Goeller, B., Tanner, C., Sukias, J., and Craggs, R.., 2019. Improving edge-of-field nutrient mitigation tools to enhance contaminant attenuation and waterway health. In: *Nutrient loss mitigations for compliance in agriculture*. (Eds L.D. Currie and C.L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 32. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 8 pages.

IMPROVING EDGE-OF-FIELD NUTRIENT MITIGATION TOOLS TO ENHANCE CONTAMINANT ATTENUATION AND WATERWAY HEALTH

Brandon Goeller, Chris Tanner, James Sukias, and Rupert Craggs

National Institute of Water and Atmospheric Research (NIWA) Ltd,
PO Box 11115, Hillcrest, 3216 Hamilton
Email: Brandon.Goeller@niwa.co.nz

Abstract

Artificially-drained agricultural lands can be significant sources of diffuse nutrients, sediment, and faecal contaminants to aquatic ecosystems. These contaminants degrade water quality, mahinga kai (food gathering locations), and recreational values of waterways over significant areas of New Zealand. To mitigate these adverse impacts, edge-of-field tools, such as riparian buffers, constructed wetlands, and emerging options such as denitrifying woodchip bioreactors, and filamentous algae nutrient scrubbers (FANS), can be implemented to intercept and attenuate contaminants. Besides improving water quality, these mitigation tools will likely help to improve the ecosystem health of receiving waterways, thereby ensuring that farming can be sustainable and economically viable within the new paradigm of ‘farming within limits’. For example, the nutrient attenuation performance of edge-of-field tools is influenced by environmental parameters like dissolved oxygen and nitrate-nitrogen concentrations, dissolved organic carbon availability, flow and temperature regimes, and fine sediment accumulations. These parameters are also linked to the overall health of waterways by influencing rates of organic matter decomposition, nutrient cycling, aquatic food webs, and biodiversity. However, a clearer understanding of how edge-of-field tools might improve catchment water quality, mahinga kai, and aquatic ecosystem health is needed to support and guide their implementation, especially for newer tools like denitrifying bioreactors and FANS. Evaluations of the potential ecosystem-level impacts of edge-of-field mitigation tools should be conducted at ecologically-relevant spatial and temporal scales and should also incorporate Mātauranga Māori (traditional knowledge) to promote holistic resilience, sustainability, and cultural acceptability. Overall, a combination of economic, logistical, cultural, and ecological information will be required to support the implementation of edge-of-field mitigation tools that enhance contaminant removal and waterway health.

Introduction

Diffuse-source agricultural contaminants, including nutrients, fine sediment, and faecal contaminants, degrade water quality, mahinga kai (food gathering locations), and recreational values of waterways over significant areas of New Zealand. Limits being set under the government’s National Policy Statement for Freshwater Management and its National

Objective Framework (NOF) will help to address this degradation. The NOF mandates that limits be set on several attributes of freshwaters to ensure human and ecosystem health be maintained or improved (e.g., nitrate-N and ammonium-N limits for streams; total N and total P limits for lakes) (Ministry for the Environment 2017). However, balancing agricultural production with waterway health will require significant changes to land-uses and stocking intensities across large areas of the country. Source controls of nutrient losses through improved on-farm nutrient and grazing management are the most cost-effective initial responses to meet nutrient limits, but these will often be insufficient to achieve the required reductions in leaching losses and surface runoff (Conley et al. 2009). Therefore, other nutrient management practices, such as edge-of-field nutrient mitigation tools, are needed to intercept and attenuate diffuse nutrient pollution from agricultural drainage water (Faust et al. 2018). The mitigation of agricultural contaminants with edge-of-field tools is an effective approach to protect and rehabilitate aquatic ecosystem values and functions, while reducing costs and maintaining agricultural outputs.

Tools to reduce agricultural contaminant loss should seek to intercept the hydraulic pathways (flow paths) of nutrient delivery and provide conditions to enhance nutrient attenuation in riparian zones and within receiving waterways (Newcomer Johnson et al. 2016, Neilen et al. 2017, O'Brien et al. 2017). A variety of edge-of-field nutrient attenuation tools are suitable for targeting surface and subsurface drainage discharges, including: riparian fencing and vegetated buffers (McKergow et al. 2016, Vidon et al. 2018), constructed wetlands (Mander et al. 2017, Wang et al. 2018), denitrifying bioreactors (Schipper et al. 2010, Christianson et al. 2012), and FANS (Sutherland and Craggs, 2017). However, the pollution mitigation efficiencies of these tools, as well as their implementation costs, can vary due to challenges associated with treating variable drainage discharges and fluctuating nutrient loads common throughout New Zealand (Tanner and Sukias 2011, Sukias et al. 2018). Moreover, the suites of potential ecological benefits, farming impacts, and environmental trade-offs differ among mitigation tools (Christianson et al. 2013). Therefore, besides overcoming the administrative, socio-economic, and technical barriers to implementation (David et al. 2015), enhancing the uptake of edge-of-field contaminant mitigation tools also requires practical knowledge to inform how existing and newer tools can impact the water quality and cultural values of waterways.

The increased implementation of edge-of-field mitigation tools has the potential to protect waterways from degradation and provide benefits to ensure the ecological health of receiving streams, lakes, and estuaries. However, the positive and negative impacts of edge-of-field mitigation tools on waterway health are not well-understood or accounted for in management, particularly for newer tools such as denitrifying bioreactors. Implementing these tools to enhance waterway health is in the direct interest of the human societies that also depend on them for ecosystem services, including provisioning (e.g., production of food and water), regulating (e.g., controlling climate and disease), supporting (e.g., nutrient cycles and oxygen production), and cultural (e.g., spiritual and recreational benefits) services (Millenium Ecosystem Assessment 2005). Moreover, maximising the aquatic ecosystem benefits of edge-of-field contaminant mitigation tools by emphasizing their ecosystem service provision is aligned with Māori cultural principals of kaitiakitanga (stewardship) and the protection of mahinga kai. To inform management decisions and research needs around edge-of-field contaminant mitigation tools in agricultural landscapes, we discuss the potential aquatic ecosystem and farm benefits versus the potential disservices (negative impacts) provided by riparian buffers, constructed wetlands, and denitrifying bioreactors.

Impacts of edge-of-field mitigation tools on aquatic ecosystems and farms

Implementing riparian buffers, constructed wetlands, bioreactors, and FANS should generate significant aquatic ecosystem benefits across New Zealand, by boosting contaminant attenuation, improving aquatic habitat and biodiversity, mitigating downstream flooding, and enhancing waterway recreation and aesthetics (Table 1). Riparian buffers and constructed wetlands that intercept agricultural runoff offer an expanded portfolio of ecosystem benefits compared to bioreactors (Stutter et al. 2012). These include the regulation of runoff, erosion, and stream temperature, as well as carbon sequestration, biomass production, habitat creation, and enhanced biodiversity (Christianson et al., 2014). These environmental benefits can also generate substantial co-benefits on farms, for example by providing clean water for stock, attenuating excess nutrients, shading and sheltering stock, producing plant or algae biomass from recovered nutrient contaminants for use as a soil amendment, fodder and timber, and contributing to farm aesthetics and enjoyment (Table 1). Importantly, obtaining the optimal combination of environmental and farm co-benefits from these mitigations will be highly dependent on the mitigation design and landscape context (i.e., the location and spatial extent of mitigations within a catchment, relative to the ecological integrity of that catchment). For example, considering the proximity of riparian buffers or constructed wetlands relative to stream reaches with suitable habitat and the connectivity and distance along aquatic and terrestrial dispersal corridors will be important when evaluating their ecological impacts. Hence, the agricultural and landscape settings, as well as the range of ecological functions fulfilled by edge-of-filed contaminant mitigation tools, need to be considered when selecting and siting appropriate mitigation tools to rehabilitate waterway health and ecosystem services in receiving waterways.

In addition to the ecological and farm benefits produced by edge-of-field pollution mitigation, there may also be potential for environmental disservices or ‘pollution swapping’. These arise due to naturally-occurring biogeochemical reactions that are driven by the strong redox gradients sometimes produced within riparian and wetland sediments or bioreactor media. Accounting for the pollution swapping potential of nutrient attenuation tools as compared to agricultural sources is important to evaluate their overall environmental impacts (Fenton et al. 2016). The potential environmental disservices provided by riparian buffers, constructed wetlands, bioreactors, and FANS are also summarised Table 1. For example, constructed wetlands and bioreactors may produce greenhouse gases (GHG) (Christianson et al. 2013, Jahangir et al. 2016). Similarly, the gaseous emissions of CO_2 and N_2O from bioreactors can be significant, given that these often have high dissolved organic carbon (DOC) and operate under a range of redox conditions associated with variable discharge and influent water chemistry (Moorman et al. 2010, Warneke et al. 2011). FANS could increase both the temperature and pH of the drainage water. However, if designed and operated appropriately, these issues can be managed. For example, GHG emissions from constructed wetlands and bioreactors are likely to be no greater than emissions from other agricultural sources or nitrate-polluted waterways (Elgood et al. 2010, Groh et al. 2015).

Compared to riparian buffers and wetlands, ecological evaluations of bioreactor performance are sparse, or primarily focus on the potential of bioreactors to contribute to pollution swapping via the creation of GHG and other undesirable products, such as hydrogen sulphide or methyl mercury, associated with strong and variable bioreactor redox gradients (Weigelhofer and Hein 2015, Fenton et al. 2016). However, there are other potential side effects of bioreactors that should be accounted for, such as the flush of high DOC within the first weeks of operation, the discharge of anoxic effluent, and the potential mobilisation of dissolved reactive phosphorus (DRP) (Table 1). These environmental stressors that might be released from bioreactors may have deleterious effects on the ecological health of waterways (Goeller et al. 2016). Therefore, waterway managers will need to account for and minimise some of these negative impacts. For example, organic pollution negatively affects sensitive macroinvertebrate taxa, which are indicators of ecosystem health and structure (Camargo and Alonso 2006). Thus, significant releases of DOC in the initial phases of bioreactor operation, as well as the release of anoxic effluent, could be potentially detrimental to downstream biota. Goeller et al. (2016) proposed that the performance of woodchip bioreactors and the structure and functioning of stream biotic communities are linked by environmental parameters like dissolved oxygen and nitrate-nitrogen concentrations, dissolved organic carbon availability, flow and temperature regimes, and fine sediment accumulations. However, better evidence and practical knowledge are needed to shed light on how new and existing edge-of-field contaminant mitigation tools can impact water quality, mahinga kai, and recreational values of waterways.

To improve our understanding of how bioreactors enhance desirable stream ecosystem functioning, future assessments of field-scale bioreactors should evaluate the influences of bioreactor performance on ecological indicators such as primary production, organic matter processing, stream metabolism, and invertebrate and fish assemblage structure and function (Goeller et al. 2016). These evaluations of the potential ecosystem-level impacts of edge-of-field mitigation tools should be conducted at ecologically-relevant spatial and temporal scales and should also incorporate Mātauranga Māori (traditional knowledge) to promote holistic resilience, sustainability, and cultural acceptability. Ecological evaluations of bioreactors should follow protocols similar to that of other restoration and management contexts (Goeller et al. 2016), whereby local climate and biophysical conditions are known, areas of bioreactor implementation are compared to upstream and downstream reaches with no bioreactors, and ecological indicators are measured on realistic timescales (i.e., multiple years). Such knowledge is required to understand the true water quality and ecological benefits of denitrifying bioreactors and to guide their implementation in real agricultural contexts. Importantly, the in-stream water quality and ecological impacts of these mitigations may only be apparent when other catchment-scale pressures such as sedimentation issues or degraded in-stream habitat have already been addressed (Goeller et al. 2016). This may require implementing multiple, different mitigation tools within a catchment to ameliorate downstream nutrient loads and improve ecological health.

Conclusions

Riparian buffers, wetlands, and FANS can provide a broader suite of ecosystem services than bioreactors. In comparison, however, riparian planting may offer only limited treatment for nitrate from tile drains or riparian seeps (Jaynes and Isenhart, 2014; Mayer et al., 2007). Hence, bioreactors, constructed wetlands, and FANS that treat subsurface and surface drainage could provide substantial contaminant mitigation that can complement the implementation of riparian buffers across New Zealand's agricultural landscapes (McKergow et al. 2016). Thus, as the uptake and implementation of these tools increases, management plans will need to evaluate the benefits, as well as any potential environmental disservices and pollution-swapping phenomena, associated with edge-of-field contaminant mitigation. Due to the variable nature of contaminant loss and attenuation processes across New Zealand's agricultural landscapes, there is unlikely to be a single mitigation tool or silver bullet for solving nutrient problems in agricultural waterways. Therefore, continuing to improve and implement multiple 'site appropriate' edge-of-field tools will be important to protect the values and services provided by our waterways.

Implementing edge-of-field tools and accounting for their impacts within farm nutrient budgets and farm environment plans will be an important part of improving the water quality and ecological health of catchments throughout New Zealand. For newer tools like denitrifying bioreactors and FANS, we must also acknowledge and account for their ecosystem health functions, especially as their implementation increases throughout a catchment. Edge-of-field contaminant mitigation tools have great potential to make significant contributions to improving water quality, stream health, and ecosystem services if they are tailored to site-specific conditions and implemented strategically with land-based and stream-based mitigation tools within catchments throughout New Zealand. Overall, this will require combining economic, logistical, cultural, and ecological information to support the implementation of edge-of-field mitigation tools that enhance contaminant attenuation and waterway health.

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Table 1: Overview of the potential farm benefits and aquatic ecosystem impacts associated with mitigation targets for riparian buffers (RB), constructed wetlands (CW), denitrifying bioreactors (BR), and filamentous algae nutrient scrubbers (FANS). The corresponding impacts associated with mitigation targets are indicated by ‘x’.

Mitigation target	**Farm benefit**	**RB**	**CW**	**BR**	**FANS**	**Aquatic ecosystem benefit**	**Environmental disservice**	**RB**	**CW**	**BR**	**FANS**
Contaminant attenuation	clean water for stock	x	x	x	x	overland or subsurface flow filtering	anoxic effluent discharged to waterway during low flows		x	x	
	clean water for stock	x	x	x	x	faecal contaminant removal	waterfowl E.coli source	x	x		
	nutrient attenuation	x	x	x	x	nutrient uptake and denitrification	dissolved P mobilisation, nitrous oxide emission	x	x	x	
	improved greenhouse gas budget	x	x		x	carbon sequestration	greenhouse gas pollution swapping, release of sulphides		x	x	
	erosion control, stock management	x				bank stabilization and damage control	invasive weed habitat	x	x		x
Aquatic habitat and biodiversity	shelter for livestock, fodder or timber source	x	x			shade, in-stream temperature and vegetation control	decreased in-stream nutrient uptake and solar disinfection	x			x
	streambed stabilisation	x	x			wood and leaf litter inputs, habitat and food web enhancement	high flush of dissolved organic carbon			x	
	refugia for pollinators or bio-controlling animals	x	x			habitat and biodiversity enhancement	fish passage barriers		x		
Downstream flood mitigation	flood mitigation	x	x	x	x	increased water infiltration and retention	localised sedimentation	x	x	x	
Recreation and aesthetics	farm aesthetics and enjoyment	x	x		x	natural function and landscape fit	weed and pest habitat	x	x		x