Background document

Goeller’s work is mainly focussed on the analysis of Nitrogen and reactive Nitrogen in aquatic spaces (Goeller *et al.*, 2016, 2020, 2023; Goeller, Burbery, *et al.*, 2019; Goeller, Febria, *et al.*, 2019). Nitrogen excess in water bodies can lead to eutrophication issues. The risks of the adverse effects of nitrogen are heightened since there are cumulative effects of agricultural pressures on water bodies, with less room for surface water and increased bio-chemical input from farmlands (Goeller *et al.*, 2016). In his paper ‘Springs drive downstream nitrate export from artificially-drained agricultural headwater catchments’ (Goeller, Febria, *et al.*, 2019) Goeller examines with his co-authors the movement of nitrogen in nine different low-land headwaters. This approach was chosen due to the high focus on ground-based control methods/attempts/experiments to extract excess nitrogen from soils, all the while the gulleys and other water rich spaces in agricultural landscapes can move nitrogen in short amounts of time. If the nitrogen enters the groundwater through a gulley or drainage ditch, it also circumvents riparian buffers and other great nitrogen management methods (Goeller, Febria, *et al.*, 2019). To gain a better understanding of spatial and temporal fluxes in these nitrogen movements the researchers took probes at the end of the downstream every two-four weeks, as well as measuring some hydrographic data such as wetted width. The water level was measured hourly and rain data was taken from online resources. For better precision in their results they were also very selective to only sample when there was enough flow.
They saw no significant relationship between daily local rainfall and discharge. However, they found a significant relationship in seasonality and nitrate-nitrogen loads. They even found that ‘Waterways with greater discharge generally also had higher fluxes of nitrate-nitrogen at catchments outlets, irrespective of the magnitude of nitrate-nitrogen concentrations’ (Goeller, Febria, *et al.*, 2019, p. 124). Overall they were able to show too high Nitrate-Nitrogen concentrations in catchments, highlighting the need to take measures at the source and headwaters to effectively reduce downstream concentrations of Nitrate-Nitrogens (Goeller, Febria, *et al.*, 2019).

A possible method to limit Nitrate-Nitrogen (Nr) from circulation are bio-reactors, which are proven to enhance Nr removal. This was studied by Goeller et al. in the 2016 paper ‘Thinking beyond the Bioreactor Box: Incorporating Stream Ecology into Edge-of-Field Nitrate Management’ (Goeller *et al.*, 2016). However, these bioreactors, which are ‘typically woodchip-filled excavations that promote anaerobic redox conditions’ (Goeller *et al.*, 2016, p. 867) are prone to pollution swapping, meaning the result of their processes are other toxic gases or substances, negating their benefits in being reductive. This means that bioreactors need to be installed carefully and constructed with local conditions in mind, then they can slow or decrease Nitrogen-Nitrate uptake into streams. As an example, bioreactors are sensitive to high fine sediment loads which reduce their usefulness significantly, meaning in such cases they need to be accompanied by fine sediment decreasing measures. They argue that bioreactors can therefore be seen as a small-scale tool to help meliorate in-stream conditions, however there is a lack of research into bioreactors as edge-of-field tools. The authors also propose a thorough list of how to study bioreactors in the future (Goeller *et al.*, 2016).

Three years later, Goeller et al. publish a study on bioreactor efficacy titled: ‘Capacity for bioreactors and riparian rehabilitation to enhance nitrate attenuation in agricultural streams’ (Goeller, Burbery, *et al.*, 2019). In their analysis the researchers compared similar, close to each other, 1-km long headwater reaches. One as a control, the other with riparian rehabilitation. The rehabilitative measures comprised of three woodchip bioreactors placed in the zones of high groundwater seepage. One bioreactor was an exception to this, being a bed directly intercepting a tile drain discharge. Physico-chemical parameters as well as nutrient loads were measured for 18 months prior to implementation, as well as for two years afterwards to compare the before and after effects of the measures. While they were not able to differentiate how much each bioreactor contributed to denitrification on their own, as a sum they were able to show depletion in Nitrogen-Nitrate concentration after implementation, although only under low-flow conditions (Goeller, Burbery, *et al.*, 2019).

Edge-of-field tools are seen as important in other works of Goeller et al., in his 2020 paper ‘Combining Tools from Edge-of-Field to In-Stream to Attenuate Reactive Nitrogen along Small Agricultural Waterways’ (Goeller *et al.*, 2020) the researchers argue for a close working relationship of scientists with farmers to stack tools for nitrogen attenuation to overcome limiting factors of single measures. These tools are e.g. grass filter strips, denitrification beds, constructed or enhanced wetlands, riparian vegetation, reshaping of riverbeds or in stream geomorphic measures. The researchers gave each tool a value for a certain benefit, making it easy to see where blind spots are in various tool compositions. While this tool stacking framework is seen as required for effective nitrogen attenuation, it should also not replace local, real hydrological data and expert opinions (Goeller *et al.*, 2020).

For one of the aforementioned tools, the wetlands, a dedicated paper was published; ‘Dual Purpose’ Surface Flow Constructed Treatment Wetlands Support Native Biodiversity in Intensified Agricultural Landscapes (Goeller *et al.*, 2023). In this research the ecological value of agricultural wetlands was analysed. While these kinds of wetlands are not the optimal wetland habitat, they still are sufficient to support wetland dwellers and serve as stepping stone habitats for others. However, there is an issue with invasive species pushing out natives, due to their better adaptability to these irregular kinds of wetlands. To summarize: Wetlands can serve as a habitat for native species, however they do not work without some kind of human intervention/help. This includes pest control and better connectivity between wetlands, so that species are not trapped and isolated, the other purpose of retaining water or attenuating pollutants were not the focus of this study (Goeller *et al.*, 2023).

References

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