5) The levels of nitrate were most successfully diminished at ML7-2, ML7-5, and ML7-6 (Fig. 6 & 7).
6) With the supply of additional acetate over longer times, the problematic strata – exhibiting high v – were also treated to below the nitrate target levels (Fig.6 & 7).
7) The importance of dispersion in the method is shown by the contrasting success of nitrate removal in ML5 (close to the injection source of acetate) and ML7 (removed from the injection source).

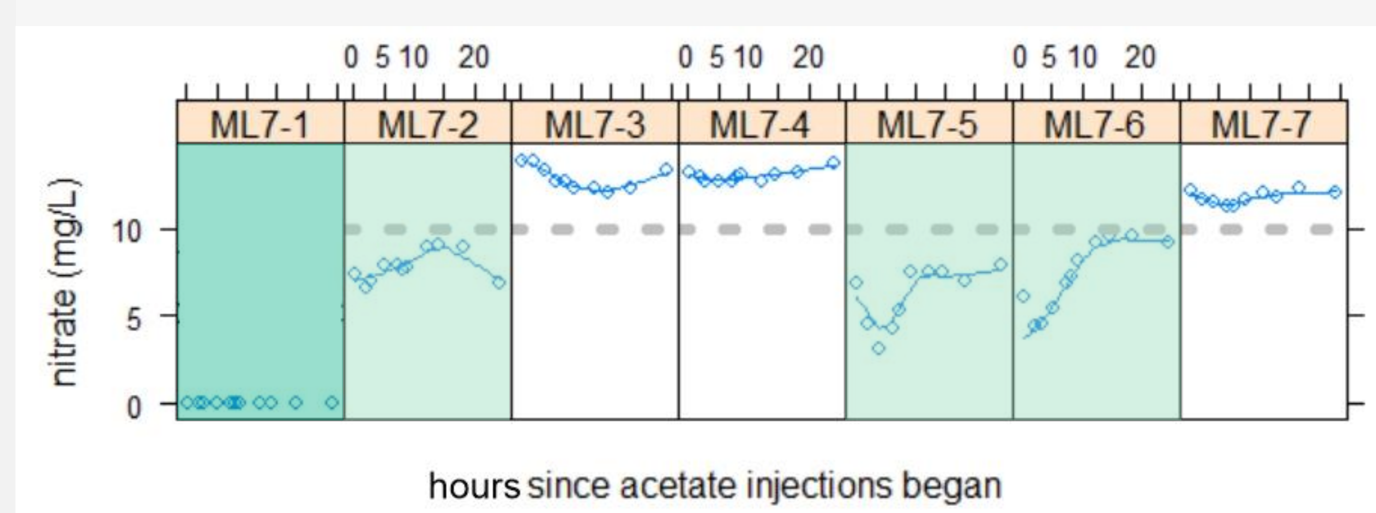


Figure 6. Change in nitrate levels at monitoring site 7 following a single injection (note time scale in hours). Figure modified from Critchley, K. et al., 2014.

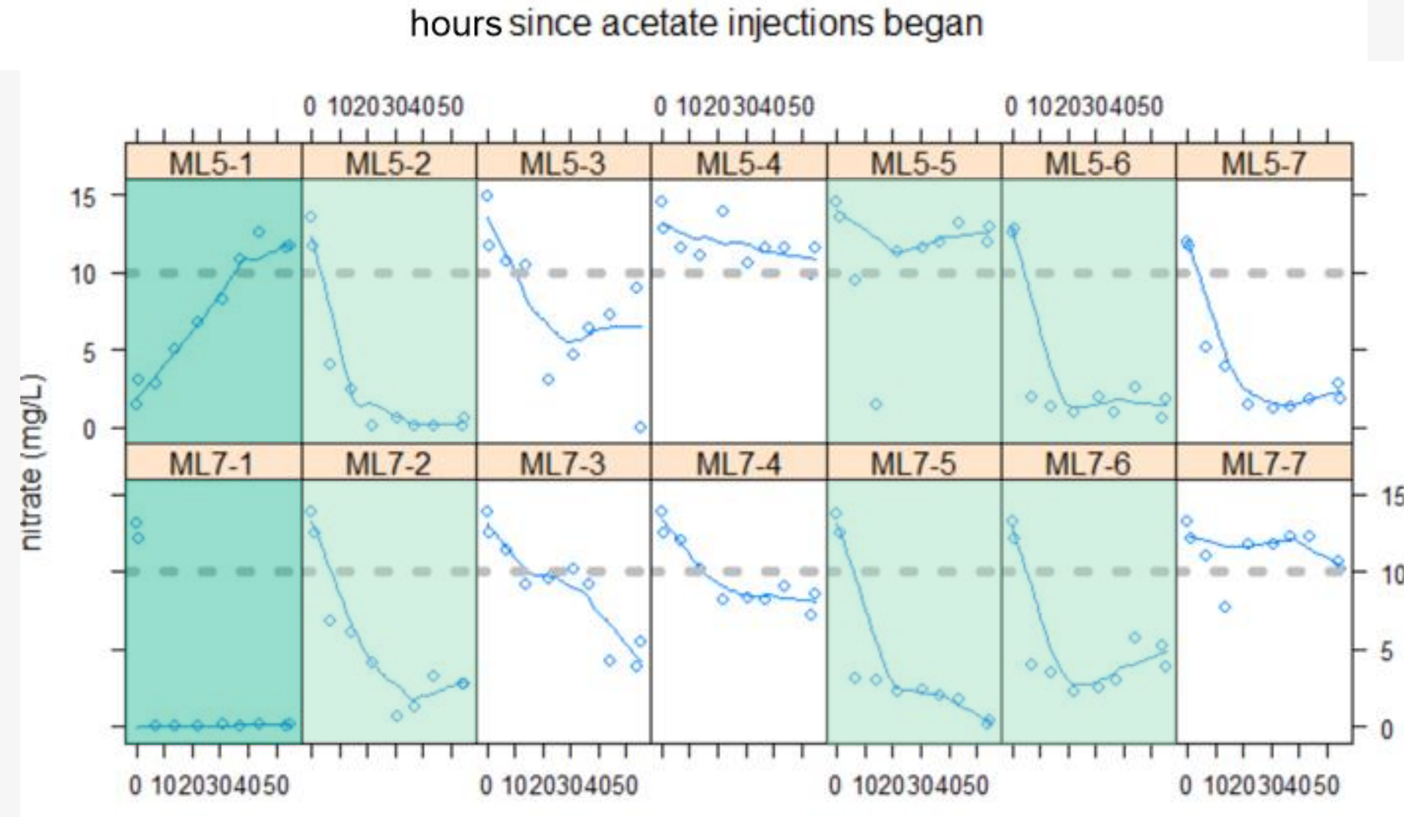


Figure 7. Change in nitrate levels at monitoring site 5 and 7 over an extended time (note time scale is days). The regulatory level of nitrate is shown by the dashed line. Note nitrate removal at ML7-3 and 4 is shown to be problematic in the earlier experiment. Figure modified from Shaw, J. et al, 2022.

Conclusions

These past studies found that:

1) CIS works as a short-term remediation practice.
2) CIS does not work uniformly throughout the aquifer.
3) Success of denitrification is dependent primarily on the hydrogeology rather than biology or chemistry.
4) Increasing the C:N ratio fosters greater nitrate removal in high velocity layers.

Future Work

Future work for this project seeks to scale up the CIS to accommodate the entire Woodstock municipal water supply (Figure 8). In addition, the CIS should be modified to target specific layers with specific acetate concentrations to increase the efficiency of the denitrification treatment. As this process is currently manually operated, future work may seek to automate the process.

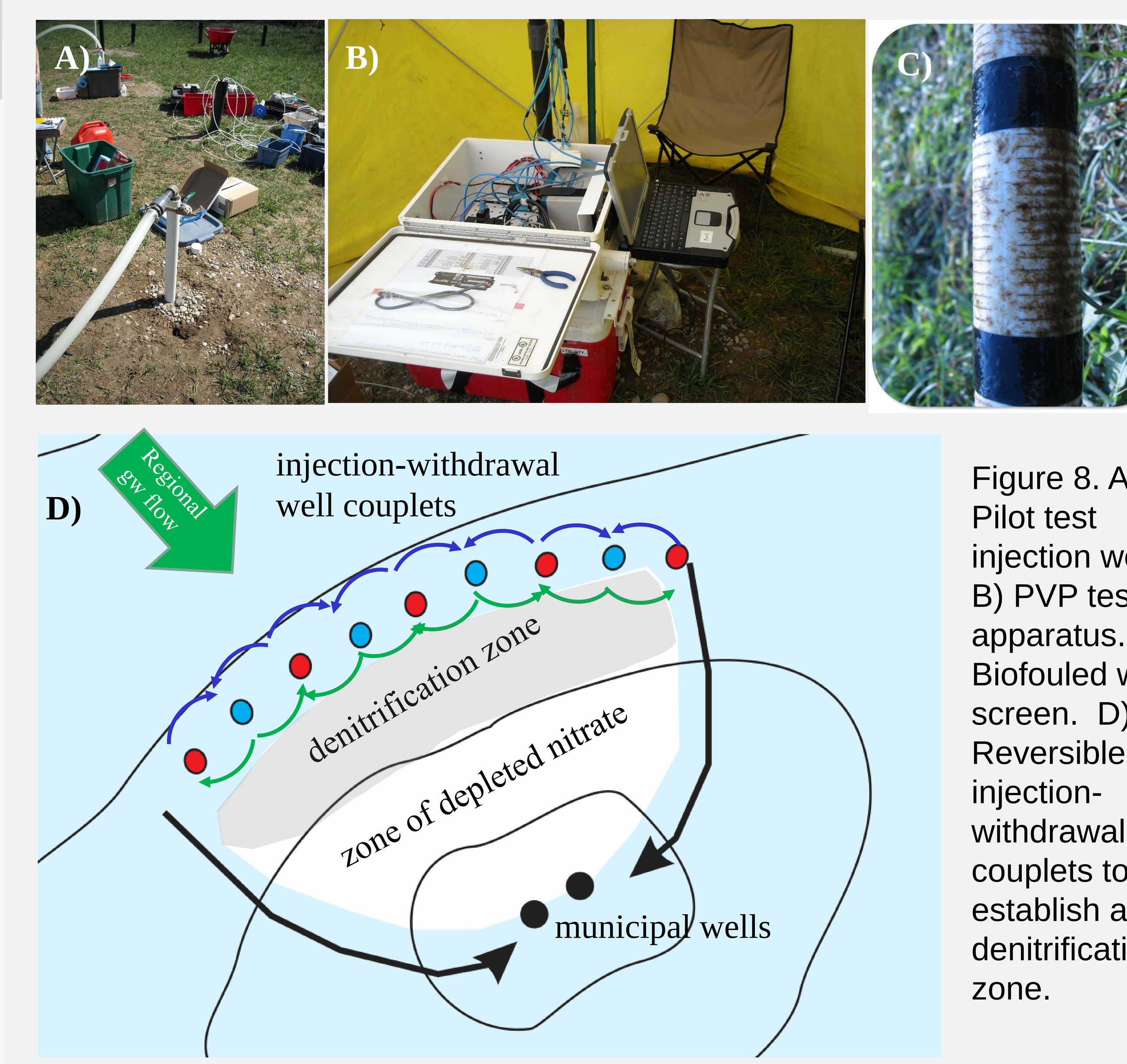


Figure 8. A) Pilot test injection well. B) PVP testing apparatus. C) Biofouled well screen. D) Reversible injection-withdrawal well couplets to establish a denitrification zone.

Acknowledgements & References

Acknowledgements:
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References:
Critchley, K., Rudolph, D.L., Devlin, J.F., and Schillig, P.C., 2014, Stimulating in situ denitrification in an aerobic, highly permeable municipal drinking water aquifer: Journal of Contaminant Hydrology, v. 171, p. 66–80, doi:10.1016/j.jconhyd.2014.10.008.
Shaw, J., Devlin, J.F., Rudolph, D., and Schillig, P., in prep, Extended pilot test of a cross-injection in situ denitrification system for pre-emptive treatment of municipal well water: Journal of contaminant hydrology.