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Use of integrated constructed wetlands for the control of N_2O and NO_3 losses from agriculture

Figure 1 Integrated constructed wetland, Dunhill, Co Waterford.

Key external stakeholders:

Farmers, Department of Agriculture, Food & Marine, Environmental Protection Agency, Local Authorities

Practical implications for stakeholders:

Integrated constructed wetlands can help to improve the quality of surface waters and the underlying groundwater.

Main results:

- The research found that groundwater was a major sink for NO_3 accounting for removal rates of 54-79% of NO_3 added.
- Denitrification accounted for 14-16% of the NO_3 sink.
- Dissimilatory nitrate reduction to ammonium accounted for 40-63% of the groundwater NO_3 sink.
- The DNRA rates matched the ambient groundwater NH_4 concentrations observed with higher DNRA observed in groundwater with higher ambient NH_4 concentrations.
- The fate of the NH_4 formed through NO_3 reduction is unknown but could be immobilized in the aquifer, further reduced to N_2 gas or nitrified again to form NO_3.

Opportunity / Benefit:

- Within agriculturally dominated catchments ICWs can assist in the improvement of both surface waters flowing through them and the underlying groundwater.

Collaborating Institutions:

Vesi Environmental Ltd., Waterford Co. Council, Trinity College Dublin, University College Dublin

Teagasc project team:
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1. Project background:

Reducing nitrate (NO_3) loss to water is a national priority to help improve water quality and achieve the requirements of the Nitrates and Water Framework Directive. Denitrification is a permanent sink for N inputs in groundwater which converts NO_3 to environmentally benign dinitrogen (N_2). But denitrification can lead to emissions of nitrous oxide (N_2O) an intermediate product that is a potent greenhouse gas with a global warming potential 298 times of CO_2. Indirect N_2O fluxes arising from ground and surface waters are significant and a potentially important component of global N_2O budget, which is required to estimate to prevent pollution swapping (N_2O for NO_3). The production, movement and consumption of N_2O in groundwater are particularly poorly understood. There is a clear need for further research on the spatial controls of N_2O production and reduction in groundwater. The Intergovernmental Program on Climate Change (IPCC) suggests that 0.25% (range 0.05 to 2.5%) of fertilizer N addition to crop fields is emitted as N2O from groundwater, an indirect EF5g that has great uncertainty and that requires verification over a range of hydrogeological environments.

Integrated constructed wetlands have been used in Ireland and other countries to treat polluted water from agricultural, industrial and municipal sources. Nitrogen entering natural wetland systems can undergo a series of transformations. Nitrogen fluxes from productive agricultural landscapes, attenuation of NO_3 loss to streams and potable groundwater and the potential for pollution swapping due to N_2O emission are key determinants of the efficacy of nutrient loss mitigation measures in Ireland. Developing our understanding of these processes is of critical importance in facilitating the sustainable expansion and intensification of Irish agriculture. In wetlands both ground/drainage waters consume NO_3 and produce/reduce N_2O while passing through and from the agricultural landscape to the receptors. But until now, no direct comparisons between N_2O measurement in groundwater and associated drainage outlets along the flow path have been reported. Moreover, the effect of accelerated groundwater discharge via field drains on convective N_2O emissions to receptors has not been studied up to now.

2. Questions addressed by the project:

The objective of the research was:

- To quantify N_2O production and reduction rates in the wetland sub-soils along groundwater flow paths;
- To quantify NO_3 reduction via denitrification in groundwater beneath an integrated constructed wetland;
- To quantify N_2O emission factors for groundwater (EF5-g)

3. The experimental studies:

The denitrification process is difficult to measure, and existing methods are problematic. Methods used to evaluate or estimate N removal via denitrification in wetlands are problematic and often involve the use of inhibitors, artificially elevated substrate concentrations, and/or physically altered conditions (Groffman et al., 2006). However, relatively new in situ “push–pull” methods allow for measurement of wetland denitrification under more realistic conditions and for evaluation of the ability of different features to affect N flows in the landscape. In situ push-pull method, being used by researchers to determine in situ denitrification rates in shallow groundwater in riparian zones will be evaluated here in natural wetland sites. Dissolved N_2O and N_2 can be quantified using headspace extraction technique and membrane inlet mass spectrometry (MIMS), respectively. A novel method will be developed to understand NO_3 reduction processes in natural wetland soils/sub-soils, associated groundwater and drain outlets in agricultural ecosystems is of huge importance to better understand and to manage risks of NO_3 delivery to surface waters and indirect N_2O emissions to atmosphere.

4. Main results:

Groundwater denitrification was investigated in the groundwater benath the integrated constructed wetland (ICW) located in Dunhill, Co. Waterford. This ICW was designed by Vesi Environmental Ltd. and is run by Irish Water/Waterford County Council to treat municipal waste water from Dunhill village. The effluent is treated as it passes through a number of wetland cells before it discharges to the Anne river. https://www.water.ie/community/wetlands-wastewater-treatment/dunhill-integrated-constructed-wetland/

Elevated ammonium (NH_4) was detected historically in the groundwater close to the ICW and the ICW was implicated as the source of the NH_4. The environmental quality standard for NH4 is ?? mg/L.

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The research has highlighted that ICWs and groundwater NO3 transformations in anaerobic carbon rich subsoils is complex. This research shows that ICWs significantly influence NO_3 attenuation in the groundwater beneath them and that only focusing on NO_3 attenuation within ICWs can underestimate their environmental benefits. Heretofore under investigated processes such as dissimilatory nitrate reduction to ammonium maybe more widespread in the environment resulting in the conversion of NO_3 to NH_4 which may have greater ecological impacts. The occurrence of NH_4 in the aquatic environment does not always indicate point sources of pollution but could reflect NO_3 reduction from diffuse sources of pollution particularly in anaerobic carbon rich soils and subsoils associated with wet clay rich soils. The environmental fate and impact of the NH_4 generated from NO_3 reduction needs to be further investigated.

5. Opportunity/Benefit:

Integrated constructed wetlands have been used to improve water quality in areas impacted by a range of pollutants. Within agriculturally dominated catchments ICWs can assist in the improvement of both surface waters flowing through them and the underlying groundwater. Only focusing on NO_3 attenuation within ICWs can underestimate their environmental benefits. The process of DNRA needs to be further investigated in wet carbon rich soils that occur in wet areas of Ireland and the environmental impact of NH_4 needs to be further assessed. There is an urgent need for ICWs to be considered as an option to improve water quality and biodviserity on farms. These benefits are coupled with carbon storage and flood attenuation. Barriers to uptake need to be identified to facilitate the uptake of ICWs to provide multiple ecosystem services.

6. Dissemination:

The results of the project have been presented at national and international conferences. Two papers were published and there is a further paper in preparation.

Main publications:

Jahangir M.M.R., Fenton O., Müller C., Harrington R., Johnston P., Richards K.G. (2017) In situ denitrification and DNRA rates in groundwater beneath an integrated constructed wetland, Water Research 111: 254-264.

Jahangir M.M.R., Richards K.G., Healy M.G., Gill L., Müller C., Johnston P. and Fenton O. (2016) Carbon and nitrogen dynamics and greenhouse gas emissions in constructed wetlands treating wastewater: a review. Hydrol. Earth Syst. Sci., 20, 1–15.

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