Natural Nitrate Removal in Shallow Subsurface Stream Flows

Abigail Heath, Eric Peterson, Catherine O'Reilly, Wondwosen Seyoum, Illinois State University Department of Geography, Geology, and the Environment, Normal, IL

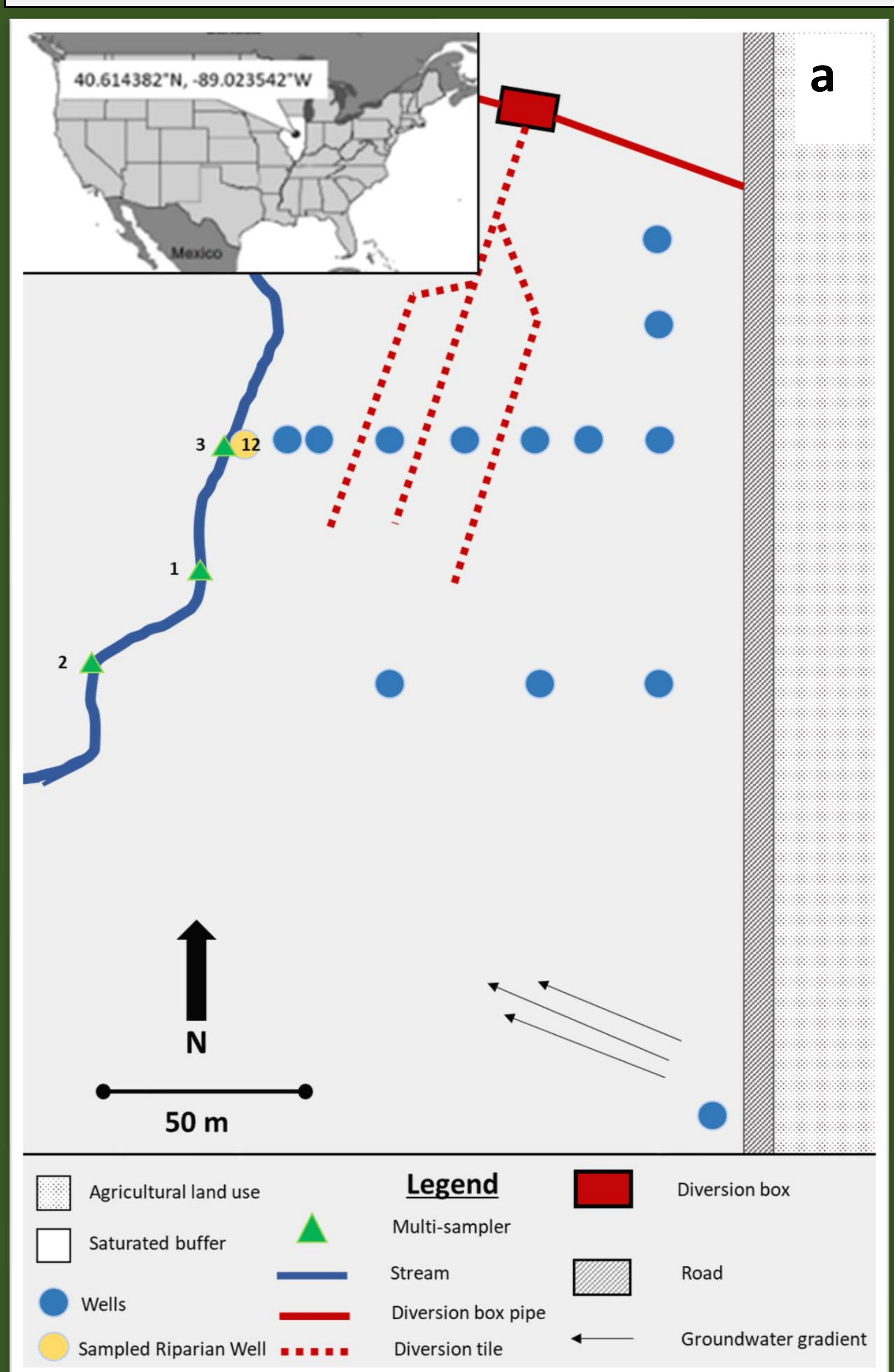
Illinois State University
Illinois' first public university.

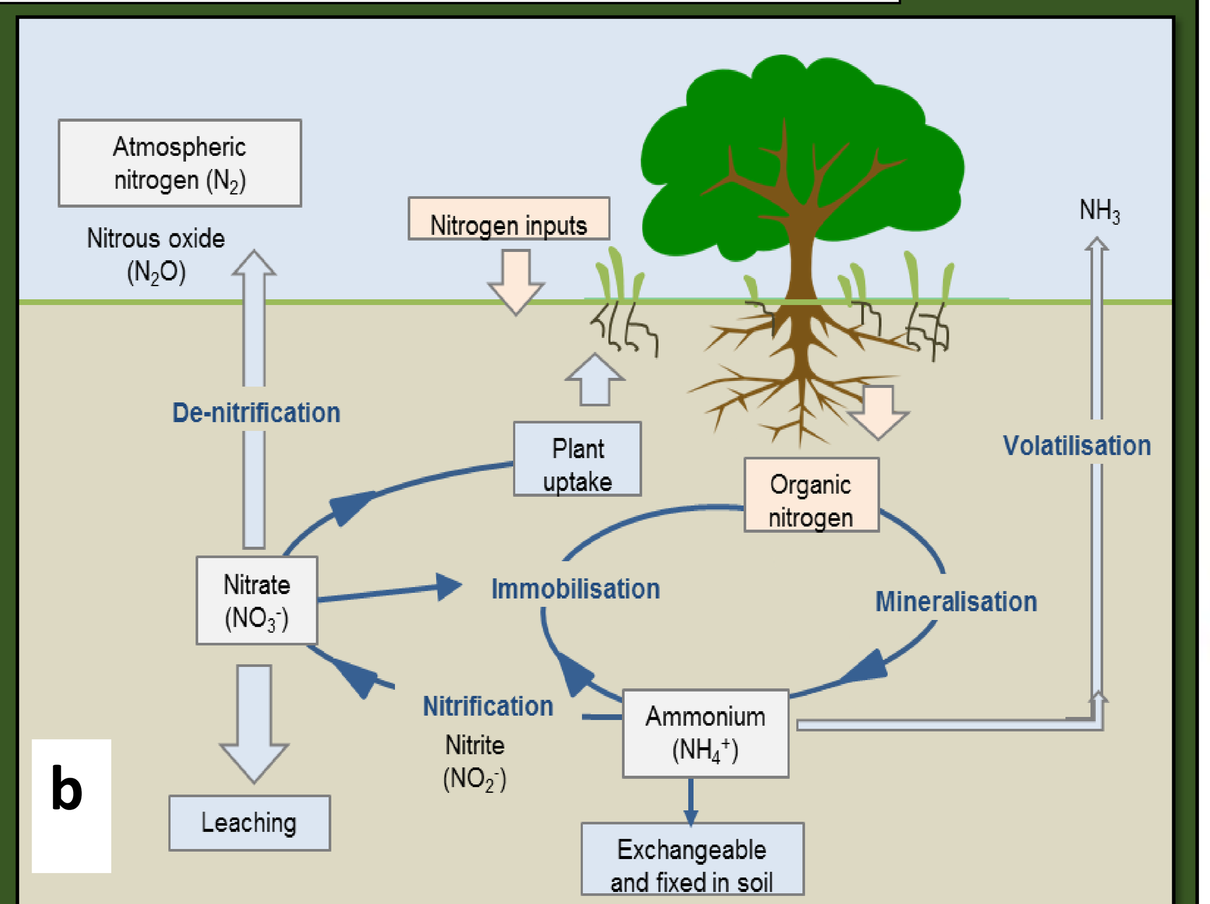
Background

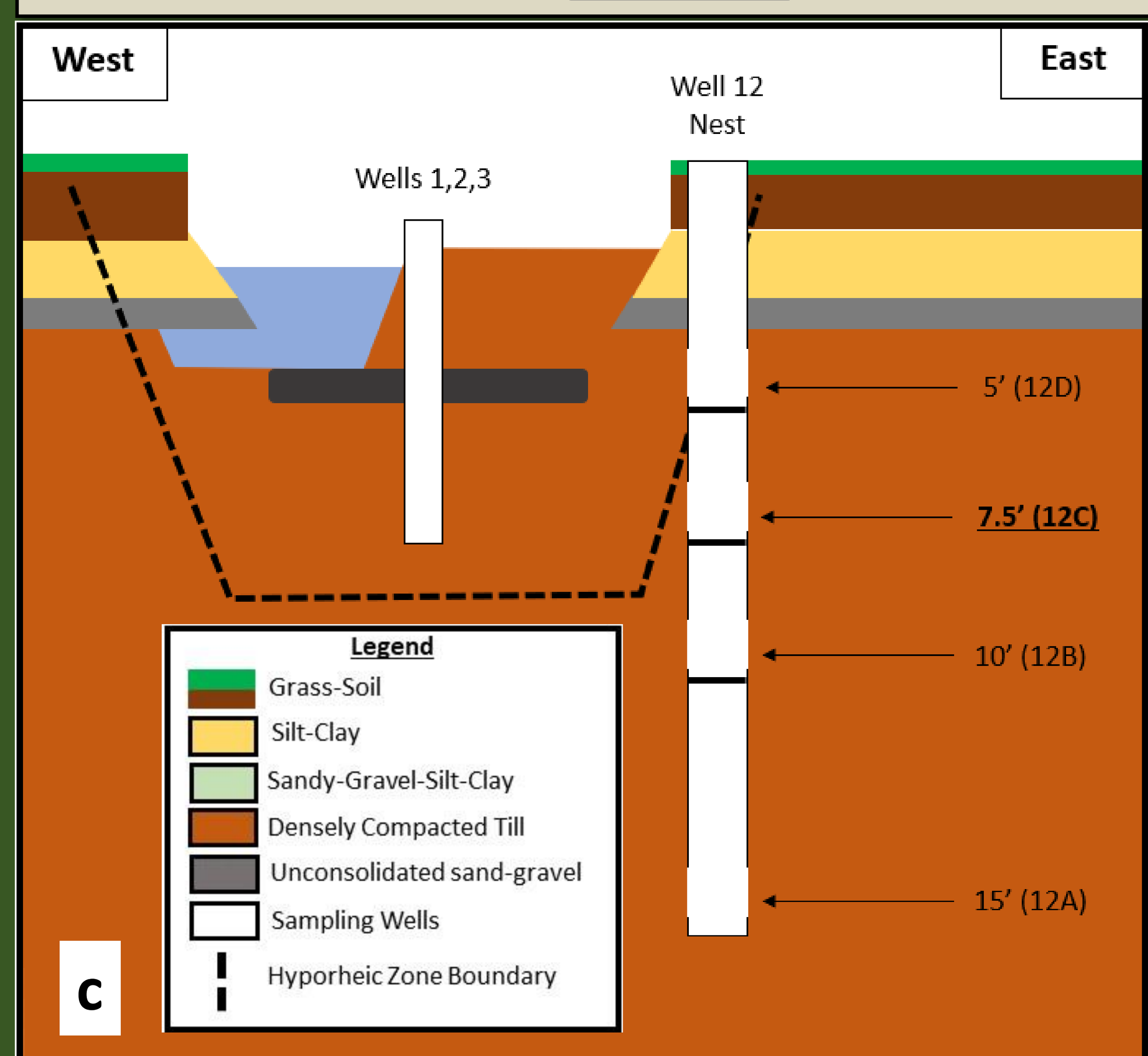
- Nitrate naturally occurs in the environment, but because it is necessary to ecological production, greater quantities are applied to the environment every year via sources like nitrogen-rich fertilizers to further increase biological production (1).
- The transport and fate of nitrate is highly controlled by streams.
- Nitrate removal can be via denitrification, removal of excess nitrate through reduction to dinitrogen in anoxic, organics-rich environments (2) or plant uptake and assimilation.
- These processes can occur in a segment of stream substrata called the hyporheic zone (HZ), a segment of substrata and porewater below a stream where stream water and shallow subsurface waters interact.
- This study will analyze particular physical processes in a stream to determine their contribution to nitrate removal in stream environments.
- The stream that will be studied for this project, T3, is located in central Illinois and is a quintessential example of the streams found in high nitrate-producing agricultural lands seen throughout the Midwest.
- **This study will support whether remediated agricultural streams have the potential to remove nitrate naturally from the environment.**

Research Questions

1) What percent of water contributing to hyporheic flow in a stream originates from surface water flow and groundwater flow?
2) What is the trend of nitrate removal depth-wise and laterally in the subsurface below streams?
3) How far does stream hyporheic flow extend into riparian subsurface storage and how does this contribute to the nitrate removal or lack thereof seen in question #2?







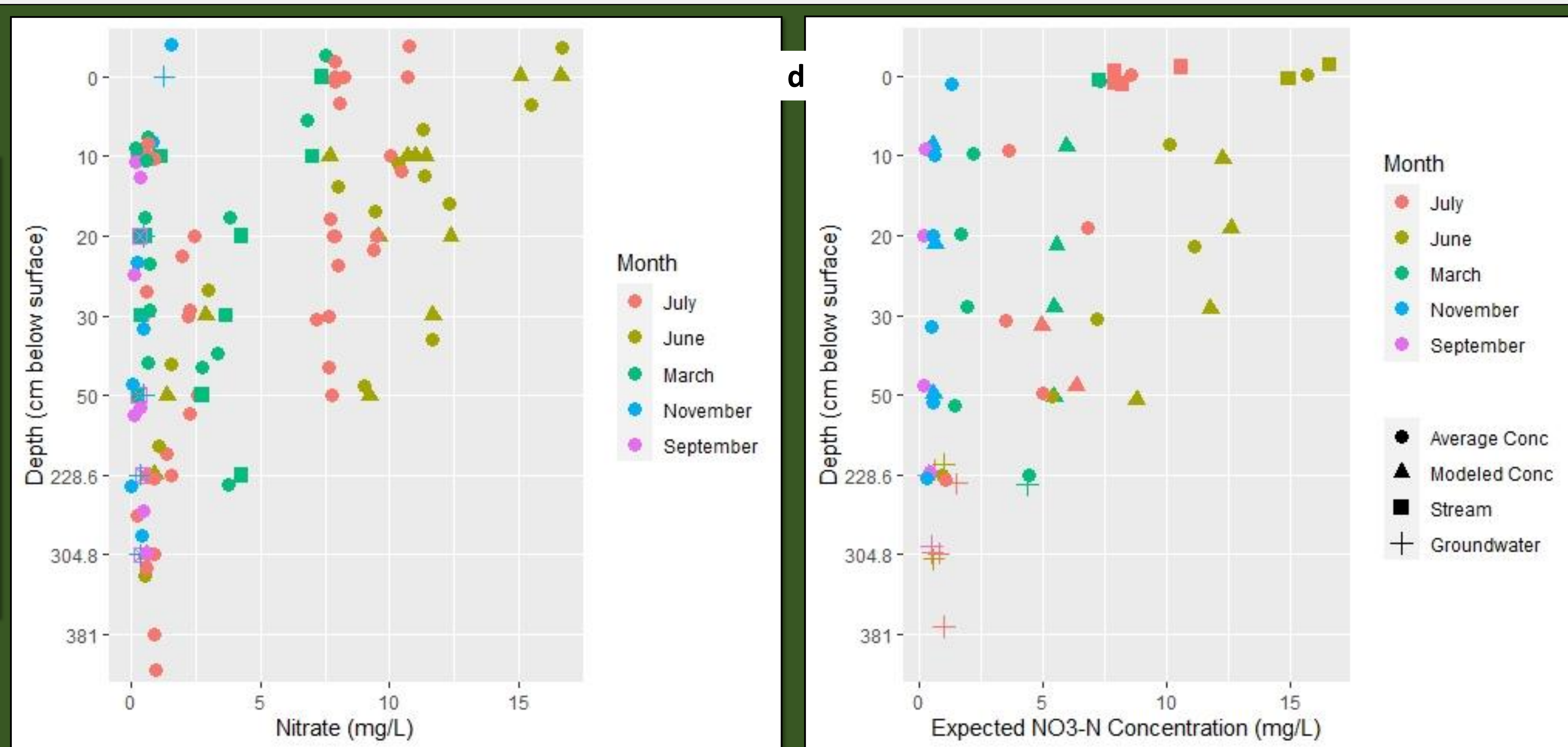
a) Map of Well sites at study area.
b) The nitrogen cycle.
c) Diagram of wells and sampling depths.
d) Measured (left) and modeled (right) amount of NO_3-N to be observed in the HZ versus measured NO_3 concentrations.

Methods

1) Installed 3 multilevel samplers in-stream to sample water at 10 cm, 20 cm, 30 cm, and 50 cm depth along the length of the stream at the T3 site. Sampled these wells, adjacent riparian wells, and the stream itself monthly from June to November of 2020 and in March of 2021.
2) Analyzed these samples for nitrate and anion (chloride, bromide, and sulfide) concentrations using the ISU Ion Chromatograph and tested for dissolved oxygen levels and temperature in-field using a YSI probe.
3) Created a two-component mixing model for surface and groundwater mixing in the HZ using Chloride measurements as proxy for water mixing dynamics to compare measured results to modeled (expected) Nitrate and determine flow patterns of this streambed zone.

Discussion

1) The model showed that surface water contribution accounted for up to 68% of water in the HZ at depth in the peak of the growing season, but there was great temporal variation in this amount.
2) In the peak of growing season, Nitrate concentrations show a distinct trend from surface to depth, with highest concentrations seen at the surface, lowest in groundwater, and a general decreasing trend through the HZ, with the exception of 20 cm depth.
   a) In most cases, the model predicted higher levels of Nitrate than were actually observed, further supporting removal processes occurring in the HZ.
   b) This removal could be due to myriad reasons, including dilution and plant uptake. The increase in Nitrate seen at 20 cm depth specifically could be caused by nitrification, but elucidating the exact causes for Nitrate flux in this zone requires further study.
3) Nitrate levels in the riparian subsurface were very low, and indicate that HZ mixing does not extend substantially into the banks of the stream in this matrix environment.



Conclusion

- Surface water and groundwater are mixing along the depth of the HZ in this study area.
- Nitrate is being removed, potentially by a variety of processes, along the depth of the HZ, except at 20cm depth.
- Riparian HZ interaction in this stream is fairly limited.

A better understanding of how different water sources contribute to the hyporheic zone and how that water flows through this zone will better equip regulators and remediators to use streams and their hyporheic zones to remove excess nitrate from agricultural runoff, contributing to healthier ecosystems and drinking water.

Acknowledgements

Thank you to the generous funding provided by the organizations pictured right, to my committee, Dr.'s Eric Peterson, Catherine O'Reilly, and Wondy Seyoum. Thank you also to my field assistants Caitlin Noseworthy, Cavien Satia, Jack Wassik, and Eli Schukow.

Bloomington Illinois
IWRC Illinois Water Resources Center
Illinois Lake Management Association

References

1) Ehrhardt, S., Kumar, R., Fleckenstein, J.H., Attinger, S., and Musolff, A., 2019, Trajectories of nitrate input and output in three nested catchments along a land use gradient: Hydrology and Earth System Sciences, v. 23, p. 3503–3524, doi: 10.5194/hess-23 3503-2019.
2) Baker, M.A., and Vervier, P., 2004, Hydrological variability, organic matter supply and denitrification in the Garonne River ecosystem: Freshwater Biology, v. 49, p. 181–190, doi:10.1046/j.1365-2426.2003.01175.x.