Otago Regional Council

Document Id:

MEMORANDUM

To:

From: **Tapuwa Marapara**

Date: **October 2022**

Re: **Mitigations for minimising nutrient loss from farming systems**

Name	Role	Date Completed
Ben Mackey	Reviewer 1	Oct 2022
Graeme Doole (AgResearch Ltd)	Reviewer 2	Nov 2022

Purpose

This document generally characterises the mitigation options that could be adopted on a farm to reduce nutrient loss. Likely reductions in nutrient loss are provided as indicative and generic starting point, to then be considered in light of individual farms. The cumulative effects of stacking/aggregating the mitigations are discussed in another report[1] by Sise et al., (2022). Pastoral and or cropping operations can adopt the mitigations to reduce environmental impacts.

The main mitigations described include:

- Fertiliser management
- Effluent management
- Winter crop management

[1] Options for improving water quality within the Otago region: Development of GMP & GMP+ scenarios project report. Prepared for Otago Regional Council. Written by Sise, J., Glennie, S., McCall, M., Wilson, K., (2022)

- Riparian management
- Irrigation management
- Alternative forages
- Land retirement options

The mitigations include activities that are already being or will be implemented within individual farms over the next 2-5 years and these are categorised as Good Management Practices (GMP). Other mitigations are categorised as Good Management Practices Plus (GMP+) for activities that are considered more difficult, expensive or take longer time frames to implement, and others are categorised as Good Management Practices Plus Plus (GMP++) for additional "outside of the box" activities that won't be easily adopted due to technology, cost and time, particularly if the potential environmental benefits don't outweigh the impediment to mitigation implementation (Sise et al., 2022).

The list of mitigations described is not exhaustive, to sharpen the focus on those options that are most relevant to our assessment. Relative cost breakdowns are categorised as Low, Medium and High for each contaminant, with an indicative annual cost per hectare. Nitrogen (Low <100, Medium 101-366, and High >366 $/ha/yr); Phosphorus (Low <111, Medium 112-476, and High >476 $/ha/yr); Sediment (Low <81, Medium 82-169, and High >169 $/ha/yr); Microbes (Low <129, Medium 130-192, and High >193 $/ha/yr). These categories are based on literature from Landscape DNA (https://landscapedna.org/actions/filter/?contaminant_pathway=&land_use=).

Disclaimer

This report is a working document and suggestions are welcomed for mitigations that are not included in the discussion. It is a guidance tool on potential on-farm mitigations that could be adopted to reduce nutrient loss. It is a preliminary document to provide indications of effectiveness and costs based on New Zealand literature. Likely reductions in nutrient loss and associated costs are provided as indicative and generic starting point, to then be considered in light of individual farms. The effectiveness of actions can be optimised by matching the right actions to the landscape setting. Practitioners or applicants seeking to adopt the discussed mitigations will need to prepare a quantitative and property specific assessment of nutrient loss levels, impact of mitigation measures and associated present value costing.

GMP: Fertiliser options							
Description		Target Nutrients	Land use, Soil, and landscape features	Reductions in nutrients	Costs	Limitations	References
Optimal Olsen P	Phosphate fertiliser applications are matched to the soil Olsen P target ranges for optimum growth of pasture and forage crops and to avoid excess P lost in runoff. Regular soil testing provides an indication of the adequacy of P levels for optimum crop and pasture growth and can be used to guide application rates.	P	All Pastoral and cropping systems	An estimated 30-37% reduction in P loss has been predicted by using fertiliser inputs to maintain Olsen P soil target values in Manawatu	Costs are based on soil P requirements but are generally estimated to be low .	Varies according to soil types. High Olsen P levels are needed in soil for reductions in fertiliser applications to be observed	McDowell et al., 2003a Monaghan et al., 2008 Low et al, 2017 Landscape DNA https://landscapedna.org/actions/filter/?contaminant_pathway=&land_use=
Less soluble fertiliser	Superphosphate fertiliser is replaced with low soluble Reactive Phosphate Rock (RPR). RPR is much less soluble than Superphosphate with approximately only 1/3 of the total phosphate contained being available in the year it is applied. The low solubility of RPR increases P use efficiency and reduces phosphorus loss in runoff compared to superphosphate.	P	All pastoral and cropping systems but most relevant to hill country operations. Ideal where the risk of overland flow is high	RPR has been shown to decrease P loss by 33% at a catchment scale	Costs based on soil requirements, but are generally low .	Effectiveness depends on soil type, climatic conditions, and rate of application. Use of RPR is limited to where soil pH is <6, and rainfall is greater than 800mm	McDowell et al. 2003a Low et al., 2017 Landscape DNA https://landscapedna.org/actions/filter/?contaminant_pathway=&land_use=
Reduce nitrogen fertiliser	Nitrogen fertiliser is a significant contributor to the deterioration of water quality. This mitigation focuses on shoulder season (spring/autumn) reductions in nitrogen fertiliser applications to pasture (not crops). Note: this is more suited as a dairy strategy due to the high reliance on N fertiliser.	N	All pastoral and cropping systems	23-42 % reductions in N loss if applications in high-risk months (autumn & winter) are avoided	Costs will vary according to the farmer's ability and how their supplement and crop	Requires expertise to optimise harvested feed under low inputs. Farmer must be willing to adopt the good management practices	De Klein et al., 2011 Low et al., 2017

	Reducing the leaching risk involves limiting the fertiliser application to less than 50 kg N/ha in any single application, avoiding applications when soil temperatures are below 6°C, avoiding use when pasture growth is limited by very dry or very wet conditions and only applying fertiliser to meet plant requirements. Same level of production can be attained with a more conservative use of N fertiliser				policy changes with removal of N fertiliser.		
GMP: Farm dairy effluent (FDE)							
Description		Target Nutrients	Land use, Soil, and landscape features	Reductions in nutrients	Costs	Limitations	References
Increase FDE area	The area available for dispersing FDE to land is increased by approximately 100% to reduce potential loading of nutrient to soil. A nutrient budget together with N loading limits of 150 kg N/ha/yr are used to determine appropriate block size for FDE dispersal. The area to which effluent is applied should preferably be soils that have low risk runoff. Solid separation components should be included to the system if there is a large cow herd of e.g., > 500 cows	N, P	Dairy. On artificially drained or impeded drainage, coarse soil structure on sloping land > 8°, application of 150 kg N/ha/yr is recommended when soil water deficit (SWD) exists. On well drained flat land, applications of 150kg N/ha/yr. should be	Increase in effluent application area from 12 to 19 ha, cutting out extra N fertiliser, reduced N leaching by 18% and N loading by 37%		Increased labour requirements	Houlbrooke, 2008 Dairy NZ, 2015

			avoided during rainfall events				
Defer and apply low rate DFE application to land	FDE applications are deferred to low-risk times through the year (Nov – March) and applied through low-rate sprinklers (<12mm), however, this would require additional effluent storage holding capacity to implement. Deferred irrigation involves storing effluent in a pond, then irrigating it strategically when there is a suitable soil water deficit, thus avoiding the risk of generating surface runoff and/or direct drainage of effluent. Soil water deficits can be measured in the field on a volumetric basis using soil moisture tools.	N, P Can also potentially reduce faecal microbes	Dairy. Works on high-risk soils, i.e., poorly drained, and artificially drained.	5% reduction in N loss and 1 kg P/ha for phosphorus were reported on a NZ dairy farm case study 0- Up to 33% reduction in loss of microbes	Will vary depending on scale of existing farm infrastructure or upgrade	Sealing of ponds, management of effluent system, irrigator type, type of effluent storage facility	Houlbrooke, 2008 Low et al., 2017 https://landscapedna.org/actions/filter/?contaminant_pathway=&land_use=
GMP: Winter crop options							
Description		Target Nutrients	Land use, Soil, and landscape features	Reductions in nutrients	Costs	Limitations	References
On/off grazing	Animals are left to graze on winter crop for 10hrs (vs 24 hrs) to reduce the time available for urine (primarily) to be deposited on bareground. When stock are not on crop, they are assumed to be either grazing pasture or present on wintering pads.	N, P Can potentially reduce Sediment and faecal microbes as well	Dairy, beef, sheep	60% reduction in N leaching losses. 15-30% reduction on P loss on sedimentary soils 30% reduction in microbes and sediment	Will vary depending on type of pad	Careful management of animals to avoid any welfare issues due to proximity in the standoff pad	Monaghan et al., 2008 https://landscapedna.org/actions/filter/?contaminant_pathway=&land_use=
Catch crops	A catch crop is used to absorb (catch) nitrogen which would otherwise be lost to drainage or surface runoff. A wide range of crops can do this, for example oats, wheat, and Italian rye grass. Crop rotations are altered to mimic the practice	N, Sediment	Pastoral and cropping systems	40% reduction in N leaching when oats are planted and achieve yields of up to 12 t DM/ha	As of 2017, it was estimated that prices are low for both N and sediment	While there are significant N leaching reductions associated with certain crops, there might be little	Lincoln Agritech: http://www.lincolnagritech.co.nz/capabilities/capabilities-and-

	of sowing an annual crop (e.g., oats) after grazing to utilise surplus nitrogen within the soil root zone. In each situation, an Oat crop is sown in the month following final defoliation and is either grazed in situ or harvested for silage (dairy -Autumn sown, dry stock – spring sown). Benefits include stabilisation of soil from erosion, increase in organic matter which in-turn improves soil structure and drainage, and cycling of mobile nutrients from previous crop			Planting Oats in June, reduced N leaching by 22% in Southland, 20% in Hawkes Bay and 34% in Waikato	depending on crop grown	impacts on whole farm results depending on crop rotations	projects/catch-crops Dairy NZ https://www.dairynz.co.nz/feed/crops/catch-crops/ Barber, 2014 Low et al., 2017
GMP: Riparian options							
Description		Target Nutrients	Land use, Soil, and landscape features	Reductions in nutrients	Costs	Limitations	References
Buffer strips	Buffer strips are used to mimic fenced riparian areas which filter overland water flow from critical source areas. Buffer strips reduce the momentum and magnitude of surface runoff, thereby allowing nutrient removal. Effectiveness varies based on hydrology, vegetation, and buffer width. The buffer strips are considerably larger for sheep & beef land especially where rolling/steep land types form a significant area of the model farm.	Sediment Particulate N & P	All farming enterprises Accessible margins alongside waterways	During active growing season of vegetation, buffer strips have been shown to reduce nitrogen by up to 93 %. Phosphorus removal rates of 43% can be achieved with 4.6m wide buffers and up to 98% can be removed with 27m wide buffers. Buffer strips that are 9.1m wide have	Price varies based on buffer width, area and vegetation used.	Plants may take numerous years to mature, and recommendations should be site specific. Requires active vegetation management of weeds and plants	Dairy NZ (n.d) https://www.dairynz.co.nz/media/1569771/riparian-mgmt-otago.pdf Low et al, 2017

				been reported to reduce sediment loss by 84%, while 4.6m wide strips can remove 74 %. Generally, buffer zones of over 10m are more effective.			
Wetland	Enhancing and maintaining existing wetlands. Wetlands can be sinks or sources of P, depending on factors such as loading rates and layout. The retention of particulate phosphorus associated with sediment deposition is usually large, especially if the input is sediment rich (e.g., from cropland or derived largely from surface runoff). However, the ability of wetlands to retain particulate P decreases with time as the wetland becomes choked with sediment and/or plant growth, and hence uptake of P, levels off.	Sediment , N, P,	All farming operations Naturally boggy areas receiving some surface runoff that contain dissolved and particulate contaminants from a surrounding catchment.	50-75% N reduction 10% P reduction from surface runoff 60 % reduction of sediment in overland flow entering the wetland.	Enhancement and maintenance costs associated with fencing, e.g., 3 electric for sheep & beef, 2 wire electric for dairy. Cost of 1 weed spray per hectare per year	May require fish passages If there are small size and numerous scattered wetlands, costs may increase from the need to fence and enhance the wetlands . Potential loss of land that could have been used for production.	Low et al., 2017
Stock Exclusion	Direct deposition of faecal nutrients into waterways occurs if stock have access to the waterways. This access can also cause bank destabilisation, which mobilises nutrients as erosion occurs. This mitigation ensures that stock are permanently excluded from streams, rivers, and other waterways on farm by fencing or using shade trees to draw sheep and cattle away from vulnerable areas.	P, E-coli, N	Pastoral farming operations	10-30% decrease in dissolved and particulate P	Based on costs of fencing, and riparian establishment The additional cost of water reticulation necessitated by stream fencing can be prohibitive,	Potential loss of land that could have been used for production.	McDowell, 2012 Low et al., 2017. Journeaux & van Reenan, (2016)

	Sediment and microbes are filtered by riparian vegetation, and the source of soil and pasture damage is removed allowing restoration.				especially on sheep and beef farms where streams often provide stock water.		
Grazing management of critical source areas (CSA)	Targeting least risky areas (tops of paddocks) and reducing grazing in or towards critical source areas, such as waterways or paddock depressions.	N, P, S, Microbes	Dairy, sheep and beef Grazing winter forage crops, but also applicable to summer crops	Considered highly effective at reducing losses due to overland flow, depending on slope and rainfall			Orchiston et al., 2013 Low et al., 2017
GMP: Irrigation							
Description		Target Nutrients	Land use, Soil, and landscape features	Reductions in nutrients	Costs	Limitations	References
Reduce flood irrigation outwash	This mitigation targets dissolved and particulate phosphorus. Much water exits border dyke irrigation bays (25-50% of total application) and this water contains 3-5 kg P/ha/yr. There is currently a mandate for all border dyke and flood wash irrigation to be superseded with spray irrigation by 2030, so this will help address nutrient loss from these inefficient systems.	Dissolved and particulate P	Dry stock and dairy	If bays are laser-levelled and widened, P loss is reduced by 40%.	Medium to High	A switch to spray irrigation will have high initial investment costs.	McDowell & Nash, 2012 Houlbrooke et al., 2008a https://landscapedna.org/actions/filter/?contaminant_pathway=&land_use=
GMP+: Fertiliser options							
Description		Target Nutrients	Land use, Soil, and landscape features	Reductions in nutrients	Costs	Limitations	References
Reduce seasonal and crop	Seasonal use of nitrogen fertiliser is further reduced to limit synthetic N use on pasture to spring and summer (October –	N	All pastoral and cropping systems	>33 % reductions in N loss if applications in	Costs can be significant but are highly	Requires expertise to optimise harvested feed	Low et al., 2017

fertiliser rates	February). Crop N applications are also reduced for dairy and dairy support models.			high-risk months (autumn & winter) are avoided	variable across different land use systems are unlikely to change as they are dependent on current farm fertiliser expenditure	under low inputs. Farmer must be willing to adopt the good management practices Farmers often see N application as a mitigation for risk	
GMP+: Winter crop options							
	Description	Target Nutrients	Land use, Soil, and landscape features	Reductions in nutrients	Costs	Limitations	References
On/off grazing	This mitigation restricts cattle and sheep to maintenance feeds of 4 hours instead of 24 hours on crops during winter, before moving them to a stand-off facility or pasture. This reduces direct faecal and urine deposition on crop and/or pasture. Stand-off facilities including herd homes, free-stall barns, feed pads, and wintering pads are some of the options that are required for this system to effectively work. Research shows that N and P losses are greater from winter grazed forage crops than winter grazed pasture.	N, P Can potentially reduce sediment and faecal microbe delivery to water, as well	Dairy, Sheep, Beef	67-100% reduction in N loss, 34%-66% reduction in P loss Urination on crops and pasture were reduced by 50% of daily output relative to business as usual (24-hour grazing)	Costs are estimated to be high for both N and P	Significant capital investment on stand-off infrastructure will be required if it's unavailable on the farm. Pollution swapping by increasing nitrous oxide emissions.	https://landscapedna.org/actions/filter/?contaminant_pathway=&land_use= McDowell & Nash, 2012 Low et al., 2017
GMP+: Riparian options							
	Description	Target Nutrients	Land use, Soil, and landscape features	Reductions in nutrients	Costs	Limitations	References
Constructed Wetlands	A constructed wetland can be fitted into a farm system to capture sediment, and filter nutrients before water flows into	N, P, Sediment	All farming operations	NIWA recommend a size of 1%-5% of the	Estimated cost reduction for N is Medium .	Newly constructed wetlands take a number of years to	NIWA www.niwa.co.nz

	rivers, lakes, and estuaries. The shape, depth and size of constructed wetlands will determine their effectiveness in improving water quality. Oblong shapes with a length x width ratio from 5:1 to 10:1 can slow water speed allowing sediment to settle, sunlight to kill bacteria, and nutrients to be assimilated. A depth of 1-2m will slow down and increase the residence time of water for sediment capture. A depth of less than 0.5m for 70% of the wetlands is ideal for nitrogen removal as it allows vegetation to grow and strip nutrients. Several small wetlands are ideal for capturing sediment and phosphorus, as they can be located at the sediment source and easily cleaned. Large wetlands are ideal for reducing nitrogen and bacteria as they can store more water for long periods.			wetland's catchment (100-500m^2 per ha) for 30% – 80% nitrogen reductions. A case study of a constructed wetland (1.7% of the catchment) in a critical source area to capture drain and surface runoff from a rolling hill country, reported 70% reduction of sediment and 30% reduction in nitrogen and phosphorus loss to waterways.	Cost for P reduction is high .	reach full maturity. Initial investment is large. Land used for wetlands takes out areas for production. Construction is limited to relatively flat land and is most efficient in lower portions of the catchment.	Environment Southland (n.d) https://www.es.govt.nz/repository/libraries/id:26gi9ayo517q9stt81sd/hierarchy/community/farming/good-management-practice/documents/Land%20sustainability%20guides%20and%20factsheets/A%20guide%20to%20constructed%20wetlands.pdf Low et al., 2017
GMP+: Wintering barn/stand off							
Description		Target Nutrients	Land use, Soil, and landscape features	Reductions in nutrients	Costs	Limitations	References
Wintering barn	All dairy and dairy support animals are wintered in a covered wintering barn (4 months from autumn until calving). No winter crops are grown on the dairy or support blocks. Silage made on farm or	N, P	Dairy, beef, sheep, deer All soil types.	N leaching losses can be reduced by 60%		Requires significant capital investment in infrastructure is not present on farm. Maintenance	Low et al., 2017.

	purchased is used to support animal intake in the barns.			Can reduce P loss by 15-30% on sedimentary soil		cost for effluent management, cleaning, and surface materials.	
GMP+: Irrigation							
Description		Target Nutrients	Land use, Soil, and landscape features	Reductions in nutrients	Costs	Limitations	References
Efficient irrigation	This involves improving irrigation infrastructure. All k-line and lateral spray irrigation are converted to variable rate pivot and solid set irrigation with soil moisture sensors for irrigation scheduling. This reduces excessive water flowing through the root zone and reduces the risk of nutrient contamination in ground water. Irrigation efficiency also involves irrigating only at trigger levels (50% of plant available water) and using routinely measured soil moisture information. Irrigation systems should be adjusted to apply relatively small amounts of water e.g., 15mm, depending on the soil water holding capacity.	N	All farming systems	Average reduction of N loss to water is 27% (range is 4-58%)	High initial investment. Helps to improve farm resilience to changes in water supply.	Changes in water application may affect the average annual pasture production.	Bright et al., 2018
GMP++: Technology							
Description		Target Nutrients	Land use, Soil, and landscape features	Reductions in nutrients	Costs	Limitations & Complexity	References
Incorporate plantain into pasture mix	This involves use of plantain in a rye grass/clover pasture mix. This mitigation targets nitrogen. Research shows that Plantain can reduce urinary nitrogen excreted from grazing ruminants, therefore reducing N leaching to ground water.	N	Dairy, intensive Sheep & Beef	There is 30% less N loading per hectare from cow urine with a 20-30% proportion of plantain in the pasture.	Seed broadcasting cost is approximately $240/ha	This mitigation would take many years to implement as farms generally take 15+ years to complete a pasture renewal cycle. This	Dairy NZ https://www.dairynz.co.nz/media/5794666/plantain-dairy-grazing-management_a

						mitigation assumes the pasture renewal cycle is complete and the entire farm has 15% plantain mix in the pasture sward.	4-web-booklet.pdf Low et al., 2017
GMP++: Land use change/land retirement							
	Description	Target Nutrients	Land use, Soil, and landscape features	Reductions in nutrients	Costs	Limitations	References
Forestry	The mitigation combines retiring the pasture area of steep, highly erodible land and changing that land to pine plantation forest. Tree roots protect soil on steep slopes from mass movement erosion. This is mostly effective for reducing phosphorus and sediment loss to water ways. Stock numbers are adjusted to account for land loss assuming that the poorest areas were converted to forest.	Sediment and P	All farming enterprises, particularly hill country sheep and beef. Steep slopes	Up to 90% reduction in erosion and sediment loss .	Estimated on average to be low , but could be higher, considering that pines are in the Emissions trading scheme .	Trees will take a number of years to grow, hence response rate is low. Forest harvest leads to high sediment loss during harvest and in the subsequent year, However, sediment losses during harvest are highly episodic and return to pre-harvest levels under standard practice within 2-6 years	Doole, 2015 Dymond et al., 2006 https://landscapedna.org/actions/filter/?contaminant_pathway=&land_use=
Grass filter strips	Grass strips reduce nutrients in surface runoff by filtration, deposition and	N, P, particula	All farming enterprises,	On permeable, low clay content	Costs can be based on	Clogging of strips with sediment,	Low et al., 2017

	improving infiltration. They intercept surface runoff during irrigation or rainfall events. Grass strips are applicable to waterway edges and in-paddock.	te nitrogen, sediment , and faecal microbes	particularly cropping. Low to moderate permeability soils, moderate to steep slopes, climate with high intensity rainfall where surface runoff is a significant contaminant pathway.	soils with flow channelised through the riparian zone, grass strips reduce sediment by 20-30%, phosphorus by 15-30% and nitrogen by 10-20%. On permeable, low clay content soils with slopes encouraging even flow reduction, grass strips can reduce sediment by 40-80%, phosphorus by 30-60% and nitrogen by 20-40%. Strips between 1-4m can achieve reductions but maximum benefits are achieved at widths greater than 6m. Buffer success is also dependent on slope, vegetation type and density, flow	alternative costs of three electric fences for sheep and beef, two wire fences for dairy and one weed spray per hectare per year.	weed management is required, buffer success depends on topography, vegetation type, vegetation density, and soil type.	

				convergence, soil type and topography.			

References

Barber, A. (2014). Erosion and sediment control guidelines for vegetable production. Agrilink New Zealand, Auckland, New Zealand

Bright, J., McIndoe, I., Birendra, K.C. (2018). Reducing nutrient loss through improving irrigation efficiency. Report prepared for the Fertiliser Association of New Zealand. RD18000/1

DairyNZ (n.d). https://www.dairynz.co.nz/media/5794666/plantain-dairy-grazing-management_a4-web-booklet.pdf. Retrieved September 2022

Dairy NZ (n.d). https://www.dairynz.co.nz/media/1569771/riparian-mgmt-otago.pdf. Retrieved September 2022

Environment Southland (n.d). https://www.es.govt.nz/repository/libraries/id:26gi9ayo517q9stt81sd/hierarchy/community/farming/good-management-practice/documents/Land%20sustainability%20guides%20and%20factsheets/A%20guide%20to%20constructed%20wetlands.pdf. Retrieved August 2022

de Klein, C. A. M., and R. M. Monaghan. (2011). The effect of farm and catchment management on nitrogen transformations and N_2O losses from pastoral systems — can we offset the effects of future intensification? Current Opinion in Environmental Sustainability 3:396-406

Doole, G. (2015). Description of options defined within the economic model for Healthy Rivers Wai Ora Project. Prepared for the Technical Leaders Group of the Healthy Rirs/Wai Ora Project

Dymond, J.R., Ausseil, A.G.E., Shepherd, J.D., and Buettner, L. (2006). Validation of a regionwide model of landslide susceptibility in the Manawatu-Wanganui region of New Zealand, Geomorphology 74, pp. 70-79

Houlbrooke, D. J., D. J. Horne, M. J. Hedley, V. Snow, and J. A. Hanly. (2008). Land application of farm dairy effluent to a mole and pipe drained soil: implications for nutrient enrichment of winter-spring drainage. Australian Journal of Soil Research 46:45-52.

Landscape DNA. (n.d). Table of actions. Retrieved September 2022 from https://landscapedna.org/actions/filter/?contaminant_pathway=&land_use=

Lincoln Agritech: http://www.lincolnagritech.co.nz/capabilities/capabilities-and-projects/catch-crops. Retrieved August 2022

Low, H., McNab, I., Brennan, J. (2017). Mitigating nutrient loss from pastoral and crop farms. A review of New Zealand Literature. Rural advice- Horizons Regional Council

McDowell, R. W., R. M. Monaghan, and P. L. Carey. (2003a). Potential phosphorus losses in overland flow from pastoral soils receiving long-term applications of either superphosphate or reactive phosphate rock. New Zealand Journal of Agricultural Research 46:329-337

McDowell, R. W., & Nash, D. (2012). A review of the cost-effectiveness and suitability of mitigation strategies to prevent phosphorus loss from dairy farms in New Zealand and Australia. *Journal of Environmental Quality*, *41*(3), 680-693.

McDowell, R. (2012). Challenges and opportunities to decrease phosphorus losses from land to water. AgResearch: Palmerston North, New Zealand.

Monaghan, R. M., de Klein, C. A., & Muirhead, R. W. (2008). Prioritisation of farm scale remediation efforts for reducing losses of nutrients and faecal indicator organisms to waterways: A case study of New Zealand dairy farming. Journal of Environmental Management, 87, 609-622

Orchiston, T.S., Monaghan, R.M., & Laurenson, S. (2013). Reducing overland flow and sediment losses from winter forage crop paddocks grazed by dairy cows. In L.D. Currie & C.L. Christensen (Eds)., Occasional Report No. 26 Accurate and Efficient Use of Nutrients on Farms, (pp. 1-7). Retrieved from http://www.massey.ac.nz/~flrc/workshops/13/Manuscripts/Paper_Orchison_2013.pdf

NIWA (n.d). www.niwa.co.nz. Retrieved August 2022