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ACCOUNTING FOR HEADWATER SEEPAGE WETLAND NITROGEN ATTENUATION IN FARM ENVIRONMENTAL PLANNING

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Abstract

We assessed the nitrogen removal performance of a small natural headwater wetland (2.8% of catchment) in a pastoral agricultural catchment in Waikato, New Zealand over two-year period (2011–2013). Flow and water quality samples were collected at the top and bottom of the wetland, and in piezometers installed at strategic points inside and outside the wetland. A simple dynamic model operating on an hourly time step was used to assess wetland nitrogen removal performance. The model showed that despite large episodic inputs of highly contaminated surface run-off during heavy rainfall, shallow groundwater was the dominant source of flow and N load. The concentrations of nitrate-N, Dissolved Inorganic Nitrogen and Total-N were always lower at the outlet of the wetland regardless of flow conditions or seasonality, even during winter storms. The modelled water quality measurements showed high seasonal variability of pollutant loads with wetland N removal efficiency best during low flow, and poorest during high flow events and low temperatures. Overall, the wetland was estimated to reduce headwater nitrate-N loads by 76% and TN loads by 57%.

Introduction

Over 70% of stream length and the majority of diffuse nitrogen and phosphorus losses from agricultural land are generated in first-order headwater catchments (Alexander et al. 2007; McDowell et al. 2017; Wohl 2017). Natural headwater and riparian wetlands are a relatively common feature in rolling and hilly parts of New Zealand (Hughes et al. 2016; McKergow, et al. 2014) and are known to be effective in attenuating diffuse contaminant losses (Petersen et al. 2001; Jordan et al. 2003; Knox et al. 2008). However, compared to constructed wetlands with discrete inflows and outflows (e.g. Tanner and Sukias 2011), their contaminant removal performance is poorly characterised. Groundwater seepage inflows and outflows are difficult to access and measure, and overland flow inputs are highly episodic. These diffuse, and spatially and temporally variable inflows and outflows make assessment complicated and often subject to considerable uncertainty.

We measured and modelled nitrogen reductions in a small natural headwater wetland in a grazed pastoral agricultural catchment in Waikato, New Zealand over a two-year period to assess its performance. The acute impacts of grazing events on water quality exiting the wetland have been previously reported (Hughes et al. 2013, 2016).

Methods

The wetland is located on a dairy farm near Kiwitahi in the headwaters of the Toenepi catchment in Waikato (Figure 1). The wetland catchment is hilly with Morrinsville clay soils (NZ Soil Classification: Orthic Granular). The ∼0.15 ha wetland occupies 2.8% of its surface catchment and is enclosed in a ∼1.9 ha paddock rotationally grazed by dairy cows. It has an area of ~0.15 ha (2.8% of surface catchment) and an average slope of 3.5°. The wetland vegetation is dominated by glaucous sweet grass (Glyceria declinata), an introduced perennial aquatic grass widely naturalised in New Zealand, with scattered rushes and sedges.

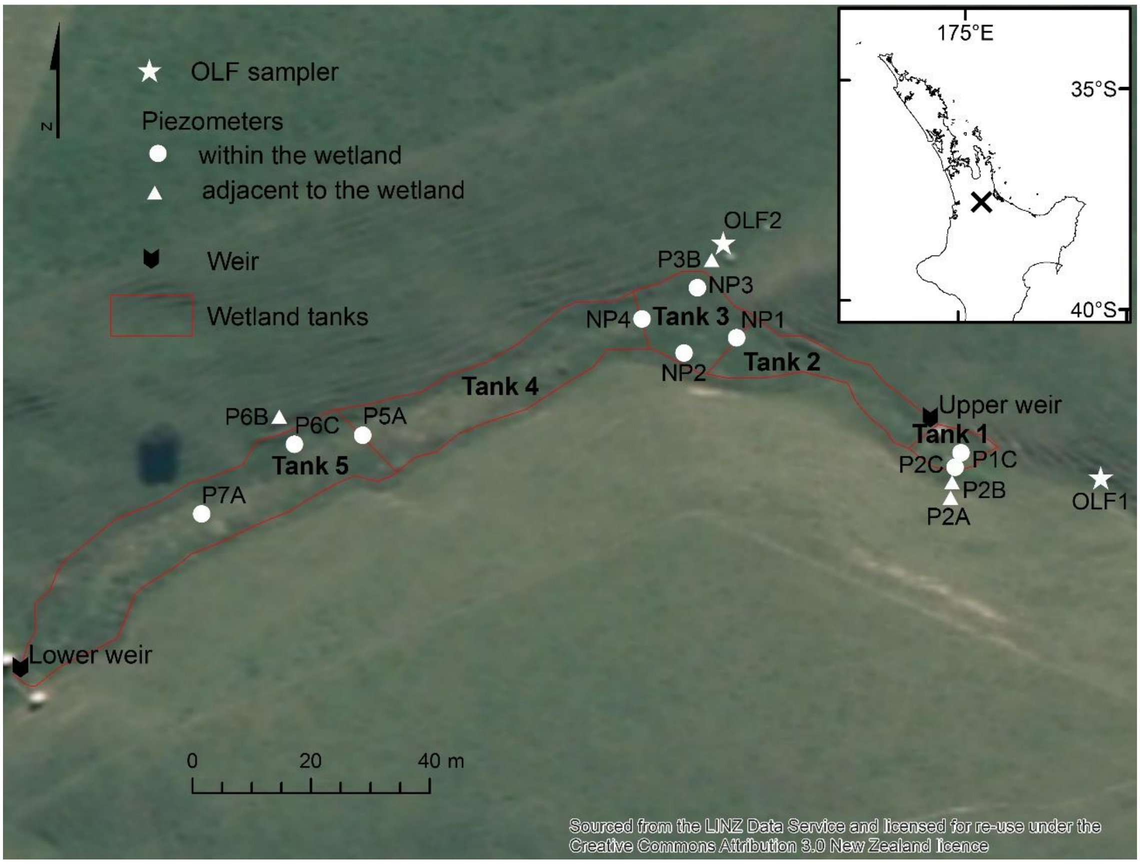

Figure 1. Wetland study site location in the North Island of New Zealand, showing sampling weirs, piezometers, overland flow samplers and conceptual tanks used for modelling of wetland hydrology and N attenuation.

Flow and water quality samples were collected at the wetland upper and lower locations, and piezometers sampled inside and outside the wetland. A simple dynamic model operating on an hourly time step was used to assess wetland removal performance for key N species (Fig. 2). Hourly measurements of inflow, outflow, rainfall and Penman-Monteith evapotranspiration estimates were used to calculate dynamic water balance for the wetland. A dynamic N mass balance was calculated for each N component by coupling influent concentrations to the dynamic water balance and applying a first order areal removal coefficient (k_{20}) adjusted by seasonal air temperature. (Kadlec 2012; Tanner and Kadlec 2014). Full methods are detailed in Uuemaa et al. (2018).

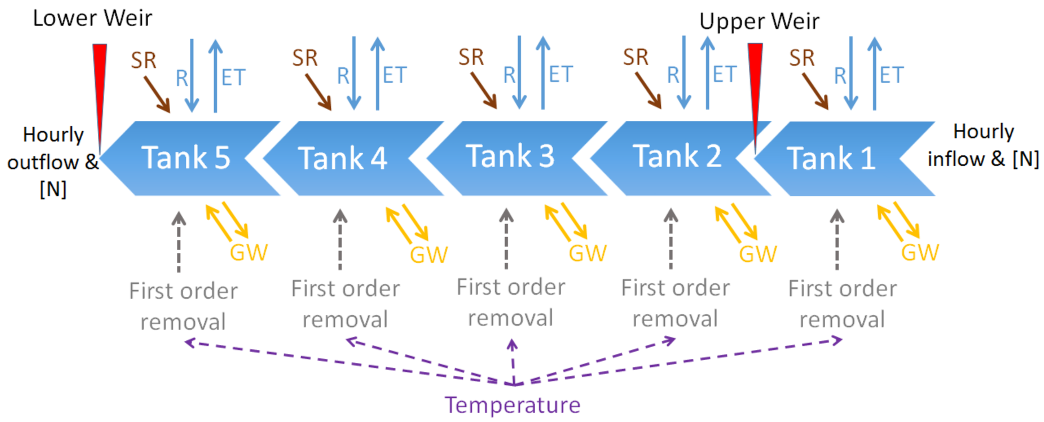

Figure 2. Conceptual diagram of the wetland model. Rainfall (R), evapotranspiration (ET), groundwater (GW) seepage in or out based on each tank's area, surface runoff (SR), and first order N removal adjusted by ambient temperature are calculated for each tank on an hourly time step.

Results and Discussion

The results are fully presented and discussed in Uuemaa et al. (2018); here we provide a brief summary. The measured concentrations of nitrate-N, dissolved inorganic N and Total-N were always lower at the outlet of the wetland regardless of flow conditions or seasonality, even during winter storms. However, except during occasional large surface run-off event, flow measured at the upper weir was only a small fraction of that measured at the lower weir, indicating substantial groundwater seepage inputs to the wetland between the upper and lower weirs.

The dynamic hydrological sub-model calibrated with flow data from the upper and lower weirs and local climatological data provided a rational approach to estimate relative inflows to the wetland from different pathways. It showed groundwater accounted for ~95% of the inflow to the wetland. Linking this information with median concentrations of N species measured in the different inflows to the wetland (groundwater and overland flow) showed that loads of nitrogen in and out of the wetland varied markedly, with maximum loads in winter and spring (Fig. 3). Groundwater accounted for the majority of the N load into the wetland, dominated by nitrate (~60% of in-load) and organic forms (~30% of in-load); see Figure 4.

Overall the wetland was estimated to reduce headwater Total N loads by 57%, comprised of 76% reduction of net nitrate-N loads; 73% reduction of net ammonium-N loads, 26% reduction of organic-N loads. Passage of shallow nitrate-rich groundwater into the wetland up through the organic-rich, anaerobic base of the wetland is likely to have stimulated the high denitrification rates achieved. Net removal of organic-N was less effective, resulting in it becoming the dominant form leaving the wetland (56% of out load). Decay processes in the wetland ecosystem, which regenerate N from plant detritus and biofilms, are likely to have created these high natural background concentrations of organic-N.

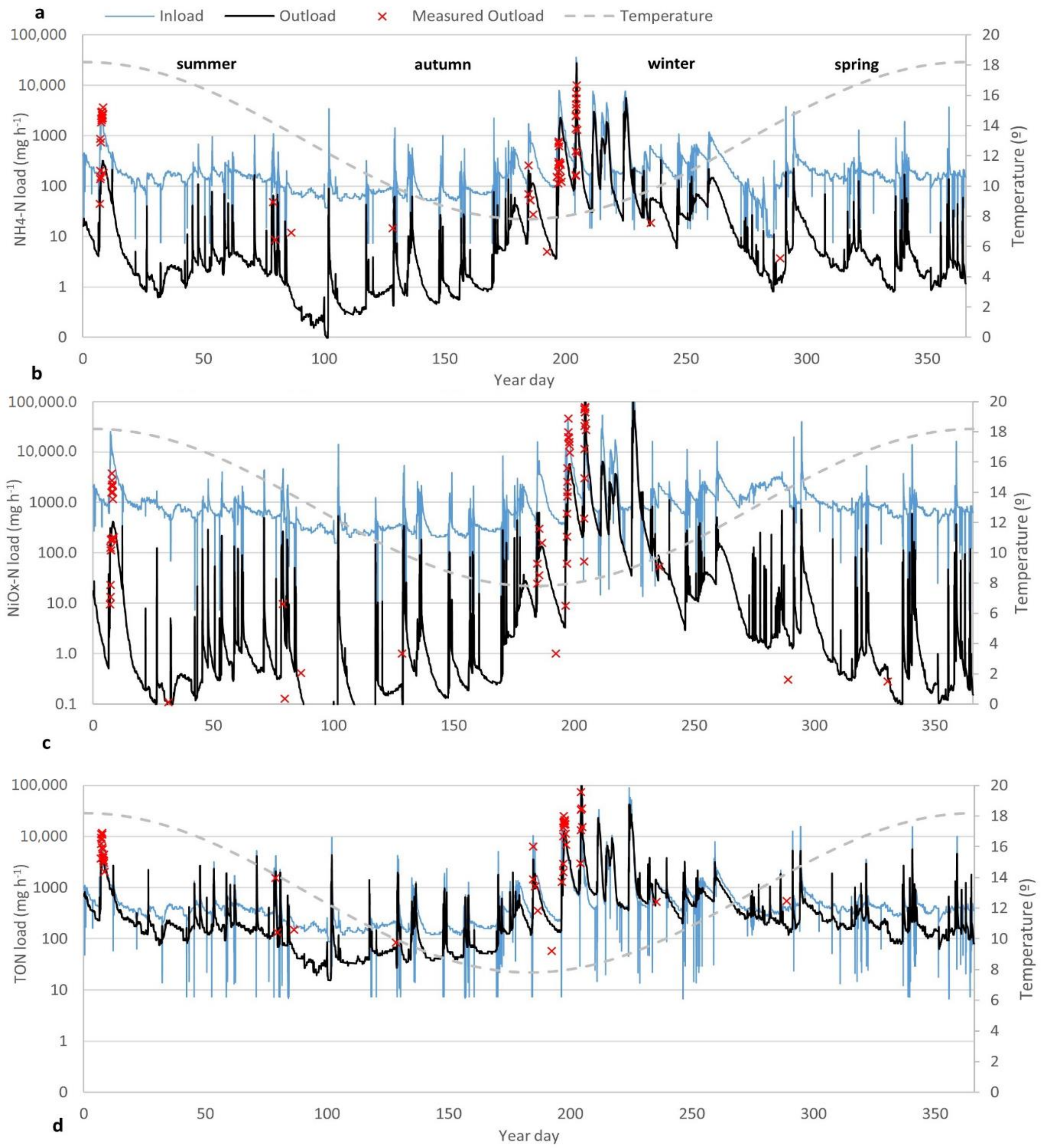

Figure 3. Time series for 2012 showing modelled and measured inflow and outflow (a) ammonium-N (NH_4-N); (b) nitrate-N (NOx-N); and (c) Total Organic N (TON) loads at the upper and lower sampling weirs.

This study has developed an improved method to estimate the hydrology and N removal performance of small seepage wetlands located in the headwaters of pastoral catchments. The results show that these wetlands can be very effective at attenuating nitrogen loads. As their N removal efficiency per unit land area is high, farmers should consider maintaining and rehabilitating such wetlands to reduce N losses from their farms. NIWA and DairyNZ are working together with other agencies to quantify the nutrient removal capabilities of natural and constructed wetlands, so they can be appropriately recognised in farm nutrient budgets (Wright-Stow et al., 2018).

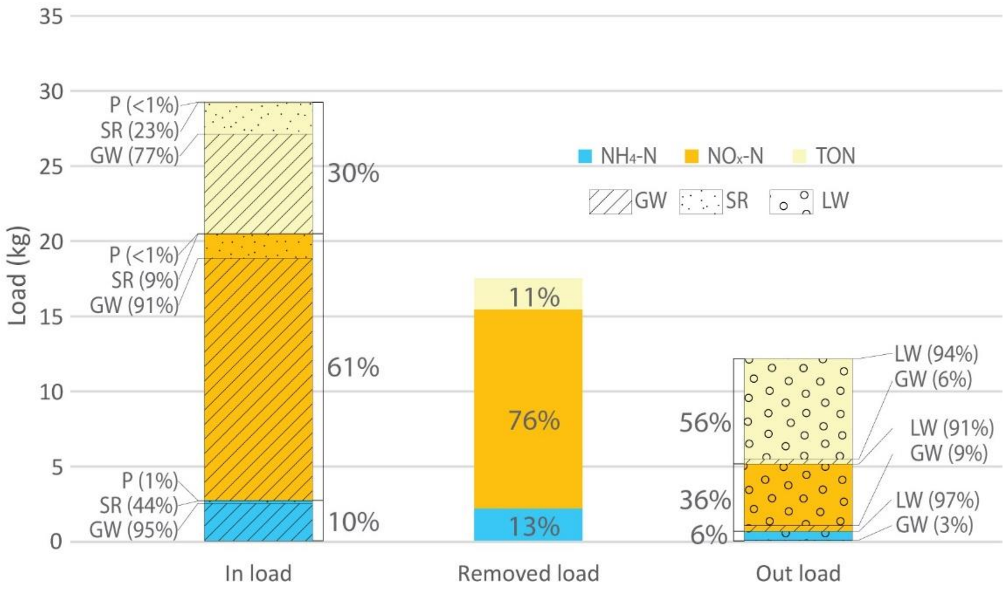

Figure 4. Proportions of total nitrogen components entering, leaving, and removed by the wetland. P = precipitation; SR = Surface runoff; GW = Groundwater; LW = Lower weir.

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References

Alexander R.B., Boyer E.W., Smith R.A., Schwarz G.E., Moore R.B. (2007). The role of headwater streams in downstream water quality. *Journal of the American Water Resources Association* 43(1), 41–59

Hughes, A., McKergow, L.A., Sukias, J.P.S. Tanner, C.C. (2013) Influence of livestock grazing on wetland attenuation of diffuse pollutants in agricultural catchments. In: Accurate and efficient use of nutrients on farms. (Eds L.D. Currie and C L. Christensen). Occasional Report No. 26. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. http://flrc.massey.ac.nz/publications.html.

Hughes, A.; Tanner, C.C; McKergow, L.A.; Sukias, J.P.S. (2016). Unrestricted dairy cattle grazing of a pastoral headwater wetland and its effect on water quality. *Agricultural Water Management* 165,72–81

Jordan, T.E.; Whigham, D.F.; Hofmockel, K.H.; Pittek, M.A. (2003). Nutrient and sediment removal by a restored wetland receiving agricultural runoff. *Journal of Environmental Quality* 32, 1534–1547

Kadlec, R.H. (2012). Constructed marshes for nitrate removal. *Critical Reviews in Environmental Science and Technology* 42, 934–1005.

Knox, A.K.; Dahlgren, R.A.; Tate, K.W.; Atwill, E.R. (2008). Efficacy of natural wetlands to retain nutrient, sediment and microbial pollutants. *Journal of Environmental Quality* 37, 1837–1846.

McDowell, R.W., Cox, N., Snelder, T.H., (2017). Assessing the Yield and Load of Contaminants with Stream Order: Would Policy Requiring Livestock to Be Fenced Out of High-Order Streams Decrease Catchment Contaminant Loads? *Journal of Environmental Quality* 46, 1038-1047.

McKergow, L.A.; Rutherford, J.C.; Timpany, G.C. (2012). Livestock-Generated Nitrogen Exports from a Pastoral Wetland. *Journal of Environmental Quality*, 41, 1681–1689,

O'Geen, A.T.; Budd, R.; Gan, J.; Maynard, J.J.; Parikh, S.J.; Dahlgren, R.A. (2010). Mitigating Nonpoint Source Pollution in Agriculture with Constructed and Restored Wetlands. In *Advances in Agronomy*, Volume 108; Academic Press: Cambridge, MA, USA.

Peterson, B.J., Wollheim, W.M., Mulholland, P.J., Webster, J.R., Meyer, J.L., Tank, J.L., Marti, E., Bowden, W.B., Valett, H.M., Hershey, A.E., McDowell, W.H., Dodds, W.K., Hamilton, S.K., Gregory, S., Morrall, D.D., 2001. Control of nitrogen export from watersheds by headwater streams. *Science* 292, 86-90.

Tanner, C.C.; Kadlec R.H. (2013). Influence of hydrological regime on wetland attenuation of diffuse agricultural nitrate losses. *Ecological Engineering* 56, 79-88

Tanner, C.C.; Sukias, J.P.S. (2011). Multi-year nutrient removal performance of three constructed wetlands intercepting drainage flows from grazed pastures. *Journal of Environmental Quality* 40, 620-633.

Uuemaa, E., Palliser, C., Hughes A.O., Tanner, C.C. (2018). Effectiveness of a natural headwater wetland for removing agricultural nitrogen loads. *Water* 10, 287; http://www.mdpi.com/2073-4441/10/3/287/htm

Wohl, E. (2017). The significance of small streams. *Frontiers in Earth Science* 11, 447–456.

Wright-Stow, A.; Tanner, C.C.; Matheson, F.; Stephens, T.; Quinn, J.; Burger D.; Young, J. (2018). Accelerating uptake of constructed wetlands and riparian buffers by quantifying contaminant attenuation performance: A proposed national investigation. In: Farm Environmental Planning: Science, Policy and Practice (Eds. L.D. Currie and C.L Christensen). Occasional Report No. 31. Fertilizer and Lime Research Centre, Massey University, 7-9 February, 2018. http://flrc.massey.ac.nz/publications.html.