Mitigating nutrient loss from pastoral and crop farms

A review of New Zealand Literature

Helene Low, Ian McNab, Jesse Brennan
Rural advice – Horizons Regional Council

Executive summary

This document has been generated as part of Horizons re-examination of the One Plan Consent process in response to the Environment Court Declaration, April 2017. It is a compilation of mitigations that a pastoral and/or cropping farm operation could use to reduce its environmental impact.

The research cited in this report indicates that these mitigations can reduce nitrogen, phosphorous, sediment and/or E. coli losses to ground and surface water. This will enable farmers that use the relevant mitigations to reduce the adverse effects on the environment and their N-losses closer to the cumulative N-loss limits based on Land Use Class (LUC) as expressed in Table 14.2 of the One Plan, 2012. The main mitigations described in this report include:

- Wetlands
- Riparian management
- Fertiliser management
- Effluent management
- Crop management
- Alternative forages and pasture species

Some mitigations included in this report are not yet in Overseer. Including non-Overseer mitigations in a Nutrient Management Plan, may allow a farm to submit an application that shows lower N-loss than Overseer reports indicate, provided that sufficient evidence of those mitigations accompanies the consent, and supported by the relevant science. The reduction of nitrogen lost to the environment from the mitigations is highly variable due to the complex biological systems involved, so reasonable estimates based on the research will have to be developed that will stand legal and scientific scrutiny and enable these N-loss reductions to be included in Intensive Land Use Consents.

Other good Nutrient Management Practices to reduce losses to waterways that do not have an N-leaching figure attached:

- Storage and managing leachate from silage stacks
- Crop management – swales and strategic grazing
- Strategies to reduce pugging and soil compaction

Other good Nutrient Management Practices to reduce losses to waterways that are wholly or partially represented in Overseer:

- 18 month lactations
- Once a day (OAD) and 16 hour milkings for whole or parts of the lactation
- Bunding of culverts and bridges (may be captured in 'Stock exclusion' option in Overseer)

Disclaimer

The following document is a guidance tool on potential mitigations a farm could employ to reduce their nutrient loss. The list is not exhaustive, and it is a preliminary document to provide indications of effectiveness based on New Zealand literature. This report is a working document, and suggestions are welcomed for mitigations not captured in this report.

The descriptions of the mitigation options in this document, including likely reductions in nutrient loss, are provided as an indicative and generic starting point, to then be considered in light of individual properties. Applicants seeking to adopt and rely on any of the mitigation measures will not be able to simply adopt the indicative nutrient loss reduction figures that have been provided.

A properly prepared quantitative and property specific assessment of nutrient loss levels, including the impact of any mitigation measures, would need to be included with the relevant application for resource consent.

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Glossary

Active bed (i.e. waterbody or waterway)	The bed of a river that is intermittently flowing and where the bed is predominantly unvegetated and comprises sand, gravel, boulders or similar material (Horizons One Plan, 2012)
Attenuation	The permanent loss or temporary storage of nutrients, sediments, or microbes during the process of transportation between where they are generated e.g. paddock, and where they can impact water quality e.g. downstream (McKergow, Tanner, Monaghan & Anderson, 2007)
Breeding worth	Industry index that ranks bulls and cows on their ability to breed efficient and profitable replacement dairy heifers (Dairy NZ, 2016)
Bund	Any structure that is used to contain liquid and prevent contaminants being released to the environment (Environmental Protection Authority, 2012)
Denitrification	Microbial production of nitric oxide (NO), nitrous oxide (N_2O) and $N_{2,}$ from nitrate (McKergow et al., 2007)
Dry matter	Dry weight of pasture in kilograms per hectare above ground level (Meat New Zealand, 2002)
Dyking	A practice that creates a series of closely-spaced soil dams in wheel tracks where water is captured in small soil indentations (Barber, 2014)
Eutrophication	An increase in the amount of nutrients available in a waterbody, which can proliferate the amount of algae present, and lead to water quality degradation (National Institute of Water and Atmospheric Research (NIWA), n.d).
Gibberellic acid	A plant growth regulator found in most plant species, which stimulates cell expansion. GA can be used to promote grass growth without Nitrogen in cooler seasons, where pasture is in a slow growth phase (Jiang, 2011).
Grass filter strip	A managed band of dense grass used to filter runoff (McKergow et al., 2007)
Hydrolysis	The rapid transformation to ammonium by urease, which creates localised alkaline conditions in the soil. This allows the ammonium to form ammonia gas, which can then be lost from the soil through volatilisation (Foundation of Arable Research (FAR), n.d.[b])

Mole drain	A type of subsurface drain composed of networks of unlined channels below the soil surface to remove excess water from the soil profile. Mole drains can only be made in heavy soils, with a clay subsoil. Long lasting drainage channels require a clay content of 30-35% (FAR, n.d. [a])
Sedimentation	The process of particles and materials depositing at the bottom of a water body to form sediment (Tanner, Sukias & Yates, 2010)
Sediment trap	Excavations in the bed of a watercourse designed to settle and trap coarse particles (McKergow et al., 2007)
Silt trap	A structure to impound surface runoff and ensure sufficient time for suspended sediment to settle. Functionality is increased with volume (Barber, 2014)
Senescence	The process of ageing and eventual leaf death in pasture (Wims, 2016)
Tile drain	A type of subsurface drain composed of networks of perforated plastic tubes below the soil surface to remove excess water from the soil profile (FAR, n.d. [a])
Volatilisation	The degradation of urea during the first 48 hours after application, which can result in varied amounts of ammonia being lost from the soil, and released into the atmosphere as ammonia gas (NH_3) (FAR, n.d. [c])

List of acronyms

BW	Breeding Worth
CSA	Critical Source Area
DC	Duration Controlled (grazing)
DM	Dry Matter
GA	Gibberellic Acid
GFS	Grass Filter Strip
N	Nitrogen
P	Phosphorus
PUE	Protein use efficiency
RG	Rye grass
S&B	Sheep & Beef (intensive)
S	Sediment

Key

*	Low density: 1% (100m^2/ ha) of contributing catchment (5ha)
**	Moderate Density: 2.5% (250m^2/ha) of contributing catchment (5ha)
***	High Density: 5% (500m^2/ha) of contributing catchment (5ha)
^	Assumes most of N in form of Nitrate (~80%) with removal likely to be better in warmer areas of the country and in low-runoff and/or flow variability conditions
#	Area requirement = 10 x average channel density (m^2/ha) (17-30m/ha) with an average width of 10m on both banks
+	Low density: 1% (100m^2/ha) of contributing catchment (100-500ha)
$	2.5% (250m^2/ha) of contributing catchment (100-500ha)

Chapter 1: Attenuation tools

1.1 Wetlands

	Natural seepage wetland – Paddock
Description	Natural seepage wetlands occur where ground and subsurface water flow re-emerges via springs or seeps. Also known as riparian wetlands, flushes, and valley bottoms, they often occur in naturally boggy areas along the margins of flowing water, and headwaters of catchments. Saturation status can be seasonal, and sizes depend on topography, ranging up to 1ha in area. Natural seepage wetlands could include reinstating existing wetlands, or fencing off wet areas on farm.
Target nutrient	N, P, S
Land use	All farming operations Naturally boggy areas receiving some surface runoff from a surrounding catchment that contains dissolved and particulate contaminants
Likely reductions in nutrient loss	*Low* and high density***:* Reduction ranges: N – 50-75% P – 10% from surface runoff S – 60% of overland flow entering the wetland
Costs	Assume costs: 5 wire (3 electric) for sheep and beef, 2 wire electric for dairy. Assume 1 weed spray per hectare a year
Benefits	High nitrate removal rates; More efficient than other surface wetland systems as water emerges through the wetland soils, which increases contact between water and organic soil, therefore increasing the effectiveness of the denitrification process; Costs of restoring, enhancing (e.g. planting, fencing) and continued maintenance are likely to be low; Utilises land that would otherwise be seasonally ineffective
Limitations	Number and condition of seepage wetlands in the region is uncertain, thus so too is the removal that may occur as a result of wetland enhancement; Lack of information on how to restore effective existing seepage wetlands; Mass removal of nitrate limited by small hydraulic loading rates; Fencing and enhancement is likely to be inexpensive but the small size and scattered distribution will increase these costs
References	▪ McKergow, Tanner, Monaghan & Anderson (2007) ▪ Hamill, MacGibbon & Turner (2010) ▪ Hughes, McKergow, Tanner & Sukias (2013) ▪ McDowell, Wilcock & Hamilton (2013) ▪ Tanner, Sukias, & Burger (2015)

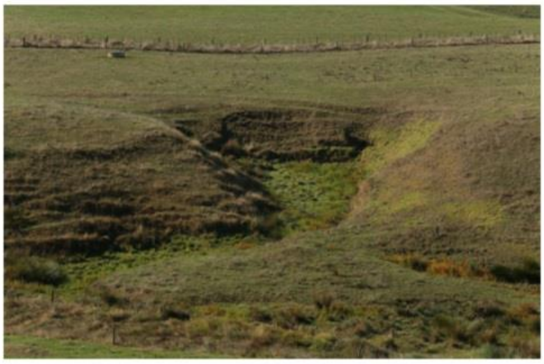

Figure 1 Natural seep area on farm - there is potential here to plant and fence the area to achieve nutrient uptake. Retrieved from https://www.dairynz.co.nz/media/5787389/making-the-most-of-wet-areas-on-farm.pdf

	Facilitated wetland – Paddock, farm and catchment	
Description	Facilitated wetlands involve the modification and damming of existing landscape features e.g. gullies, depressions and valleys, to achieve nutrient removal	
Target nutrient	S, N, P	
Land use	All farming operations Where wet areas, gullies and depressions intercept surface and shallow subsurface runoff, and spring flows	
Likely reductions in nutrient loss	*Low density**: Reduction range: N^ – 30% (annual range 10-40%) P – 50-60% of particulate P S – ~60% of annual load in surface runoff	*Moderate density**:* Reduction range: N^ – 60% (annual range 40-80%) P – 60-80% of particulate P S – ~80% of annual load in surface runoff
Costs	*Low density**: Establishment: $5.50/m^2 = $550/ha of catchment Maintenance : $15/ha/year	*Moderate density**:* Establishment: $6.50/m^2 = $1625/ha of catchment Maintenance: $25/ha/year
Benefits	Wildlife habitat; Landscape aesthetics; Low maintenance requirements, i.e. supplementary planting, excavation of sediment (2 yearly or roughly) and weed control; Using natural landscape features improves cost-effectiveness; Wetlands bring biodiversity enhancement on farm	
Limitations	Removes land from production; May be no suitable areas on farm for this particular type of wetland, or the catchment lies outside of the farm area; Wetlands can take numerous years to mature; Year to year fluctuations in nutrient removal; Plants need to be harvested and removed otherwise a significant proportion of up taken nutrients will be released when plants die and decompose; Assumptions of cost based on clay subsoils and exclude a synthetic liner; Requires flood water diversion channels	
References	▪ McKergow et al. (2007) ▪ Hamill et al, (2013) ▪ Tanner et al. (2015) ▪ Praat, Sukias, & Faulkner (2015)	

Figure 2 Previously a gravel pit, the area has now been converted into a facilitated wetland to remove dissolved nutrients. Retrieved from http://www.es.govt.nz/council/major-projects/Pages/Waituna-Lagoon.aspx

	Constructed surface wetland – Paddock, Farm and catchment	
Description	Constructed surface flow wetlands are defined as manmade systems built in the lower reaches of river and stream catchments, to extract nutrient loads from agricultural surface drainage waters. Mimicking the hydrological and biological processes in natural wetlands (including soils, microbial assemblages, and vegetation), constructed wetlands aim to remove, absorb and store nutrient loads in the receiving waters. P and S treatment is achieved through sedimentation, and nutrient treatment more generally is enhanced by manipulating flow paths, water depths, and vegetation characteristics	
Target nutrient	S, N, P	
Land use	All farming operations Surface drains carrying surface and shallow sub-surface run off containing contaminants	
Likely reductions in nutrient loss	*Low density*:* Reduction range: N^ – 30% (annual range 10-40%) P – 50-60% of particulate P S – ~60% of annual load in surface runoff	*Moderate density**:* Reduction range: N^ – 60% (annual range 40-80%) P – 60-80% of particulate P S – ~80% of annual load in surface runoff
Costs	*Low density*:* Establishment $11/m^2 = $1100 per hectare of catchment Maintenance: $10/ha/year	*Moderate density**:* $13/m^2 = $3,250 per hectare of catchment Maintenance: $15/ha/year. Assumptions of cost based on clay soils (exclude synthetic liner)
Benefits	Ability to remove a significant proportion of a catchments N and P load; Low maintenance requirements, i.e. supplementary planning, excavation of sediment (2 yearly or roughly), and weed control; Considerable seasonal variation in treatment performance, which is advantageous for reducing the concentration of dissolved nutrients during summer when most required by algae; Alongside nutrient uptake, constructed wetlands have aesthetic values in addition to providing biodiversity enhancement	
Limitations	Newly constructed wetlands take a number of years to reach full maturity; Large initial investment; Land used for wetlands takes out areas for production, thus requires goodwill from farmers; Wetlands need to be built on relatively flat land, and are most efficient in lower portions of the catchment; Uncertainty surrounds the lifespan of constructed wetland functionality; Plants need to be harvested and removed otherwise a significant proportion of up taken nutrients will be released when plants die and decompose; Requires flood water diversion channels	
References	▪ McKergow et al. (2007) ▪ Tanner, Sukias & Yates (2010) ▪ Sukias & Tanner (2011) ▪ Hamill et al. (2015) ▪ Tanner et al. (2015)	

Figure 3 Owl farm in Cambridge - a constructed surface wetland. Retrieved from http://www.stuff.co.nz/business/farming/91113123/owl-farm-wetland-removes-most-nitrates-in-first-water-samples

	Stream flow wetland – Agricultural catchment	
Description	Wetlands developed at the base of a catchment or adjacent to sensitive receiving waters are suitable to treat agricultural runoff. A weir can be constructed across stream/drain to divert normal flows through the wetland, with water then returned back to the stream or adjacent receiving waters.	
Target nutrient	S, N, P	
Land use	All farming operations Land at the base of a catchment/sensitive waters (100-500ha), that would receive drainage and streamflow from surface and subsurface runoff from grazed land	
Likely reductions in nutrient loss	*Low density*:* Reduction range: N^ – 30% (annual range 10-40%) P – 50-60% S – ~60% of annual load	*Moderate density**:* Reduction range: N^ – 60% (annual range 40-80%) P – 60-80% S – ~80% of annual load
Costs	*Low density*:* $15-30m^2 = $3,000-$7,500/ha of catchment Maintenance: $10/ha/year	*Moderate density**:* $15-30m^2 = $3,000-$7,500/ha of catchment Maintenance: $15/ha/year
Benefits	Wetlands sized to treat runoff from a larger sub-catchment; Cost based on 2.3ha wetland built for Environment Bay of Plenty; Costs assume clay subsoils thus exclude a synthetic liner, include engineering specialist design, and construction of a timber weir; Benefits can be derived similar to other wetland types e.g. enhanced biodiversity on farm, etc.	
Limitations	May require fish passes; Costs vary significantly depending on the extent of excavation and underlying soil material; Newly constructed wetlands take a number of years to reach full maturity; Large initial investment	
References	▪ McKergow et al. (2007)	

	Constructed subsurface wetland – Paddock, Farm and catchment	
Description	Constructed subsurface flow wetlands hold the same definition as surface flow wetlands, being manmade systems built in the lower reaches of catchments to extract nutrient loads. Subsurface flows are intercepted from agricultural drainage waters, such as mole and tile drains. Mimicking the hydrological and biological processes in natural wetlands including soils, microbial assemblages, and vegetation, constructed wetlands aim to remove, absorb and store nutrient loads in the receiving waters. P treatment is achieved through sedimentation. Nutrient treatment more generally is enhanced by flow paths, water depths, and vegetation characteristics	
Target nutrient	N, P, S	
Land use	All farming operations Where subsurface mole/tile drains carry runoff dominated by dissolved contaminants	
Likely reductions in nutrient loss	*Low density*:* Reduction range: N^– 30% (range 10-40%) P – minimal without P sorbing minerals S – 30-50% assuming majority of sediment is fine clays and silt	*Moderate density**:* Reduction range: N^ – 60% (range 40-80%) P – minimal without P sorbing minerals S – 40-70% assuming majority of sediment is fine clays and silt
Costs	*Low density*:* Establishment: $11/m^2 = $1100 per hectare of catchment Maintenance: $10/ha/year	*Moderate density**:* Establishment: $13/m^2 = $3,250 per hectare of catchment Maintenance: $15/ha/year
Benefits	As above for constructed surface wetlands: Intercepts flow paths that may otherwise bypass natural attenuation processes in shallow groundwater, and riparian zones; Wildlife habitats; biodiversity enhancement; Ability to remove a significant proportion of a catchments N and P load; Low maintenance costs (one weed spray a year and inspection)	
Limitations	As above for constructed surface wetlands: Requires suitable areas on farm (i.e. catchment within farm area); Requires flood water diversion channels and a sediment trap for enhanced removal; Can take numerous years for vegetation to mature to full nutrient removal potential	
References	▪ McKergow et al. (2007) ▪ Tanner, et al. (2010) ▪ Hamill et al. (2010)	

1.2 Riparian Management

	Riparian buffers – Paddock
Description	A riparian buffer is a band of managed vegetation between agricultural land, and waterways. Planting native species and trees along the sides of waterways act as an attenuation zone for nutrients and sediment from surface and subsurface runoff. Riparian buffers reduce the momentum and magnitude of surface runoff, thereby allowing for nutrient removal. Riparian buffers should be a secondary restorative measure after controlling pollutants at their original sources
Target nutrient	S, Particulate N and P
Land use	All farming enterprises Accessible margins alongside waterways
Likely reductions in nutrient loss	Effectiveness is dependent on hydrology, vegetation, and buffer width. N - Between 2.2 and 7.6 milligrams of N/m^2/day (up to 93% removal) during active growing periods in summer; decreases between 27 and 28 percent of these values during winter P – removal rates of 43% can be achieved with buffers 4.6m, to 98% removal with buffers 27m wide S – 9.1m buffer strip 84% removal, 4.6m buffer strip 74%
Costs	Price is dependent on area, buffer width, and vegetation used. Dairy NZ has a Riparian Planner tool that calculates costs based on water ways on farm. In cropping: $100 to $250/ha. Assume costs: 2 wire electric fence and 1 weed spray per hectare a year & loss of productive land
Benefits	Provides in stream values including channel shading, improved aquatic habitat, and wood and leaf supply to waterways; Landscape aesthetics; Recreational and cultural benefits e.g. harvesting of flax and other plants; More effective than grass strips; Provides bank stabilisation, flood control and stock exclusion; Short-term grazing or other harvesting is recommended to maintain functionality; The greater the buffer zone the increased biodiversity and reduced need for maintenance
Limitations	Buffer zones over 10m are more effective; Requires active vegetation management of weeds and plants; As with wetland vegetation, riparian plants can take numerous years to mature; Effectiveness is dependent on buffer width and vegetation composition; There is no "one size fits all" approach, meaning sites should be considered on an individual basis
References	▪ Parkyn, Shaw & Eades (2000) ▪ Parkyn (2004) ▪ McKergow et al. (2007) ▪ Wilcock et al. (2008) ▪ Dairy NZ (n.d.)

Figure 4 Example of a well vegetated buffer strip. Retrieved from http://www.ruraldesign.co.nz/integrated-catchment-management/

	Stock exclusion from waterways - Farm
Description	Stock access to waterways can result in direct deposition of faecal nutrients into the waterways as animals wallow. Access can also cause bank destabilisation, which mobilises nutrients as erosion occurs. Ensuring that stock are excluded from all streams, rivers and other waterways on farm by fencing off these areas reduces direct nutrient loss into waterways. This can be achieved by stream fencing, or using shade trees to draw cattle away from vulnerable areas.
Target nutrient	P, E-coli, N
Land use	All farming operations
Likely reductions in nutrient loss	Losses due to cows in streams are approximately 0.5 kg P/ha/year Can result in a 10-30% decrease in both dissolved and particulate P Annual farm scale losses of 0.04kg P/ha from dung and 1.0kg N/ha from urine can be observed from stock access, so excluding stock can result in reductions of this scale
Costs	Assume costs for fencing, and riparian establishment if chosen as management option (as above)
Benefits	Permanent exclusion can remove faecal deposition from waterways and riparian areas proximal to the stream where run-off can deliver pathogens; Sediment and microbes are filtered: Source of soil and pasture damage is removed allowing restoration
Limitations	Can take out land that may have otherwise been used for production; Requires a change in management practice for some farmers
References	▪ Collins, et al. (2007) ▪ McDowell (2012) ▪ Parfitt, Frelat, Clark, & Roygard (2013) ▪ Lucci & Laurenson (2016)

Figure 5 Stock fenced off from a waterway. Effectiveness could be enhanced by planting the buffer area with vegetation. Retrieved from http://www.ruralnewsgroup.co.nz/item/12009-new-stock-exclusion-rules-require-greater-flexibility-feds

	Grass filter strips – Paddock
Description	A grass filter strip (GFS) is a band of managed grass which acts as a buffer between a water body, and potential contaminant loading source. A GFS aims to intercept surface runoff during irrigation or rainfall episodes to remove pollutants by physical filtering, infiltration, and deposition. A GFS is applicable in many situations, including riparian (along waterway edges), and in-paddock. Identifying critical source areas where water converges in swales or the bottom of gullies can be of benefit on farm, and at a catchment level
Target nutrient	S, P, Particulate N, Faecal Microbes
Land use	All farming enterprises, particularly cropping Low to moderate permeability soils, moderate to steep slopes, climate with high intensity rainfall where surface runoff is a significant contaminant pathway
Likely reductions in nutrient loss	Permeable , low clay content soils with flow channelised through the riparian zone reduction range [#]: S – 20-30% P – 15-30% N – 10-20% Permeable , low clay content soils with slopes encouraging even flow reduction range[#]: S – 40-80% P – 30-60% N – 20-40% Permeable , high clay content soils with slopes encouraging even flow reduction range[#]: S – 40-50% P – 20-40% N – 10-20%
Costs	Assume costs: 5 wire (3 electric) for sheep and beef, 2 wire electric for dairy. Assume 1 weed spray per hectare a year
Benefits	Has the potential to stabilise stream banks; Reduced topsoil loss from paddocks; Significant reductions in faecal bacteria from dairy shed effluent e.g. campylobacter and E. coli (80-95% with GFS between 1-4m)
Limitations	Requires weed management; Strips can become clogged with sediment; Buffer success is dependent on slope, vegetation type and density, flow convergence, soil type, topography; Strips between 1-4m can achieve reductions but maximum benefits are achieved at widths greater than 6m
References	▪ Parkyn (2004) ▪ McKergow et al. (2007) ▪ Wilcock, Elliot, Hudson, Parkyn & Quinn (2008) ▪ Wilcock et al. (2009)

1.3 Sediment tools

	Traps, Dams and Ponds – Paddock, Farm
Description	Excavations in the bed of a watercourse are designed to capture the downstream movement of sediment. Water flows are slowed and energy reduced to filter sediment and allow grass growth. Sediment traps should be considered tertiary to prevention; primarily changing land management to reduce erosion and sediment transport e.g. conservation tillage, and secondary keeping sediments on land before they reach the drainage network e.g. grass filter strips. Sediment traps are also required as the upstream component of a constructed wetland.
Target nutrient	P, S
Land use	All farming operations, particularly Cropping/Vegetable growing Surface runoff in ephemeral channels where streamflow can be diverted during flooding events
Likely reductions in nutrient loss	A sediment trap taking surface runoff from the base of a moderately sloping race with a grass filter strip beyond the trap before the stream showed 44% reduction in dissolved reactive phosphate (DRP), 49% reduction in total dissolved phosphate and a 10% reduction in total P. Can also remove 10-20% of particulate P.
Costs	Establishment: ranges between $750-1,300 ha/year, or $360 per kg P retained ha/year Maintenance: $75/ha/year Recommended capacity is 0.5% (50m^3/ha) for catchments less than 5ha, and 1% (100m^3/ha for catchments over 5ha
Benefits	Potential to buffer storm events and downstream flooding; Can reduce the need for drain clearing costs; Stored run-off can be used as a source of livestock drinking water or as an alternative irrigation source; Duck shooting potential on farm; Improved landscape aesthetics;
Limitations	May require resource consent; Ineffective at high flows when mass sediment is being transported; May alter drain hydraulics; Can be ineffective at decreasing P losses if sediment is finely textured (wetlands can capture these particles); Potential for negative impacts on downstream flow e.g. dissolved oxygen which can impact aquatic biodiversity, and water temperatures; Effectiveness depends on the volume of inflow, shape, and the type of incoming particles
References	▪ Hudson (2002) ▪ McKergow et al. (2007) ▪ Dresser (2008) ▪ McDowell & Nash (2012) ▪ McDowell et al. (2013) ▪ Barber (2014)

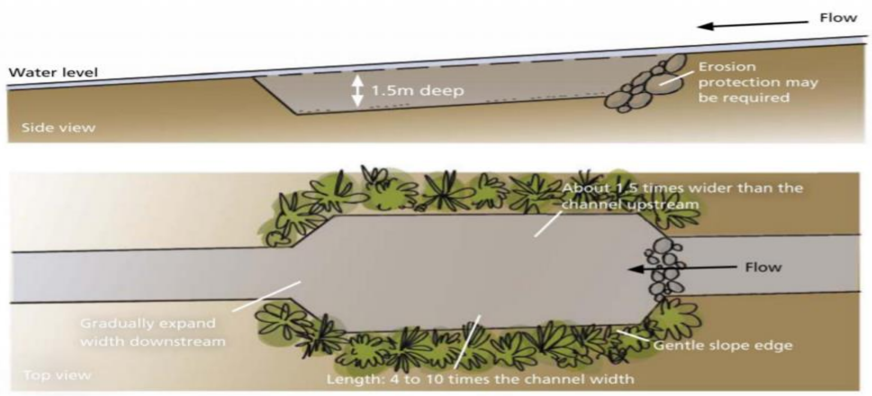

Figure 6 Side and top-view diagram of a sediment trap. Retrieved from https://www.dairynz.co.nz/media/254172/5-9_sediment_traps_2012.pdf

Chapter 2: Fertiliser management

	Buffer distances for fertiliser application – Paddock, Farm	Appropriately timed N fertiliser application – Paddock, Farm
Description	Implementing a minimum 10m buffer strip between application of ground fertiliser and open water as a good nutrient management practice	*Although Overseer can model the reductions that can be made by reducing or managing fertiliser use, it is important to understand how these reductions can be managed and the benefits on farm.* Apply N at particular times of the year, and avoid high risk periods such as Autumn and Winter. The leaching risk of N will increase from fertiliser applications when N application rates exceed the N uptake potential of the pasture. Current fertiliser guidelines include: ➢ Limiting the rate to less than 50 kg N per hectare in any single application per grazing rotation; ➢ Not applying N fertiliser when soil temperatures are below 6°C; ➢ Avoiding application when pasture growth is limited by very dry or very wet conditions, or through soil compaction ➢ Only apply fertiliser to meet plant requirements, e.g. fertiliser amounts at sowing
Target nutrient	N, P	N
Land use	All farming enterprises	All farming enterprises
Likely reductions in nutrient loss	Similar for riparian buffer effectiveness, if land is managed in the same manner	Poorly timed applications (for example in Autumn and Winter) can result in 23-42% leaching loss of the N applied, thus we can expect this reduction range with appropriately timed N applications
Costs	Depends on action – essentially no cost for maintaining filter strip unless the riparian area is managed, thus assume costs of planting and weed spraying	Costs do not change, as it is dependent on current farm expenditure for fertiliser. Good management practice does not cost in this case.
Benefits	Best practice; Reduces chance of direct fertiliser deposition and flow on effects of nutrient loss in waterways; Establishing a riparian buffer brings benefits as detailed above e.g. biodiversity, filter for sediment, etc.	The same level of production can be attained with a more conservative use of N fertiliser (approximately 10% less); Good practice will avoid runoff and can use the fertiliser efficiently lowering costs required
Limitations	Requires precision GPS modelling for accuracy of application; Can take out land that may have otherwise been used for production	Requires education on best management practice, and farmer willingness
References	▪ Fertiliser Association (2014)	▪ De Klein, Monaghan, Ledgard, & Shepherd, (2010) ▪ Parfitt, Frelat, Clark, & Roygard (2013)

2.1 Phosphorus management

	Maintaining good Olsen P health – Paddock, Farm	Use less soluble P fertilisers – Paddock, Farm
Description	*Although Overseer can model the reductions that can be made by reducing or managing fertiliser use, it is important to understand how these reductions can be managed, and the benefits on farm.* Limiting P fertiliser application to only soil maintenance needs, or lower to avoid any excess P loss based on regular soil tests. This is due to the magnitude of the runoff being generally proportional to soil P concentration. Generally P fertiliser usage can be relatively high on farms, and although it is important to have adequate soil P fertility for optimum clover growth, only applying minimum levels of P on farm can greatly reduce the risk of P runoff. Generally, direct losses from P fertiliser are low if a farm is using best management practices	Using reactive-phosphate-rock (RPR) on pastures with acidic soils rather than more soluble P fertilisers, due to more soluble fertilisers being able to move short distances to streams. P losses are generally created from dissolved P which is immediately available for algal growth, which is to be avoided
Target nutrient	P	P
Land use	All farming operations	All farming operations Most relevant to hill country operations
Likely reductions in nutrient loss	It is estimated that around 20 percent of dairy farms in the North Island, would observe a 7 – 37% reduction in P loss by applying no more than the optimum P amounts for those soils. Two Manawatu Catchments have predicted P loss reduction of 30-37% by using fertiliser inputs to maintain Olsen values	RPR has been shown to decrease P loss at a catchment scale by approximately 33% in comparison to highly water soluble superphosphate. Can result in a 5-20% decrease in P for both dissolved and particulate P using RPR
Costs	Assume costs for fertiliser based on soil requirements	In a case study of hill country maintenance P (15kg/ha) and S (12 kg/ha as sulphate or 10kg/ha as fine S) plus sufficient lime at 244kg/ha required fertiliser application: Total cost $97.70/ha
Benefits	Can save on fertiliser costs; Optimising Olsen P levels can ultimately give production benefits e.g. clover growth	Previous studies have shown that the efficiency of phosphorus in soils is important to improve pasture or crop yields and to prevent any eutrophication of waterways; Applications should be in fine enough form to stimulate soil microbial activity and maintain soil pH
Limitations	Differs between soil type; Soils need good Olsen P levels to observe reductions; Requires change in practice to only maintain optimal P levels in optimum agronomic range	Any gains will depend on weather conditions, soil type and fertiliser management practises; The magnitude of loss will also depend on the rate of application, form and solubility of P; RPR can be used where annual rainfall is >800mm and soil pH is <6.
References	▪ Monaghan, de Klein, & Muirhead (2008) ▪ Anastasiadis, Kerr, MacKay, Roygard, & Shepherd, (2012) ▪ Parfitt, et al. (2013)	▪ McDowell (2012) ▪ Group One Consultancy Ltd (n.d.)

Chapter 3: Grazing tools

	Duration Controlled Grazing – Paddock, Farm
Description	DC grazing is a system based upon grazing pasture for shorter periods (commonly 4 hours) before moving cows to a stand-off facility for excretion and rumination. Stored effluent from stand-off facilities is then applied to pasture as slurry when nutrients are required, and when soil conditions are suitable. Stand-off facilities including herd homes, free-stall barns, feed pads, stand off pads, and wintering pads/barns are some of the infrastructure options that are required for an off-pasture animal confinement system to work effectively. As a type of DC grazing, cows can be stood off from pasture during winter where the risk of nutrient loss to waterways is higher. The same benefits and costs can be derived, but over a smaller period
Target nutrient	N, P
Land use	Dairy
Likely reductions in nutrient loss	Massey University Manawatu field trial comparing standard grazing (7 hours per day grazing, 13 hours per night grazing at 22kg TN/ha found that DC grazing (4 hour day or night grazing) resulted in a 36% reduction in total nitrogen to pasture (14kg TN/ha) Urinations on pasture and laneways were reduced from 85% of daily output from "business as usual" (i.e. 24 hour grazing excluding milking times) to 56% with 8 hours of grazing between milking and 50% with 4 hours of available grazing after each milking. This means up to 119 grams per cow per day less of urinary nitrate-N will be subjected to pasture
Costs	N – $41-130 per kilogram of N retained a year ($/kg of nutrient retained/year) P – $41-108 kg P retained per year S – $151-790 kg S retained per year *Capital costs:* Free stall barn: Infrastructure and effluent system costs: $1,500 to $2,000/cow Herd homes: $1,800 to $2,000/cow Covered, deep litter standoff with drainage and effluent capture: $1,200 to $1,500/cow
Benefits	Reductions in direct faecal and urine deposition to pasture; Allows for reductions in pasture damage during wet periods which ensures that the soil structure, drainage and pasture production are maintained; Less fertiliser required; Pasture production in spring compared to wintering on paddock; Reduced need for grazing off farm; Suitable and clean area for calving; Herd urine captured on stand off facilities significant for N reduction; Protection of farm drainage networks; Body weight and conditions scores of cows can be maintained or even increased; Cows are protected from adverse climatic conditions; Better utilisation of supplementary feed; Increased milking period with reduced numbers of dry/empty cows
Limitations	Requires significant capital investment if infrastructure is not present on farm; Research is required to determine how DC grazing can be carried out along with slurry management without compromising pasture production; Greater quantities of effluent; Higher risks of animal health problems e.g. lameness; Maintenance costs e.g. effluent, cleaning, surface materials; Often requires feed supplementation to ensure adequate intakes; Depressed net pasture growth rates because of greater losses through senescence; "pollution swapping" by increasing nitrous oxide emissions; Significant variation in costs due to climate, soil types, and frequency of use; Problems with modelling in OVERSEER®; Reductions in nutrient loss are dependent on no further intensification
References	Clark et al. (2010); Christensen, Hanly, Hedley & Horne (2011, 2012); Beukes et al. (2013); Journeaux (2013); Dairy NZ (2014); Macdonald, Rowarth, & Scrimgeour (2015); Laurenson, van der Weerden, Beaukes & Vogeler (2017)

Figure 7 Example of a free stall barn. Retrieved from https://www.dairynz.co.nz/farm/off-paddock-facilities/freestall-barn/

	Using feedpads or wintering pads – Farm
Description	Similar to DC grazing, infrastructure can be used to keep animals off pasture during the winter months (autumn until calving for 4 months) e.g. a feedpad, where effluent is collected. Keeping animals off pasture during high risk periods can significantly reduce the amount of N lost from urine, and effluent generated by the animal
Target nutrient	N, P
Land use	Dairy/beef
Likely reductions in nutrient loss	N leaching losses were estimated to be reduced by 60%. Farms that are on sedimentary soil and have a wintering pad can have a 15 – 30% reduction in P loss
Costs	Varies depending on type of pad
Benefits	Increase in pasture production due to efficient use of effluent; Reduce pugging of pasture; Improved animal welfare, shelter, and ability to feed out efficiently; Targets urine patches as the largest source of N loss on farm
Limitations	Feedpad type; Effluent storage and management required; Animals should be managed appropriately to avoid any welfare issues
References	▪ Monaghan, et al., (2007) ▪ Monaghan, de Klein, & Muir-head (2008) ▪ Anastasiadis, Kerr, MacKay, Roygard, & Shepherd, (2012)

Figure 8 Example of a covered feedpad. Retrieved from http://www.nrc.govt.nz/Environment/Farm-Management/fde/feed-pads/

Figure 9 Example of a wintering barn. Retrieved from https://www.sheds.co.nz/tools/blog/wintering-barns-and-dairy-sheds/

Chapter 4: Plant Growth hormones

	Gibberellic acid – Paddock
Description	Use of GA plant growth hormone to reduce N-fertiliser application in early spring. Reduces N-content of pasture
Target nutrient	N
Land use	All farming enterprises
Likely reductions in nutrient loss	Reduce annual urine-N leaching 4-29% by reducing N-intakes by stock
Costs	5 kg costs $2,800, which equals $1.80 per gram. Application at 20g/ha =$36/ha
Benefits	Increased pasture production in August-September; Reduced need for N-fertiliser applications
Limitations	Must be used within 5 days of grazing; Applied as liquid so requires spray equipment or contractor
References	▪ Ghani, Ledgard, Wyatt & Catto (2014) ▪ Bryant, Edwards & Robinson (2016)

Chapter 5: Hydraulic connectivity

	Managing runoff from farm infrastructure – Paddock, Farm
Description	Surface runoff from farm infrastructure has been highlighted as a potential greater source of P, S load and microbial loss to waterways than runoff from pasture. Management requires good track design, bunding of culverts and bridges, careful driving/ use of lightweight vehicles, and gently sloped revegetated batters to reduce bank erosion
Target nutrient	P, S, Faecal Microbes
Land use	Dairy, Intensive S & B Any on farm infrastructure including gateways, lanes and tracks
Likely reductions in nutrient loss	Application of steel melter slag rich in Iron and Aluminium oxides encased in mesh to the side of laneways: decreased Total P loss in runoff by 95% and suspended sediment by 99%. Could reduce losses by 0.1 kg P/ha/yr
Costs	Varies dependent on farm structure
Benefits	Well maintained laneways can increase milk production with improved health and cow traffic flow; Efficiently designed and constructed laneways can reduce issues of lameness; Water directed to paddocks will be less likely to flow into waterways
Limitations	Can be difficult and costly to change established farm infrastructure; May not be practical depending on topography, etc.
References	▪ McKergow et al. (2007) ▪ McDowell (2007) ▪ Dresser (2008) ▪ Parfitt, Frelat, Clark, & Roygard (2013)

Figure 100 Retaining walls and drainage on a farm track. Retrieved from http://johnstoneng.co.nz/wp-content/uploads/2015/05/Retaining-Walls-and-Drainage.jpg

Chapter 6: Effluent management

	Using effluent as a fertiliser – Paddock, Farm
Description	Application of effluent to land using low rate deferred irrigation will minimise the risks of nutrients leaching. This involves storing farm dairy effluent in a holding pond, and applying it strategically when the soil water deficit is enough to prevent any direct drainage. Using an irrigator that can apply very low application rates of effluent can reduce the likelihood of any overland flow and the effluent can be recycled at the root zone more efficiently. To reduce the risk of nutrient loss on farm, apply no more than the maximum annual rates of N, split application, and have exclusion periods for animal grazing after application. The application of effluent to land should be restricted to those soils that have a low risk of runoff. Low rate effluent application increases nutrient use efficiency, and reduces nutrient losses. Poorly timed liquid and sludge applications will greatly increase the risk of nutrient losses to waterways, that could otherwise be used to grow more feed on farm.
Target nutrient	N, P
Land use	Dairy
Likely reductions in nutrient loss	A direct effluent discharge from an aerobic pond has been shown to discharge 35 kg of P per 100 cows, whereas samples of winter drainage from grazed plots sprayed with effluent has only been shown to discharge 10 kg of P per 100 cows; therefore showing that less P is lost using differed irrigation of effluent. Deferred effluent irrigation on a case study farm in NZ found a 5% reduction in N loss and could reduce P loss by 1 kg P/ha/year
Costs	May have to upgrade effluent infrastructure i.e. new effluent pond, lining an existing effluent pond, new irrigator, upgrade of sumps/wedges which will need to comply with your regional council's rules; Costs will vary depending on scale of existing farm infrastructure, or upgrade
Benefits	Effluent can be used as a substitute for fertiliser, so farm wide costs on fertiliser can be reduced; Can save 10 – 15% in a farm's annual fertiliser requirement.
Limitations	Sealing of ponds; Type of effluent storage facility; Management of effluent system; Irrigator type; Soil type; Weather; Farm drainage systems; Only having the minimum area permissible (150kg N/ha) creates animal health risks due to elevated soil potassium
References	▪ Monaghan, et al., (2007, 2008) ▪ Monaghan (2011 ▪ Parfitt et al., 2013)

Figure 111 Effluent being sprayed to pasture via a travelling irrigator. Retrieved from http://www.ruralnewsgroup.co.nz/dairy-news/dairy-management/treat-poo-as-fert

Chapter 7: Crop management

	Benched/contoured headlands – Paddock	Contour drain - Paddock
Description	A measure to direct soil and water runoff to the side of the paddocks, or a particular drain within a paddock. The headlands are shaped away from the rows with runoff directed to an earth bund. Headlands are grassed to encourage silt and sediment uptake before entering drains	Contour drains are temporary drainage to collect runoff water. By reducing the length of rows that runoff water can flow down, water is collected in shallow drains that run at a gradient across the slope of paddocks. This allows water to be channelled into permanent drains
Target nutrient	S	S
Land use	Cropping, Vegetable production	Cropping, Vegetable production
Likely reductions in nutrient loss	50-80%	30-70%
Costs	$65/ha	$75/ha
Benefits	Used in good effect to break up the length of long paddock runs; Grassing headlands protects them from scouring and encourages silt to drop out before flowing to surface drainage	Contour drains must discharge into permanent drains otherwise erosion is just shifted to the margins; The steeper the slope, the greater the number of contour drains needed
Limitations	Construction of the headland; Rainfall and management can all impact the effectiveness of the headland	
References	▪ HortNZ (2010) ▪ Barber (2014)	▪ Barber (2014)

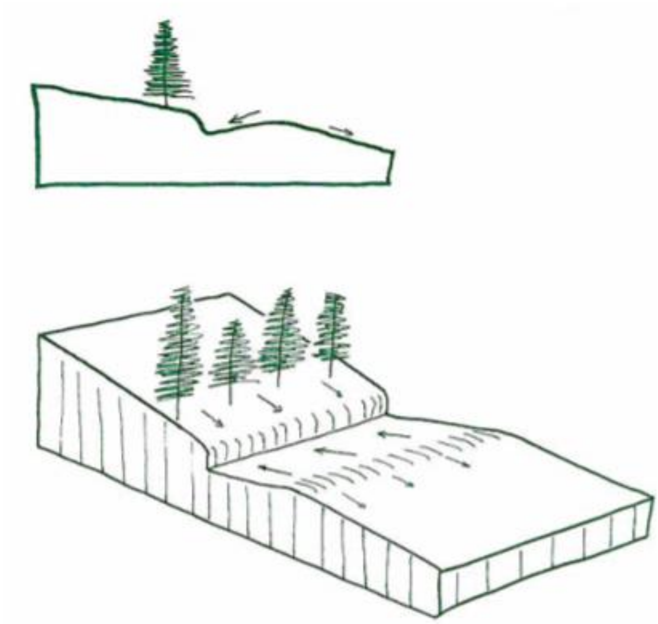

Figure 127 Diagram of a benched headland. Retrieved from https://www.horizons.govt.nz/HRC/media/Media/One%20Plan%20Documents/COP-Vegetable-Growing-in-MWRC-2010-V2.pdf

	Controlled drainage – Paddock, Farm	Wheel track ripping/dyking – Paddock
Description	Restrict or control drainage discharge to prevent it from leaving the system using a weir or water flow control to raise the water level in the drainage outlet, and hold water in the drain. The drainage levels ensure optimal plant productivity, but can be a potential route for dissolved nutrients loss. To help reduce the risk of nutrient loss an option is to use weirs to strategically control drainage	Compacted wheel tracks can act as drainage channels. Ripping wheel tracks to below the cultivation compaction zone allows water to infiltrate into the soil, thus aims to reduce crop and soil loss. Similarly, dyking is a simple practice that creates closely spaced soil indentations along tracks which can achieve the same effect
Target nutrient	N	S
Land use	Cropping, Vegetable production	Cropping, Vegetable production
Likely reductions in nutrient loss	Studies have shown N loss reduction ranging from 57 – 86%, but this varies dramatically with soil types. It is mostly effective on mainly flat with a gentle gradient land, and land that has an impermeable clay layer about 1-3m below the surface	50-80%
Costs	Cost is dependent on existing drainage systems	$35/ha
Benefits	Can be used to accommodate the growth of specific crops, soil types and reduce the stress to crops; Soil water storage; Flood attenuation	Primary measure for minimising runoff, which reduces soil and nutrient loss, thus takes pressure off sediment control devices e.g. sediment traps; Reduced erosion rate; Minimised paddock ponding
Limitations	Water depth and water table management; Soil type; Land use type; Crop type; Requires active management; Unsuitable for mole-tile drained land	Wheel tracks used for spraying should not be ripped, as loose tracks make spraying difficult
References	▪ McKergow et al. (2007) ▪ Ballantine & Tanner (2013)	▪ Barber (2014)

Figure 133 Example of wheel track ripping. The water logged tracks have not been ripped, as they are used for the sprayer. Retrieved from http://www.hortnz.co.nz/assets/Uploads/Auckland-Waikato-ES-Control-Guidelines-1-1.pdf

Figure 144 Example of wheel track dyking. Retrieved from http://www.hortnz.co.nz/assets/Uploads/Auckland-Waikato-ES-Control-Guidelines-1-1.pdf

	Cover crops – Paddock	Super silt fence - Paddock
Description	A crop which is grown to be ploughed into the soil, but not harvested , in order to improve soil quality	Temporary sediment trapping measure for runoff from catchments smaller than 0.5ha, and a slope of 40m. Geotextiles with good filtering characteristics are attached to a wire fence posts e.g. a chain link fence, to capture sediment. Super silt fences are best suited for cultivated growing situations
Target nutrient	N, S	S
Land use	All farming operations	Cropping, Vegetable growing
Likely reductions in nutrient loss	Mean reductions in N leaching for an early sown cover crop in March 70-80%, late sown cover crop in June approx. 25% (Waikato)	80-95%
Costs	Range from $80/ha dependent on cover crop grown	$380/ha
Benefits	Stabilises soil to help prevent erosion; Improves drainage and soil structure; Traps nutrients left in the soil from previous crops; Stimulates soil biological activity; Some species can be nitrogen fixing; Can smother weeds and reduce weed control costs	Can serve as a better constructed, and more permanent silt trap
Limitations	Can have significant reductions in total N leached for certain crops e.g. barley, but can have very little impact on whole farm results dependent on rotation	If used on larger catchments, consideration of site characteristics is needed, or alternative mitigations may be more appropriate; Slope steepness determines design criteria
References	▪ HortNZ (2010) ▪ Barber (2014) ▪ Zykowski, Teixeria, Malcolm, Johnstone & de Ruiter (2016)	▪ Barber (2014)

Figure 155 Oats emerging through the pervious crop. Retrieved from http://www.hortnz.co.nz/assets/Uploads/Auckland-Waikato-ES-Control-Guidelines-1-1.pdf

Figure 166 Example of a super silt fence. Retrieved from http://esccanterbury.co.nz/wp-content/uploads/2017/02/sc-super-silt-fence.jpg

	Decanting earth bund – Paddock
Description	A decanting earth bund is a temporary berm of compacted soil to create a damming area where ponding can occur. They are constructed along flat contours at the bottom of paddocks. By moving the headland further up the paddock, the full width of the paddock allows runoff to be held long enough for sediment to drop out
Target nutrient	S
Land use	Cropping, Vegetable growing
Likely reductions in nutrient loss	80-95% Recommended capacity is 0.5% (50m^3/ha) for catchments less than 5ha, and 1% (100m^3/ha for catchments over 5ha
Costs	$130/ha
Benefits	Avoids the need to build deeper silt traps
Limitations	Decanting rate needs to be monitored to ensure sediment has time to settle
References	▪ Barber (2014)

Figure 177 Example of a decanting earth bund. Retrieved from http://www.hortnz.co.nz/assets/Uploads/Auckland-Waikato-ES-Control-Guidelines-1-1.pdf

	Grazing management – Paddock
Description	Stock grazing crops where there is a risk of sediment and nutrient losses by overland flow should start in the least risky areas (tops of paddocks), and graze towards the highest risk areas, such as paddock depressions or waterways (called Critical Source Areas, CSA). Depressions and grass buffers alongside waterways should be left un-tilled and grazed last, if at all.
Target nutrient	N, P, S
Land use	Dairy, S & B Grazing forage crops, particularly in winter, but applicable to summer crops as well
Likely reductions in nutrient loss	Highly effective in reducing losses due to overland flow, depending on slope and rainfall
Costs	Minimal extra cost; Areas of land not sown will reduce total yield fractionally (less than 2.5% of paddock area in trials)
Benefits	Reducing losses from overland flow means top soil and the nutrients it contains are kept in the paddock
Limitations	
References	▪ Orchiston, Monaghan & Laurenson (2013)

Figure 188 Cows grazing the last bite of a winter crop of kale. Retrieved from http://www.agresearch.co.nz/news/trial-suggests-winter-management-can-cut-runoff-losses/

Chapter 8: Alternative forages

	Chicory – Paddock	Plantain - Paddock
Description	Use of chicory (and clover) as a summer crop, sown in spring, and permanent ryegrass pasture can be over-sown into the chicory/clover crop in autumn; and/or included in a ryegrass/clover pasture mix sown in autumn.	Use of plantain as a summer crop; and/or included in a ryegrass/clover pasture mix
Target nutrient	N	N
Land use	Dairy, Intensive S & B	Dairy, Intensive S & B
Likely reductions in nutrient loss	Known effectiveness for reducing N leaching, but literature is sparse. 33% reduction in available soil N pool from chicory/clover pastures compared to ryegrass/clover pastures.	Plantain reduced NO_3-N loss from urine from 340 kgN/ha (RG + clover) to 240 kg N/ha from plantain pastures 29% reduction 20% reduction in N-leaching from urine spots. In round figures there is 30% less N loading per ha from cow urine when there is a reasonable proportion of plantain in the pasture (probably need 20 to 30%)
Costs	Chicory seed $24/kg (including super strike) $1000-1500/ha	Plantain seed $20/kg (including super strike)
Benefits	Deep tap root reduces N-loss after winter crop; Reduces N-leaching; Total annual dry matter (DM) production can be close to that achieved with ryegrass based pasture, however, pastures with chicory grow better in summer and maintain feed quality over this period; Chicory swards can consistently produce better quality feed than plantain, sustaining between 12 and 13MJ ME/kg DM throughout the year	Total annual dry matter (DM) production can be close to that achieved with ryegrass based pasture, however, pastures with plantain grow better in summer and maintain feed quality over this period; Winter-active and persists longer in ryegrass pasture mix, resulting in more forage dry matter production and less N-leaching from pasture
Limitations	Chicory should not be grazed in winter; Prices vary depending on how the seed is applied; Chicory can yield less DM than plantain and more plants died over an 18-month period; Costs of using chicory or plantain vary depending on how the seed is applied, i.e. if broadcast over existing pasture the cost will merely be the cost of the seed	Costs of using chicory or plantain vary depending on how the seed is applied, i.e. if broadcast over existing pasture the cost will merely be the cost of the seed; Susceptible to broad leaf herbicides, so controlling weeds can be more difficult compared to ryegrass pasture, for example.
References	▪ Perks (2011) ▪ Lucci, Shepherd & Carlson (2015) ▪ Edwards & Cameron (2016) ▪ Sebie & de Klein (2015)	▪ Gawn, Harrington & Matthew (2012) ▪ Ledgard (2015) ▪ Box, Edwards & Bryant (2016) ▪ P. Kemp, personal communication (June 13, 2017)

Figure 200 Cows grazing chicory. Retrieved from https://www.dairynz.co.nz/about-us/research/

Figure 1919 A crop of plantain. Retrieved from https://www.dairynz.co.nz/feed/crops/plantain/

	Pasture mixes – Paddock	Italian ryegrass - Paddock
Description	A combination of plantain and chicory mix pastures	Use of faster growing pasture species to reduce N-leaching in winter
Target nutrient	N	N
Land use	Dairy, Intensive S & B	Dairy, Intensive S & B
Likely reductions in nutrient loss	20% reduction in urine-N concentration, 18% reduction in urinary –N excretion, Urinary N output half that of cows grazing RG	24-54% less leaching of NO_3 compared to Perennial RG pasture
Costs	$20-24/ha for over-sowing 1 kg/ha. If added to pasture mix it is usually sown at 2 kg /ha, so $40-48/ha over above the normal cost of new pasture. If the land is sprayed cultivated and sown with clover as a summer crop, it can cost $1500/ha with or without the seed, which at 6 kg herb/ha & 6 kg clover can cost around $500/ha	18 kg seed/ha @ $25/kg = $450/ha plus sowing
Benefits	Both species really came into their own for animal production when the quality of ryegrass pasture dropped to 9.6MJ ME/kg DM in summer; Feeding first year chicory or plantain to between 20-40% of the total diet increased DM intake of cows by about 1kg per day, and milk solids by about 17 percent compared with cows fed ryegrass pasture only; Feeding either chicory or plantain can reduce the concentration of nitrogen in cow urine, so there is a evident potential environmental benefit from these species through lower nitrate leaching	Costs to establish these forages if yields are sufficient, are off-set by the gains in feed quality and supply at critical times of the year; High yield and can be grazed in autumn to put weight on cows before winter; Establishes quickly and grows well in winter periods; Reductions in soil damage as soils aren't saturated, which enables Italian RG to be sown to remove the fallow period after fodder beet has been eaten, meaning cows only need maintenance through winter; Reduced N leaching; Enables feed supply management; If grown after a summer crop it also enables another spraying out of problem weeds before permanent pasture is sown the following autumn
Limitations	Sowing herbs limits the use of herbicide to control broadleaf weeds in pasture; Weed control is limited to topping and/or more expensive herbicides	
References	▪ Woodward, Waghorn, Bryant & Benton (2012) ▪ Totty, Greenwood, Bryant & Edwards (2013) ▪ Edwards et al. (2015) ▪ Edwards & Cameron (2016)	▪ Malcolm, Cameron, Di, Edwards & Moir (2014)

Figure 211 Up close photo of Italian ryegrass. Retrieved from https://www.dairynz.co.nz/media/4439057/technical-series-june-2016.pdf

Note: Herb/clover mixes can be used multiple ways, for example as stand-alone summer crops or added to rye-grass pastures. Mixtures can be over-sown (broadcast) to fill in spaces in damaged or over-grazed pasture, or under-sown into run-out ryegrass pastures. They establish best in spring and can last for 2-3 seasons, with the clover used to suppress weeds where herb plants have died. Forage herbs can be used as part of a pasture mixes at 1-2kg/ha, as a specialist sole crop, or mixed with white and/or red clover. Herb/clover pastures can also be used where weed grasses are a problem such as needle grass or couch, with these sprayed out while paddocks are in herbs (Edwards & Cameron, 2016).

Figure 222 Clover and plantain mixed pasture. Retrieved from http://www.stuff.co.nz/business/farming/agribusiness/74661433/inverary-station-team-runs-the-rule-over-its-farm-performance

	Fodder beet – Paddock
Description	Use of fodder beet as an autumn/winter crop
Target nutrient	N
Land use	Dairy, Intensive S & B
Likely reductions in nutrient loss	Nutrient loss is achieved by a reduction in urine N concentration: 3g N/litre (L) with fodder beet or kale, compared to RG at 7g N/L
Costs	$3,000/ha
Benefits	Can be fed *in situ* or harvested, stored and fed on a feed pad or in the paddock; Costs to establish these forages, if yields are sufficient, are off-set by the gains in feed quality and supply at critical times of the year; High yield and puts weight on cows before winter; Reduced N leaching; Enables feed supply management
Limitations	Fodder beet is expensive to establish, with the potential for a high yield; Requires free-draining soil; Requires a high level of management due to animal health risks
References	▪ Jenkinson, Edwards & Bryant (2014)

Figure 233 Cows break feeding on a fodder beet crop. Retrieved from http://www.premierrural.co.nz/agri-business/fodder-beet/

Chapter 9: Cow genetics

	Animal breeding and/or Bull selection – Farm
Description	Identifying cows that are able to produce more milk from the same amount of feed, or having fewer cow numbers with high genetic merit and high breeding worth (BW) cows. NZ BW (genetic merit) linked to higher PUE (protein use efficiency)
Target nutrient	N
Land use	Dairy
Likely reductions in nutrient loss	Could be effective based on protein use efficiency statistics: Low BW - 0.28g MS/g protein High BW - 0.30g MS/g protein
Costs	Varies dependent on cow breed
Benefits	Higher protein use efficiency reduces N-loss
Limitations	Difficult to find a clear correlation. It is a risky breeding strategy to select for 1 trait, making improvements in NUE slower than what otherwise be the case.
References	▪ Wheadon, Cheng, Dewhurst & Edwards (2013)

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