Ministry for Primary Industries
Manatū Ahu Matua

An assessment of climate mitigation co-benefits arising from the Freshwater Reforms

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Prepared for the Ministry for Primary Industries

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Contents

Page

1. Summary

Background

The National Policy Statement for Freshwater Management (NPS-FWM) 2014 supports improved freshwater management in New Zealand by directing regional councils to establish objectives and set limits for freshwater in their regional plans. The question this project aims to address is whether there are biophysical co-benefits or additional risks for GHG emissions arising from farmer responses to these freshwater reforms (FWR). This will allow MPI to assess what progress can be achieved in decreasing GHG emissions by the freshwater reforms and could inform future development of GHG and freshwater policies.

There is a wide range of projects focused on estimating GHG emissions from farm systems and the effects of various interventions. However, the added value of this project is that it (a) links water quality and GHG emissions, (b) estimates the implications across a range of sectors, (c) provides MPI with an early indication of co-benefits or otherwise (scope and size) likely to be achieved by water policy reforms, and (d) engages industry partners to provide and validate sector information. It also gives an early warning of potential mismatches between policy for water quality and effects on GHGs.

Approach

Our approach focused on the farm level. Regional Council implementation of the NPS-FWM is still evolving. We therefore first engaged with six 'indicator' Regional Councils to: understand the Regional Council response to freshwater reforms and how policy will be implemented; understand the main enterprises that will likely be impacted and their typical environments (e.g. landscape, soil type, rainfall); and developed a suite of likely policy responses based on these discussions with Regional Councils. There are a range of approaches to limit setting being used by the Regional Councils. Nitrogen is the main issue but not in all catchments; many receiving waters are also affected by P and faecal indicator organisms (FIOs). Our conclusion was that it was best to cover a range of N, P and sediment targets given uncertainty in the eventual targets and likely variation between regions and sectors:

Sector	*Proposed reductions (farm scale) across regions*		
	Nitrogen	Phosphorus	Erosion risk
• Dairy • Dairy support	10-40%	5-20%	0-5%
• Sheep, beef or deer • Other livestock (pigs, goats) • Arable/cropping • Fruit, viticulture or vegetables	5-10%	5-20%	10-30%

An analysis of potential mitigations was then undertaken, compiling exhaustive lists for each sector (dairy, beef & sheep and cropping), including a qualitative assessment of their potential co-benefit for GHG emissions. This compilation of potential mitigations and the qualitative analysis of these mitigations set a framework for testing our results. The analysis of individual mitigations for reducing farm nutrient losses to water suggested that most would have a small but positive effect on decreasing GHG emissions. To quantify the system effects, we undertook analysis by sequentially adding mitigations and modelling to farm systems and modelling the response in terms of reductions in losses to water and GHG emissions. This approach allowed us to estimate the range of mitigations required to achieve a range of target reductions.

The mitigations started with those with low/nil cost and deemed relatively easy to implement, through to infrastructure and system changes. Not all were applicable to all farms. A key assumption for dairy was the aim to maintain production levels. It was assumed that most of the mitigation options would have no impact on production, with the remaining few having a relatively minor impact on production. We borrowed heavily from the experiences in the Pastoral 21 (P21) programme, which has shown that it is feasible to decrease N (and P) losses from dairy systems by as much as 40% while generally maintaining production.
For beef and sheep, it was assumed that there would be two drivers for on-farm change: addressing soil erosion and the associated emissions of sediment and P through ecological and built infrastructure; and the ongoing drive to increase meat and fibre production through improvements in sheep genetics, the performance of high fecund ewes, high growth rates in young stock, changes in cattle policy away from breeding cows to dairy beef and environmental management beyond direct mitigation of emissions to air and water (e.g. shade and shelter). The former bring with it some enterprise change and the latter eco-efficiency benefits.

The challenge with cropping systems was how to model some of these mitigations within OVERSEER as arable farming systems have complex rotations and event-specific activities with varying degrees of leaching risks. Nevertheless, we were able to estimate the potential benefits of a range of mitigations across a number of different rotations.
Forestry represents an important part of GHG balances in catchments. We therefore made an assessment of the likelihood of how farms might respond to ETS rules and how this might drive on-farm responses to GHG mitigation using planted trees. This assessment is integrated into our farm modelling for each sector.

Modelling was undertaken using OVERSEER version 6.2.1 (April 2016) supported with Farmax modelling to ensure that the pastoral systems were feasible and any effects of mitigation on feed supply/production were captured. From this analysis we were able to draw conclusions about the potential impacts of FWR on N (and P losses) and the resultant implications for GHG emissions.

Results

The sectors differed in absolute amounts of modelled GHG emissions and in amounts of modelled N and P loss to water. When drawing national scale assessments, the relativity between sectors in terms of GHG emissions and land coverage need to be considered.

Sector	N and P loss (kg/ha)		GHG	Contribution (%)			Area
	N	P	(kg CO_2-e/ha)	CH_4	N_2O	CO_2	(M ha)
Sheep & Beef	11-31	0.2-5.3	1288-7431 [4861][1]	34-81	15-65	1-5	7.7
Median	*16*	*1.0*	*4734*	*57*	*41*	*2*	
Dairy	36-61	0.5-2.3	9427-18459	46-69	17-47	7-15	1.5
Median	*44*	*1.1*	*11769*	*66*	*22*	*12*	
Cropping	14-240	0.1-2.5	1326-15000 [5980][2]	0-14[3]	17-87	13-83	0.5
Median	*32*	*0.4*	*3696*	*0*	*40*	*51*	
Forestry[4]	0.5-6	0.2	(27000)-(48000)				1.5

[1]lower maximum if the two most intensively managed farms are excluded; [2]lower maximum if the Southland vegetable farm is excluded (high N_2O emissions); [3]Three rotations included grazing animals, which caused methane emissions; [4]Literature values

In terms of the ability of farms to decrease nutrient losses by implementing a range of mitigations, results from our sector analyses of individual farm scenarios are reasonably consistent with other published analyses. Our modelling suggests that, for dairy, N losses on a farm could be reduced by 10-20% without housing, based around lower N inputs into the system – with minimal impact on production. Reduced inputs would benefit (or have little effect on) profit, supported by recent research in the Pastoral 21 programme. However, attaining a 40% reduction in N losses would require infrastructure changes such as standing cows off paddock for periods during autumn and winter. The P21 programme shows that these extra costs negate any financial benefit from reduced inputs, a detailed financial analysis has not been considered here. The analysis has highlighted uncertainty around the degree of pollution swapping if housing is implemented, which could negate a large proportion of total benefits accrued form implementing less costly mitigations. Quantifying this pollution swapping risk associated with housing should be a research priority.

For sheep and beef, analysis showed the ongoing productivity gains possible by the sector from per animal performance improvements and shifting the use and management of sensitive land both contribute to reductions in sediment, P and to a lesser extent N losses and GHG emissions. The environmental gains from improved animal performance reflects two factors. First, more of the feed grown through the spring and summer is eaten by young growing animals that can be turned into saleable product before the autumn and winter months and second fewer capital stock are wintered reducing pressure on landscapes during the vulnerable wet winter months.

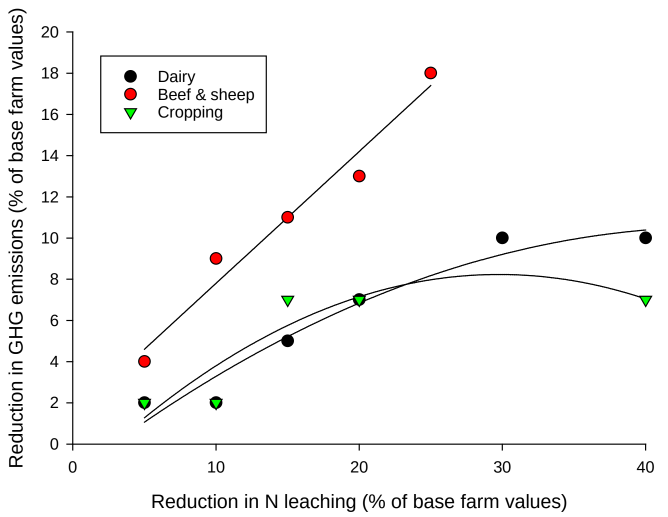
Modelling suggested there was less scope in the arable industry to implement wide-ranging mitigations in complex rotations; however, where they could implemented in a rotation, the result was, on average, a c. 45% reduction in N leaching (and a 7% decrease in GHG emissions). The analysis suggested additional gains could be made from the following:

- Big wins in terms of reduced N leaching losses and GHG emission gains come from improved irrigation practice
- Options to improve N use efficiency, while still at a research stage, is another opportunity for a big gain in N leaching reduction and GHG emission reduction from these systems (although there are diminishing returns from reducing N losses in relation to GHG gains).

The role of forestry will depend on the rules developed for gaining C credits on farms, regulated by current ETS rules which could change post Kyoto. Use of trees in sensitive parts of the farm to reduce P and sediment loss from Critical Source Areas is most applicable to the beef and sheep sector. There is less scope for incorporating trees into dairy farms without compromising production.

Any modelled assessment is sensitive to the assumptions made in terms of: the base farm set up; the mitigations implemented on the farm; and some of the underlying modelling algorithms/assumptions. Consequently, although findings from this study have generally agreed with other published studies, all have relied (by necessity) on assumptions about farm management decisions, modelling and especially on OVERSEER.

The benefits to GHG emissions from FWR will depend on the size of N leaching (and P loss) reductions finally achieved by FWR and the proportion of land where mitigations will need to be implemented. There is still considerable uncertainty about this as regional policy continues to evolve. However, distilling data from the numerous model scenarios summarised in the report suggested that, for the range of farms that were modelled, there was a general trend of reduced GHG emissions with a reduction in N leaching losses:

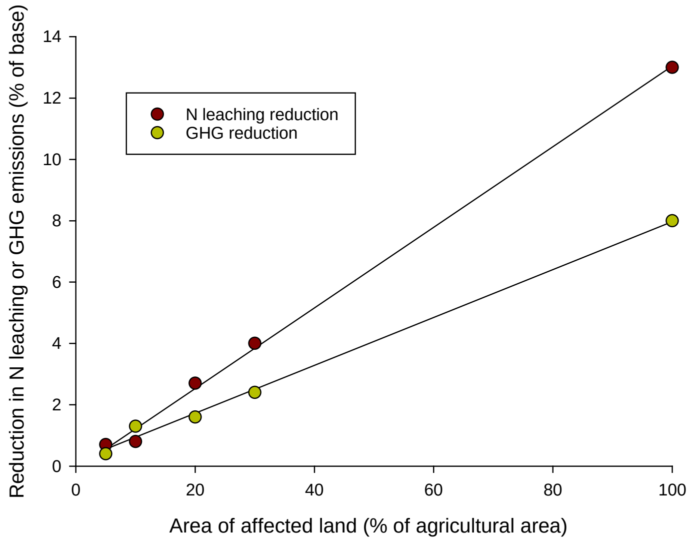


The estimates hide a range of values, but suggest a law of diminishing returns for the dairy and arable sectors but not for the sheep and beef sector. However, for that sector, (a) within the bounds of mitigations that were tested, it was not feasible to move beyond a 25% reduction in N losses, and (b) even then, the number of farms in the group that we modelled that were able to achieve the target losses declined with each 5% incremental reduction in N leaching. The reason for the difference between the sheep and beef sector and the other two sectors is due to two factors (i) planting of trees to reduce erosion effectively reduces the grazed area and (ii) associated with a lift in per head performance is a decrease in the number of capital stock wintered. Both these factors lower the risk of N leaching losses.

Implications

Modelling suggests that although there is not a 1:1 relationship between N leaching reduction and GHG emission reduction, GHG emissions tend to reduce with reduced N leaching losses. The relationship becomes closer to 1:1 if trees are incorporated into the mitigation mix if intensification of the remaining productive land does not negate some of these benefits.
The original scope of the project was to focus on farm level investigations to assess the relationship between mitigations to decrease nutrient and sediment losses and effects on GHG emissions. However, we also conducted a very rough assessment of scaled-up effects by developing a simple spreadsheet model using our median baseline N losses and GHG emissions to populate the model. We then used GHG emission reductions associated with target N leaching reductions of 5-40% (interpreted from the Figure above) and national land-use statistics to examine a scenario for target N leaching reductions of 10% (Sheep and beef, cropping) and 20% (dairy).

A 100% implementation of these target reductions on pastoral and cropping land resulted in an estimated reduction in N loss of 13% and GHG emissions of 8%. The national-level benefit then depends on the 'efficiency factor' that is applied to implementing the policy across regions. In the model this is a linear relationship (Figure below). This suggests that even a 30% implementation efficiency would yield only a 4% reduction in N loss overall and a concurrent 2-3% reduction in GHG emissions:



These average values for GHG mitigation hide a range of values determined by the wide diversity of enterprise types, options and locations in relation to nutrient management. However, GHG emissions are not catchment specific, unlike water quality issues, and are accumulated to a national scale.

As stated before, this is based on a policy of no major enterprise change in the dairy and cropping sectors, but on-farm tree plantings and ongoing investment in higher animal performance in the sheep and beef sector. The introduction of trees on a sheep and beef farm effectively reduces the grazed area. The investment in higher per head performance in the sheep and beef sector, which reduces the number of animals wintered, appears to break the law of diminishing returns between N loss reduction and GHG emission reduction. One conclusion is that further gains beyond the estimated 8% would require land-use change.

2. Background

The main agricultural greenhouse gases (GHGs) comprise nitrous oxide (N_2O) emissions from agricultural soils and methane (CH_4) from animal enteric fermentation. Agriculture contributed 46% of all of New Zealand's GHG emissions in 2012, i.e. 35 Mt CO_2-e (MfE 2014). Enteric fermentation generated 84% of New Zealand's total CH_4 emissions in 2012, and 97% of New Zealand's total N_2O emissions came from agricultural soils. Therefore, if New Zealand is to decrease its GHG emissions, a reduction in agricultural GHGs must be targeted. While there are currently no policies that directly drive reductions in agricultural CH_4 and N_2O emissions, there may be co-benefits from other policies such as the freshwater reforms.

The National Policy Statement for Freshwater Management (NPS-FWM) 2014 supports improved freshwater management in New Zealand by directing regional councils to establish objectives and set limits for freshwater in their regional plans (Anon. 2014). The question this project aims to address is whether there are biophysical and economic co-benefits or additional risks for GHG emissions arising from farmer responses to these freshwater reforms. This will allow MPI to assess what progress can be achieved in decreasing GHG emissions by the freshwater reforms and could inform future development of GHG and freshwater policies.

There is some evidence at a farm level that practices to decrease N leaching can drive decreased GHG emissions. Farm system modelling studies have shown that a combination of mitigations can be incorporated into dairy production systems to achieve the same level of production with lower GHG emissions. For example, de Klein et al. (2010) used the OVERSEER Nutrient Budgets model to estimate the effect of a number of interventions on N_2O emissions from dairy production systems 3 and 4. They estimated that, at the farm system level, use of maize silage (low N feed), nitrification inhibitors and feed/wintering pads would decrease emissions by 24-38% or 0-12% for systems 3 or 4, respectively. Importantly, it was estimated that these changes would also decrease nitrate leaching losses by 30-40%.

Mackay et al. (2011) explored the relationship between changes in the inputs (e.g., livestock numbers, nutrients) and outputs (e.g., meat and fibre, greenhouse gas (GHG) emissions, nitrate) of the MAF Sheep and Beef Farm Monitoring models that cover hard hill country (Gisborne and Central North Island) and easy hill finishing (Manawatu) over the last 20 years using the OVERSEER nutrient budget model. They found that in hard hill country extensive sheep and beef farm operation, productivity gains made since 1989/90 translate into significant eco-efficiency gains, including a 47% increase in saleable product/ha (107 to 167 kg/ha), 21% reduction in nitrate leaching per kg of saleable product (0.065 to 0.054 kg N per kg animal product) and 40% reduction in the GHG emissions per kg of saleable product (27 to 19.2 kg CO_2-e per kg animal product). These eco-efficiency gains, however, did not extend to include an overall reduction in N leaching or GHG emissions per hectare, although there was no increase. In the easy hill finishing operation, where the MAF model farm size more than doubled over the last 20 years, there was little change in the eco-efficiency, but again also little change in total emissions. The decrease in emissions per unit of product reflects two factors. One, more of the feed grown through the spring and summer is eaten by young growing animals that can be turned into saleable product before the autumn and winter months. Second, less live weight per unit product sold is carried into winter, reducing the number of urine patches and the potential for N losses by leaching. The reduction in the kg CO_2-e per kg animal product/ha reflects in part the increased allocation of the total feed grown to saleable product and less to the maintenance of capital livestock.

Decreased N losses to water may not be the only driver for reduced GHG emissions. Sediment and the associated phosphorus (P) loss both contribute directly to degraded water quality and regional councils and Beef + Lamb NZ have been actively encouraging conservation-driven tree planting through the mechanisms of various forms of soil, land and farm conservation plans. Such planting involves pines and spaced-planted poplars and willows across approx. six million ha of hill and steep pastoral land. Douglas et al. (2013) estimated total GHG emissions from an open pasture system in hill country of 4.8 t CO_2-e/ha compared with 4.2-4.4 t CO_2-e/ha for a farm system with spaced trees (poplar and willow) planted for soil conservation. The reduction was largely because the tree pasture system maintained or improved animal productivity with a reduced stocking rate, because of the improved environment. This analysis did not include consideration of any changes to soil carbon from the reduced risk of erosion or the additional carbon stored in trees and it did not consider the impact an enterprise change to a forested woodlot as another soil conservation measure would have on the total GHG balance for the farm.

Pastoral farming is the primary source of emissions but other sectors can similarly introduce mitigation strategies. Forests have played and will keep playing an important role in GHG and nutrient reduction initiatives as net carbon sinks and low nutrient emitters, respectively. The inclusion of forestry either at the sub-enterprise level (e.g. forests planted in dairy farms) or as a whole enterprise could not only reduce abatement costs but will also offer other types of environmental benefits to society (e.g. recreation and biodiversity). Inclusion of forestry at the sub-enterprise level could include mixed systems such as riparian forests and forestry belts in pastureland, forestry-horticulture and short-rotation woody crops for bioenergy production. Following economic principles, Doole (2013) identified forest as one mitigation option would need to expand in the Upper Waikato catchment for the catchment to comply with certain nutrient limits. Furthermore, with the upcoming ETS reforms, rural entrepreneurs might rely on additional cash inflows due to the carbon offset payments received by including forests within their landscape management plans.

The horticultural sector, and in particular intensive arable cropping, kiwifruit production and commercial vegetable production, can use moderate to large amounts of nitrogenous fertilisers. The NPS-FWM will therefore likely result in some changes to these production systems, with knock-on impacts on GHG emissions.

However, there may not always be benefits from freshwater reforms to GHG emissions. For example, ‘pollution swapping’ may occur, whereby management actions to decrease one source of N loss inadvertently increase loss via another pathway (Oenema et al. 2009). Or the changes required by a farm to meet water quality targets may be insufficient to affect emissions of N_2O and/or CH_4 emissions.

There is a wide range of projects focused on estimating GHG emissions from farm systems and the effects of various interventions. However, the added value of this project is that it (a) links water quality and GHG emissions, (b) estimates the implications across a range of sectors, (c) provides MPI with an early indication of co-benefits or otherwise (scope and size) likely to be achieved by water policy reforms, and (d) engages industry partners to provide and validate sector information. It also gives an early warning of potential mismatches between policy for water quality and effects on GHGs.

This will contribute to ensuring the land-based sectors are economically, environmentally and socially sustainable and continue to improve productivity and the efficient use of natural resources. The results will also contribute to the sectors’ understanding of GHG emissions and their mitigation. In the longer-term, it will enable them to understand and manage the economic implications arising from climate change.

2.1 Objectives

1. To identify the range of likely primary industry sector management responses to freshwater reforms that will likely also impact GHG emissions
2. Based on a synthesis of enterprise case studies, to provide an assessment of the likely range and scale of benefits to GHG mitigation from freshwater reforms
3. To highlight any potential conflicts between water and GHG policies.

3. An assessment of the policy landscape and available mitigation options

3.1 Policy landscape

Regional Councils appear to be developing their responses to the NPS-FWM in different ways and within different timescales. It is therefore difficult at the moment to form a complete picture of the likely final policy landscape that will result from the NPS-FWM. Our approach therefore was to engage with six 'indicator' Regional Councils to:

1. Understand the Regional Council response to freshwater reforms and how policy will be implemented.
2. Understand the main enterprises that will likely be impacted by freshwater reforms and their typical environments (e.g. landscape, soil type, rainfall)
3. Develop a suite of likely policy responses based on these discussions with Regional Councils.

Six Regional Councils were selected due to their differing water quality challenges and approaches to the freshwater reforms:

- Waikato Regional Council
- Bay of Plenty Regional Council
- Horizons Regional Council
- Gisborne District Council
- Environment Canterbury
- Southland Regional Council

We adopted a number of approaches to information gathering: using our own knowledge gained when interacting with these regional councils in the past; published resources that were available; interviews with key individuals in each regional council. The information we required was:

(a) How far advanced are they in working through policy
(b) Scale of the issues (proportion of catchments affected)
(c) Contaminants of concern (and how they vary across the region)
(d) Land uses / enterprises of concern
(e) Any information sources that describe these

We also gathered statistics on the main agricultural enterprises to identify the major land uses that would also form the basis of our future modelling.

3.1.1 Conclusions

Details are attached in Appendix I, with findings summarised below.

Limit setting

There are a range of approaches to limit setting being used by the Regional Councils. Nitrogen is the main issue but not in all catchments; some receiving waters are affected by P and, to a lesser extent, faecal indicator organisms (FIOs).

Some approaches are centred on reducing nutrient losses from a baseline of current nutrient loss (e.g., Taupo). Others have decided to set an allowable limit for permitted activities based on land use through sector norms and good management practice (e.g., Rotorua, Canterbury), or limits linked to the land rather than land use (e.g., Horizons), or catchment characteristics (e.g., Southland) to reach a sustainable load to water bodies. The Taupo catchment aims to reduce overall loads through a nutrient trading scheme. The setting of limits on P loss is restricted to a few plans. The emphasis is on encouraging the adoption of practices through farm plans including tree planting, limiting cattle grazing on steep slopes in winter, riparian margins and fencing, managing soil P fertility levels and reducing the risk of P and sediment movement via erosion.

Because of the differences in approaches, we have modelled the reduction in nutrient losses and the risk of erosion by simulating the effects of a range of mitigation strategies with the aim to achieve the following reductions over current conditions (Table 3.1). These reductions are based on the information that we have been able to collect from Regional Councils and cover both current reductions and future (e.g. 20 year) planned reductions.

Table 3.1. Proposed reductions in nutrient losses and erosion risk, on a farm scale, across regions and by sector.

Sector	*Proposed reductions (farm scale) across regions*		
	Nitrogen	Phosphorus	Erosion risk
• Dairy • Dairy support	10-40%	5-20%	0-5%
• Sheep, beef or deer • Other livestock (pigs, goats) • Arable/cropping • Fruit, viticulture or vegetables	5-10%	5-20%	10-30%

Enterprises

The regions selected give a good mix of enterprises that allow us to build up a national picture as well as to undertake detailed farm-level evaluation. The advantages of selecting regions for a more detailed analysis of the farm types before scaling up lay in the resulting good mix of the main farm types of interest.

- Southland: Dairy systems 2, 3, and 4; winter cropping dairy support. Sheep & Beef systems. Reductions in N, P and sediment desired, depending on physiographic zone.
- Canterbury: Sheep & Beef; Dairy including irrigation (systems 3-4). Mainly N.
- Manawatu-Wanganui: Sheep & Beef, focussing on sediment and P issues
- Gisborne: Sheep & Beef, sediment only. Vegetables, Fruit - N & P
- Waikato: Dairy systems 2 and 4 (Mainly N), Sheep & Beef (P and sediment), Arable/maize (mainly N); Dairy goat (Mainly N)
- Bay of Plenty: Dairy systems 2 and 4, Beef, Fruit (kiwi fruit) (Mainly N). Forestry

3.2 Mitigations and possible farm responses to limit setting

The range of mitigation options available to reduce sediment and nutrient losses to water were collated (Appendix II). We compared this with an independent compendium of potential mitigations – the UK 'User Manual' (Cuttle et al. 2016). In this work, a 'User Manual' of 83 mitigation methods was compiled and through extensive modelling (underpinned by expert opinion) an assessment of each mitigation was made for size of effect on nutrient losses to water and individual GHG emissions. We believe this is one of the most comprehensive resources available and the farm typologies used in their assessment (and environments) map well against New Zealand enterprises and conditions.

We mapped our list of proposed mitigations against this User Manual and have summarised their estimates of effect sizes in Appendix II. The key points from this comparison with UK data indicated:

- The majority of individual mitigations are ranked as having a 'low' effect.
- There are few mitigations that result in potentially high reductions in GHG emissions. The main ones relate to tree planting, with moderate to high effects on NH3 and N_2O emissions from these practices. However, this assessment is misleading because it refers to emissions only from that converted land area and does not factor in farm system effects, e.g. intensifying other areas of land to compensate for lost area. Note that this assessment excludes C sequestration effects in soil and biomass pools.
- There are some uncertain effects and possible increases in emissions relating to restricted grazing (animals off pasture) which results from larger housing losses and the associated deferred effluent irrigation. This is potentially important because restricted grazing is seen as an effective tool to decrease nutrient losses to water.
- Other mitigations have potential to increase GHG emissions. These include those:
    - that use more energy (increased CO_2 emissions), e.g. for cultivation
    - that increase the potential for N_2O emissions, e.g. adoption of direct drilling where this might result in more compaction of the soil surface; although there is a counter-argument that direct drilling increases macropores in the soil surface, which reduces N_2O emissions under saturated conditions.
- One anomaly stands out: where irrigation has potential to increase N_2O emissions. However, this compares with a baseline of no irrigation, whereas the actual definition of our mitigation is 'better irrigation management'. Then, we would expect N_2O emissions to decrease due to better use of water and fewer occasions with ponding/saturated conditions.
- Use of wetlands indicates increased GHG emissions. Again, this has important implications because use of wetlands is seen as a possible solution for capturing N and sediment losses.

We identified from our large list of potential mitigations those that would most likely be used to achieve target reductions. Tables A2.5-A2.7 in Appendix II summarise these for key enterprises. The list is based on those that were most practical and cost effective. Section 5 within this report documents the final list of mitigations that were incorporated into our farm modelling.

3.2.1 Conclusions

In summary, this compilation of potential mitigations and the qualitative analysis of these mitigations set a framework for testing our results. The analysis of individual mitigations suggests that most have a small but positive effect on decreasing GHG emissions. However, some have been identified that have potential to increase GHG emissions, with most uncertainty around the potential for pollution swapping by diverting urine from paddocks into storage during periods of housing stock.

It should be noted, however, that this analysis does not include assessment of combined effects, the complex interactions that result from those combinations and the farm management changes implemented by farmers using these mitigations. Consequently, any testing has to understand these interactions and take them into account during interpretation of the results. For example: previous research was able to model mitigation but when actual farms actual farms were modelled where a mitigation had been implemented (e.g. faster lamb growth), farmers bought in more lambs to finish and GHG emissions went up even though EI went down (R. Dynes, Pers. Comm.).

4. Forestry

The aim of the analysis of forestry options was to assess their potential in a role for on-farm mitigation on nutrient/sediment and GHG emissions, before undertaking an assessment of farm-scale impacts of a range of mitigations as outlined in Section 5.

4.1 Background

The environmental services provided by forests are being increasingly recognised (Yao et al. 2013, Allen et al. 2013). In the context of the Freshwater Reforms, the benefits of tree planting include:

- Reduced average sediment and particulate P loss due to reduced erosion on many sites, depending on slope and soil type. Commercial forestry land is vulnerable for several years after harvest.
- Reduced average soil N and C losses from soil disturbance (cultivation) if the land was previously cultivated
- Reduced losses of N through N fertiliser application, because the afforested area will no longer be fertilised. However, farm fertiliser use may increase due to intensification elsewhere on the farm and legacy emissions will continue – the rate of change in emissions following a land use change is not well understood.
- Reduced emissions (and E. coli) from livestock, due to the removal of livestock from afforested area. Total farm livestock numbers may not decrease due to intensification elsewhere on the farm.

Tree planting provides greenhouse gas benefits in a number of ways:

- direct uptake of CO_2 by trees;
- long-term storage in harvested wood products;
- direct substitution of fossil fuels through the use of biomass for bioenergy;
- indirect substitution of fossil fuels through substituting low-emissions wood products for fossil fuel-intensive products;
- reduction of emissions due to displacement of the pre-afforestation land use (e.g. enteric fermentation, fertiliser, soil cultivation);
- reduction in soil carbon loss due to reduced erosion
- increased carbon sequestration in deeper soil layers through deeper rooting system of trees.

However, there are limitations of forest-based mitigation:

- The conversion of grazing land to forest may result in a reduction in emissions from that land without leading to overall GHG benefits at the global, national or farm level. For example, the landowner may intensify production elsewhere on their property, or less emissions-efficient producers in New Zealand or overseas may compensate for the loss in production. Fossil-fuel emissions from activities required to establish and manage the mitigated land use may increase.
- Accounting rules under the ETS may not correspond exactly to the international accounting rules used for New Zealand's obligations. The accounting rules are subject to change, as are the definitions and assumptions used by New Zealand. The landowner can only accrue benefits if the mitigation practice adopted are recognised in the current regulations. The same applies to nutrient emissions benefits under nutrient management schemes. These benefits can be more or less than those actually seen by the environment – for example, regulations may include default sequestration rates or nutrient emission levels for defined management options.

However, the major limitation to tree planting as a greenhouse gas mitigation strategy relates to the time dimension and permanence.

4.1.1 The time dimension in greenhouse gas mitigation through afforestation

Just as deforestation represents a one-off transfer of carbon from the terrestrial biosphere to atmosphere, afforestation represents the reverse process. This is the case regardless of whether the forest is established with native or plantation species, whether trees are harvested or not, or whether trees are harvested in large or small groups. As long as the forest replaced a non-forest land use it will contain a larger carbon stock, averaged over time and space.

However, the presence of a forest carbon stock is not an indication of a net carbon sink. A net sink (positive sequestration) will occur while the forest is increasing in area and/or average age and therefore average biomass per hectare. This will not occur indefinitely. A forest of a finite area – whether management includes harvesting or not – is likely to eventually become carbon neutral. A carbon neutral forest will no longer offset ongoing farm emissions. The sequestration benefit essentially lasts from establishment until the long-term average carbon stock is reached. There may be ongoing benefits from wood products (long term storage, direct and indirect substitution), but these are more difficult to quantify. For forestry to keep offsetting farm emissions, the forest must keep expanding in size and/or in average carbon stock per hectare (e.g. by extending the rotation length). Expansion of forest size is likely to require off-farm planting.

It is therefore critical to specify a timeframe when talking about carbon sequestration by forests. The time horizon is also important when looking at alternative afforestation options. Native forest regeneration has a low annual sequestration rate, but native forests may eventually store a large amount of carbon when they reach a state of carbon neutrality (when gains due to growth are offset by losses due to tree death and decay). The appropriate mitigation response depends on the urgency with which emissions must be reduced. If there is little or no urgency, then achieving a low but positive sequestration rate over 150-300 years may be acceptable. If the intention is to maximise sequestration in the period to 2050, then a fast-growing plantation species may be preferable – even if a large proportion of carbon sequestered is subsequently re-emitted at harvest. This time-frame may still be sufficient to "buy time" to develop economically viable livestock emission mitigation solutions.
In this report the time dimension is allowed for by presenting alternative sequestration rates for commercial forestry:

1. Mean average annual sequestration from establishment to maturity i.e. ignoring emissions at harvest.
2. Mean average annual sequestration to half the final carbon stock before harvesting. This is a simple metric that approximates claiming sequestration credits up to the long-term carbon stock in forests where stands are repeatedly harvested and replanted.

4.2 Effects of afforestation on nutrient and sediment losses to water

4.2.1 Nitrogen leaching

Nitrogen in a mature forest cycles between the vegetation and soil organic matter in an almost closed cycle. Davis (2014) provides a review of N losses from forests in New Zealand. Planted forests that were established on land cleared of indigenous forest generally show the same low losses of N. The slightly higher losses from planted forests established on pasture sites is a legacy effect of the previous land use and are still low compared with other land uses. There are interventions that cause leaching to increase, including:

- Spot spraying for pre-establishment weed control;
- Fertiliser application
- Harvesting (although the effect is small and short-lived as weeds re-establish).

N uptake by trees is low from mid-rotation through to harvest and can be maximised by correcting limitations to tree growth (e.g. diseases) and by selecting species with high N requirements (Davis 2014). Any requirement to achieve minor reductions in N losses from plantation forests are likely to be met through productivity gains in the course of normal forest management. This includes the use of better genetic stock and better site occupancy through higher tree stocking. The result would be an equivalent increase in carbon sequestration. If the forest then reached a new stable equilibrium carbon stock, the nutrient supply would again be in excess of demand and losses may increase again.

Nitrogen use by tree crops can be modelled using NuBalm (Smaill et al. 2011), which has recently been integrated with the Forest Carbon Predictor model (FCP: Beets et al. 2011). NuBalm tracks nutrient supply and demand during the life of the stand, providing estimates of pools and losses over time. Figure 4.1 shows an example of the accumulation of N in crop tree biomass during a rotation of radiata pine on an ex-pasture site in the Central North Island. Results for two regimes are given (with and without thinning) although neither was optimised for nutrient uptake.

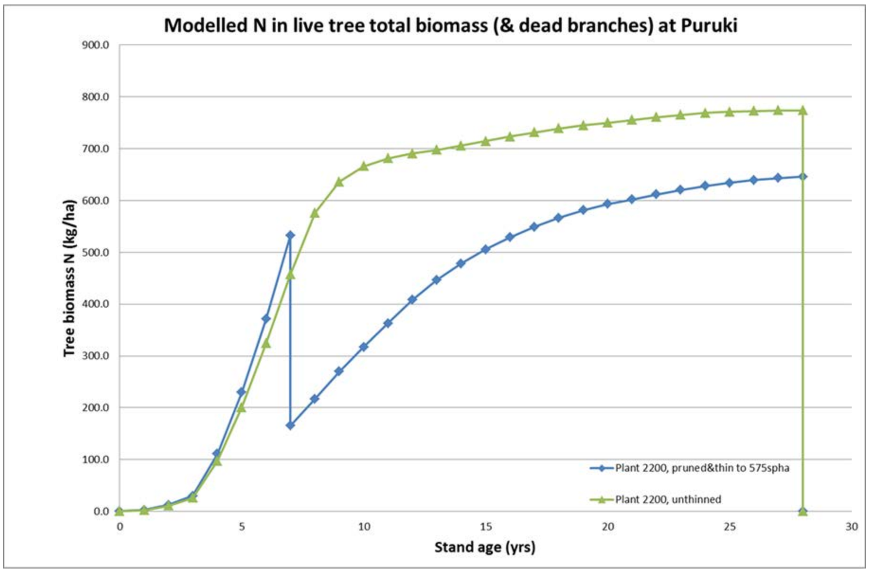


Figure 4.1: Example of modelled N content in thinned and unthinned P. radiata stands.

The NuBalm module within FCP accumulates N in the various tree components, so that various degrees of extraction at harvest can be modelled. Figure 4.1 suggests that about 600 kg N/ha could be removed if entire trees (including roots) were removed at harvest. If the N contained in dead organic matter is included (e.g. in thinned stems), the total accumulation of N in this stand over a rotation increases to about 1200 kg N/ha, although it would be difficult to collect and remove it all at harvest. The amount of N stored in subsequent rotations would decline somewhat as the decay of dead organic matter releases N that is surplus to stand requirements.

In practice, a regime specifically geared towards nutrient stripping could be used. For example, a higher initial stocking and repeated unthinned eight-year rotations would increase nitrogen removals by the stand shown in Figure 4.1. This is discussed in a later section.

Note that while mature forests may not extract nutrients in groundwater that originate from elsewhere on the farm, a benefit may accrue for the land area actually planted under nutrient limit regulations, because assumed emissions may decrease from the baseline associated with the previous land use baseline to a lower level assumed for forestry.

4.2.2 Impact of forest on P and sediment loss

The main benefit from forestry in terms of P and sediment loss mitigation is due to a reduction in erosion where trees are planted on steep slopes in particular. Trees also reduce overland water flows through rainfall interception and evapotranspiration. Most of the trapping of sediment and particulate nutrients in surface flow is achieved by ground cover vegetation, so the main benefit of adding forest tree species to a riparian zone will be in the additional width of the riparian. There will normally be ground vegetation within the forest and a wider riparian zone will allow more infiltration. However, a dense canopy cover may lead to a decrease in ground vegetation, and there may be soil disturbance associated with planting trees or windthrow. If a portion of the riparian zone is harvested, this will increase the risk of sediment loss.

According to the New Zealand Poplar and Willow Research Trust (2013), riparian tree buffers can reduce phosphorus loss. The mechanism for this appears to be stabilisation of stream banks. Willows have been extensively used for this purpose in New Zealand but it is now recognised that crack and grey willows can choke waterways and they are no longer recommended. A review by Hughes (2016) highlighted the lack of quantitative research on the effectiveness of riparian management in reducing stream bank erosion in New Zealand. The exclusion of stock was generally reported as the main factor leading to improvements, but it is usually assumed that the extensive and overlapping root systems of tree species will also play a role.

The proposed National Environmental Standard for Plantation Forests particularly targets potential erosion and sedimentation arising from activities such as mechanical land preparation, earthworks, quarrying, and river crossings and harvesting. However, the proposed rules are variations of existing regional rules. In many cases sedimentation can be reduced by taking more care with road building and harvesting. This would not affect net GHG emissions but could reduce profitability. On very high erosion risk slopes it will be necessary to weigh up the cost of extracting logs, the risk of a storm event and the consequences of breaching the allowed sediment levels. No land use is immune to the effects of high intensity, long return period storm events, and it is possible that some sites may be best left unharvested. This would have a positive effect on greenhouse gas uptake until the carbon stock stabilised (perhaps following regeneration to natural forest). Revenue (and to a lesser extent profit) would be reduced. There would be a similar outcome from the use of wider set-backs (such as riparians and unharvested coastal strips). Longer rotations and the use of species that occupy the site more rapidly would also reduce erosion risk by reducing the vulnerable post-harvest area in a given time period. Again, greater carbon sequestration would result.

4.3 Assessment of benefits and co-benefits from trees

Three specific mitigation options involving tree plantings were assessed:

1. Riparian forests (and woodlots)
2. Nutrient-stripping short-rotation crops
3. Space-planted poplars

4.3.1 Riparian forest (and woodlots)

Freshwater benefits from fenced riparian zones arise mainly from the exclusion of stock from direct access to the waterway and banks (where they may disturb the soil). Vegetation in the riparian zone also acts to filter run-off, tapping particulate P and sediment. A ground cover of rank pasture is often sufficient unless over-land flows become channelled.

The addition of tree species to riparians provides a range of benefits including biodiversity, habitat, landscape amenity and regulation of water temperature. Specific benefits in terms of nutrient and sediment discharge over and above a fenced riparian with ground cover only may be marginal. One exception is the use of trees to stabilise eroding stream banks. Trees may also be useful if land within the riparian zone itself is eroding.

Greenhouse gas co-benefits arise due to the sequestration of carbon in riparian trees. If the area planted meets the requirements in the regulations, these benefits may accrue to the landowners under the ETS or nutrient regulations.

Practical aspects of riparian forests

A landowner may consider that if land must be retired for riparians, then ensuring it also meets the requirements for sequestration credits under the ETS may be worthwhile. The criteria to be met involve firstly planting 'forest tree species'. It is very difficult for native tree species to self-establish in grassed riparians, but once colonising shrub species are established it can be assumed that native forest will eventually regenerate in most areas where a seed source is available. Without management intervention, a riparian zone is unlikely to transition from grasses to woody weed species to forest quickly, if at all.

The minimum forest width criterion is not typically met by riparian planting on flatter productive farm land due to a reluctance to lose productive land. Creating a riparian forest would require fencing about 15 m on either side of an internal stream. The entire forest created must be within the property of the ETS participant, so a 30 m buffer is required if the stream is a property boundary. Narrower riparians can qualify if they are contiguous with an area of post-1989 forest on the property that does meet all criteria, which is more likely on a sheep and beef farm than a dairy farm.

Forest boundaries are mapped to the outer edge of tree foliage at maturity. The ETS Mapping guide allows a buffer of four metres for young trees to account for canopy growth, suggesting that 22m from fence to fence would be sufficient to create a 30 m wide forest. In practice, trees would not be planted within about 1.5 m of the fences, so a slightly wider fenced zone would be needed. If the un-vegetated stream channel is more than 15 m wide it will need to be mapped separately, meaning that that riparian on either bank would be considered separate forest areas, requiring 30 m width each. However, the width of unplanted features such as tracks and streams within the forest area is also measured from the edge of the tree canopies, rather than trunk to trunk. If this distance is less than 15 m or the feature is less than 1 ha, it can be considered to be part of the forest land area. This is important, because generally tree planting must be set back from the stream margins – sedges and rushes are preferred except on steeper eroding banks where the extensive root systems of trees are more useful.

Figure 4.2 gives an example of riparian design used by the Taranaki Regional Council. The suggested fence-to-fence width here ranges from 8 to 16 m plus the width of the channel.

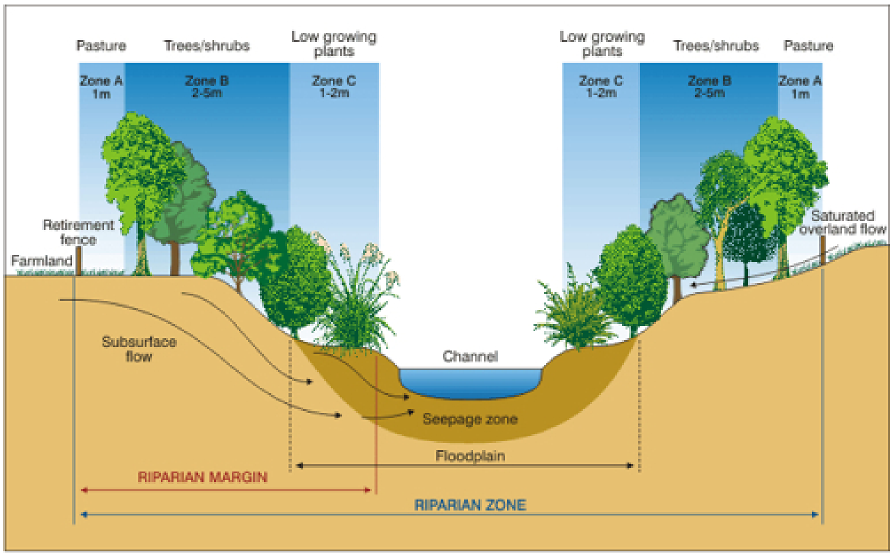


Figure 4.2: Taranaki Regional Council riparian design for dairy farm[1]

Tree canopies will extend over the channel to some extent and also beyond the fence lines, and the width of the channel itself is the key to determining whether or not an ETS-compliant forest is created. As Table 4.1 shows, these guidelines would not allow the riparian zone to qualify as a forest if the channel was only 1 m wide. With a buffer riparian zone of 4 m either side of the channel, the channel itself would need to be 16m wide to create a 30 m wide forest, while if the buffer was doubled to 8 m the channel width required would be halved to 8 m.

Table 4.1: Total forest width for riparians established according to TRC guidelines in Figure 4.2.

Scenario	Width (m)			
	All vegetation (land retired)	Channel	Dripline beyond fence	Total
1 TRC 4+4a	8	1	6	15
2 TRC 4+4b	8	16	6	30
3 TRC 8+8a	16	1	6	23
4 TRC 8+8b	16	8	6	30
5 Overshoot 15+15	30	18	6	56
6 ‘Typical’	26	2	2	30

Scenario 5 shows that fencing a 15 m buffer on either side of a wide streambed could result in a forest with a width well above the requirements. Here it is assumed that the tree canopy would extend across the low growing plants and a further 2 m across the stream. The gap between canopies spreading from either side of the stream would then be 14 m – just inside the maximum permissible width for a non-forest feature. Scenario 6 suggests a more typical situation with a narrow channel, forest trees set back further from the fence line and a safety margin for the total forest width, resulting in a retired width of 26 m. A riparian following this design could have an inner 8 m wide zone of native vegetation with an 18 m wide zone of commercial forestry outside it. This would minimise the land required to be taken out of grazing, while still protecting the waterway and meeting the forest definition under the ETS. At least some of the land would still make a financial return.

[1] Taranaki Regional Council (undated) Plants for riparian margins. Sustainable Land Management Number 25. http://www.trc.govt.nz/assets/Publications/information-sheets-and-newsletters/land-management-information-sheets/riparian-management-information-sheets/25plants-for-riparian-margins09.pdf

For the following calculations we assume that the creation of a riparian that qualifies as an ETS forest requires land within 15 m either side of the stream channel to be fenced off, although as noted above, there is some potential to reduce this buffer depending on the width of the streambed. To achieve the minimum forest size of 1 ha then requires 333 m of continuous stream length at 30 m width.

Quantifying N, P and sediment benefits of riparian forests and woodlots

It is simplest to assume that riparian forest will confer no additional benefit in terms of particulate P and sediment loss over a non-forested riparian. Woodlots planted on slopes prone to erosion will be beneficial. In the short-term trees will take up N but the N supply in pastoral soils is likely to be in excess of tree demand and in the longer term nutrient cycling within the forest means that there will not be an ongoing benefit. Management specifically designed to remove nutrients are discussed separately in the next section.

Quantifying GHG co-benefits

The options for riparian forests and woodlots considered are:

(a) Indigenous forest, using ETS lookup tables.
(b) Planted forest, using ETS lookup tables
(c) Planted forest, using modelled estimates for regional farm types.

Indigenous forest is assumed to be non-commercial (unharvested). A planted forest could be established using a species capable of storing a high carbon stock (e.g. redwoods), although the ETS table available is lower than for radiata pine.

Indigenous forest.

The riparian design would be similar to that shown in Figure 4.2. Although it may include a rank grass strip inside the fence and low growing vegetation adjacent to the stream channel, it is assumed that the whole fenced area qualifies as forest, as measured between canopy driplines.

The indigenous forest ETS lookup table reaches 323.4 t CO_2/ha after 50 years. The annual sequestration rate varies over time is assumed to decline to 1.1 t CO_2/ha per year by age 50. The mean over 50 years is 6.5 t CO_2/ha/year, but under the ETS rules only the actual units earned to date are claimed. Note that if the age 50 annual increment of 1.1 t CO_2/ha/year was maintained indefinitely, it would take another 550 years to reach the mean stock for tall natural forest assumed by MFE in the 2015 GHG inventory submission (based on LUCAS plot data). No attempt has been made to model regional indigenous forest growth rates for this report – it has been assumed that the national ETS lookup table provides a reasonable approximation.

Converting the net present value (NPV) of carbon revenues to an annuity allows a comparison of the GHG co-benefit with the livestock revenue foregone (Table 4.2). A fixed annual ETS administration fee of $60/ha is included. These estimates are for carbon net revenues only – they do not include the cost of fencing, site preparation, planting and weed control.

Table 4.2. Annuity value of carbon uptake by indigenous forest (8% discount rate).

Carbon price	Net Present Value	Annuity
$1	-$656	-$63.30
$5	-$345	-$33.30
$10	$44	$4.30
$15	$433	$41.80
$25	$1,212	$116.80
$50	$3,157	$304.50

Planted forest – ETS lookup tables

The ETS lookup tables for radiata pine project the carbon stock reached at age 50 to be about four times higher than for indigenous forest. These ETS tables are conservative estimates - actual growth rates on productive farmland would be higher still. The advantage of the lookup tables is that they do not require the expense of a field survey.
Plantation species in a riparian are best used in conjunction with permanent vegetation on the stream margins to provide continuous stream shading and protection from surface runoff, particularly after harvesting. Therefore a 30 m wide riparian zone could include a plantation species while also containing a high proportion of non-commercial forest. The ETS would not require the unstocked area to be delineated separately if it was less than 15 m in width. One option would be a 20 m wide strip of plantation species outside a 10 m wide zone containing the channel and permanent vegetation.

The ETS tables for plantation species also assume variable annual sequestration over time and harvesting adds a further complication, as some units earned during the rotation must be surrendered to cover harvesting emissions. Government has indicated that for post-2020 sequestration reporting and accounting, New Zealand intends to use a long-term averaging approach. This is useful for harvested forests because it removes the risk associated with having to pay a liability at harvest. They have not suggested the averaging period length deemed appropriate – the long-term average will increase slightly over multiple rotations, particularly if the pool of harvested wood products is included.

A simple approach is to simply credit half of the expected carbon sequestration to the end of the rotation. The net present value assuming a carbon price of $15/t CO_2 is shown in Table 4.3, together with the equivalent annuities. A flat annual ETS administration fee of $60/ha has been used with sequestration credits assumed to be earned annually. Only the cash flows associated with carbon trading are included - costs of forest establishment and management are excluded.

Table 4.3: Regional sequestration rate, net present value (NPV) and equivalent annuity for ETS radiata pine lookup tables, assuming claim half credits to age 28 and 8% discount rate. Assumed price of carbon = $15/t CO_2.

	Sequestration rate, (t CO_2/ha/year)	NPV ($/ha)	Annuity ($/ha/year)
Auckland	14.3	1845	167
Waikato/Taupo	13.5	1698	154
BOP	12.6	1535	139
Gisborne	14.4	1864	169
Hawkes Bay/SNI	14.2	1832	166
Nelson/Marlborough	11.3	1304	118
Canterbury/West Coast	9.2	930	84
Otago	10.9	1244	113
Southland	12.5	1515	137

Planted forest – modelled sequestration rates for farm types

The additional cost in carrying out a field survey to determine carbon stocks may be justified if the growth rate is higher than assumed by the ETS lookup tables and is mandatory if the landowner has over 100 ha of forest. The Forest Investment Framework (FIF) was used to estimate sequestration rates and carbon and timber annuities for the farm types identified by AgResearch. FIF is a spatially explicit economic tool that brings together a range of forest growth and environmental models and combines them with spatial biophysical and economic data (Barry et al. 2014). The process of determining the areas within each farm type and the calculation of timber NPV are described in is described in Appendix III.

4.3.2 Nutrient-stripping short rotation forestry

Forest management regimes can be designed to maximise uptake of N from soils and groundwater and storage in biomass which is harvested and removed from site. If tree species such as eucalypts or poplars are used there would be no difficulty in reaching the ETS forest thresholds of 30% canopy cover and 5m height within a rotation of 7-15 years, and possibly also with much shorter rotations.

Quantifying N benefits of short rotation forestry

Short rotation hardwoods have been proposed as a means of rapidly removing nutrients from the soil, with biomass to be harvested in 7-8 years before nutrient cycling within the plantation occurs. Nicholas et al. (unpublished) reviewed the use of hardwood in land treatment effluent schemes. Eleven sites were evaluated of which seven were still receiving waste water applications and only one was being actively managed to remove biomass (for firewood). Each site had a wide range of species, stocking rates and application rates. The best performing species were E. maidenii, E. botryoides, E. nitens, and A. melanoxylon, but only when matched to appropriate sites. On some sites growth was very poor (MAI 1.5 m3/ha/year). The most productive species were:

- E. nitens in Southland (MAI 43.5 m3/ha/year at age 12; mean height 24.9 m)
- E. maidenii at Waihi Beach (MAI 25.3 m3/ha/year at age 9; mean height 15.1)
- E. botryoides at Whiritoa, Coromandel Peninsula (MAI 17.5 m3/ha/year at age 3; 7.9)
- E. globulus at Whitianga (MAI 17.3 at age 11; 14.7 m)
- A. melanoxylon at Puhoi. (MAI 14.0 at age 13; 13.1 m)
- E. ovata at Blenheim (MAI 13.9 at age 12; 16.0 m)

Radiata pine was also growing well at several sites, and was suggested as a better option for those sites where effluent application had stopped and the rapid early growth and coppicing ability of hardwoods was evidently no longer required.

Nitrogen fluxes were tracked in the Whakarewarewa forest effluent trial. Tomer et al. (1997) found that N losses from the site approached the desirable limit on an annual average basis, and showed a distinct seasonal variation. Leaching fluxes of N were less than half of the load applied. Crop uptake removed about 11% of the applied effluent N, and upland soil denitrification accounts for less than 1%. This suggests that soil N storage, N uptake by understory plants, and turnover of organic N have combined to be an important aspect of the N budget. Growth rates and survival were generally poor for all species at the Whakarewarewa site. Thorn et al. (1997) cautioned that fully stocked plantations may not be achieved on high fertility treatment sites, due to excessive windthrow following growth stimulation and development of excessive crown mass relative to root strength and stability.

Franklin et al. (2016) reviewed the potential for poplar and willow silvopastoral systems to mitigate nitrate leaching from intensive agriculture in New Zealand. Leaching can be high at the time of establishment and after harvest, but overall nitrogen uptake rates are closely linked to biomass production. A case study on irrigated land in Canterbury found that the crop height would have to be kept below 4 m to allow the highest irrigator to pass, so the ETS forest definition threshold would not be reached. A trial undertaken in the Wairarapa suggested that up to 400 kg N/ha /year could be removed over two years by short rotation coppiced willow from treated dairy effluent. Actual uptake in the second year was less due to adverse weather conditions and the impact of poplar rust. Mean tree height did not reach 5 m (Snow et al. 2003). In another trial three years of eucalyptus growth when irrigated with meatworks effluent took up 217 kg N/ha/year and 18 kg P/ha/year (Guo et al. 2003).

Quantifying GHG co-benefits

A nutrient stripping regime requires the regular removal of biomass, with the biomass removed usually intended for bioenergy applications. This means that there is little long term storage of carbon on- or off-site.

Short rotation willows are being trialled in the Taupo catchment as a means of reducing nitrate inputs to the lake, with additional value to the grower from biomass produced for bioenergy and chemical extraction for the food and pharmaceutical industries. Reported dry matter (DM) production was up to 24 t DM/ha/year in the first year of growth in a plot irrigated with effluent (Snowden et al. 2013).

Sims et al. (2001) reported on an experimental trial with trees grown at 5000 stems/ha for three years followed by a coppice rotation of another three years. Tree heights exceeded 5 m in all cases after the full six years (though not at the initial harvest after three years). Total biomass yield of the best species/cultivars exceeded 35 t DM/ha/year, but this includes the biomass removed at the first harvest. Figure 4.3 shows the carbon stock over time in a hypothetical short rotation coppice Eucalyptus crop based on this value and the following assumptions provided by Sims et al. (2001):

- the yield of a first coppice Eucalyptus harvest can be double that of the initial single stem harvest,
- the second coppice harvest is about 150%,
- the third coppice harvest is about 100%, i.e. the same as the original single stem harvest.

It was also assumed that the stumps would be removed after the third coppice harvest and replanted, with a yield gain of 10% due to superior genetics and management and that this yield gain would be achieved each time stumps were removed (i.e. every 12 years). A carbon fraction of 0.5 was assumed. Soil carbon changes were not included.

The long-term average carbon stock increases slowly due to the gain in yield assumed in this example but is still low compared with a normal radiata pine regime. The rapid average sequestration rate over the first six years is not sustained and the biomass removed is not put into long term storage, although it may substitute for fossil fuels. If sequestration is claimed on the same basis suggested for radiata pine, equivalent rates would be:

- 2.8 t CO_2/ha/year (assuming claim half the year 30 stock, divided by 30 years); or
- 5.1 t CO_2/ha/year (assuming the long-term average stock (estimated in year 60) is claimed, divided by 28 years).

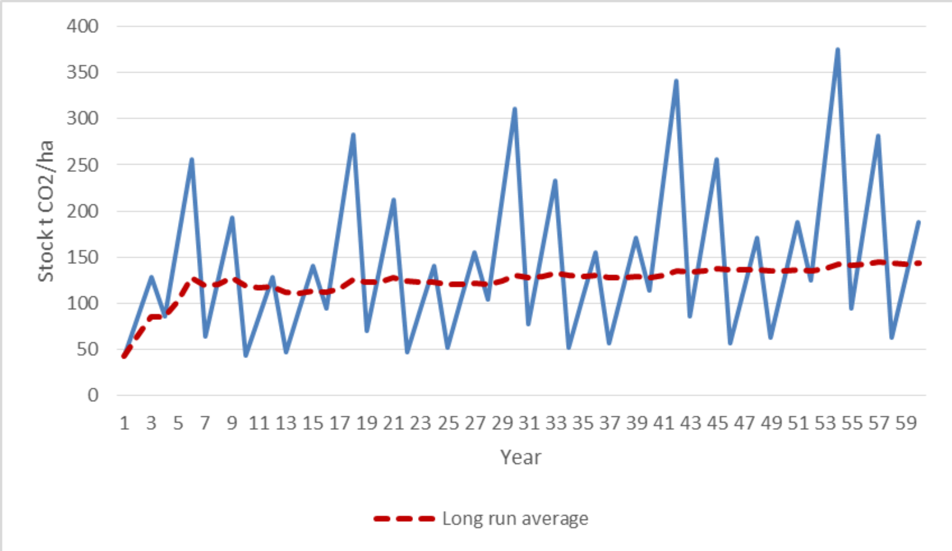


Figure 4.3: Whole tree carbon stock in repeated Eucalyptus coppice rotations.

It would also be possible to claim the MPI Lookup table value for hardwoods, which is based on Eucalyptus nitens grown for pulp over a 25-year rotation. This has a much higher sequestration rate over the full rotation, but only reaches 13 t CO_2/ha by the age three harvest at which point an ETS harvest return would be required. The lookup tables assume that all of this biomass decays over ten years as post-harvest residues, so decay from accumulating harvest residues means that the estimated stock would not exceed 30 t CO_2/ha/year. The estimated sequestration rate is therefore likely to be well below actual sequestration.

In summary, the direct greenhouse gas mitigation benefits and ETS financial returns from coppice stands on very short rotations do not appear to be high (unless the carbon price is much higher than today). Without these GHG co-benefits it may be better to grow an annual non-forest crop for nitrogen uptake.

4.3.3 Space-planted poplars

Historically, poplars and willows have been widely planted in New Zealand. The use of poplars as a soil management tool accelerated in the 1950s in recognition of extensive soil loss through erosion. The popularity of poplars with farmers is due to a number of factors:

- ability to maintain pasture productivity - grass grows right up to the trunk, deciduous trees don't shade pasture in winter;
- erosion control due to extensive, strong root systems;
- dry out wet soil;
- provide shade in summer and wind shelter for stock, pasture, crops;
- foliage can be used as stock fodder;
- cheap to establish (poles and wands);
- limited time that stock must be excluded after planting;
- can be cheap to re-establish (coppice);
- amenity autumn colours;
- timber can be produced in short rotations (20-25 years);
- Potential credits from carbon sequestration.

However, they do present some issues. Large trees can become dangerous as brittle branches fall in high winds, damaging buildings and blocking roads and tracks. It is therefore recommended that they be felled from age 20-30.

Planting density is a compromise. For erosion control, timber production and carbon sequestration, a high planting density is preferable. However, maintenance of high pasture productivity requires a low planting density. The Bay of Plenty Regional Council recommends 200 stems/ha for timber production, 100 stems/ha for agroforestry and 25-40 stems/ha for erosion control. A planting density of 400 stems/ha has been recommended for timber production in Northland.

The New Zealand experience with radiata pine agroforestry shows the difficulty in reaching a suitable compromise. At low stockings, pasture growth is maximised but the trees are short, with heavy branching, low wood density and a tendency to lose tops in strong winds. At higher stockings pasture is quickly suppressed (Hawke, 2011). The best combination of forestry and pasture appears to be pasture with shade and shelter trees, with a separate woodlot. Similarly, the best solution for severely eroding land is permanent forest cover.

Quantifying N, P and sediment benefits of riparian forests

Franklin et al. (2016) reviewed the potential for poplar and willow silvopastoral systems to mitigate nitrate leaching from intensive agriculture in New Zealand. However, the benefits came from short rotation coppice regimes regularly harvested for bioenergy, as discussed in the previous section. Space-planted poplars or willows would have little impact on nutrient discharge from groundwater.

The main purpose of space planted poplars on New Zealand farms is to prevent erosion, and therefore reduce losses of sediment and particulate phosphorus. They also reduce run off through rainfall interception. Erosion can cause nutrient losses through leaching, overland flow, microbial oxidation and in sediments discharged into waterways.

Many variations in spacing have been suggested. In general, the wide spacing that provides sufficient erosion control with mature trees will leave the land vulnerable to slippage in the first decade after planting. When trees are harvested and replanted the old root systems will continue to provide some protection while the new trees become established. Staggered replacement of trees maximises erosion control at the expense of the profitability of harvesting.

McIvor (2015) recommends a spacing of 12-15 m on slopes, with closer spacing where the slope is unstable. About 30-50 mature stems/ha (18-14 m spacing) was considered necessary for water management, topsoil retention and slope protection over erosion-prone land, while enabling 87-92% of pasture production. The National Poplar and Willow Users Group (2007) state that planting at 15 m spacing (50 stems/ha) is usually considered to be the lowest density, and 8-10 m spacing (100-150 stems/ha) is more preferable.

A Ministry of Agriculture and Forestry workshop on poplar and willow planting on the East Coast reached a consensus on the spacing required to achieve erosion control for moderate earthflows and slumps: 10-12 m spacing after thinning or 70-100 stems/ha (MAF 2008). A closer spacing of 7 -10 m (100-200 stems/ha) was seen as necessary for severely slumping land. Evidence from field surveys also suggested that densities of more than 100 stems/ha were needed to achieve stability on severely eroding sites. In contrast, Douglas et al. (2009) reported that space planted trees at densities of 30-60 stems/ha (13-18 m spacing) reduced soil slippage at 65 sites by an average of 95%. It was suggested that trees under about 10 cm in dbh provide little or no benefit while for trees over 30 cm dbh, the benefit from 100 stems/ha is no greater than from 36 stems/ha.

Basher (2013) reviewed erosion processes and their control and noted many studies that suggest that the presence of tall, closed-canopy, woody vegetation typically leads to a 70–90% reduction in the amount of landsliding. Sedimentation rates were 50-90% less under forest than pasture in one study following Cyclone Bola. There is considerable spatial variability due to factors such as geology and slope. Basher (2013) also noted there was little quantitative work on the effectiveness of space-planted trees, particularly in a whole hillslope context. Several studies found that space-planted trees had performed poorly in practice due to poor establishment and maintenance.

Dymond et al. (2010) developed an erosion model that assumed that close-canopy trees reduced erosion by 90% over 20 years and space-planted trees reduce erosion by 70% over 15 years. They found no published studies where the effect of space-planted trees on sediment yield has been measured at a small catchment scale.

Quantifying GHG co-benefits

Space planted poplar trees rapidly sequester carbon due to their high growth rates, but the typically low stockings favoured in order to maintain pasture production would appear to limit their usefulness as a greenhouse gas mitigation tool. In addition, to qualify under the ETS there is a requirement for the potential to reach 30% canopy cover. Nevertheless, the ETS Land Classification Guide explicitly states that ""agroforestry plantings may qualify as forest land, as may both space- or close-planted poplars and willows used for erosion control on grazing land." The Guide to Mapping Forest Land for the ETS provides further details on delineating areas of agroforestry or erosion control plantings as forest land.
The potential of space planted poplars to reach 30% canopy cover depends on the cultivar and planting density. Implied mean tree canopy diameters and areas are shown in Figure 4.4. Canopy diameters of over ten metres have been reported for mature poplar trees.

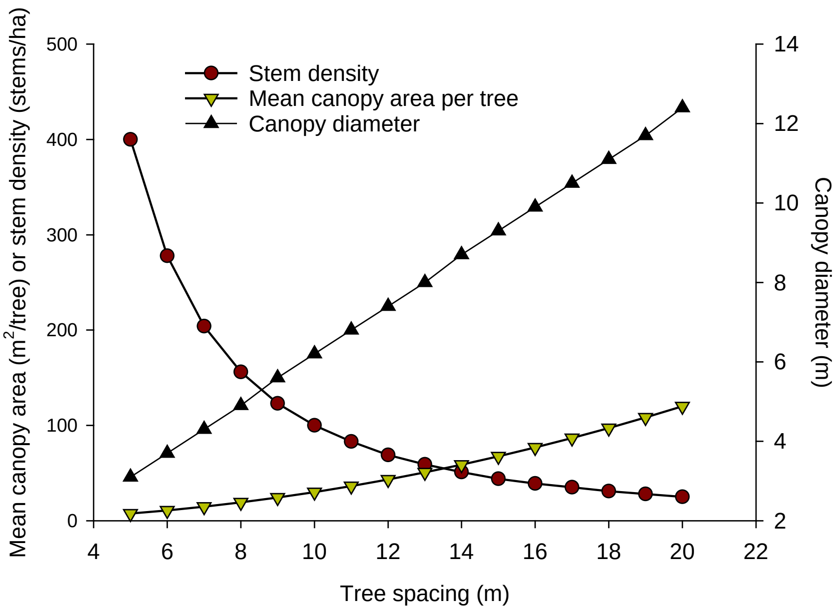


Figure 4.4: Required tree canopy dimensions at different spacings for forest to reach 30% canopy cover threshold.

Garth Eyles, a Trustee of the New Zealand Poplar and Willow Research Trust, reported that 30% canopy cover could be achieved by age 12 in Kawa poplars at 19 m spacing (39 stems/ha). Keeping canopy cover below 30-40% is also required to keep pasture production to at least 75% of open pasture (Wall, 2006).

Few estimates of carbon stocks have been reported for widely-spaced poplars. The total carbon pool measured in a mature poplar-pasture system (55.5 t/ha) was 26% higher than in an open pasture system without trees (44.0 t/ha), with the extra carbon residing in poplar biomass (Guevara-Escobar et al. 2002). Poplar biomass contained 18.1 t C/ha in total (although the net increase over pasture was only 11.5 t/ha1, due to the loss of pasture). The sequestration rate in the trees over 30 years (37 stems per ha, or 16 m spacing) was 2.3 t CO_2/ha/year. The net sequestration rate (taking into account lower stocks in the carbon pool) was 1.8 t CO_2/ha/year. These are mean rates to maturity without accounting for emissions from harvesting.

Planted at 16 m spacing may eventually achieve 30% canopy cover but would leave the land vulnerable to slippage for many years and would achieve little carbon sequestration. A grower with less than 100 ha would nevertheless be entitled to use the MPI Lookup table for Hardwoods. This table is based on Eucalyptus nitens grown on a 25-year pulpwood regime and offers a mean sequestration rate before harvest that is ten times higher: 26.3 t CO_2/ha/year to age 20 (or 13.2 t CO_2/ha/year if half the sequestration is claimed).

Financial return as a timber species

Poplar was one of the species assessed by the NZ Forest Service for use as a timber species. There are extensive plantations in China and India and it is also widely grown in Italy and France. While it is fast growing and readily established, it has not been widely grown as a plantation species in New Zealand. It competes directly with radiata pine being a light-coloured, general purpose timber but has lower wood density than radiata pine and is not as strong, being brittle when grown on exposed sites. More attention has been paid to species that can occupy site or market niches where radiata pine cannot compete. Currently markets in New Zealand are limited, but logs have been shipped to China. Poplars may still have potential on the basis of shorter rotations and greater public acceptance of the forest appearance, but this is likely to be as a close-grown plantations.

Widely-spaced trees on slopes may cost as much to harvest as the revenue from log sales, because yields per hectare would be low and harvesting on steep, erodible slopes is expensive (and sometimes inappropriate). The high cost of building a road to harvest steep sites can only be justified if sufficient volume is available. The Hawkes Bay Regional Council suggested that poplar plantations on suitable sites will yield 200-250 m3 of sawlogs per hectare at 15 to 18 years of age at a final spacing of 100 stems/ha.

An NPV and annuity have not been calculated for space-planted poplars because the yields, log prices and harvesting costs at low planting densities are too uncertain. Dominati and MacKay (2013) estimated an annuity of $104 from timber production of poplars at 50 stems/ha, but this was based on a discount rate of 3%. At 8% the NPV would be negative. The MPI Lookup table for exotic hardwoods can be used to estimate the carbon annuity. Note that this limits the use of space-planted poplars to less than 100 ha – otherwise the field measurement approach must be used to estimate actual carbon sequestered, which is likely to be much lower.

4.4 Summary

Tables 4.4-4.6 provide the ETS sequestration values that can be used for riparian forests, woodlots and space-planted poplars on North Island sheep and beef farms, as well as modelled values for radiata pine in riparian forests and woodlots. Table Interpretation:

Farm type: r = rolling; e = easy hill; s = steep hill; f = flat.

Actual to age 28: These are sequestration estimates for radiata pine modelled in the Forest Investment Framework (FIF). Values are up to the year of harvest at age 28, so they do not take into account the obligation to surrender units at harvest. Values shown are the area-weighted mean for the farm type, and the means of the worst 20% of farm area and the best 20%, to indicate the range of growing conditions.

Claim half credits: This assumes that only half the credits are claimed over the rotation with no further emissions or liabilities after that point – i.e. it is assumed that the long term average stock of repeated rotations is about half the age 28 stock. The mean for all area within the farm type was used.

C annuity: This is the NPV of the net revenues from carbon trading calculated by FIF, after conversion to an annuity. FIF bases the NPV on a fixed annual administration fee while claiming half of the credits as above. Values are given for three carbon prices and the discount rate used was 8%.

Timber annuity: This is the NPV of the net revenues from forest management and harvesting calculated by FIF, after conversion to an annuity. It excludes carbon net revenues and assumes a discount rate of 8%. Values are given for the area-weighted mean of all area within the farm type, and also the mean of the worst performing 20% by area.
Total forest annuity: This is the sum of the mean carbon and timber annuities, assuming a carbon price of $15.

ETS Lookup – Indigenous: The sequestration rate is the mean over 50 years from the national MPI ETS Lookup Table for indigenous forest. The annuity value assumes a carbon price of $15, a discount rate of 8% and an annual fee of $60 to cover ETS registration and administration fees. The mean sequestration rate over 28 years is slightly higher 8.7 t CO_2/ha/year because the rate declines over time. It is 1.1 t CO_2/ha/year by age 50.

ETS Lookup – Radiata: The sequestration rates are from the regional MPI ETS Lookup Tables for radiata pine. Both the full rate ignoring harvest and the “claim half” rate are given. The annuity value is over 28 years and is based on claiming half the credits. It assumes a carbon price of $15, a discount rate of 8% and $60 annual ETS administration fees, but does not include any other costs of revenues.

Table 4.4. North Island S&B Farms: Estimated sequestration rates (t CO_2/ha/year), and carbon and timber annuities ($/ha/year)

Farm ID	C sequestration estimates				C Annuity			Annuity			ETS Lookup		ETS Lookup		
	Actual to age 28			Half credits	C price			Timber		Total forest	Indigenous		- Radiata pine		
	Mean	Worst 20%	Best 20%	Mean	$15	$25	$50	Mean	Worst 20%	Mean[1]	Mean seq	C annuity	Mean seq	Claim half	C annuity
Wai SB1r	45	41	49	22.3	297	538	1142	317	198	614	6.5	42	27.0	13.5	154
Wai SB1s	46	41	53	23.2	312	563	1191	294	154	605	6.5	42	27.0	13.5	154
Wai SB2s	46	42	52	23.0	308	556	1177	293	157	600	6.5	42	27.0	13.5	154
BoP SB1s	44	33	51	22.1	293	532	1128	297	174	590	6.5	42	25.1	12.6	139
Man SB1e	43	38	45	21.7	286	520	1105	371	293	657	6.5	42	28.5	14.2	166
Man SB1s	44	41	48	22.1	293	532	1129	312	157	606	6.5	42	28.5	14.2	166
ManSB2r	47	41	54	23.5	315	569	1202	422	165	738	6.5	42	28.5	14.2	166
ManSB2e	41	39	43	20.5	268	490	1044	336	252	604	6.5	42	28.5	14.2	166
ManSB2s	44	40	48	21.9	290	527	1119	312	160	603	6.5	42	28.5	14.2	166
Gis SB1s	46	45	49	22.9	307	555	1174	278	99	585	6.5	42	28.8	14.4	169

[1] Assumed price of carbon = $15

Table 4.5. South Island S&B Farms: Estimated sequestration rates (t CO_2/ha/year), and carbon and timber annuities ($/ha/year)

Farm ID	C sequestration estimates				C Annuity			Annuity			ETS Lookup		ETS Lookup		
	Actual to age 28			Half credits	C price			Timber		Total forest	Indigenous		- Radiata pine		
	Mean	Worst 20%	Best 20%	Mean	$15	$25	$50	Mean	Worst 20%	Mean[1]	Mean seq	C annuity	Mean seq	Claim half	C annuity
Can SB1e	28	23	31	13.8	159	309	683	75	2	75	6.5	42	18.4	9.2	84
Can SB1s	31	23	39	15.4	185	352	769	94	-6	94	6.5	42	18.4	9.2	84
Can SB2f	35	31	40	17.7	222	414	892	271	179	271	6.5	42	18.4	9.2	84
Can SB2r	32	26	38	15.9	193	364	793	216	103	216	6.5	42	18.4	9.2	84
Can SB2e	27	21	31	13.7	157	306	676	114	-14	114	6.5	42	18.4	9.2	84
Sou SB1f	41	37	45	20.4	266	486	1037	369	282	369	6.5	42	24.9	12.5	137
Sou SB1r	38	29	43	18.8	239	442	949	262	117	262	6.5	42	24.9	12.5	137
Sou SB2f	38	34	41	18.9	242	447	958	297	247	297	6.5	42	24.9	12.5	137
Sou SB2r	38	32	42	18.9	241	445	956	237	137	237	6.5	42	24.9	12.5	137

[1] Assumed price of carbon = $15

Table 4.6. Dairy Farms: Estimated sequestration rates (t CO_2/ha/year), and carbon and timber annuities ($/ha/year)

Farm ID	C sequestration estimates				C Annuity			Annuity			ETS Lookup		ETS Lookup		
	Actual to age 28			Half credits	C price			Timber		Total forest	Indigenous		- Radiata pine		
	Mean	Worst 20%	Best 20%	Mean	$15	$25	$50	Mean	Worst 20%	Mean[1]	Mean seq	C annuity	Mean seq	Claim half	C annuity
Waikato	46	40	54	22.8	304	601	1092	341	167	644	6.5	42	27.0	13.5	154
BoP	48	41	53	23.8	320	631	1144	366	267	686	6.5	42	25.1	12.6	139
Southland	39	34	43	19.5	251	462	989	324	224	575	6.5	42	24.9	12.5	137

[1] Assumed price of carbon = $15

4.5 Conclusions: Implications for farm/catchment assessment of co-benefits

Modelled growth rates for radiata pine on pastoral land are much greater than the default rates assumed in the ETS lookup tables, even if only the least productive 20% of land is allocated to forestry. High sequestration rates can be maintained in radiata pine for at least 50 years but will not be sustained indefinitely, regardless of whether the forest is harvested or not. Greenhouse gas benefits from carbon sequestration by trees will only offset ongoing farm emissions for a finite period. There will still be a benefit due to lower emissions from forestry land compared with the land use displaced. This also applies to losses of N, P and sediment.

Large-scale afforestation is not possible as a mitigation option in this project given the requirement to maintain existing farm production. It may still be possible to maintain farm profitability with a greater area of afforestation on many sheep and beef farms, assuming the investment can be financed. However, the annuity value from timber and carbon is unlikely to compete with dairy returns. Afforestation as a mitigation option on dairy farms (including riparian planting that meets the forest definition) could still play a role. Monge et al. (2016) carried out a stochastic economic assessment of land use in the Waikato catchment. They found that while dairy farming generated the highest returns, if payments for nitrogen and carbon were included together with a consideration of commodity price volatility, farmers could adopt forestry as part of a portfolio depending on their level of risk aversion.

5. Agricultural sector analysis - approach

The overall approach was, wherever possible, to generate 'abatement curves' by sequentially stacking mitigations to understand the interaction of N/P losses and GHG emissions for the pastoral sector. The complexity and variation in cropping rotations meant that the abatement curve approach had to be modified because not all mitigations could be applied to all rotations, nor at multiple points in a single rotation.

Modelling was based on the enterprises identified in conjunction with Regional Councils (Section 3.1), as listed in Appendix IV. This approach also allowed us to look at the range of mitigations required to reach a range of water quality targets given that targets and policy are still developing. Modelling was undertaken using OVERSEER version 6.2.1 (April 2016). Initial analysis was undertaken with the previous version but numbers changed slightly between versions so the analyses were rerun. The assumptions around each mitigation for each sector are detailed below.

5.1 Dairy

Based on the approaches described in Section 3.2, a final list of candidate measures was constructed, and placed in an order starting with low/nil cost and easy to implement through to infrastructure and system changes. Table 5.1 summarises this sequence of additive mitigations that were applied to the range of dairy farms. Not all were applicable to all farms.

A key assumption was the aim to maintain production levels. It was assumed that most of the mitigation options would have no impact on production, with the remaining few having a relatively minor impact on production. We borrowed heavily from the experiences in the Pastoral 21 (P21) programme, which has shown that it is feasible to decrease N (and P) losses from dairy systems by as much as 40% while generally maintaining production.

Table 5.1: Mitigation scenarios and categories modelled for each of the Dairy farms ordered by our assessment of ease/cost of implementation.

Code	Mitigation	Category
M1	Optimum Olsen P	Efficiency gains
M2	Low solubility P fertiliser	Efficiency gains
M3	Increased effluent application area	Efficiency gains
M4	Reduce inputs of N fertiliser to winter forage crops coming out of long term pasture; and excessive N inputs to effluent blocks	Efficiency gains
M5	Strategic grazing of winter forage crops	Efficiency gains
M6	Better irrigation management	Additional infrastructure
M7	Deferred irrigation (pond storage)	Additional infrastructure
M8	Constructed/Facilitated wetland	N or C capture
M9	Decrease stocking rate to match lower N inputs (and increased per head performance)	Less N in the gate
M10	Change supplementary feed to Low N feed	Less N in the gate
M11	Restricted grazing (Tailored to region) - winter use	Additional infrastructure
M12	Restricted grazing (Tailored to region) - winter and autumn use	Additional infrastructure
M13	Grass buffer strips	N or C capture
M14	Fenced riparian corridors	N or C capture
M15	System 5 intensification	Additional infrastructure

5.1.1 Assumptions used to model each mitigation scenario

Efficiency gain measures

A selection of relatively simple and low cost mitigation measures were modelled using the following assumptions:

- **M1:** Olsen P levels would reduce from a starting value of 40 mg L-1 to a biological optimum level of 33 mg L-1. Maintenance fertiliser P inputs were adjusted to match the associated lower soil Olsen P level, reducing in most cases from 40 to 35 kg P/ha/year.
- **M2:** A lower solubility form of fertiliser P (RPR) would be applied to soils that have a modest or high risk of surface runoff (poorly-drained and/or sloping soils).
- **M3:** Because effluent is a particularly rich source of N and potassium (K), it makes good economic sense to ensure that inputs of these effluent nutrients are matched to provide the agronomic requirements of pastures on the effluent-treated parts of the farm. The area of each farm receiving effluent was therefore increased so that effluent supplied the equivalent of 75 kg K/ha/year.
- **M4:** This scenario reduced the inputs of fertiliser N to farm blocks that were deemed to have unnecessarily high inputs of N in total (combined inputs from fertiliser, supplement and effluent sources):
  - For crop blocks, fertiliser N inputs were reduced from 130 to 100 kg N/ha/year.
  - For all farm blocks, N fertilisation was reduced to ensure that combined N inputs did not exceed 200 kg N/ha/year (or, in the case of the more intensive Canterbury D2 farm, did not exceed 250 kg/ha/year).
- **M5:** This scenario was applied to forage crop blocks that were grazed during winter and assumed that strategic grazing methods to protect critical source areas (such as gullies and swales) were implemented to reduce sediment and P losses by 80% (as per Telford P21 research findings). This scenario was not applied to the North Island dairy farms (Waikato and Bay of Plenty farms) because there was no winter crop.

Additional infrastructure

The mitigation measures requiring the purchase of additional infrastructure were:

- **M6:** Based on some earlier assessments for a “typical” (i.e. composite) Canterbury dairy farm practising water irrigation, it was assumed that investment was made to change from boom irrigation (50% of milking platform) to pivot irrigation. Modelled drainage outputs were reduced from 286 mm per annum (boom) to 205 mm (pivot) and had the consequence of reducing estimates of N leaching losses. North Island dairy farms were not irrigated.
- **M7:** To capture a scenario where farm dairy effluent (FDE) was managed under a deferred irrigation scenario, effluent management descriptors in the OVERSEER model were changed from "spray regularly" to "spray infrequently"; the effluent tabs on effluent blocks were also modified to apply only in low risk months (Nov-Apr inclusive; low rate and active management were also assumed). Not modelled for flat, free-draining land where risk of incidental losses of FDE are low.
- **M11:** A covered winter pad was used to winter cows off-paddock during June and July; the animals were no longer grazed on swede paddocks but the land was instead used for growing pasture and harvesting baleage/silage, and carrying young stock. The nutrients removed from these paddocks as silage fed on the winter pad were replaced with nutrients from solid effluent applications. The area of land receiving effluent was increased to account for the additional N and K generated in liquid effluent derived from the winter pad.

- **M12:** This scenario extended the M11 scenario by utilising the pad for 12 hours per day (overnight) during the months of March to May as a strategy for reducing urinary N returns to pasture during autumn; fertiliser N inputs to effluent blocks were reduced accordingly.
- **M15:** This scenario describes the system-level changes that might be expected if the Southland D2 farm was further intensified to become a system 5 farm where c. 30% of the diet was sourced from imported feeds (PKE and pasture silage mainly). As per case study observations, cow numbers and per cow milksolids production were increased by 6 and 17%, respectively. The use of the wintering pad was also extended to reflect the increased time cows spent off-paddock to take in the large amount of supplement offered.

Less N in the gate

- **M9:** This scenario focussed on reducing the amounts of N fertiliser used on the farms:
- Fertiliser N use on milking platforms reduced by c. 40% (typically from c. 140 to 80 kg N/ha/year).
    - Only 40 kg N/ha/year of fertiliser used on effluent blocks (nil for Sou_D2).
    - The amount of N fertiliser applied varied slightly between regions and systems with the re-sizing of the effluent block following the K rule mentioned for M3 above (≤75 kg K/ha/year) and the assumption of similar pasture production across blocks of land.
    - Adjustments made to reduce peak cow numbers and slightly increase per cow production to account for reduced total feed availability, consistent with some of the principles identified in the P21 research programme.
- **M10:** Imported high-N feeds replaced with locally-relevant low(er)-N feeds.

N or C capture

- **M8:** Wetlands were assumed to intercept 75% of farm area drainage; 2% of catchment area dedicated to wetland installation. Not modelled for flat, free-draining land.
- **M13:** 10-m wide buffer strip initially assumed, with a total stream length based on 30 m per ha; catchment = whole block but didn't seem to change losses. Scenario removed for Southland and Canterbury farms due to minimal effectiveness (little overland flow for Canterbury farms, and buffer strips bypassed due to mole-pipe presence assumed for Southland dairy farms).
- **M14:** Whilst riparian tree plantings are unlikely to comply with ETS criteria, a generic scenario was constructed to consider the carbon off-sets that could be possible. Assumptions made were:
    - the water quality benefits of riparian tree corridors are most likely to manifest as improved habitat conditions such as stream bank stabilisation, shading to reduce temperature fluctuations, etc. For the reasons documented for scenario M13 (above), N and P removal rates were assumed to be nil.
    - the areas to be taken out of pasture production were assumed to be at least 15 m wide (For ETS qualification, they in fact would need to be 30 m wide): assuming a stream density of 25 m/ha, a 15 m corridor (one side of stream) would remove 3.75% of productive area, or 0.0375 tree hectares per total farm hectares.
    - A C removal rate of 6.5 t CO_2-e/ha/year was assumed for indigenous forest riparian plantings.
        - C removal = 0.0375 ha/ha * 6.5 t CO_2-e/ha/year = 0.244 t CO_2-e/ha/year.

5.2 Sheep and Beef

The future possible changes in the sheep and beef sector that will most influence emissions to water and to air are likely to be achieved by via a two-fold strategy. Firstly, by addressing soil erosion and the associated emissions of sediment and P through ecological and built infrastructure. Secondly, by the ongoing drive to increase meat and fibre production through improvements in sheep genetics, the performance of high fecund ewes, high growth rates in young stock, changes in cattle policy away from breeding cows to dairy beef and environmental management beyond direct mitigation of emissions to air and water (e.g. shade and shelter). The former brings land use change and the latter eco-efficiency benefits. Based on the approaches described in Section 3.2, a list of mitigation and future possible enterprise, performance and practice change on sheep and beef farm systems were constructed, and placed in an order reflecting the likely chronological order they would be implemented are listed in Table 5.2.

Table 5.2: Mitigation and future possible enterprise, performance and practice change on sheep & beef farm systems.

Code	Mitigation and changes in land use practice and to the farm system	Category
SBM0	Base farm assumes 100% pastoral	
SBM1	Effective pastoral base	
SBM2	Low solubility P fertiliser, reduce N inputs	Efficiency gains
SBM3	Increased soil conservation plantings	Reduce soil erosion
SBM4	Lift reproductive performance of ewes	Efficiency gains
SBM5	Change in cattle policy	Efficiency gains
SBM6	Change in enterprise mix and soil conservation plantings	Reduce soil erosion
SBM7	Lifts in animal performance	Efficiency gains
SBM8	Riparian plantings and wetland protection	Less sediment and P
SBM9	Fencing of the balance of waterways (to exclude cattle)	Less sediment and P
SBM10	Conservation trees for erosion and for creating a kinder environment	Additional infrastructure
SBM11	Improvements in animal performance	Efficiency gains
SBM12	Restricted grazing	Less sediment and P
SBM13	Restricted grazing and standoff pad	Additional infrastructure
SBM14	Fenced riparian corridors	Sediment and P capture
SBM15	Combination of 13 and 14	
SBM16	Impact of spaced tress on water balance	Reduce sediment and P losses in
SBM17	Combination of 14 and 16	run-off

5.2.1 Assumptions used to model each mitigation and future enterprise, performance and practice change on sheep and beef farm systems.

The majority of the likely future changes in the sheep and beef sector that will influence emission to water and also to air will be determined by the sector's drive to increase meat and fibre production and ongoing response to environmental challenges, which includes soil erosion and sediment loss. The following step-wise approach was taken, with each step building on the previous change.

- **SBMO** - The base data for the sheep and beef enterprises from the six regions used in the study were sourced from the Beef and Lamb NZ economic service farm survey 2014. http://www.beeflambnz.com/information/on-farm-data-and-industry-production/
- **SBM1** - For this study we assumed as a base line for modelling that of total farms hectares, 85% was in pasture (10% in regenerating bush, and 5% in pines). Spaced tree plantings occupied 30% of the area and the wide-spaced planted conservation

trees (poplar and willows) were at a planting density of 10 m by 10 m (100 stems/ha). Compared with open pasture, annual pasture production under the spaced trees was reduced to 89% of the open pasture.

- **SBM2** - A phosphorus fertiliser with lower water solubility (e.g. Di-calcium phosphate with a low water solubility, but high citric acid solubility, or a reactive phosphate rock (RPR) with a low water and moderate citric acid solubility) would be applied to soils with low P sorption capacity or on moderate or steep slopes with a high risk of surface runoff. Shift from the use of nitrogen fertiliser to increase the base pasture growth rates on the farm to an option where N fertiliser is used only when a feed shortage is predicted. This will reduce the use of fertiliser N to a third of current use and in so doing reduce the risk of N loss directly from the fertiliser and indirectly from urine patches from the increased animal production The reduction in N fertiliser use was reflected in a decrease in stocking rate equivalent to stock units (SU) carried = Current total SU - ((reduction in N x 10 kg DM)/550 kg DM). This is based on the assumption that 1 kg N will grow 10 kg dry matter (DM) and that one SU consumes 550 kg DM per annum.
- **SBM3** - Increase the amount of the poorest steep land planted in pines from 5 to 10% and also increase the area of the steep land in spaced planted conservation trees from 5 to 10% to reduce the risk of soil erosion, and protect infrastructure and receiving water bodies.
- **SBM4** - Sheep reproductive performance is lifted by 20%, through a combination of improved genetics, feeding and husbandry. Beef cow performance is held at 94% calving. An increase of this magnitude is well within current industry practice (http://portal.beeflambnz.com/tools/lambs/ August 2016).
- **SBM5** - Change to the cattle policy with a shift from breeding cows and the sale of rising one year olds and rising 2 year old cattle to the buying of weaners that are finished within 12 months, has become a common practice in some parts of the country only. This reduces the live weight loadings on hill soils during winter months.
- **SBM6** - A conscious change in enterprise to extend the pine blocks on the farm to cover 20% of the most erosion prone and poorest producing steep land. Increase the area of the steep land in spaced planted conservation trees from 10 to 20%. The spaced tree plantings on the steep land occupy 30% of the area at a planting density of 10m by 10m (100 stem/ha). Spaced planted conservation trees are introduced to 20% of the easy hill as a strategy to improve the living environment for livestock, while reducing the risk of erosion. The spaced tree plantings on the easy hill occupy 20% of the area at a planting density of 15m by 15m (44 stems/ha). Compared with open pasture, annual pasture production under the spaced trees on easy hill is reduced to 89% of the open pasture.
- **SBM7** - There is a further lift in the sheep flocks reproductive performance (30% above base), through the introduction of hogget lambing and ongoing improvements in the genetic merit, feeding and husbandry of the livestock. The improved feeding and husbandry has increased birth and weaning weights of lambs.
- **SBM8** - Major primary and secondary stream networks on the farm are fenced and the reticulated water systems have been extended. The riparian area amounts to 0.25% of the farm land area (up to 25 ha). The impact of the riparian margin is limited to the reduced grazing area. A wetland representing 0.03% of the farm land area (3 ha) has been fenced and protected from livestock
- **SB M9** - All streams are fenced to exclude cattle. In places on the farm this is limited to a single wire.
- **SB M10** - The area of the steep land in spaced planted conservation trees is increased from 20 to 40%. Similarly, the area of the easy hill in spaced planted conservation

trees is increased from 20 to 40% to provide a shelter and shade for the high performance animals at the critical times of late winter, early spring and summer.

- **SB M11** - Further livestock improvements with the reproductive performance of the ewe flock up by 40% from base sheep (155% docking) and higher lamb growth rates. An increase of this magnitude would at the limit of current industry practice (http://portal.beeflambnz.com/tools/lambs/ August 2016). All cattle are sold prime. The increase in the weaning weight of lambs is 50% of the rate of increase in lambing percentage (e.g. lambing up by 20%; weaning weight by 10%). The increase in lamb live weight gain was calculated on same basis as weaning weights.

Mitigations for sheep and beef operations in specific regions. These are not cumulative unless otherwise stated

- **SB M12** - To reduce the losses of sediment and P from mob stocking the grazing of the winter crop is limited to 8 hours on a 24 hour cycle.
- **SB M13** - This is an addition to SB M12 with the animals held on a stand-off pad, basic uncovered organic matter pad for the 16 hours the animals are not on the winter crop. This stand-off practice would be used from the 15th May till 15th September.
- **SB M14** - Influence of the riparian margin on the amount of sediment, P, E coli and N removed from water before entering the water course.
- **SB M15** - This is a combination of two mitigations: limiting the amount of time livestock are on a winter crop each day (SB M12) and the characteristics of the riparian margin (SB M14).
- **SB M16** - In addition to the impact the space tree has on pasture growth, due to competition for light, water and nutrients, accounts for the impact the space trees has on the water balance as it influences evapotranspiration rates (base X 1.18) and effective rainfall (base X 0.95) compared to open pasture (Guevara-Escobar et al. 1998).
- **SB M17** - This a combination of the effectiveness of different riparian margins (SB M14) and inclusion of the impact of space planted trees has on water balance (SB M16)

General comments

The input of P fertiliser was sustained by reallocating the P applied to areas planted in pines to the balance of the pastoral farm. Olsen P values on the areas remaining in pasture increase by the same % as area retired to pines.
Pasture production on the first 10% of the steep land planted in pines only produced half of the average amount of forage of the steep land area. Pasture production on the second 10% of the steep land planted in pines produced 70% of the average amount of forage of the steep land area. Riparian plantings were pro rata across the steep land and easy hill. Wetlands are on the easy hill block, and have a catchment area 20 times the area of the wetland.

Carbon stocks

The amount of carbon sequestered in regenerating native scrub and forestry, spaced planted conservation trees (Poplar and willow), Radiata pine plantations, riparian and wetlands was estimated using carbon sequestration rate (t CO_2/ha/yr) for each region in New Zealand from the MPI Lookup Tables for indigenous and Radiata pine, with the following assumptions

- Radiata pine = Area in hectares by “half” the average carbon sequestration rate (t CO_2/ha/year) for each region.
- Space planted conservation trees on steep land =. Assume that 30% of the area in hectares has a space tree planted at a density of 100 stems/ha. Adjust the “half” the average carbon sequestration rate (t CO_2/ha/year) for pines each region by 100/350.

- Space planted conservation trees on hill land. Assume that 20% of the area has a space tree planted at a density of 44 stems/ha. Adjust the "half" the average carbon sequestration rate (t CO_2/ha/year) for pines in each region by 44/350.
- Regenerating native forestry and scrub = Area in hectares. Assume that the area has 75% canopy cover and average carbon sequestration rate (t CO_2/ha/year) for indigenous forestry in each region.
- Riparian and wetland areas. Area in hectares, assume canopy cover of 50% and average carbon sequestration rate (t CO_2/ha/year) for indigenous forestry in each region. **Notes**:
  - The calculation of the carbon stocks is just that: a quantification of the carbon. No attempt is made to determine compliance with domestic or international rules.
  - This is a conservative estimate given that the indigenous forest plantings would be eligible to use the full lookup value. As there is no harvest, we could have assumed the full lookup table value of 6.5 t CO_2/ha/year on average for 50 years. The ETS lookup table for exotic hardwoods can currently be used for space-planted poplars, with much greater assumed sequestration.

5.3 Arable

Following the detailed analysis of potential mitigation methods undertaken by the research team (Appendix IV), further discussions were held with the industry to refine these mitigation options. The options are listed in Appendix V and could be further grouped as summarised in Table 5.3. What has not been considered is the ongoing gains from the efficiencies (e.g. harvest index) captured by plant breeders in calculating future potential reductions.

The challenge was how to model some of these mitigations within OVERSEER as arable farming systems have complex rotations and event-specific activities with varying degrees of leaching risks. A problem was that many of the mitigation strategies around reducing N inputs by improving the temporal and spatial placement of fertilisers cannot be directly modelled in OVERSEER. The solution was to estimate by how much current typical fertiliser inputs could be decreased if these mitigations strategies were applied - without reducing yields. However, overall we struggled to find evidence in the literature for such rather arbitrary input. Therefore, we took an alternative approach to reduce fertiliser inputs in steps of 5% between 5 and 20% to evaluate the effects of these reductions on nutrient losses and greenhouse gas emissions. This alternative approach highlights the sensitivity of nutrient inputs on losses and emissions.

Table 5.3: Cropping mitigations grouped according to type.

Category	Mitigation description
Better fertiliser management	• Matching fertiliser applications to plant demand • Account for soil mineralisation during growth period and for nutrients retained by catch crops • Soil testing prior to fertiliser application • Split N fertiliser applications to match plant demand; fertigation to apply little amounts of fertiliser often • Improve placement of fertiliser (broadcast or knifing of fertiliser) • Improve selection of fertiliser material (controlled release fertilisers; CRFs) • Use precision cropping technologies for fertiliser application (GPS guidance); Calibration of fertiliser spreader
P strategies – managing Olsen P	• Manage soil P levels within acceptable productivity norms (e.g., maize 15-30 mg/L Olsen-P)
Residue management	• Improve residue management

Category	Mitigation description
Catch crops	• Plant 'catch' crops (CC) or double-sown crops and minimize fallow periods in rotations
Irrigation	• Better irrigation management: match irrigation supply with infiltration rates (will vary with soil type and condition)
Reduced cultivation	• Use reduced cultivation practices, such as minimum till or direct drill • Optimise timing of cultivation practices (early harvest, establishment of crops in autumn or late cultivation to shorten fallow period) • Wheel track ripping or furrow dyking

Residue management (retained, burnt, grazed or removed) should be explored as potential mitigation strategy to reduce nutrient losses. Residue management affects the soil's organic matter pool, N mineralization potential and thus, also the N availability for crops. During severe droughts cereal residues are often baled and fed to livestock; but more routinely cereal residues are retained and incorporated. The literature reveals contrasting results of residue incorporation on N losses (Thomsen and Christensen, 1998). Straw aside, it is practically difficult to change the management of green residues (e.g. vegetable trimmings) that are susceptible to mineralisation, other than by changing harvesting date or removing residues at harvest.

Catch crops can reduce nitrate leaching. However, a large variability in the effectiveness of catch crops was reported in the literature, and is very dependent on crop, soil and weather interactions. Teixeira et al. (2016) identified sowing time, weather and soil type as main drivers for the observed variability. Catch crops provide some scope (variability aside), but their use will be limited because many rotations already minimise bare soil and because of the challenges of establishing and growing catch crops in winter.

Finally, irrigation practices were optimized in the irrigated standard scenarios. Assuming that no further investments into the infrastructure are to be made, optimising irrigations decisions include soil moisture monitoring as well as adjusting the trigger point used for irrigation management decisions.

Simply, the complexity of crop rotations (See Appendix V) made it impossible to apply a single mitigation throughout the rotation and therefore made the abatement curve approach adopted for pastoral systems infeasible. Practically, mitigations listed in Table 5.3 would only be implemented at points in the rotation and not in all of the rotations that we constructed). Because of these challenges, the following strategy for modelling these systems was adopted:

1. Investigate sensitivity to irrigation management changes
2. Investigate sensitivity to N fertiliser inputs
3. Investigate systems effects from combined mitigations where they were feasible within a rotation. Mitigations could not be applied to all of our model rotations. Where they could they focused on N fertiliser management, catch crops and reduced cultivation.

6. Agricultural sector analysis - results

6.1 Dairy

Baseline GHG emissions for the 8 farms studied ranged from 9400 to 15600 kg CO_2-e/ha (Figure 6.1). With the exception of the Southland S4 farm, methane made up c. 66% of total emissions, nitrous oxide c. 21% and carbon dioxide c. 12%. OVERSEER estimated that the more intensive of the two Southland systems would generate 45% of total emissions from N_2O; the same contribution as methane.

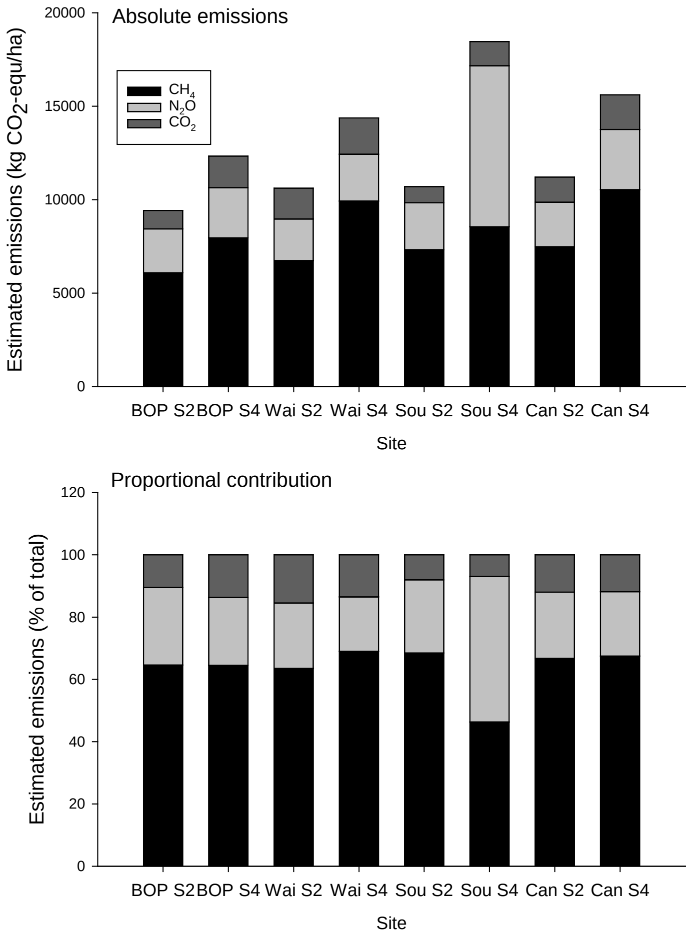


Figure 6.1: OVERSEER estimates of GHG emissions from the 8 dairy systems that were modelled (baseline losses).

Figures 6.2 and 6.3 show abatement curves for two contrasting sites when mitigations were progressively implemented. Appendix VI has graphs for all sites, which show that trends were similar at all of the sites.

The feature of both of these sites in Figures 6.2 and 6.3 is the generally flat response in terms of GHG emissions compared with the large reductions in N leaching achieved at both sites. Large reductions in P loss were also achieved by the implemented mitigations at the Southland site; this soil-type and environment are conducive to large losses of P and sediment. Baseline P loss estimates were 1-2 kg P/ha, compared with 0.5 kg P/ha on the flatter more free draining Waikato model farm. As a result, small changes in P loss estimates as mitigations were added in the Waikato had a large effect on the % change, hence the apparent large effects on losses in Figure 6.3.

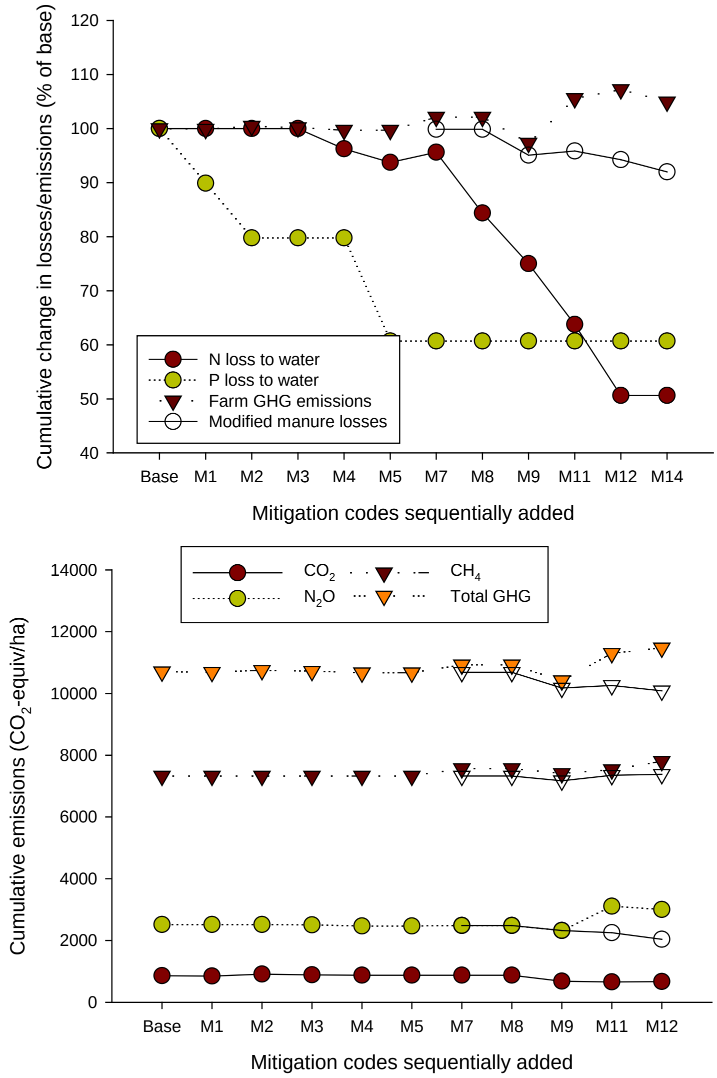


Figure 6.2: Abatement curves for the Southland Dairy farm (System 2). The top graph shows the cumulative change in N and P losses from the root zone or GHG emissions as mitigations are progressively added; the lower graph shows the absolute amounts. The open symbols refer to estimates when assuming that manure collection and storage does not increase the GHG emissions from animal excreta (compared with the same amount of excreta deposited onto pasture during grazing). Mitigation M10 is omitted because it was not relevant to this farm.

Both Figures 6.2 and 6.3 show apparent increased GHG losses when restricted grazing (by seasonal housing) was introduced into the mitigation list. This was due mainly to OVERSEER estimating greater N_2O emissions from the extra effluent/manure captured periods of housing. This was consistent across all sites and is discussed further below.

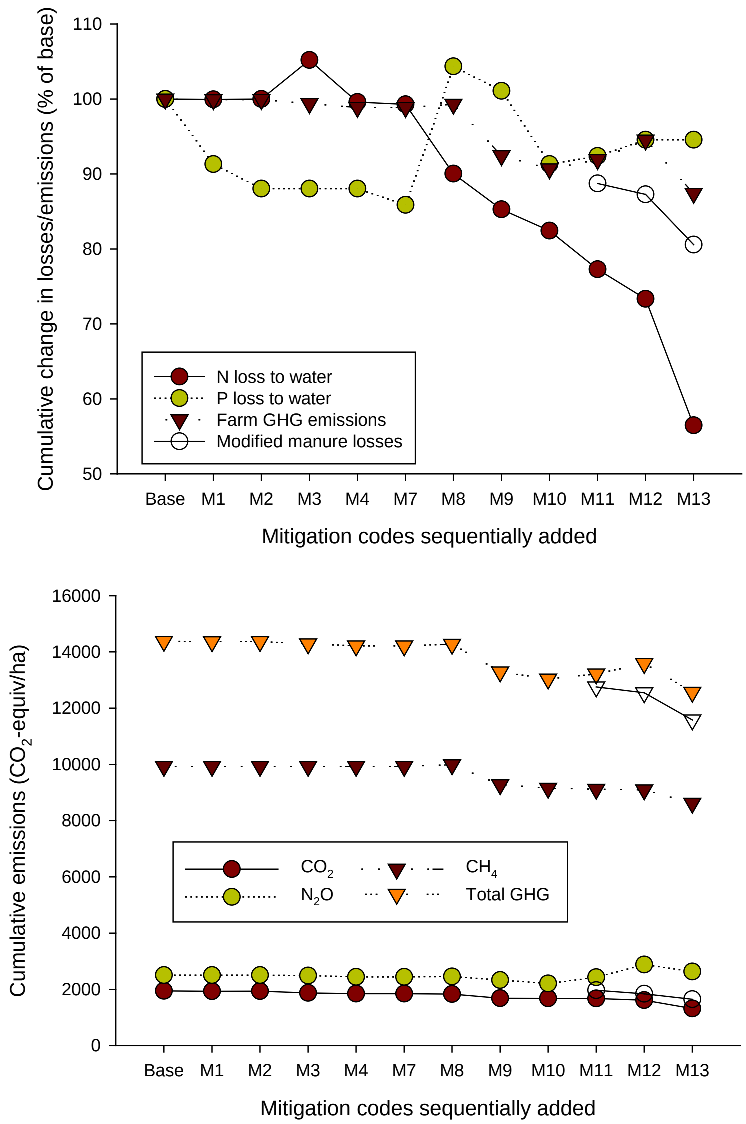


Figure 6.3: Abatement curves for the Waikato Dairy farm (System 4). The top graph shows the cumulative change in N and P losses from the root zone or GHG emissions as mitigations are progressively added; the lower graph shows the absolute amounts. The open symbols refer to estimates when assuming that manure collection and storage does not increase the GHG emissions from animal excreta (compared with the same amount of excreta deposited onto pasture during grazing).

Table 6.1 summarises the range of combined mitigations to achieve target N leaching reductions of 5-40%, in line with the potential reductions identified in some catchments by some Regional Councils (Table 3.1). Reasonably consistent trends can be seen in Table 6.1. A 5% reduction in estimated N leaching was achieved generally by implementing options up to M4-M6, which are low cost options based around better management of fertiliser and effluent sources (and better management of winter crop grazing in Southland). A 10% leaching reduction was obtained by implementing extra mitigations up to about M7/M8. M8 is the wetland option. A 20% reduction required implementation of at least up to mitigation M9, which was the reduced N input and decreased stocking rate scenario to make better use of the pasture that was grown. Again, this is a low cost option. Achieving a 40% decrease required infrastructure changes with restricted grazing (housing) during winter months (M11), or during the autumn and winter (M12). Buffer strips were also required on some farms to meet this target.

Table 6.1: Summary of mitigations required to achieve the target N leaching reductions and the estimated reductions in associated GHG emissions and P losses. Grey highlighted cells marks the range of modelled values depending on how emissions from effluent are accounted for (see text for details).

		Target reduction in N leaching			
		c. 5%	c. 10%	c. 20%	c. 40%
Mitigation level required to achieve target					
System 2	Wai	M1-M4	M1-M8	M1-M9	M1-M12
	BoP	M1-M4	M1-M8	M1-M9	M1-M12
	Sou	M1-M5	M1-M8	M1-M9	M1-M11
	Can	M1-M6	M1-M6	M1-M9	M1-M11
System 4	Wai	M1-M8	M1-M8	M1-M10	M1-M13
	BoP	M1-M4	M1-M7	M1-M8	M1-M13
	Sou	M1-M4	M1-M7	M1-M8	M1-M11
	Can	M1-M3	M1-M4	M1-M9	M1-M11
Associated reduction in GHG (emissions (% of base)					
System 2	Wai	1	1	8	4 - 13
	BoP	1	1	8	6 - 16
	Sou	0	(+2) -1	3 - 5	(+6) - 4
	Can	4	4	8	1 - 10
System 4	Wai	1	1	9	13 - 19
	BoP	2	2	2	11 -22
	Sou	1	(+1) - 1	(+1) - 5	(+1) - 7
	Can	3	3	9	3 - 11
Mean[1]		*1.6*	*1.1-1.8*	*5.8-6.8*	*3.8-12.8*
Associated reduction in P loss (emissions % of base)					
System 2	Wai	12	15	17	17
	BoP	8	21	21	22
	Sou	39	39	39	39
	Can	20	20	20	30
System 4	Wai	4	4	9	5
	BoP	16	18	18	23
	Sou	0	48	48	47
	Can	9	9	9	9
Mean		*14*	*22*	*23*	*24*

[1] where a range is quoted, the two means are calculated by incorporating the lower or higher effectiveness values into the calculated average

Based on an assessment of Table 6.1, reductions in target N leaching look to have the following effects on GHG emissions at an individual farm level:

- 5-10% decrease in N loss = <2% decrease in GHG emissions
- 20% decrease in N loss = 6-7% decrease in GHG emissions
- 40% decrease in N loss = 4-13% decrease in GHG emissions

The wide modelled range of potential benefits to GHG emissions from a 40% decrease in N leaching (4-13%) is due to uncertainty around the effects of 'pollution swapping' when housing and additional manure storage is required on farm. For the combined mitigation scenarios, the use of an off-paddock facility was modelled by OVERSEER to increase N_2O and overall GHG emissions from stored effluents. These increases offset any decreases in emissions due to avoiding urine deposition on the paddock. This is the major reason why housing negated any gains in GHG reductions from the mitigations that were applied before the housing options (M11 and M12) were implemented in the abatement curve. To a much lesser extent, OVERSEER predicts increased CH_4 emissions under some storage conditions – though the predominant effect is on N_2O emissions. Detailed examination of the OVERSEER files shows that subtle changes in manure storage conditions and management specified in the files (i.e. the possibility of exporting effluent) could have large effects on estimated CH_4 and N_2O generation.

The estimated increases in GHG emissions following introduction of housing may be a pessimistic projection, given that recent research suggests that N_2O emissions from stored effluents may not be as large as initially believed (and currently modelled by OVERSEER) (e.g. Laubach et al. 2015). The authors state “Nitrous oxide emissions from anaerobic ponds are negligible” and “It thus seems appropriate for inventory purposes to assume a zero emission factor for direct N_2O emissions from FDE ponds in New Zealand”. However, the risk of pollution swapping is supported by the suggested effects of housing and manure storage on GHG emissions in the UK User Manual (this report, Section 3.2, also Appendix II), although the authors of that report note some uncertainty about the effects. To investigate the impacts of pollution swapping arising from housing/manure storage further, we undertook two additional analyses:

1. Correlation of % change in N leaching and GHG emissions based on scenarios that did not include housing (thus avoiding this complication), i.e. up to mitigation M9 (or M10, where applicable) - Analysis 1.
2. A best-case scenario was assumed where storage of manure does not increase GHG emissions compared with the same amount of excreta deposited during grazing, and % changes were recalculated (Analysis 2).

The redrawn Figures show a better relationship between GHG and N leaching reductions.

Analysis 1

Figure 6.4 shows a reasonable relationship between GHG emissions and N leaching when expressed as proportion of the baseline farm when housing options are excluded. However, there are differences between regions, the main one being this dilution of benefit in Southland due to apparent high background N_2O emissions. Heavy textured soils are predicted to emit higher background levels of N_2O so that the % change of mitigations on GHG emissions is diluted by these background losses. However, some are also associated with the wetland option that was implemented which is modelled to have large effects on N losses with little effect on GHG emissions. The fitted line in Figure 6.4 translates to a linear reduction of c. 3% in GHG emissions from a 10% decrease in N leaching and a 7% decrease in GHG emissions from a 20% decrease in N leaching.

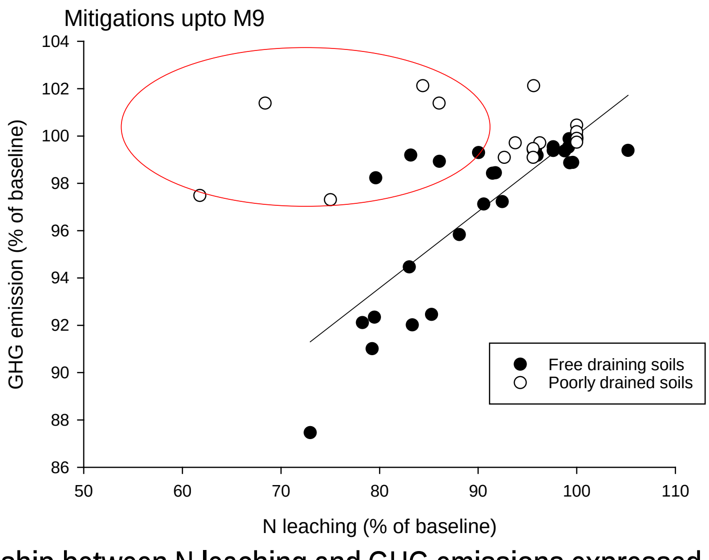


Figure 6.4: Relationship between N leaching and GHG emissions expressed as a % of the baseline. Mitigations up to and including M9 (decreased stocking) rate included. Note that points in the red circle are associated with wetlands (M8). The regression line is fitted only to the closed circles (free draining soils).

Adjusted for housing losses of N_2O and CH_4 **Not adjusted**

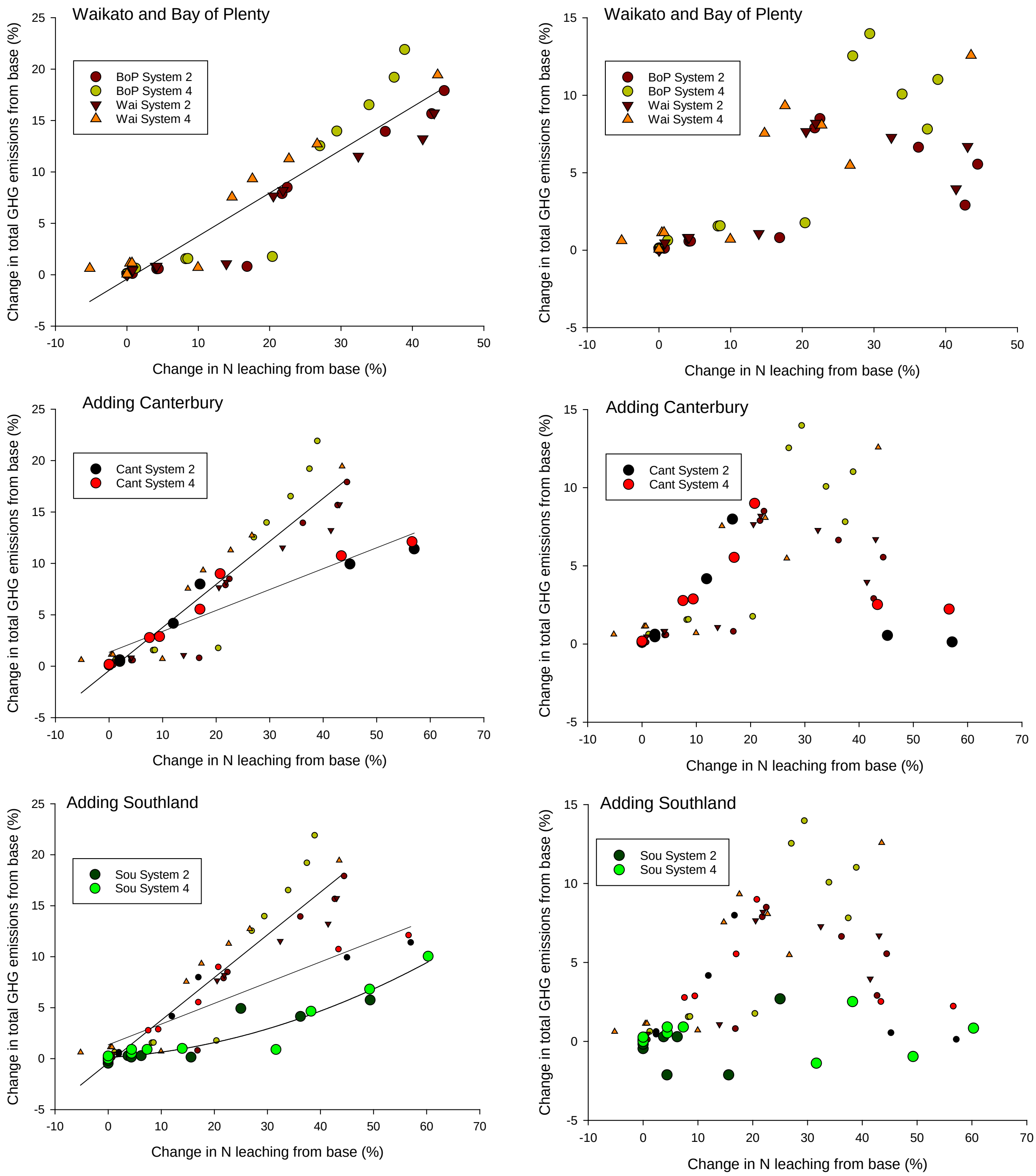


Figure 6.5: Relationship between reduction in N leaching losses and reduction in GHG emissions at current levels of milk production, with and without adjusting for increased losses in housing from effluent storage, i.e. assuming that manure collection and storage does not increase the GHG emissions from animal excreta (compared with the same amount of excreta deposited onto pasture during grazing).

Analysis 2

Figure 6.5 shows that without the pollution swapping effect associated with housing, there is a much stronger relationship between reductions in N leaching and reductions in GHG emissions. Individual locations differ in the relationship. Again, most notably, the heavy textured pallic soils in Southland are less responsive in GHG emissions reduction due to the large background N_2O emissions estimated by OVERSEER.

6.1.1 Sensitivity to changes in replacement rate

Our scenarios were developed in the absence of significant changes in replacement rate (we have assumed the industry standard of 23%) and dairy farm emission optimisation measures other than the improved feed conversion efficiency (feed offered to MS produced) from adopting M9 (i.e. improved pasture management, sharp reductions in animal numbers, feed intake and N fertiliser use, improved timing of N applications, varying lactation lengths). However, other modellers have incorporated the scenario of a reduced replacement rate of 17% based on improved reproductive performance. To test the sensitivity of our results to changing the replacement rate, we re-ran a collection of scenarios from M9 onwards with the decreased replacement rate. The results were consistent across scenarios and farm-types, giving us a c. 3% additional reduction in GHG emission reduction. Thus, when trying to achieve a 20% decrease in N leaching, which required us to use a reduced stocking rate, incorporation of a reduced replacement rate increased the GHG mitigation benefit to 9-11%; a 40% target for N leaching would increase GHG mitigation benefit to 7-16% (adapted from Table 6.1).

6.1.2 Dairy – key points from analysis

The overall message appears to be that on a single farm, implementation of water quality measures will have small but positive effects on GHG emissions from dairy farms at the current levels of milk production. This is on the assumption that the mitigations needed to drive reductions in N losses excluded housing. Our abatement curves suggest that reductions in N loss up to 20% can be achieved without invoking the need for housing. In that case a 10% reduction in N loss could yield a 2% decrease in GHG emissions; a 20% reduction in N loss could yield a decrease in GHG emissions of c. 9-11% (including adjustments for reduced dairy replacement rate).

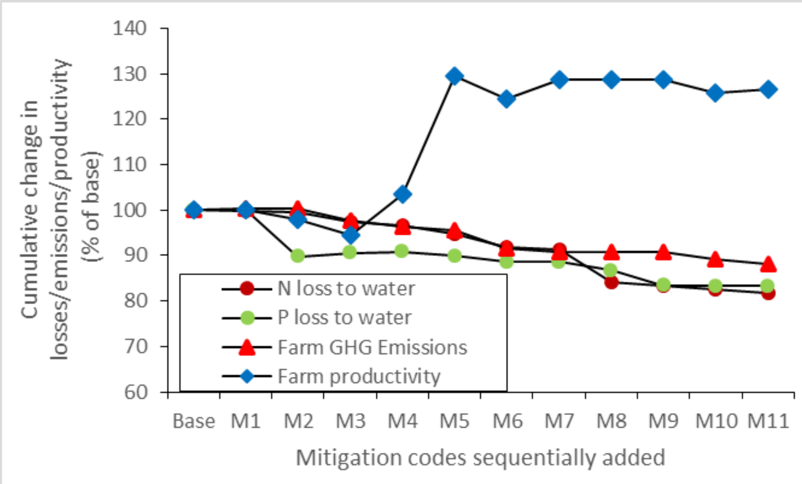
Clearly, there appears to be more uncertainty around the potential effects on GHG emissions from seasonal housing of animals and the larger volumes of manure generated and stored. In some of the case studies this negated much or all of the gains made by implementing the earlier mitigation options (M1 to M10). Further aspects are dealt with in more detail in the Discussion (Section 7).

6.2 Sheep and Beef

Baseline GHG emissions for the 19 sheep and beef farms in the six Regions included in the study, ranged from 1288 to 7431 kg CO_2-e/ha (Figure 6.6). If the intensive Waikato bull beef system (Wai SB2) and intensive Southland sheep breeding and finishing operations (Sou.SB1) are omitted the range is lowered and narrowed to 1288 to 4861 kg CO_2-e/ha. Total emissions increased with rainfall in each region. Methane made up 34-81% of total emissions, nitrous oxide 15-65% and carbon dioxide only 1-5%. Nitrous oxide emission as a percentage of total GHG emissions was higher on the poorly drained soils and increased with rainfall.

Figure 6.6: Estimates of GHG emissions from the 19 sheep and beef systems that were modelled (baseline losses) using OVERSEER.

Figures 6.7-6.9 show the cumulative percent changes in emissions to air and water and farm productivity and the actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice on sheep and beef operations in the Manawatu under 800 and 1400 mm rainfall and in Southland, respectively, The stepwise introduction is effectively a progressive chronological on-farm implementation pathway. Appendix IV includes the other 16 sheep and beef operations modelled as part of the study.



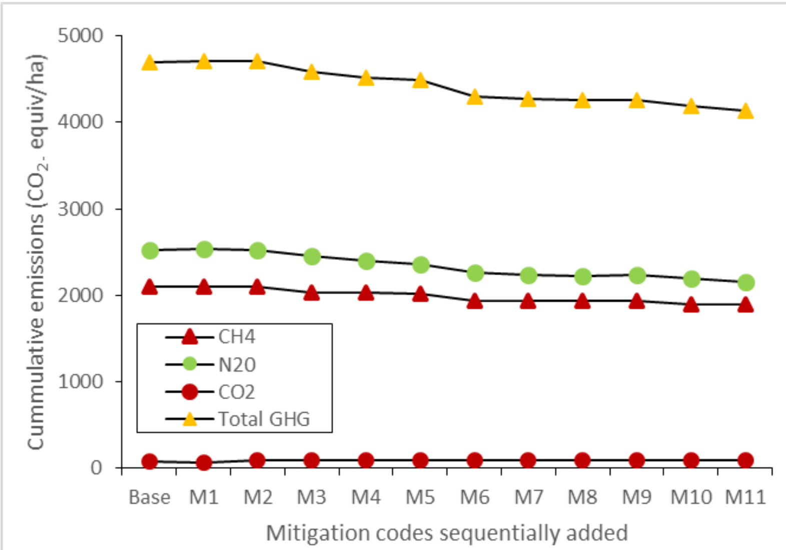
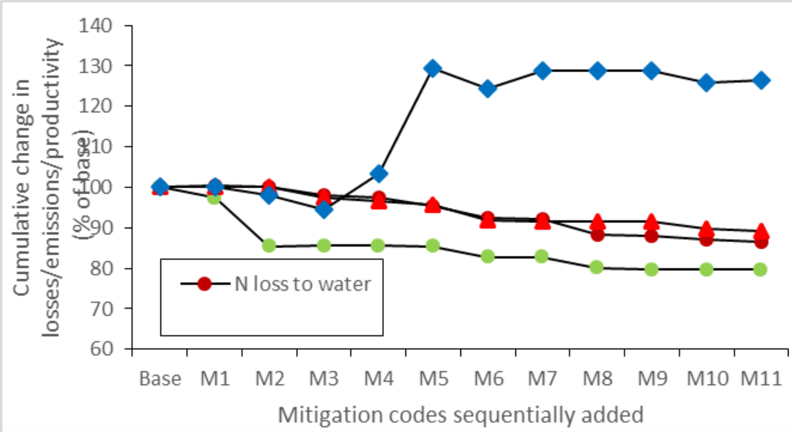


Figure 6.7: Cumulative percent changes in (a) emissions to air and water and farm productivity (meat and wool) and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Manawatu sheep and beef system on Pallic soil with 800 mm rainfall.

As a generalisation with the stepwise introduction of mitigations and changes in enterprise, performance and practice on-farm, there was an initial decline in P losses to water, a slow decline in N leaching and GHG losses, and an increase over time in farm productivity compared with the base farm. The lift in per hectare performance is the product of (a) increased reproduction performance of the ewe and higher weaning weights and growth rates of lambs and (b) the shift from breeding cows and the finishing of older cattle to a policy of buying weaners and finishing in 12 months. These changes in sheep and cattle performance and in the cattle policy both represent efficiency gains, with more of the grown forage eaten by a young growing animal and fewer animal wintered. Furthermore, these farm productivity gains are achieved despite a decline in the total hectares on the farm in pasture and without the need for any increase in inputs. They include the re-allocation of existing inputs (e.g. fertiliser that would have been applied to the areas planted in pines to the area remaining in pasture), and with the increase in per head performance fewer lighter animals wintered on-farm each year. The net effect is a reduction in emissions to both water and air. The actual size of the reductions in emissions on any one of the 19 sheep and beef farms was influenced by the stocking rate, sheep to cattle age class ratio and performance levels of the base farm, as well as the ratio of flat to rolling, hill and steep land on the farm, the soil type and rainfall.

For example the jump in productivity on the sheep and beef operations in the Manawatu, Gisborne, BOP and Waikato operations reflects the shift from breeding cows to trading cattle and buying and selling prime cattle with a minimum carried into a second winter.



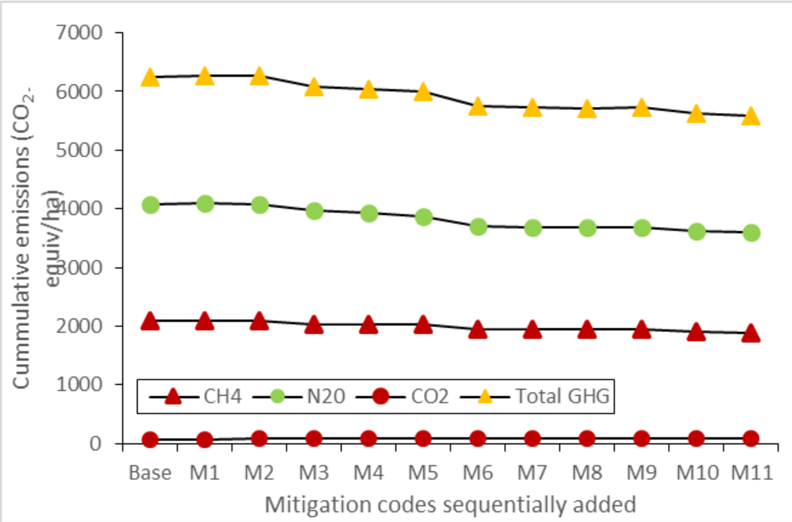


Figure 6.8: Cumulative percent changes in (a) emissions to air and water and farm productivity (meat and wool) and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Manawatu sheep and beef system on Pallic soil with 1400 mm rainfall.

For the Southland operation (Figure 6.9) standing the animals off the winter crop for 16 hours on pasture (SB M12) or on a stand-off pad made up of an uncovered organic matter pad for the 16 hours when not on the winter crop (SB M13) did not change the farm emission profile to either air or water compared with adopting mitigation SB M11 (Figure 6.9). Adding a filtering function to the riparian margin (SB M15) had a positive impact on P losses, but not the other three contaminants.

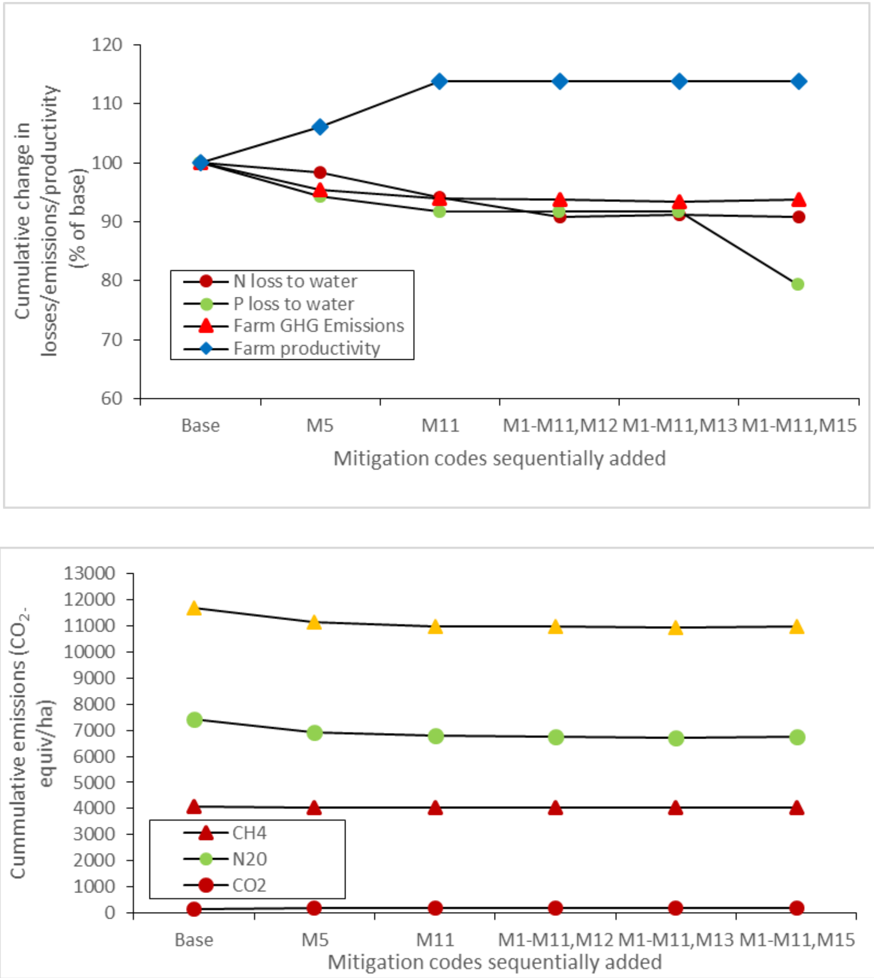


Figure 6.9: Cumulative percent changes in (a) emissions to air and water and farm productivity (meat and wool) and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Southland intensive sheep breeding and finishing operation. ‘M5’ and ‘M11’ on the x axis denotes combined mitigations M1-M5 and M1-M11, respectively.

Table 6.2 summarises the stepwise introduction of mitigations and changes in enterprise, performance and practice on-farm required to achieve the target N leaching loss reductions and the associated reductions in GHG emissions, P losses and farm productivity. The target N leaching reductions of 5-10%, are in line with the reductions in N losses to water required in some catchments for Regional Councils to achieve their fresh water objectives (Table 3.1). With the exception of two of the Southland cases, a 5% reduction in estimated N leaching was achieved generally by implementing options up to M3-M5. Apart from the minor gains from reduction in N fertiliser use, most of the reduction in N leaching was due to soil conservation plantings – effectively reducing the area under grazing – combined with the lift in on-farm productivity, reducing the numbers of ewes and larger cattle wintered. A similar picture emerges when looking at a 10% reduction, although the options on two of the Southland farms were limited. It is important to remember that the absolute losses of N from these sheep and beef systems is 2-5 fold lower than a dairy system.

Targeting a reduction in N leaching losses of 5% resulted in a reduction in P loss on average of 11%, with a ranged from 3-23% with the smallest losses associated with systems also struggling to limit N leaching. The average reductions in GHG emissions was much smaller (4%) with a range from 1-10%. Critically the stepwise introduction of mitigations and changes in enterprise, performance and practice on-farm to achieve the 5% N leaching reduction resulted in an average increase in farm productivity 110% of base farm with a range from 94-130%. Chasing a 10% reduction in N leaching did not reduce P losses any more, but the average reduction in GHG emissions more than doubled to 9% and average farm productivity above the base farm showed further gains (116% of base).

Table 6.2: Summary of the stepwise introduction of mitigations and changes in enterprise, performance and practice on-farm required to achieve on the target N leaching loss reductions and the associated reductions in GHG emissions, P losses and farm productivity. N.Ac denotes that the target was not achievable on that farm with the mitigations we applied.

Farm I.D.		Target reduction in N leaching					
		c. 5%	c. 10%	c. 15%	c. 20%	c. 25%	Max
Mitigation level required to achieve target							
NI Class 3	Wai SB2*	M1-M4	M1-M5		M1-M11	N.Ac	20
	Man SB1 800	M1-M5	M1-M7	M1-M8	M1-M11	N.Ac	18
	Man SB1 1200	M1-M5	M1-M8	M1-M11	N.Ac	N.Ac	15
	Man SB1 1400	M1-M5	M1-M8	M1-M11	N.Ac	N.Ac	14
	Gis SB1 800	M1-M3	M1-M5	M1-M6	M1-M8	M1-M10	25
	Gis SB1 1200	M1-M2	M1-M5	M1-M6	M1-M8	M1-M10	23
	Gis SB1 1400	M1-M2	M1-M4	M1-M6	M1-M8	M1-M10	23
NI Class 4	BoP SB1*	M1-M5			M1-M11		20
NI Class 5	Wai SB1*	M1-M4				M1-M11	24
	Man SB2 800	M1-M5	M1-M6	M1-M8	M1-M10	N.Ac	21
	Man SB2 1200	M1-M5	M1-M6	M1-M9	N.Ac	N.Ac	17
	Man SB2 1400	M1-M5	M1-M6	M1-M8	N.Ac	N.Ac	16
	Gis SB2 800	M1-M3	M1-M6	M1-M8	M1-M9	N.Ac	20
	Gis SB2 1200	M1-M3	M1-M6	M1-M9	N.Ac	N.Ac	17
	Gis SB2 1400	M1-M3	M1-M6	M1-M9	N.Ac	N.Ac	17
SI Class 6	Can SB2	M1-M5	M1-M11	N.Ac	N.Ac	N.Ac	11
	Sou SB2	M1-M11	N.Ac	N.Ac	N.Ac	N.Ac	4
SI Class 7	Sou SB1	M1-M11	N.Ac	N.Ac	N.Ac	N.Ac	6
Associated reduction in GHG emissions (% of base)							
NI Class 3	Wai SB2	4	4		12		12
	Man SB1 800	4	9	9	12		12
	Man SB1 1200	4	9	11			11
	Man SB1 1400	4	9	11			11
	Gis SB1 800	2	7	13	13	16	17
	Gis SB1 1200	2	8	13	14	17	17
	Gis SB1 1400	2	7	13	14	17	17
NI Class 4	BoP SB1	4			10		10
NI Class 5	Wai SB1	5				21	21
	Man SB2 800	4	8	9	11		12
	Man SB2 1200	5	8	9			12
	Man SB2 1400	5	8	9			12
	Gis SB2 800	5	13	13	16		17
	Gis SB2 1200	5	12	13			17
	Gis SB2 1400	5	13	13			17
SI Class 6	Can SB2	10	11				11
	Sou SB2	1					1
SI Class 7	Sou SB1	6					6
	Mean[1]	*4*	*9*	*11*	*13*	*18*	*13*
Associated reduction in P loss (% of base)							
NI Class 3	Wai SB2	21	22		28		28
	Man SB1 800	10	11	13	17		17
	Man SB1 1200	15	20	21			21
	Man SB1 1400	15	20	20			20
	Gis SB1 800	6	7	8	10	14	14
	Gis SB1 1200	7	6	8	10	11	11
	Gis SB1 1400	7	7	8	11	11	11
NI Class 4	BoP SB1	18			23		23
NI Class 5	Wai SB1	23			28		28

Farm I.D.		Target reduction in N leaching					
		c. 5%	c. 10%	c. 15%	c. 20%	c. 25%	Max
	Man SB2 800	3	3	3	18		18
	Man SB2 1200	6	5	13			13
	Man SB2 1400	16	15	17			21
	Gis SB2 800	9	11	13	17		18
	Gis SB2 1200	9	11	14			15
	Gis SB2 1400	9	11	14			14
SI Class 6	Can SB2	7	17				17
	Sou SB2	3					3
SI Class 7	Sou SB1	8					8
	Mean[1]	*11*	*12*	*13*	*18*	*12*	*17*
Associated change in farm productivity (% of base)							
NI Class 3	Wai SB2	2	23		18		
	Man SB1 800	30	29	29	26		
	Man SB1 1200	30	29	26			
	Man SB1 1400	30	29	26			
	Gis SB1 800	-5	32	26	29	25	
	Gis SB1 1200	-2	32	26	29	25	
	Gis SB1 1400	-2	4	26	29	25	
NI Class 4	BoP SB1	21			7		
NI Class 5	Wai SB1	-1			-3		
	Man SB2 800	15	10	13	9		
	Man SB2 1200	15	10	13			
	Man SB2 1400	15	10	13			
	Gis SB2 800	-6	0	2	2		
	Gis SB2 1200	-6	0	2			
	Gis SB2 1400	-6	0	2			
SI Class 6	Can SB2	7	10				
	Sou SB2	23					
SI Class 7	Sou SB1	14					
	Mean[1]	*10*	*16*	*17*	*17*	*25*	

[1]mean reduction is calculated only for farms where the target N reduction was achieved

An estimate of the reductions in the risk of erosion following the stepwise implementation introduction of mitigations and changes in enterprise, performance and practice on-farm from SBM3 to SBM6 and SBM10 of 10%, 20-30% and >50%, respectively.

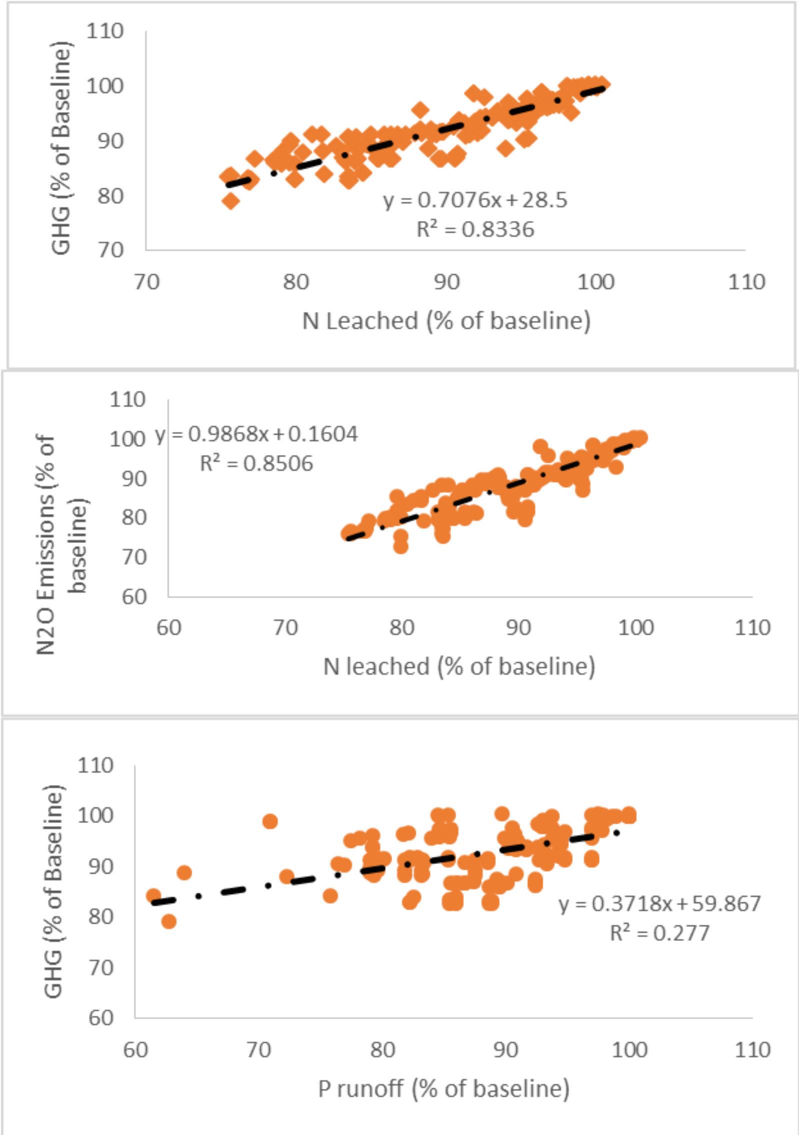


Figure 6.10: Relationship between nitrate leaching and GHG and nitrous oxide emissions and between phosphorus losses in runoff and GHG emissions as influences by the mitigations and changes in enterprise, performance and practice on the 19 sheep and beef systems from the 6 regions.

There was a very good relationship between N leaching losses and GHG emissions (Figure 6.10). It was less than a one to one ratio, with the saving in N leaching losses, not matched by the reduction in GHG emissions. The mitigations considered for the sheep and beef systems did not achieve the same level of N leaching reduction considered for the dairy farms (Table 6.2), although absolute losses are significantly less than for dairy farms.

Average annual cumulative carbon sequestration rates (kg CO_2/ha/year) from the scrub, pines, spaced trees, riparian and wetlands plantings on the sheep and beef operations on the 19 properties in the six Regions ranged from <100 to 3500 kg CO_2/ha/year (Figure 6.11). The South Island operations only have a small area planted compared with the eroding hill country operations in the Manawatu and Gisborne regions included in the study.

The changes in carbon stock as a consequence of the stepwise introduction of mitigations and changes in enterprise, performance and practice on the 19 sheep and beef systems from the 6 regions were calculated in the first instance to simply compared C budgets. For this exercise the annual accumulation rates are summed, with no distinction made between the pines and spaced trees, which have a finite life of 30 years, compared to the regenerating native vegetation. The eligibility and potential value of the C stocks to the producers was outside the scope of the project.

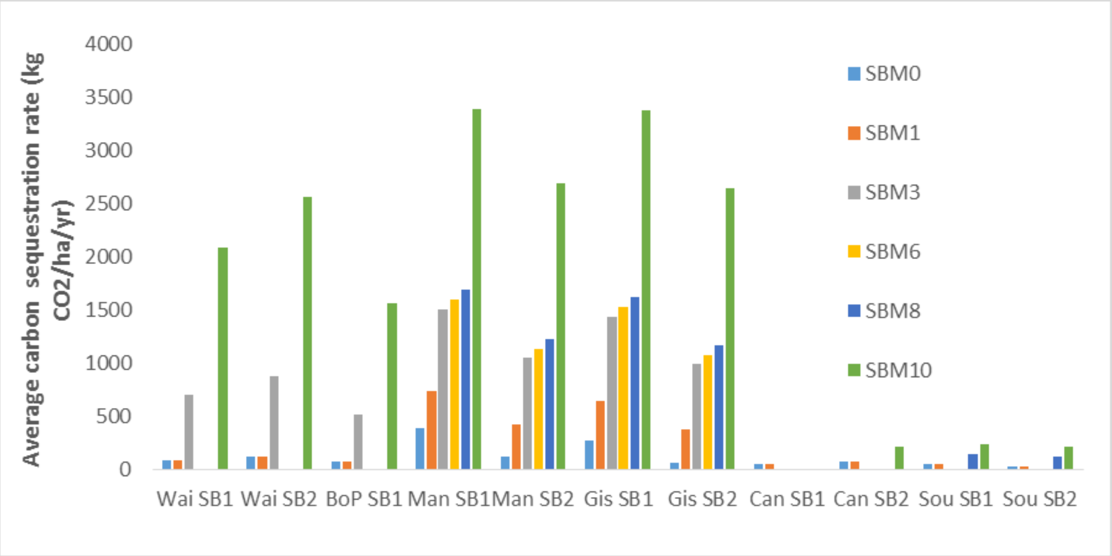


Figure 6.11. Average annual cumulative carbon sequestration rates (kg CO_2/ha/yr) from the scrub, pines, spaced trees, riparian and wetlands plantings.

6.2.1 Sheep and Beef – key points from the analysis

An important overall message emerging from this study is that potential gains in water quality and reductions in the GHG footprint of the sheep and beef industry can be advanced into the future by encouraging the sector to focus on (i) achieving the productivity gains possible through increased reproductive performance of ewes and lamb growth rates and shifting from breeding cows and older age classes of cattle to the buying and finishing of cattle in 18 months and (ii) addressing soil erosion, sediment and associated P losses The net outcome is ongoing productivity gains while slowly reducing the environmental foot print. Given the enormous potential to increase the performance of the Nations ewe flock and the greater integration of dairy beef into the sector, reducing the need for beef cows, there is for the foreseeable future ongoing reductions possible. Importantly this study was limited to what was possible. It did not include an analysis of the barriers to adoption and change to current livestock policy and performance on sheep and beef farms included in the study.

To realise and lock in the twin environmental gains of improving water quality and reduced GHG emissions the investment in new genetics and technologies to lift on farm performance must be matched with the investment in sustainable land management practices (such as tree planting), particularly on those landscapes at high risk to erosion.

The modelled gains in water quality and the reductions in GHG footprint across the 19 sheep and beef systems examined across the six regions were linked very closely to the current level of sheep performance, sheep to cattle age class ratio, the amount of land at risk from erosion, sediment and P losses, which was in turn influenced by soil type and rainfall.

6.3 Cropping

Median emissions for the 13 base farms were 3400 kg CO_2-e/ha. The range of emissions from 12 of the farms was 1238 (viticulture) – 5980 (vegetables) kg CO_2-e/ha. The Southland 'arable' (comprising cereals and potatoes, 400 kg N/ha on a pallic soil was estimated to have large emissions by OVERSEER, mainly associated with N_2O emissions (a combination of high N inputs and the pallic soil) (Figure 6.12). In general, GHG emissions comprised of N_2O and CO_2 emissions with, broadly a 50-50 split between the two (Figure 6.13). Estimated average N leaching losses were 63 kg N/ha, with a range of 5 (viticulture) – 239 (vegetables) kg N/ha.

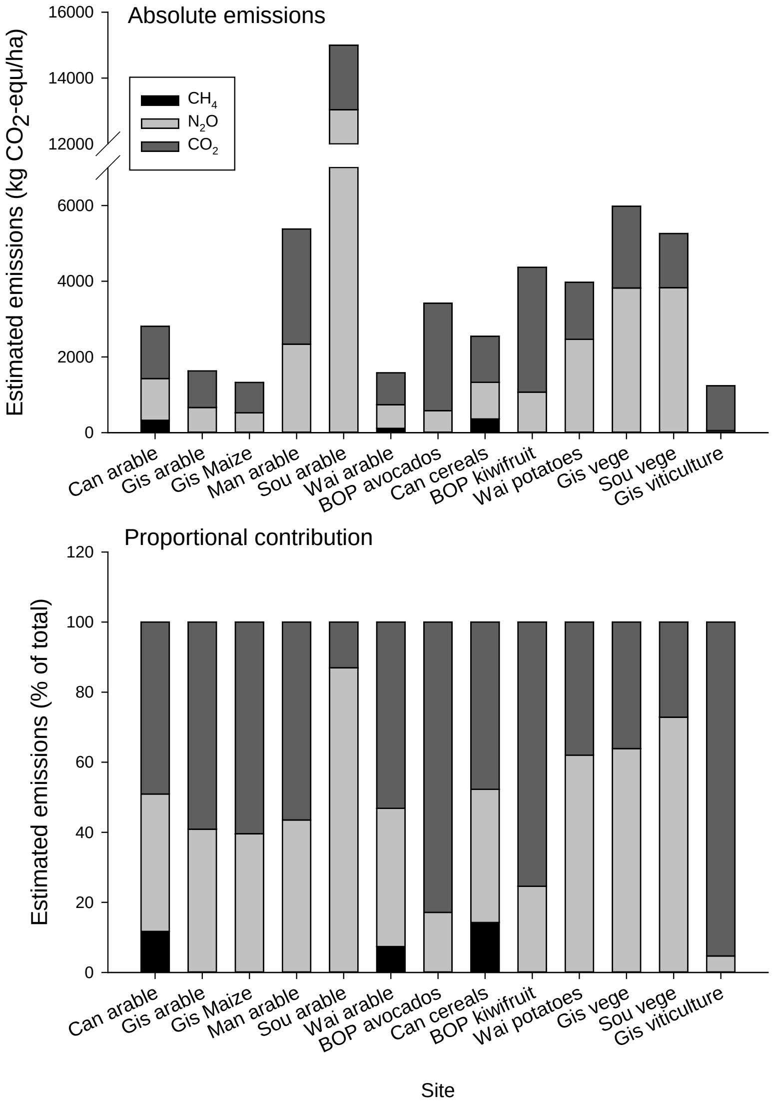


Figure 6.12: OVERSEER estimates of GHG emissions from the arable and vegetable systems that were modelled (baseline losses).

Effects of irrigation management

Six of the scenarios were irrigated. The base farms were set up with well scheduled irrigation (soil water budget-based scheduling) as the starting position. Remodelling these farms with poor irrigation management (scheduling based on fixed application depth and fixed return period) resulted in large increases in calculated drainage, with resultant large increases in N leaching.

If poorly scheduled irrigation was assumed to be the baseline position, moving to the best scheduling decreased modelled N leaching by, on average, 28% (range 5-76%), with a 30% decrease in GHG emissions. GHG emission savings came from decreased N_2O losses (less denitrification; and lower indirect losses due to less N leaching) and saved energy costs from not needing to run the irrigators for as long.

Fertiliser N management

If fertiliser technologies summarised in Table 5.3 could yield a 5% saving in inputs with no loss of yield, OVERSEER estimates that this would decrease N leaching, on average for the range of rotations modelled, by 2% and a GHG emission reduction of 1%. The estimates for 10 and 20% reductions in N fertiliser inputs are, respectively: 4% less N leaching, 3% decrease in GHG emissions; and 8% less N leaching, 5% less GHG. Figure 6.14 summarises the relationship between modelled reductions in N leached and GHG emissions for each fertiliser reduction. . As is seen elsewhere, the reduction in N leaching does not produce a commensurate drop on GHG emissions. For example, in Figure 6.13, a reduction of N leaching of 30% only produces GHG savings of about 50%.

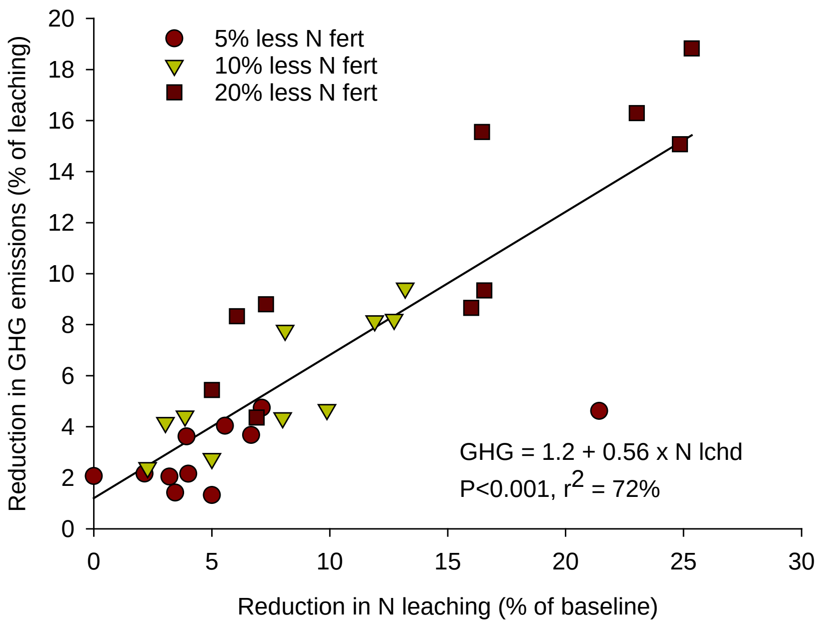


Figure 6.13: The relationship between OVERSEER-modelled reductions in N leached and GHG emissions for an assumed reduction in fertiliser inputs due to improved technologies of 5, 10 or 20% (with no reduction in yield).

Combined mitigations

Table 6.3 summarises the modelled reductions in N and P loss to water and associated decreases in GHG emissions. In terms of implementing mitigations in rotations, our analysis suggests that the range of options is limited and not always practical because of the rotation design (e.g. catch crops). In the 6 rotations we were able to test, an overall 40% reduction in N leaching achieved only a 10% reduction in GHG emissions. Thus a 10% target in N leaching (Table 3.1) is likely only to yield a small decrease in GHG emissions. This is because individual mitigations such as catch crops and different cultivations have little benefit to GHG emissions, and their effects are further ‘diluted’ because they cannot be implemented at every point in the multi-year rotation because of the nature of the rotation.

Table 6.3: Effect of mitigations integrated into a range of crop rotations on reductions in N and P loss to water and associated GHG emissions.

Farm and rotation	P run-off (kg/ha)	N leached (kg/ha)	GHG kg CO_2-e/ha)
Base farms			
Can arable	0.2	33	2810
Gis arable	0.9	29	1630
Gis arable maize	0.6	15	1326
Wai arable	0.1	14	1582
Can cereals	0.1	30	2547
Wai potatoes	0.3	82	3973
Mean	*0.4*	*34*	*2311*
With mitigations			
Can arable	0.2	25	2717
Gis arable	0.8	8	1464
Gis arable maize	0.3	5	1352
Wai arable	0.1	5	1363
Can cereals	0.1	26	2498
Wai potatoes	0.3	58	3687
Mean	*0.3*	*21*	*2180*
% change from base			
Can arable	0	24	3
Gis arable	11	72	10
Gis arable maize	50	67	-2
Wai arable	0	64	14
Can cereals	0	13	2
Wai potatoes	0	29	7

6.3.1 Cropping – key points from analysis

Overall, lower GHG than from pastoral:

- Irrigation is a key driver, mainly through energy and nitrous oxide emissions. It is a priority area. We did not include in the baseline because it skewed the results.
- This aside, N fertiliser technologies could yield some benefit – but these benefits have yet to be realised in practice. The science is still under development. Even so, a 10% saving in fertiliser (the target in Table 3.1) would yield only a 4% decrease in N leaching and a 3% reduction in GHG emissions.
- Limited options are available within a rotation to implement mitigations. Modelling, however, suggests that when implemented they could have a significant effect on N losses – but only a lesser effect on GHG emissions.
- Priorities should be irrigation management and for research to realise some of the potential benefits of more efficient fertiliser use.

7. Discussion and implications

Sources of agricultural GHG emissions are well understood, as are the immediate effects of management practices on emissions. Although N_2O emissions are modified by a range of environmental factors, soil nitrate-N and soil aeration are the two main drivers (Eckard et al. 2003). Eckard et al. (2010) separated potential management practices to decrease losses into animal- and soil-based approaches. Soil-based interventions aim to decrease the source of N (e.g. decreasing direct urine deposition onto paddocks by standing off, or decreasing N fertiliser inputs) or manage soils to avoid conditions that encourage N_2O emissions (e.g. managing stock to reduce compaction).

Not surprisingly, mitigations to reduce CH_4 emissions focus almost solely on animal efficiency (Beauchemin et al. 2008; Eckard et al. 2010) and primarily on strategies that manipulate diet (either through composition or through the use of additives to enhance utilisation and conversion of nutrients by the animal) to decrease CH_4 production in the rumen. However, another method to decrease CH_4 emissions is to increase per animal production so that fewer animals are required for the same level of production (Knapp et al. 2014). This is based on a ‘dilution’ of the effects of animal maintenance requirements, whereby fewer efficient animals produce the same output per unit of land area (Bauman et al. 1985).

7.1 Potential system implications for GHG emissions

7.1.1 Dairy

There is some evidence at a farm level that practices to decrease N leaching can drive decreased GHG emissions. Farm system modelling studies have shown that a combination of mitigations could be incorporated into dairy production systems to achieve the same level of production with lower GHG emissions.

A modelling approach based on Monitor farms (Smeaton et al. 2011) analysed both dairy and sheep and beef farms and found very high correlations (R2 0.91–0.95) between N leached and GHG emissions. Similarly, the GHG emissions per kg of product was highly and positively correlated with the intensity of N leaching per kg product. In our study there also was a general trend of reduced GHG emission with reduced N leaching, but the relationships were more varied because we modelled systems in a range of environments whereas the analysis by Smeaton et al. (2011) was based on a number of scenarios on a single soil-type/climate. Climate and soil-type, as well as system, influence modelled N leaching losses (Monaghan et al. 2008); this is exemplified by the low N leaching losses from the poorly drained pallic soil in our dataset, yet much higher N_2O emissions than the other soil-types. Most other studies have focused on a single soil-type/environment within that study.

Using the DairyNZ whole farm model, Beukes et al. (2011) identified potential co-benefits to N leaching from measures that aimed to reduce GHG emissions when from reductions in N leaching using the DairyNZ Whole Farm Model. Strategies employed to decrease GHG (CH_4 plus N_2O) emissions included: fewer animals with higher genetic merit that are milked longer; lower replacements rates; standing cows off during autumn/winter; decreased fertiliser N inputs; and incorporating some low N grain in the diet. The modelling suggested that milk production would increase by 15-20% and absolute GHG emissions would decrease by 15-20%. Critically, however, the changes to the system to address GHG emissions would also decrease N leaching losses.

The hypothesis that such a system as described above would increase production while decreasing N leaching by c. 40% was tested over 5 lactation seasons (2012-2016) as part of the Pastoral 21 (P21) programme in a demonstration farmlet in the Waikato (Macdonald et al. 2014). Results show that production was maintained (not increased) and N leaching decreased by c. 40-50% compared with the baseline Waikato system (Shepherd et al. 2014). An analysis of the Beukes et al. paper shows that their modelling decreased stocking rate from 3 cows/ha to 2.6 cows/ha, i.e. a 13% reduction in stocking rate and a 5% reduction in dry matter intake (DMI),), which resulted in an 8% decrease in enteric CH_4 production. Our modelling results compare favourably with this assessment:

- System 2 Waikato: 2.8 cows/ha decreased to 2.6 cows/ha (no change in replacement rate) = (7% reduction in stocking rate) = 2% reduction in DMI = 3% decrease in enteric CH_4
- System 4 Waikato: 3.2 cows/ha decreased to 2.9 cows/ha (10% reduction in stocking rate, no change in replacement rate)) = 5% reduction in DMI = 7% decrease in enteric CH_4

We took a more conservative view of the probable reduction in stocking rate than Beukes et al. (2011), but there was good general agreement in terms of methane emission reductions, even though Beukes et al. (2011) accounted for forage quality changes in their modelling (e.g. when fertiliser N levels were reduced), whereas we did not.

Our results on estimated reductions in N leaching from our stacked mitigations are consistent with others: Smeaton et al. (2011) demonstrated a dairy system with a 14% lower stocking rate, nil N and wintering cows off increased production by 4%, profit by 3% and N leaching decreased by 40%. The mitigations proposed by Beukes et al. (2011) and Burggraaf et al. (2011) similarly conclude that reduced N inputs, lower stocking rates and standing cows off decreases N leaching by 40-50% and increases profit. Thus, it appears that reduced profitability should not be a barrier for uptake of these mitigation options. As stated earlier, however, the P21 experience suggests that while the benefits in N leaching have been demonstrated experimentally, they have been unable to show increased production/profit in the Waikato system (a similar environment to the modelling of Smeaton and Burggraaf); a slight reduction in profitability was also observed for similar P21 farmlet experimentation undertaken in south Otago. This supports our starting position that we would maintain production/profit in the dairy scenarios rather than increase it. Profit will be highly dependent on milk price; the advantage of the proposed systems is that they are more resilient at lower milk payouts than the original higher input systems.

Our main difference with previous dairy work is the modelled implications for GHG emissions. For example, de Klein et al. (2010) used the OVERSEER Nutrient Budgets model to estimate the effect of a number of interventions on N_2O emissions from dairy production systems 3 and 4. They estimated that, at the farm system level, use of maize silage (low N feed), nitrification inhibitors and feed/wintering pads would decrease N_2O emissions by 24-38% or 0-12% for systems 3 or 4, respectively. For total GHG emissions, Beukes et al. (2011) estimate potential reductions to be around 15-20%. Burggraaf et al. (2011) estimated GHG emission decreases to be c. 24% (per ha basis) or 28% (per kg MS basis). Smeaton et al. estimated reductions in GHG emissions for their optimised intensive system of 24%.
Our analyses show a more conservative estimate of the benefit of these stacked mitigations of 7-16% of total GHG emissions when housing is included, depending on how the pollution swapping (N_2O emissions) is modelled. A key part of previous analyses has been the reduced replacement rate, leading to carrying fewer animals on-farm. In our analysis we did not include reducing replacement rates as a mitigation option, but a sensitivity analysis indicates that reducing replacement rate from 23% (the industry standard) to 18% would give an

additional 2-3% reduction in GHG emissions (with also a small benefit to N leaching); i.e. total benefit 9-19%.

Reasons for the disparity between our estimated reductions and those from previous studies include:

- The lack of specific GHG emission amelioration options (i.e. animal- or herd-based conversion efficiencies and related methane amelioration). Rather, we opted for proven options for mitigating N and P losses to the environment.
- We took a more conservative approach by preventing severe changes in feed offered and farm carrying capacity.
- A whole-system approach was followed (i.e. milking platform + needed support area to carry lactating and non-lactating animals).
- No production gains were attained.
- Nitrification inhibitors and plant growth promotants were not included in the modelling.

However, our estimates are in line with those of Vibart et al. (2015) who modelled GHG emission reductions of 8-14% for a series of Southland dairy farms covering a range of environments (reduction in modelled N leaching 33-47%). Similar to our approach, mitigation of N and P losses were a priority, whereas GHG emissions were merely a consequence of adopting such mitigation options (grouped by capital cost and potential ease of adoption in Vibart et al. 2015).

Estimates of the financial implications of implementing mitigation scenarios on the case study dairy farms.

Estimates of the financial implications of implementing mitigation measures on the case study dairy farms (modelled in sections 5.1 and 6.1) are illustrated in Figure A1.1. As described earlier in the report, the scenario in Figure A1.1 assumes that mitigation measures are progressively implemented in a sequence whereby those that are most cost-effective and incur least cost and complexity are implemented firstly, and those that are least cost-effective or very costly are considered last; in general terms, the former measures can be described as "efficiency gains" and the latter as "additional infrastructure", as outlined in section 5.1.1. Some measures, such as M5 and M7, have been shown to be highly effective for reducing losses of other water contaminants such as sediment and faecal micro-organisms. We can see from Figure A1.1 that following such a strategy has little impact on farm profitability for measures M1-M5; in some cases profitability actually increases, mainly due to savings on fertiliser expenditure. In contrast, the expensive pad or barn infrastructure associated with measures M11 and M12 is estimated to incur quite large reductions in farm profit but does deliver appreciable additional reductions in N loss.

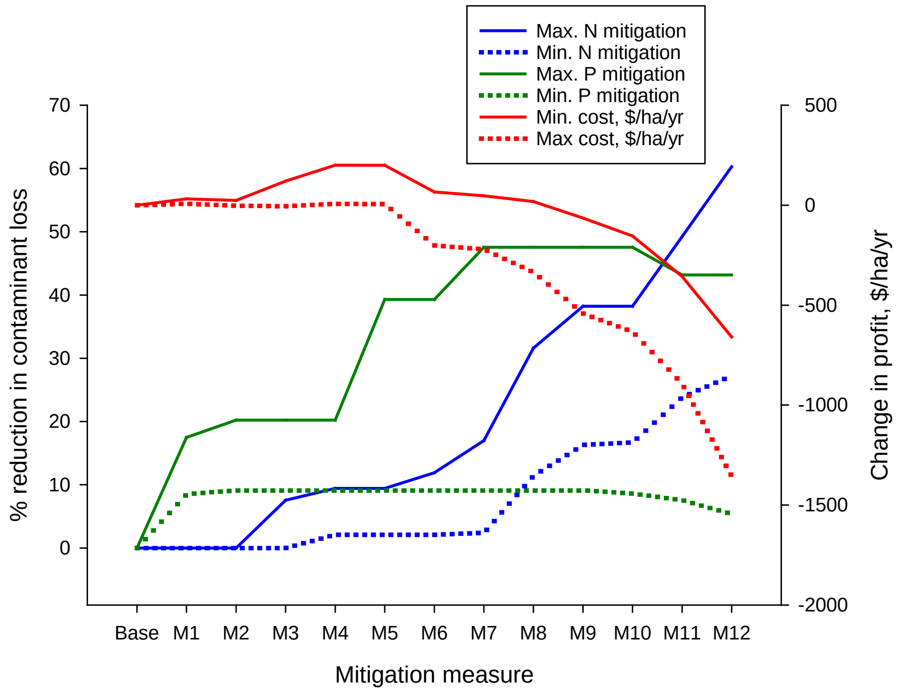


Figure 7.1: Cost-benefit curves for a "generalised" (i.e. non-targeted) mitigation cascade where measures are progressively (and thus cumulatively) implemented. Differences between "Max" and "Min" values represent the range of responses estimated for model dairy farms constructed for the Southland, Canterbury, Waikato and Bay of Plenty regions (2 farms per region).

An important feature of Figure 7.1 is the range of values presented for the 8 case study dairy farms. These reflect the variability in cost and effectiveness caused by soil and climate factors, and consequently the need or relevance of specific measures to a model farm. Some examples to illustrate this are:

- The effectiveness of improved effluent management systems for reducing contaminant losses via preferential flow through soil, or via surface runoff, is highly dependent on soil type and slope. For the artificially drained, poorly structured Pallic soil modelled for farm Sou_D2, implementation of measure M7 is thus estimated to deliver a reduction in P loss to water; although not considered in this study, it will also deliver a major reduction in farm-scale losses of faecal microorganisms. In contrast, for the flat, well-drained soils with limited propensity for preferential or overland flow (such as Can_D1/2 and BoP_D1/2), implementation of measure M7 is estimated to have minimal effect on farm scale losses of N or P (albeit it is still likely to deliver benefit in terms of reducing losses of faecal microorganisms).
- The effectiveness of wetlands (M8) is highly dependent on their ability to intercept flow discharges from farms. Modelled N effectiveness values thus ranged from nil for flat, free-draining Canterbury farms, to 16% for the poorly drained Southland farm (Sou_D2) that had some rolling topography. The annualised cost of wetlands was also assumed to vary from $30 to $300 per hectare depending on whether a facilitated or constructed wetland was required.
- The improved irrigation management scenario (M6) was only relevant to Canterbury farms with existing (boom) irrigation systems that needed up-grading.
- The assumed extent of use of an off-paddock facility (standoff pad or barn) varied between regions according to climate and soil conditions. The greatest extent of use for scenario M11 (winter use) was assumed for the cooler (and for the Southland region, more poorly drained) farms where cows were assumed to be off-paddock for 1350 hours over winter; in contrast, cows in Waikato and Bay of Plenty were assumed to on-off graze pasture (as conditions would allow) and therefore be off paddock for

only 720 hours over winter. For measure M12, the use of off-paddock facilities was extended to 2400 hours for the Southland and Canterbury farms, and to 1100 hours for Waikato and Bay of Plenty dairy farms. Whilst extended use of off-paddock facilities was modelled to deliver greater benefit in terms of reduced N leaching, it also incurred significant additional cost.

Figure 7.1 also shows the cost implications of reducing N and P losses. Because most of the P loss mitigation measures modelled in this study were assumed to incur little cost (or deliver cost savings), loss reductions of between 10 to 40% are estimated without any significant effect on profit. In the case of N loss, Figure 7.1 indicates that the annualised costs of achieving small (up to 10%), modest (up to 25%) or large (>25%) reductions in N loss are:

- Nil to $300/ha for a 10% reduction
- Nil to $1000/ha for a 25% reduction
- $200 to $1400/ha for a 40% reduction

7.1.2 Beef & Sheep

To realise and maintain the twin environmental gains of improving water quality and reduced GHG emissions the investment in new genetics and technologies to lift on-farm performance had to be matched with the investment in sustainable land management practices, particularly on those landscapes at high risk of erosion. In Southland, where there were few environmental challenges and the farm systems already had high ewe performance and cattle policy primarily around trading, the suite of mitigations and changes in enterprise, performance and practice on-farm considered in the study had little impact on reducing N leaching losses or GHG emissions, but did lift farm productivity significantly (Table 6.2). Vibart et al. (2015) estimated for the Southland region that a series of mitigations could be implemented to decrease N leaching by 34% on sheep and beef farms on average (from 10.3 to 6.9 kg N/ha) but with only a 2% effect on GHG emissions. Mitigations in Vibart et al. (2015) were broadly identified as improved nutrient management (source of P fertiliser, fenced wetland, animal exclusion from streams), improved animal productivity (improved reproductive performance and LW gain from adjusted animal numbers) and restricted grazing (riparian block, covered loafing and feeding pad for winter use).

Smeaton et al. (2011) investigated the relationship between N leaching mitigation and GHG emissions for sheep and beef scenarios. They found for these farms that ‘the optimum system was less obvious [than for dairy]’.

Decreased N losses to water may not be the only driver for reduced GHG emissions. Sediment and the associated P loss both contribute directly to degraded water quality and regional councils and Beef + Lamb NZ have been actively encouraging conservation-driven tree planting through the mechanisms of various forms of soil, land and farm conservation plans. Such planting involves pines and spaced-planted poplars and willows across approx. six million ha of hill and steep pastoral land. Douglas et al. (2013) estimated total GHG emissions from an open pasture system in hill country of 4.8 t CO_2-e/ha compared with 4.2-4.4 t CO_2-e/ha for a farm system with spaced trees (poplar and willow) planted for soil conservation. The reduction was largely because the tree pasture system maintained or improved animal productivity with a reduced stocking rate, because of the improved environment. Our analysis did not include consideration of any changes to soil carbon from the reduced risk of erosion or the additional carbon stored in trees and it did not consider the impact an enterprise change to a forested woodlot as another soil conservation measure would have on the total GHG balance for the farm.

7.1.3 Cropping

The complex nature of cropping systems means that each arable farm and each rotation is unique. A recent OVERSEER® modelling study on nitrogen losses in the Canterbury plains concluded that "the drivers of N losses are likely to be a complex web of interactions between variables" (Hume et al. 2015). This already indicates that the choice and effectiveness of mitigation strategies to reduce nutrient losses, in order to comply with the National Policy Statement for Freshwater Management, will vary largely from farm to farm and will be highly site-specific. This provides modellers with many difficulties Hume et al. (2015) found that for current practices in Canterbury 63% of the variability of N losses could be explained by three parameters, namely, N input, drainage and irrigation.

Few studies have investigated the co-benefits of N leaching reduction on GHG emissions on non-pasture land. The wide range of available rotations provided challenges but we selected what we thought was a representative range. It was notable that on closer investigation, not all of the rotations lent themselves to implementation of cultivation and catch cropping mitigations. This reflects the complexity of the rotations. Our analysis indicated the importance of good irrigation management for N leaching (and GHG) mitigation. We thought that the potentially large modelled effect of improved irrigation on N leaching and GHG emission reduction would exaggerate the effects of changed practice compared with the current industry position. Therefore, while acknowledging that this needs to be improved on some farms, we assumed good irrigation practice on the baseline farms where irrigation was included.

An analysis with industry representatives identified a number of possible techniques to improve N use efficiency, though few can either currently be modelled or have not demonstrated effects on N leaching yet. The analysis suggests that improved use of fertiliser, provided it that can maintain yields with reduced fertiliser use, would yield benefits to N leaching and GHG emissions.

7.1.4 Role of forestry/tree planting

Effects of water reforms are not expected to lead to many, if any, changes in forest management practises. Our conclusion is therefore that GHG co-benefits caused by the new policy are unlikely in to occur in commercial forests.
There will, however, be some potential GHG co-benefits from adding trees into farm systems. While benefits to GHG emission through carbon capture will occur in reality, whether they can be realised financially or even in NZ's GHG accounts will depend on compliance with current ETS rules. Our analysis suggests that this will potentially drive the largest change in sheep and beef while dairy and cropping opportunities will be lower. This is because there is more scope to plant forest of sufficient size and dimension that will qualify for ETS payments without having a significant negative effect on production or profitability (and may improve profitability if marginal land is taken out of production). However, we have also assumed that the beef and sheep sector has more scope to offset the loss of marginal land from livestock production by increasing production/profit per ha on the remaining land, while still maintain an overall reduction in GHG emissions at the farm level. In some circumstances, if the remaining farm area is managed more intensively with higher emissions, this could negate some of the forest related co-benefits. Conversely, if ETS rules are modified/relaxed in the future, more carbon capture may be able to be recognised, which may increase uptake in other sectors.

The main GHG benefits will be from carbon capture by the trees, with possibly some changes in N_2O emissions under forests. However, a key point is that forestry/tree planting for carbon benefits has a specific time frame and once full carbon capacity is reached in the forest then no further benefits can be realised without expansion of the area planted. Tree planting to offset GHG emissions from other sectors could therefore possibly be considered as a holding position until those sectors can address emission issues through changed management practices.

One possible negative effect is that the NPS-FWM also requires resource limits, e.g. water take allocation caps, setting of minimum flows and aquifer limits. As forestry is recognised as a land use that has a measurable detrimental effect on catchment water yield, it is possible as water resource limit setting advances that Regional Councils will further advance Land Use Policy and include constraints on forestry land use development in some water short catchments. This may therefore limit the further extent and growth of production forestry.

7.2 Implications of the results

7.2.1 Relativity between sectors

The sectors we have considered differ in absolute amounts of GHG emissions generated and in amounts of N and P lost to water (Table 7.11). The relative area of each enterprise, as reported by Anastasiadis et al. (2014), nationally are: c. 1.5 M ha dairy (5.7% of total land area), 7.7 M ha beef and sheep (28.8%), 0.46 M ha horticulture (1.7%) and 1.5 M ha forestry (5.7%). When making national scale assessments, the relativity between sectors in terms of GHG emissions and land coverage need to be considered.
Table 7.1. Summary of model values for the range of farms in this study.

Table 7.1: Summary of model values for the range of farms in this study.

Sector	Case study farm no.	N and P loss in water (kg/ha)		GHG	Contribution (%)			Area
		N	P	(kg CO_2-e/ha)	CH_4	N_2O	CO_2	(M ha)
Sheep & Beef	18	11-31	0.2-5.3	1288-7431 [4861][1]	34-81	15-65	1-5	7.7
Median		*16*	*1.0*	*4734*	*57*	*41*	*2*	
Dairy	8	36-61	0.5-2.3	9427-18459	46-69	17-47	7-15	1.5
Median		*44*	*1.1*	*11769*	*66*	*22*	*12*	
Cropping	12	14-240	0.1-2.5	1326-15000 [5980][2]	0-14[3]	17-87	13-83	0.5
Median		*32*	*0.4*	*3696*	*0*	*40*	*51*	
Forestry[4]		0.5-6	0.2	(27000)-(48000)	-			1.5

[1]lower maximum if the two most intensively managed farms are excluded
[2]lower maximum if the Southland vegetable farm is excluded (high N_2O emissions)
[3]Three rotations included grazing animals, which caused methane emissions
[4]Literature values

Our analysis shows that, at a farm and enterprise level, assessments are sensitive to assumptions made in terms of: the base farm set up; the mitigations implemented on the farm; and some of the underlying modelling algorithms/assumptions. Nevertheless, clear and consistent messages could be drawn from the data.

A major assumption is how the farms were set up to respond to mitigations. A key differential between sectors was that we assumed production would remain constant for dairy and the range of cropping systems evaluated, yet there would be ongoing increases in production per animal productivity in the sheep and beef sector as part of capturing the benefits of mitigation. To retain sustainable industry sectors we need to decrease N and P losses whilst increasing the profitability. The P21 farmlets have shown that it is possible to achieve significant reductions in N losses but have generally not made gains in profitability. We have borrowed heavily from those P21 experiences in developing our scenarios. The other main uncertainty around our data are the estimates of pollution swapping once housing is introduced.

A change of practices motivated by the nutrient limit setting process could potentially affect a farmer's bottom line, as was shown in economic studies that conclude that a de-intensification of dairy production would affect producers' profitability (Doole & Pannell 2012; Doole 2013). In contrast, in some situations further intensification might be the response to justify the additional capital expenditure on infrastructure, which may then result in an increase in emissions. However, farm practice change will be driven by a wide range of psycho-sociological factors that go well beyond profit maximisation, this is well demonstrated for the arable sector (Hume et al. 2015) where every farm was found to be different This data is not available for other sectors, however it would be reasonable to expect that like the arable farmers, farmers from other sectors would all implement mitigation practices differently and modify their systems in a different way; for example where lambs are grown faster and slaughtered earlier, how farmers manage feed supply will differ from conservation to purchase of more animals, each having a different impact on both nutrient losses and GHG emissions. The modelling has not considered the implications and trade-offs which would emerge depending on the returns from different stock classes on the farm. It has also not considered the issues with loss of breeding cows on pasture quality and woody weed management. However, it is necessary to include the economic bottom line regarding the different management strategies implemented to comply with the NPS-FWM, and its implications on GHG emissions, if future regional or catchment-level work were to be based on the matrix obtained in this project.

7.3 Relationships between GHG emissions and N leaching reductions – farm level

Distilling data from the numerous model scenarios summarised in the report allows us to estimate the relationships between reductions in N leaching losses and GHG emissions for the range of farm that were modelled (Figure 7.2). Figure 7.2 suggests a law of diminishing returns for the dairy and arable sectors but not for the sheep and beef sector. However, for that sector, Table 6.2 indicates (a) within the bounds of mitigations that were tested, it was not feasible to move beyond a 25% reduction in N losses and (b) even then, the number of farms in the group that we modelled that were able to achieve the target losses declined with each 5% incremental reduction in N leaching. Furthermore, the approach deemed most feasible for sheep and beef farms was reducing the grazed area through the introduction of trees for erosion control and reducing the number of animals wintered, because of the lift in per head performance. This is perhaps a key message: land-use change has potential to bring about larger gains GHG mitigation, but this may not be appropriate for all sectors, and it will only be appropriate on farms with areas of low potential productivity.

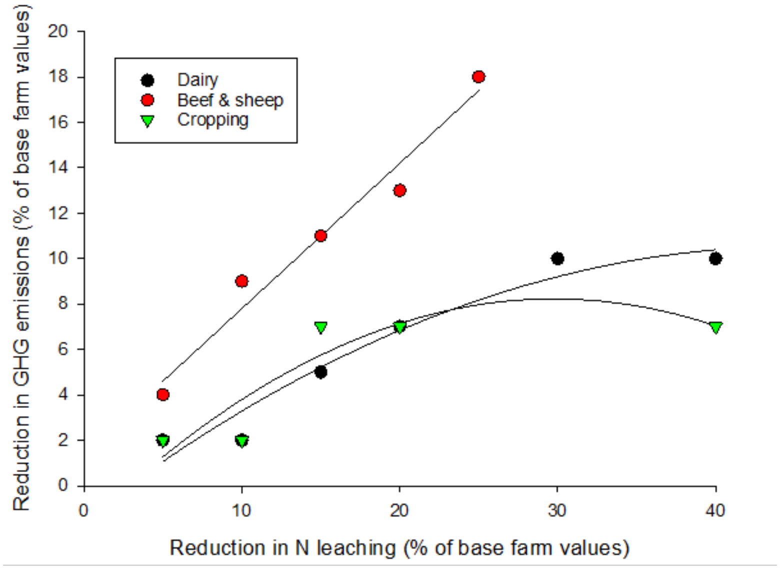


Figure 7.2: Estimates of typical potential GHG emission reductions associated with target N leaching reductions used in our modelling scenarios. Estimates are drawn from Tables 6.1-6.3.

7.4 Scaling up approximations

The original scope of the project was to focus on farm level investigations to assess the relationship between mitigations to decrease nutrient and sediment losses and effects on GHG emissions. However, with some large assumptions, we can use the data to estimate potential implications of water policy on benefits to GHG emissions and N leaching losses at a regional scale.

To do this we developed a very simple spreadsheet model using our median baseline N losses and GHG emissions to populate the model. We then used GHG emission reductions associated with target N leaching reductions of 5-40% interpreted with expert opinion from our summaries in Section 6 from each sector (Figure 7.2).

We tested spreadsheet approach with other data from the Southland region because there have been several published studies of total N leaching estimates from this region (Kaye-Blake et al. 2013; Ledgard 2014; Vibart et al. 2015). Using Southland land-use statistics published by Anastasiadis (2014) in the spreadsheet model gave a total N leaching estimate for the region from the three enterprises of 17600 t N. This is in remarkably good agreement with the values calculated by Vibart et al. (2015) who adopted a more detailed modelling approach for the region (16500-16900 t). Others have reported similar calculations in the range of 16500-18600 t, depending on assumptions (Kaye-Blake et al. 2013; Ledgard 2014). Furthermore, the split between sectors was also similar; 63/37% beef and sheep/dairy (Vibart et al. 2015) vs 60/40% in our estimates.

Table 7.2 shows the estimated effects on GHG emissions of a theoretical target reduction in N leaching of 10% for sheep and beef and (horticultural/cropping farms) and 20% for dairy farms. If all farmland achieved the target N reductions, the estimated effects would be a 14% decrease in N leaching and an 8% decrease in GHG emissions. However, this assumes that all farms needed to implement measures and all were successful. If an arbitrary ‘efficiency factor’ of 25% is introduced to recognise that not everyone would need to, nor would, be successful the result is a 3.5% decrease in regional N leaching and a 2% decrease in GHG emissions. Clearly, the results are highly dependent on the scenario and assumptions tested, but it gives an indication of the overall relationship between N leaching and GHG emissions. Being even bolder, we then entered national land-use data (Anastasiadis et al. 2014) into the spreadsheet (Table 7.2). Although the pastoral and cropping area estimates are shown in Table 7.2, we first examined the model's estimate of national losses of N by totalling the remaining land (forestry, scrub, non-productive, urban, lifestyle, indigenous forest, pasture/public land and DoC) and applied an average N loss value of 3 kg N/ha (a typical low level of N from forest and extensive pasture). This gave a total N leaching loss of 255 kt N, in line with the 2010 estimate of 271 kt N by Parfitt et al. (2012).

Focusing on the pastoral and cropping land, the estimated reduction in N loss (13%) and GHG emissions (8%) for a 100% implementation of these target reductions outlined in Table 7.2) was in line with the Southland data, which is not surprising. The national level benefit then depends on the 'efficiency' factor that is applied to implementing the policy across regions. In the model this is a linear relationship. Table 7.2 suggests that even a 30% implementation efficiency would yield only a 4% reduction in N loss overall and a concurrent 2-3% reduction in GHG emissions.

As stated before, this is based on a policy of no major enterprise change in the dairy and cropping sectors and on on-farm plantings and ongoing investment in higher animal performance in the sheep and beef sector. The introduction of trees on a sheep and beef farm effectively reduces the grazed area. Coupled with the investment in higher per head performance, which reduces the number of animals wintered, appears to break the law of diminishing returns between N loss reduction and GHG emission reduction (Figure 7.2). One conclusion is that further gains beyond Table 7.2 would require further change.

Table 7.2. An example of some simple scenarios based on scaling up of the farm analysis.

Land use	% of total area	Area (000 ha)	N leached (kg N/ha)	GHG emission. (kg CO_2-e/ha)	total N leached (t N)	tot GHG (Mt CO_2-e)	SCENARIO Target N reduction (%)	GHG reduction achieved (%)	Revised total N leached (t N)	Revised total GHG (kt CO_2-e)
SOUTHLAND REGION										
Beef & sheep	20.9	660	16	4734	10.6	3.12	10	9	9.5	2.84
Dairy	4.9	156	44	11769	6.8	1.83	20	7	5.5	1.70
Cropping	0.23	7.3	32	3696	0.23	0.03	10	2	0.21	0.03
					17.6	4.98			15.2	4.57
Effect if successfully implemented across all land								% reduction	14	8
Effect if successfully implemented across 25% of land								% reduction	3.5	2.1
NATIONAL										
Beef & sheep	28.8	7671	16	4734	123	36.3	10		110	33.0
Dairy	5.7	1518	44	11769	67	17.9	20		53	16.6
Cropping	1.7	452	32	3696	14	1.7	10		13	1.6
					204	55.9			177	51.3
*Effect if successfully implemented across **all** land*								% reduction	13	8
Effect if successfully implemented across 5% of land								% reduction	0.7	0.4
Effect if successfully implemented across 10% of land								% reduction	0.8	1.3
Effect if successfully implemented across 20% of land								% reduction	2.7	1.6
Effect if successfully implemented across 30% of land								% reduction	4.0	2.4

7.5 Case study comparisons

While the selection of staged reductions (10% etc.) to represent Regional Council policy responses is useful, it should be noted most of the measurable outcomes are still to be recognised from the National Policy Statement on Freshwater and National Objectives Framework. It should be also noted the value in freshwater policy is in the implementation and follow-up of each council at a catchment and farm scale on the broad polices and few to date actually have reduction targets locked in as enforceable limits (C. Arbuckle, Pers. Comm).

There is evidence that the mitigations that we included in the abatement curves are already being adopted by the industry as they strive to reduce nutrient losses from farms. This supports our approach. Furthermore an analysis of these examples indicates that the farms are generally starting with the low cost, easy-to-implement options, as indicated in our abatement curve approach.

7.5.1 Example 1. Dairy catchments study

Five streams in catchments with pastoral dairy farming as the dominant land use were monitored for periods of 7–16 years to detect changes in response to adoption of best management practices (BMPs) (Wilcock et al. 2013). These were the Inchbonnie and Waikakahi catchments (mainly free-draining stony soils); the Bog Burn catchment (silt-loams with mole and pipe drainage systems); and the Toenepi and Waiokura catchments (volcanic silt loams).

Surveys at the start and end of each catchment study showed an increased adoption of better effluent management, stream fencing and reduced P fertiliser inputs. Much of the change perhaps could be attributed to the Dairying and Clean Streams Accord. Interestingly, over the study periods (from 1995 or 2001 to 2008), N fertiliser inputs increased in 3 of the 5 catchments and only decreased in one catchment (Inchbonnie).

Monitoring of the streams showed a consistent downward trends in suspended solids and improved water clarity. There was also a (weaker) overall downward trend in E. coli concentrations. These improvements are in line with the adopted practices in the catchments that focussed on improved effluent and water irrigation management and stock exclusion from streams. Although P fertiliser inputs decreased, Total P concentrations in the streams were static, probably reflecting in part expected time lags between actions on the land and responses in aquatic systems. Total N concentrations increased in most of the catchments, reflecting the gradual intensification of farming as evidenced by increased milk production per hectare that was in turn supported by greater inputs of fertiliser N and purchased feed (Monaghan & DeKlein, 2014).

7.5.2 Example 2. Upper Waikato

Brocksopp et al. (2015) reported on the level of implementation of on-farm practice changes in the Upper Waikato catchment. Farms undertook a review of possible changes they could make as a part of the Sustainable Milk Plan (SMP) process. At the time of reporting, 439 farms had completed the process. Five main management areas were targeted, with four directly focused on nutrient (N and P), sediment and/or bacteria losses: nutrients, effluent, and land and waterways management.

A total of 5921 individual actions were recorded for the 642 participating farms, i.e. c. 9 actions per farm. Table 7.3 summarises the most and least popular actions that farmers identified for the 4 management areas relating to nutrient management. The list generally concurs with our abatement curves, both in content and the order of implementation, with low cost, 'low hanging fruit', options implemented first.

Table 7.3: Upper Waikato catchment: evaluation of the most and least popular voluntary actions identified by individual farms that they would implement on the farm (adapted from Burger et al. 2015).

Management area	Actions	
	Most popular	Least popular
Nutrients	Nutrient budget Fertiliser application Effluent nutrient management	Stocking rate Feed management
Effluent	Effluent planning Infrastructure/inflow capture Infrastructure/application	Infrastructure/feed storage and wintering/feed pads
Waterways	Fencing & riparian	Significant natural areas (0%)
Land	Improved crop cultivation practices Improve tracks, races, stream crossings Improve off pasture grazing practices (wintering, pugging, steep areas)	Pasture Planting for aesthetic

Mean reductions in farm nutrient losses were estimated to be 8% for N and 21% for P when all actions across all 642 SMP farms are fully implemented (Burger et al. 2016). These estimates are based on a mix of approaches, including OVERSEER, literature values and expert opinion. Potential load reductions on individual farms ranged from 0 to 35% for N and 0 to 73% for P, depending on the number and combination of actions being implemented.

7.6 Conclusions

- Results from our sector analyses of individual farm scenarios are reasonably consistent with other published analyses for reducing nutrient losses.
- Estimates suggest that, for dairy, N losses on a farm could be reduced by 10-20% without housing, based around lower N inputs into the system – with minimal impact on production. This is supported by recent research in the P21 programme. Targeting a reduction in N leaching losses of 20% resulted in a reduction in P loss on average of 23% and only a small reduction in GHG emissions of c.6%.
- The analysis has highlighted uncertainty around the degree of pollution swapping if housing is implemented on dairy farms, which could negate a large proportion of total benefits accrued form implementing less costly mitigations. Quantifying this pollution swapping risk associated with housing should be a research priority.
- For the sheep and beef sector, our analysis shows that shifting the use and management of land at risk of erosion, translates into reductions in sediment, P and, to a lesser extent N losses and GHG emissions. Less understood are the environmental gains from the ongoing productivity gains possible from improvements in per animal performance and livestock policy change. Targeting a reduction in N leaching losses of 5% resulted in a reduction in P loss on average of 11% (3-23%) and only a small

reduction in GHG emissions of 4% (range 1-10%). Importantly farm productivity increased on average to 110% of the base farm (range 94-130%).

- Modelling suggested there was less scope in the arable industry to implement wide ranging mitigations in complex rotations; however, where they were implemented in a rotation, the result was, on average, a c. 45% reduction in N leaching (and a 7% decrease in GHG emissions). The analysis suggested additional gains could be made from the following:
- Big wins in terms of reduced N leaching losses and GHG emissions come from improved irrigation practice
- Options to improve N use efficiency, while still at a research stage, are another opportunity for a big gain in N leaching reduction and GHG emission reduction from these systems. There are however diminishing returns from reducing N losses in relation to GHG emission reductions.
- The role of forestry will depend on the rules developed for gaining C credits on farms, regulated by current ETS rules which could change post Kyoto. Use of trees in sensitive parts of the farm to reduce P and sediment loss from Critical Source Areas is most applicable to the beef and sheep sector. There is less scope for incorporating trees into dairy farms without compromising production.
- Any assessment is sensitive to the assumptions made in terms of: the base farm set up; the mitigations implemented on the farm; and some of the underlying modelling algorithms/assumptions. Consequently, although agreement with other published studies are encouraging, all have relied (by necessity) on modelling and especially on OVERSEER. It was not straightforward to implement many of the potential mitigation strategies for the arable and horticultural sectors in the modelling framework, mainly because OVERSEER has been developed for assessing nutrient balances in the pastoral sectors.
- The benefits to GHG emissions from FWR will depend on the size of N leaching (and P loss) reduction targets and the proportion of land where mitigations will need to be implemented. There is still considerable uncertainty around that while regional policy continues to evolve.
- With these caveats around any estimates, a very general national scale calculation suggests that policy that would bring about on-farm changes to 20% of pastoral/cropping land would result in a 3% reduction in N leaching loads to water and would provide a benefit of c. 2% in GHG emission reduction.
- These average values for GHG mitigation hide a range of values determined by the wide diversity of enterprise types, options and locations in relation to nutrient management.
- However, in summary: co-benefits from implementing fresh water reforms on reducing GHG emissions will be small.

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