Ministry for Primary Industries
Manatū Ahu Matua

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

APPENDICES

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Prepared for the Ministry for Primary Industries

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1.1 Waikato

1.1.1 Waikato and Waipa Rivers

The Healthy Rivers: Plan for Change (http://www.waikatoregion.govt.nz/healthyrivers/) is dedicated to developing plan changes to the Waikato Regional Plan, to "help restore and protect the health of the Waikato and Waipa rivers". This project is led by the Collaborative Stakeholder Group (CSG) and supported by the Technical Leaders Group (TLG) who is responsible for collecting and analysing data and presenting results to the CSG to aid in decision making. Although the plan change is still being defined, fresh water limits will be defined giving effect to the NPS freshwater management and the National Objectives Framework and the Vision and Strategy for the Waikato and Waipa rivers. The limits focus on four contaminants, N,P E coli and sediment and the impact of these on fresh water values. The CSG have had a focus on understanding the impact of land use and land management on the generation of these contaminants and have explored a range of on farm mitigation tools and catchment wide tools such as wetlands and bunds to reduce emissions. It is likely that there will be a focus on-farm of using good practice and farm plans as initial tools to manage loss from farms. Policy is being developed to align with the requirements to reduce emissions and this may take the form of catchment rules, consented activities etc.

There are around 5,000 farms that will be affected by this new legislation, of which 2,500 are dairy farms. In general, the CSG considers N as the main contaminant from dairy and arable, while P and sediment are the contaminants of concern from drystock enterprises. Forestry is seen as less of a problem with spikes in nutrients at harvest but more important are the sediment loads coming from logging tracks. Faecal coliforms (e.g. E. coli as an indicator) are also a concern for dairy and drystock land uses.

At present, the TLG is undertaking modelling of land use and management changes to look at scenarios for a phased reduction in N, P, sediment and microorganisms. The modelling also includes economic estimates of the costs of implementing the proposed changes. The results of this modelling, and options for plan changes will be released shortly.

1.1.2 Lake Taupo

To protect the water quality of Lake Taupo, a market-based regulatory strategy has been implemented to 'cap' the inputs of N to the lake and then to reduce it by 20% by 2020 (http://www.waikatoregion.govt.nz/PageFiles/3918/V5%20Operative%20Version.pdf). The local government policy ("Variation 5") set a maximum N leaching value on individual farms based on their farming practices over the 2001-2004 benchmarking period, with N leaching calculated for these practices using the OVERSEER® Nutrient Budgets model (Wheeler et al., 2003). Nitrogen leaching is seen as the main risk to the lake, while phosphorus conditions will continue to be monitored and evaluated.

1.2 Bay of Plenty

1.2.1 Rotorua

Draft rules of the Rotorua Te Arawa Lakes Programme are based on the Lake Rotorua groundwater catchment (http://www.rotorualakes.co.nz/vdb/document/1255). The goal is to reduce the load of N to Lake Rotorua by 320 tonnes to achieve an annual N limit of 435 tonnes by 2032 (from current load of 755 t N/y), with 70% of the catchment target reached by 2022.

The strategy to achieve this target is to remove 50 t N/y through "engineering solutions" (to remove geothermal sources of N) and 30 t N/ha through gorse removal. A further 96 t N/y from dairy and 44 t N/y from drystock will be removed through Nitrogen Discharge Allowances (NDAs), and additional 100 t N/y through an incentives scheme (selling NDAs). The N leaching rates allowed for each sector are presented in Table A1.1.
Phosphorus limits are not specifically set, but are typically based on a lake's target trophic level index. Part of an individual farm property or a farming enterprise's N management plan shall identify the risks of sediment and P loss and best practices to reduce those losses shall be implemented.

Conditions set on forestry enterprises are that there is no grazing on the land, no transfer of NDAs and the period between harvesting and replanting is less than two **years.**

Table A1.1. Sustainable load to Lake Rotorua (according to Policy LR P1).

Sector	Sector area (ha)	Sustainable lake load by sector (t N/yr)	Sector proportion reduction (Integrated Framework)	N leaching rate by sector (t N/ha/yr) (OVERSEER® 6.2)
Dairy	5,016	324	35.3%	64.5
Drystock	16,266	416	17.2%	25.6
Forestry	19,215	54.0		2.8
• Production Forestry	8,946	22.5		2.5
• Bush/Scrub	10,269	30.9		3
House blocks	468	20.2		43.2

1.2.2 Wider region

The Bay of Plenty Regional council has adopted a "protect what we have" approach (Bay of Plenty, 2015a). The Regional Council has divided the Bay of Plenty Region into nine water management areas (WMAs) prioritising the Rangitaiki and Kaituna to begin the limit setting process in 2015.

The major land use activities and areas of concern in the Bay of Plenty (Bay of Plenty, 2015b) include animals grazing near waterways and soil disturbance leading to loss of sediment (e.g., earthworks) (See also Box 2A in Appendix). Specific soil types that require consideration are light volcanic soils, and steep greywacke hill country and organic (peat) soils.

1.3 Manawatu- Whanganui

Key issues for water quality in the region include: nutrient levels, algae growth and sediment. Around 75% of this region is classified as hill country and 40% of this land has potential for moderate to severe erosion. There is a need to mitigate this risk to preserve this productive land. The Sustainable Land Use Initiative (SLUI), a non-regulatory approach, that is backed up by regulations covering vegetation clearing and tracking, takes a 'mountains to the sea' approach to prevent accelerated erosion in hill country. SLUI is the key instrument being used in the region to reduce sediment and associated phosphorus losses to waterways.

The growing concern around the intensification of land use (e.g., dairy) in the region and the effect of increased nutrient and bacterial runoff on water quality was tackled in Horizons' regional policy document, the One Plan. For example, in the Upper Manawatu, one of the priority catchments (Mangatainoka), the amount of nitrogen in the river is 2.5 times the ecological limit, with 50% coming from dairy occupying less than 25% of the catchment. The One Plan has set targets for N reduction in these priority catchments (Table A1.2). Cyanobacteria, often referred to as blue-green-algae, has also been identified as an emerging issue affecting rivers and lakes in the region.

Table A1.2: One Plan Table 13-2 Cumulative nitrogen leaching maximum (kg N/ha/y) by Land Use Capability Class (LUC).

Year	**LUC 1**	**LUC 2**	**LUC 3**	**LUC 4**	**LUC 5**	**LUC 6**	**LUC 7**	**LUC 8**
1	30	27	24	18	16	15	8	2
5	27	25	21	16	13	10	6	2
10	26	22	19	14	13	10	6	2
20	25	21	18	13	12	10	6	2

1.4 Gisborne

The proposed Gisborne Regional Freshwater Plan will be publicly notified on 10 October 2015 (http://www.gdc.govt.nz/freshwater-plan/). The overall purpose of the plan is to guide the sustainable management of the region's rivers, streams, lakes, wetlands and groundwater. Two pollutants have been prioritised: pathogens (faecal coliforms) and sediment (suspended solids). Erosion creates high levels of sediment which is transported by rainfall, picks up faecal bacteria, and flows into streams and rivers. Therefore, improving water quality in this region is strongly tied to reducing erosion and reducing opportunities for faecal contamination of waterways.

River water quality is generally good in that it does not indicate high levels of nutrients, and biological indicators are generally good.

1.4.1 Erosion

Reducing erosion rates and the effects erosion has on waterways has long been a key issue, as the soft sedimentary rocks dominating in the region impose a very high erosion risk. Council's soil conservation activities seek to mitigate or prevent soil erosion caused by historical bush clearance for pastoral farming as well as more recent tree removal and earthworks.

The Sustainable Hill Country Project established the requirement for tree planting or maintaining tree cover on the most erosion-prone land. Works are to be completed and effective tree cover established by 2021. By mid-2012, 61% of properties and 90% of the land area with Land Overlay 3A requiring treatment had Works Plans completed or being progressed. The Combined Regional Land and District Plan (District Plan) requires that areas of land in Overlay 3A be treated with effective tree planting or reserve fencing.

1.4.2 Faecal coliforms

There are existing rules for riparian areas that control earthworks, vegetation clearance and structures. There is no regulation of stock access to waterways, and current rules allow stock entry to waterways. In comparison to other regions, the intensity of most farming operations would not warrant a blanket stock exclusion rule in this region.

1.4.3 Proposed freshwater targets

Most of the freshwater objectives outlined in the Proposed Gisborne Regional Freshwater plan are based on maintaining or improving nitrate, ammonia, dissolved oxygen, temperature, pH, sediment, dissolved reactive phosphorus (DRP), E.coli in rivers, and are not yet linked to farming activities. Specific Freshwater Targets have been formulated (provisionally) for three main management units (Gisborne District Council, 2015). Most of these management units target increasing dissolved oxygen levels, decreasing water temperature, reducing E.coli levels and reducing sediment loads. In the Poverty Bay Flats Freshwater Management Unit, there are also targets to reduce N and DRP concentrations. Targets are presented in the Appendix for the three main management units (Box 1A).

1.5 Environment Canterbury

Canterbury has a Land and Water Regional Plan. As well as the whole of region plan, catchment load limits are being set for each of 13 water management zones through Regional Catchment Plans and sub-catchment plans (target date 2015). The target is that by 2020, a programme will have been implemented to review existing consents where such reviews are necessary in order to achieve catchment load limits.

Many of the water management zones have been assessed and categorised as either Red (water quality not met) or as Orange (water quality at risk). The issues are predominantly N, but also relate to P, faecal indicator organisms (FIOs) and occasionally metals. Progress on environmental limit setting is variable with the four zones most advanced in the process (submission of plan and/ or decisions reached): Hurunui/ Waiau River; Hinds Plain; Selwyn-Waihora; and South Coastal Canterbury. These serve as useful indicators of likely targets across the region.

1.5.1 Hurunui/ Waiau River management zone

Phosphorus is considered to be the main contaminant of concern in this zone. Phosphorus limits are set at the 2005-10 catchment average (i.e. set for the receiving environment). Thus, P limits are at or around current values. There is some headroom for intensification, in terms of limits on N, with a 20% permissible increase in N loads at the river level. No farm limits have been set.

1.5.2 Selwyn-Waihora management zone

As with the Hurunui/ Waiau zone, the Selwyn-Waihora also is considered to be P-limited. The target reductions are:

- Reduce the receiving environment phosphorus load by 50%. Approximately half of the reduction is expected to be achieved by targeting the receiving waters (e.g., alum dosing). Although the remaining half will need to be achieved by reducing the catchment load, no specific P discharge allowances have been set because it is technically too difficult to set farm specific limits.
- For N, ‘low intensity’ users have some flexibility. From 2017, if nitrogen loss >15 kg N/ha/year (OVERSEER® estimates), farmers will need to achieve good management practice N loss rates for their existing (2009-13) land use. For nitrogen loss <15 kg N/ha/year, land use change is allowed, provided farmers operate at good management practice and loss rates do not exceed 15 kg N/ha/year.
- From 2022: all farms with losses of more than 15 kg N/ha/year will need to further reduce nitrogen losses (ranging from 30% for dairy to 7% for arable; Table A1.3).

Table A1.3: Percentage reduction in nitrate leaching applied for Zone Committee Solutions Package Selwyn-Waihora.

Land use	% reduction (nitrogen)
Dairy	30
Dairy support	22
Pigs	20
Irrigated beef, sheep or deer	13
Dryland beef, sheep or deer	2
Arable	7
Fruit, viticulture or vegetables	5
Other land use	0

1.5.3 Hinds/ Hekeao Plains management zone

The main issues in this zone relate to dairy and dairy support, with a gradual progress towards a target reduction by 2035 (Table A1.4).

Table A1.4: Target reductions (% of baseline using OVERSEER®) in required nitrogen loss rates beyond good management practice for the Hinds/ Hekeao Plains management zone.

	2020	2025	2030	2035
Dairy	15	25	35	45
Dairy support	10	15	20	25
Other agriculture	0	0	0	0

1.6 Southland

Southland is drained by four major river catchments, the Waiau, Mataura, Oreti and Aparima River. Combined, these cover 54% of the region. Pressures on water quality in Southland are mainly due to agricultural intensification, and industrial and urban waste water discharges (Environment Southland, 2015). While water quality is generally excellent in natural state areas such as Fiordland, many lowland rivers and streams show elevated levels of nutrients. Water quality issues across the region vary but include sediment, N, P and bacteria contamination. Water quality is good in conservation areas (Fiordland and Stewart Island) and in 'low intensity' (hill and high country) areas. In contrast, the Mataura and Oreti rivers are polluted often associated with the increasing pressure that growth in farming and urban communities has placed on the region's waterways.

In terms of limit setting, Environment Southland is establishing a new Water and Land Plan under a new project called: Water and Land 2020 and Beyond. The timetable for development of catchment plans is shown in Table A1.5.

Table A1.5: Timetable for development of catchment plans.

Catchment	Start date
Fiordland and Stewart Island	2016
Mataura	2017
Aparima	2017
Waiau	2018
Oreti	2018

A 2-pronged approach to managing water quality is currently being pursued. The first involves the development of a set of 'Interim Measures' that are intended to "hold the line" in terms of stopping any further decline in water quality, against the backdrop of continuing changes in land use patterns and intensity. These on-farm measures are proposed as the minimum standard for operations in Southland and are being put forward to ensure that stakeholders are in the best possible position when catchment limits will have to be set. The measures currently being considered include:

- Managing critical source areas of runoff;
- Hill country development and cultivation of steep land;
- Stock access to waterways;
- Nutrient management;
- Riparian management, and
- Managing intensive winter grazing operations.

The second approach to guide limit setting is categorizing the region into different physiographic zones. The science team at Environment Southland has identified how these zones vary according to factors such as water origin, soil type, geology and topography. Each zone is different in the way contaminants build up and move through the soil and aquifers, and into streams and rivers. This approach has provided a framework from which the council has been able to develop proposed policies and rules based on the particular issues for each zone. For example, in a zone where groundwater nitrate is the main issue, there may be more requirements around managing nitrate than in zones where nitrate is not the main issue.

2. Appendix II - Mitigations to decrease nutrient and sediment losses to water

2.1 Qualitative evaluation of individual potential mitigations

There is a range of mitigation options available that can potentially reduce sediment and nutrient losses to water. Table A2.1 presents a list of the most common approaches for meeting water quality targets. Detailed explanations of most of these mitigations and estimates of effectiveness can be found in Cairns et al. (2001), McDowell& Nash (2012) and Barber (2014).

In order to test our results from OVERSEER modelling we gathered information on the likely size of effects of individual mitigations based on results from a multi-million pound long-term project from the UK. 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 (Newell-Price et al. 2011; Cuttle et al. 2016). 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 therefore mapped our list of proposed mitigations against this User Manual and have summarised their estimates of effect sizes in Table A2.2. We identified other mitigations that could be added to our original list (Table A2.3). There were some difficulties in mapping the User Manual mitigations against our compiled list. Some were not relevant (Table A2.4), mainly due to a large emphasis on manure management.

Table A2.1: Summary of mitigations identified, target pollutant and relevant enterprise. Coloured fills denote where the mitigation is relevant to that sector X denotes the mitigations we have focused on in our modelling.

Mitigation	Target			Sector & most appropriate mitigations				
	P	N	Z	Dairy	S&B	Arable	Hort	Forestry
Optimum Olsen P	X			X		X		
Constructed/Facilitated wetland	X	X		X	X			
Sediment traps	X		X		X			
Low solubility P fertiliser	X			X	X			
Reduce inputs of N fertiliser		X		X	X	X		
Temporary fencing with geotextile to intercept sediment (silt fence)	X		X					X
Fenced Riparian forest species planting	X	X	X	X	X			X
Short rotation nutrient stripping forestry/energy regime	X	X	X	X				X
Grass buffer strips	X	X	X	X				
Account for soil mineralisation during growth period as well as for nutrients retained by catch crops		X					X	
Edge-of-field sediment traps/ filters	X		X					X
Tissue and Soil testing prior to fertiliser application	X	X				X	X	
Matching fertiliser applications to plant demand	X	X				X	X	
Planted forest or regeneration of native vegetation to reduce risk of soil erosion	X		X		X			X
Open-Spaced planted trees to reduce erosion	X	X	X		X			X
Exclusion of heavy weight cattle rom hill and steep lands in winter months	X		X		X			
Better irrigation management	X	X		X		X	X	
Stream fencing	X	X	X		X			
Restricted grazing (Tailored to region)	X	X	X	X	X			
Decrease stocking rate to match lower N inputs (and increased per head performance)	X	X	X	X	X			
Change stock class	X		X		X			
Change supplementary feed to Low N feed		X		X				
Cut and Carry	X	X	X	X				
Deferred effluent irrigation (pond storage)	X	X		X				
Increased effluent application area	X	X		X				
Reduce inputs of N fertiliser to winter forage crops coming out of long term pasture		X		X				
Strategic grazing of winter forage crops	X		X	X	X			
Alternative Wallowing	X		X		D			
Fence line pacing prevention	X		X		D			
Plant 'catch' crops and minimize fallow periods in rotations	X	X	X			X		X

Mitigation	Target			Sector & most appropriate mitigations				
	P	N	Z	Dairy	S&B	Arable	Hort	Forestry
Minimum till	X	X	X			X		
Improve placement of fertiliser (side dressing)	X	X				X		
Optimise timing of cultivation practices	X	X	X			X		
Improved residue management	X	X	X				X	
Split N fertiliser applications to match plant demand		X				X	X	
Longer rotation length	X	X	X					X
Modified forest harvesting regimes	X	X	X					X
Coppicing forest species	X	X	X					X
Alum to cropland or pasture	X			X	X			
Contour ploughing	X		X			X		
Wheel track dyking	X		X			X		
Wheel track ripping	X		X			X		
Stubble mulching	X		X			X		
Incorporation of manure after spreading	X				X	X		
Use slow release fertiliser products, or alternate fertiliser products		X		X	X	X	X	
Split pasture system (separate ryegrass & clover)	X			X	X			

Table A2.2: Estimated size of effect based on the Defra Diffuse Pollution User Manual (Newell-Price et al. 2011; Cuttle et al. 2016). See footnotes to the Table that explain the size estimates of effects. Greyed out cells are where there was no obvious match between NZ and UK descriptions. P-P = particulate P, P-S = soluble P, Z = sediment.

			Estimated size of effects[1]							
NZ Mitigation description		UK Mitigation description	NO_3-N	P-P	P-S	Z	NH_3	N_2O	CH_4	CO_2[A]
Optimum Olsen P	M32	Do not apply P fertiliser to high P index soils	-	L	M	-	-	-	-	-
Constructed/Facilitated wetland	M81	Establish and maintain artificial wetlands	L	M	L	M	-	L	L	L
Sediment traps										
Low solubility P fertiliser										
Reduce inputs of N fertiliser	M24	Reduce manufactured fertiliser application rates	L	L	L	-	L	L	-	L
Temporary fencing with geotextile to intercept sediment (silt fence)										
Fenced Riparian forest species planting										
Short rotation nutrient stripping forestry/energy regime	M3	Convert land to biomass cropping (i.e. willow, poplar, miscanthus)	M	M	L	M	L	M	L	L
	M2	Convert arable/grassland to permanent woodlands	H	M	L	M	M	H	L	L
Grass buffer strips	M14	Establish riparian buffer strips	L	M	L	M		L		L
Account for soil mineralisation during growth period as well as for nutrients retained by catch crops	(M22)	Use a fertiliser recommendation system	L	L	L	-	L	L	-	L
Edge-of-field sediment traps/ filters										
Tissue and Soil testing prior to fertiliser application										
Matching fertiliser applications to plant demand	M22	Use a fertiliser recommendation system	L	L	L	-	L	L	-	L
Planted forest or regeneration of native vegetation to reduce risk of soil erosion	M2	Convert arable/grassland to permanent woodlands	H	M	L	M	M	H	L	L
Open-Spaced planted trees to reduce erosion	(M2)	Convert arable/grassland to permanent woodlands	H	M	L	M	M	H	L	L
Exclusion of heavy weight cattle from hill and steep lands in winter months										
Better irrigation management	M82	Irrigate crops to achieve optimum yields	M	L	-	L	-	?	-	L
Stream fencing	M76	Fence off rivers and streams from livestock	L	L	L	-	-	-	-	L
Restricted grazing (Tailored to region)	M45	Out-wintering of cattle on woodchip	L	L	L	-	??	?	?	-
	M37	Reduce field stocking rates when soils are wet	L	L	L	-	L	L	?	L
	M35	Reduce the length of the grazing day/grazing season	L	L	L	-	L	L	?	L

NZ Mitigation description		UK Mitigation description	Estimated size of effects[1]							
			NO_3-N	P-P	P-S	Z	NH_3	N_2O	CH_4	CO_2[A]
Decrease stocking rate to match lower N inputs (and increased per head performance)	M41	Reduce overall stocking rates on livestock farms	L	L	L	L	L	L	L	L
Change stock class										
Change supplementary feed to Low N feed	M33	Reduce dietary N and P intakes	L	L	L	-	L	L	L	-
Cut and Carry										
Deferred effluent irrigation (pond storage)	(M52)	Increase the capacity of farm slurry (manure) stores to improve timing of slurry applications	L	L	M	-	L	?	?	-
Increased effluent application area										
Reduce inputs of N fertiliser winter forage crops coming out of long term pasture	(M22)	Use a fertiliser recommendation system	L	L	L	-	L	L	-	L
Strategic grazing of winter forage crops										
Alternative Wallowing										
Fence line pacing prevention										
Plant 'catch' crops and minimize fallow periods in rotations	M4	Establish cover crops in the autumn	M	M	L	M	-	L	-	L
Minimum till	M7	Adopt reduced cultivation systems	L	M	L	M	-	L	-	L
Improve placement of fertiliser (side dressing)	M27	Use manufactured fertiliser placement technologies	L		L	-	L	L	-	L
Optimise timing of cultivation practices	M6	Cultivate land for crops in spring rather than autumn	M	M	L	-	-	L	-	-
Improved residue management										
Split N fertiliser applications to match plant demand										
Longer rotation length										
Modified forest harvesting regimes										
Coppicing forest species										
Alum to cropland or pasture										
Contour ploughing	M9	Cultivate and drill across the slope	-	M	L	M	-	-	-	-
Wheel track dyking	M11	Manage over-winter tramlines	-	M	L	M	-	-	-	L
Wheel track ripping	M11	Manage over-winter tramlines	-	M	L	M	-	-	-	-
	(M8)	Cultivate compacted tillage soils	-	M	L	M	-	L	-	L
Stubble mulching										
Incorporation of manure after spreading	M73	Incorporate manure into the soil	L	L	L	-	M	?	-	-

NZ Mitigation description	UK Mitigation description	Estimated size of effects[1]							
		NO_3-N	P-P	P-S	Z	NH_3	N_2O	CH_4	CO_2[A]
Use slow release fertiliser products, or alternate fertiliser products									
Split pasture system (separate ryegrass & clover)									

[1]Key:
L = Low = average 10% change (range 1-30%); M = Moderate = average 40% change (range 20-80%); H = High = average 70% change (range 50-90%); - = no effect; ? = uncertain effect
Black text = reduction
Red bold text = increase
A: CO_2 effects exclude C sequestration

Table A2.3: Potential additional mitigations to decrease nutrient losses and GHG emissions and size of effects, based on the Defra Diffuse Pollution User Manual (Newell-Price et al. 2011; Cuttle et al. 2016). See Table 2 for key. P-P = particulate P, P-S = soluble P, Z = sediment.

	Mitigation description	Estimated size of effects[1]							
		NO_3-N	P-P	P-S	Z	NH_3	N_2O	CH_4	CO_2[A]
M5	Early harvesting and establishment of crops in the autumn	L	M	L	M	-	L	-	-
M10	Leave autumn seedbeds rough	-	L	-	L	-	-	-	L
M13	Establish in-field grass buffer strips on tillage land	L	M	L	M	-	L	-	L
M15	Loosen compacted soil layers in grassland fields	-	M	-	M	-	L	-	L
M19	Make use of improved genetic resources in livestock	L	L	L	-	L	L	L	-
M20	Use plants with improved nitrogen use efficiency	L	-	-	-	L	L	-	L
M21	Fertiliser spreader calibration	L	-	-	-	-	L	-	-
M23	Integrate fertiliser and manure nutrient supply	L	L	L	-	L	L	-	L
M25	Do not apply manufactured fertiliser to high-risk areas	L	-	L	-	L	L	-	L
M26	Avoid spreading manufactured fertiliser to fields at high-risk times	L	-	L	-	L	L	-	-
M30	Incorporate a urease inhibitor with urea fertiliser	L	-	-	-	M	L	-	-
M31	Use clover in place of fertiliser nitrogen	L	-	-	-	M	M	-	-
M34	Adopt phase feeding of livestock	L	L	L	-	L	L	L	-
M38	Move feeders at frequent intervals	L	L	L	L	L	L	L	L
M39	Construct water troughs with a firm but permeable base	L	L	L	L	L	L	L	L
M40	Low methane livestock feeds	-	-	-	-	-	-	L	-
M56	Anaerobic digestion of livestock manures	L	-	-	-	?	?	L	L
M63	Use liquid/solid manure separation techniques	L	L	L	-	?	?	-	L
M68	Do not apply manure to high-risk areas	L	L	L	-	-	L	-	-
M77	Construct bridges for livestock crossing rivers/streams	L	L	L	-	L	-	-	-
M78	Re-site gateways away from high-risk areas	L	L	L	L	-	L	-	L

Table A2.4: UK mitigations that are marginal or not applicable to NZ mainstream farming.

1A – Convert arable land to unfertilised and ungrazed grass
1B – Arable reversion to low fertiliser input extensive grazing
12 – Maintain and enhance soil organic matter levels
16 – Allow field drainage systems to deteriorate
17 – Maintain/improve field drainage systems
18 – Ditch management
28 – Use nitrification inhibitors
29 – Replace urea fertiliser with another nitrogen form (e.g. ammonium nitrate)
36 – Extend the grazing season for cattle
42 – Increase scraping frequency in dairy cow cubicle housing
43 – Additional targeted straw-bedding for cattle housing
44 – Washing down dairy cow collecting yards
46 – Frequent removal of slurry from beneath-slatted storage in pig housing
47 – Part-slatted floor design for pig housing
48 – Install air-scrubbers or biotrickling filters to mechanically ventilated pig housing
49 – Convert caged laying hen housing from deep-pit storage to belt manure removal
50 – More frequent manure removal from laying hen housing with belt clean systems
51 – In-house poultry manure drying
53 – Adopt batch storage of slurry
54 – Install covers on slurry stores
55 – Allow cattle slurry stores to develop a natural crust
57 – Minimise the volume of dirty water (and slurry) produced
58 – Adopt (batch) storage of solid manures
59 – Compost solid manure
60 – Site solid manure field heaps away from watercourses/field drains91
61 – Store solid manure heaps on an impermeable base and collect leachate
62 – Cover solid manure stores with sheeting
64 – Use poultry litter additives
65 – Change from a slurry to solid manure handling system
66 – Change from a solid manure to slurry handling system
67 – Manure spreader calibration
69 – Do not spread slurry or poultry manure at high-risk times
70 – Use slurry band spreading application techniques
71 – Use slurry injection application techniques
72 – Do not spread FYM to fields at high-risk times
74 – Transport manure to neighbouring farms
75 – Incinerate poultry litter for energy recovery
77 – Construct bridges for livestock crossing rivers/streams
79 – Farm track management
80 – Establish new hedges
83 – Establish tree shelter belts around livestock housing and slurry storage

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 NH_3 and N_2O emissions from these practices (M2 and M3, Table 1). *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 which results from larger housing losses and the associated deferred effluent irrigation (M35, M37, M45 and M52). This is potentially important because restricted grazing is seen as an effective tool to decrease nutrient losses to water, as demonstrated in our analysis later.

- Other mitigations have potential to increase GHG emissions. These include those: that use more energy (increased CO_2 emissions), e.g. for cultivation (M4);
- 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 (M7). One anomaly stands out: where irrigation has potential to increase N_2O emissions (M82). 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 less ponding/saturated conditions.
- Use of wetlands indicates increased GHG emissions (M81). Again, this has important implications because use of wetlands is seen as a possible solution for nutrient and sediment losses to water.

2.2 Mitigation matrix

We identified from our large list of potential mitigations (Tables above) those that would most likely be used to achieve target reductions. Tables A2.5-A2.7 summarise these for key enterprises. The list is based on those that were most practical and cost effective. We have included some extreme mitigations at the end of the list: cut and carry systems and large tree-lined riparian strips.

Table A2.5: Short-list of mitigations to achieve target reductions in N, P and sediment losses to water from dairy farms.

Category	Code	Mitigation description	Comments	Information source
Efficiency gains	M1	Optimum Olsen P	Fertiliser policy to run-down excessively high soil Olsen P levels	Fertiliser consultants
Efficiency gains	M2	Low solubility P fertiliser	Use low-solubility P fertilisers on soils and in environments where it is agronomically sensible to do so	Fertiliser consultants
Efficiency gains	M3	Increased effluent application area	Increase area to avoid excessive applications of potassium	Boyes & Monaghan (2004)
Efficiency gains	M4	Reduce inputs of N fertiliser winter forage crops coming out of long term pasture; and excessive N inputs to effluent blocks	Decrease N fertiliser applications to forage crops by c.30- 40% when crop is established after long-term grass (large soil N supply from pasture residues)	Evidence based on SFF project 11/010 (Lucci et al., 2013)
Efficiency gains	M5	Strategic grazing of winter forage crops	Protect waterway and graze towards Critical Source Areas to minimise P and sediment losses in run-off	Evidence based on P21 project (Orchiston et al. 2013)
Additional infrastructure	M6	Better irrigation management	Switch from boom to centre pivot and switch to soil moisture monitoring and variable rate applications to improve water use efficiency	Wheeler (2015)
Additional infrastructure	M7	Deferred effluent irrigation (pond storage)	Have sufficient storage of effluent to allow for more timely applications, thus avoiding run-off and leaching	Houlbrooke et al. 2004
N or C capture	M8	Constructed/Facilitated wetland	Intercept surface run-off and subsurface flows to remove N and sediment	Hughes et al. (2013)
Less N in the gate	M9	Decrease stocking rate to match lower N inputs (and increased per head performance)	Less feed grown due to lower N inputs. Match stocking rate to reduced feed grown.	Evidence based on P21 project[1]
Less N in the gate	M10	Change supplementary feed to Low N feed	Switch purchased grass silage to low-N feed types such as cereal, maize or PKE	Evidence based on P21 project[1]
Additional infrastructure	M11	Restricted grazing (Tailored to region) - winter use	June/July	Evidence based on P21 project[1]
Additional infrastructure	M12	Restricted grazing (Tailored to region) - winter and autumn use	Extend back to March to capture summer urine deposition	Evidence based on P21 project
N or C capture	M13	Grass buffer strips	Only of value if soil hydrology is such that there is significant surface water flows.	
N or C capture	M14	Fenced Riparian forest species planting	Adopt the specifications proposed in ETS (30 m buffer strips and area > 1 ha)	Scion
Additional infrastructure	M15	Cut and Carry	Extreme solution: case study only	De Klein, C. A. M. and S. F. Ledgard (2001)

[1]Dalley et al. 2015; Shepherd et al. 2014; Chapman et al. 2012; Monaghan & DeKlein 2014

Table A2.6: Candidate mitigations to achieve target reductions in N, P and sediment losses to water from sheep and beef farms

Code	Mitigation description	Comments
DrM1	Low solubility P fertiliser	Use low-solubility P fertilisers on soils and in environments where it is agronomically sensible to do so – highly suitable in these environments
DrM2	Sediment traps	Not captured in *Overseer*: effect likely to be small
DrM3	Stream fencing	
DrM4	Exclusion of heavy weight cattle from hill and steep lands in winter months	
DrM5	Decrease stocking rate to match lower N inputs (and increased per head performance)	
DrM6	Restricted grazing (Tailored to region)	
DrM7	Wetlands	
DrM8	Fenced Riparian forest species planting	Adopt the specifications proposed in ETS (discussed in Appendix II)
DrM9	Planted forest or regeneration of native vegetation to reduce risk of soil erosion	Adopt the specifications proposed in ETS (discussed in Appendix II)
DrM10	Open-Spaced planted trees to reduce erosion	Adopt the specifications proposed in ETS (discussed in Appendix II)

Table A2.7: Candidate mitigations to achieve target reductions in N, P and sediment losses to water from cropping and horticulture farms.

Code	Mitigation description	Comments
CrM1	Optimum Olsen P	Fertiliser policy to run-down excessively high soil Olsen P levels
CrM2	Tissue and Soil testing prior to fertiliser application	Best fertiliser practice
CrM3	Matching fertiliser applications to plant demand	Best fertiliser practice
CrM4	Split N fertiliser applications to match plant demand	Particularly on light (high risk) soils
CrM5	Improve placement of fertiliser (side dressing)	
CrM6	Better irrigation management	Switch from boom to centre pivot and switch to soil moisture monitoring and variable rate applications to improve water use efficiency
CrM7	Minimum till	On appropriate soils (and crops)
CrM8	Optimise timing of cultivation practices	Dependent on soil-type (and crop)
CrM9	Plant ‘catch’ crops and minimize fallow periods in rotations	
CrM10	Reduce inputs of N fertiliser	High economic risk unless base is over-fertilised to start with
HM1	Account for soil mineralisation during growth period as well as for nutrients retained by catch crops	
HM2	Tissue and Soil testing prior to fertiliser application	
HM3	Matching fertiliser applications to plant demand	
HM4	Better irrigation management	
HM5	Improved residue management	
HM6	Split N fertiliser applications to match plant demand	

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3. Appendix III - Modelling Afforestation on Farms

We used the Forest Investment Finder to estimate carbon sequestration and net present value for radiata pine afforestation on the farm types identified by AgResearch. Table A3.1 shows the farm descriptions and corresponding farm areas calculated by Scion.

Table A3.1: Farm descriptions and estimated land area.

Farm	Region	Soil (s)	Rainfall (s)	Topography	LUC	Scion farm area (ha)
Wai SB1	Waikato	Brown/Gley	900/1400	Rolling	3&4	1936
Wai SB1	Waikato	Brown/Gley	900/1400	Easy Hill	5	0
Wai SB1	Waikato	Brown/Gley	900/1400	Steep Hill	6	8252
Wai SB2	Waikato	Allophanic/Brown	900/1400	Easy Hill	5	0
Wai SB2	Waikato	Allophanic/Brown	900/1400	Steep Hill	6	18177
BoP SB1	Bay of Plenty	Pumice	1000/1800	Easy Hill	5	0
BoP SB1	Bay of Plenty	Pumice	1000/1800	Steep Hill	6&7	16090
Man SB1	Manawatu	Pallic	800/1200/1400	Easy Hill	5	207
Man SB1	Manawatu	Pallic	800/1200/1400	Steep Hill	6&7	66579
ManSB2	Manawatu	Brown/Pallic	800/1200	Rolling	3&4	9817
ManSB2	Manawatu	Brown/Pallic	800/1200	Easy Hill	5	213
ManSB2	Manawatu	Brown/Pallic	800/1200	Steep Hill	6	57472
Gis SB1	Poverty Bay	Recent	800/1400	Easy Hill	5	0
Gis SB1	Poverty Bay	Recent	800/1400	Steep Hill	6&7	67221
Gis SB2	Poverty Bay	Recent	800/1400	Easy Hill	5	same as Gis SB1
Gis SB2	Poverty Bay	Recent	800/1400	Steep Hill	6&7	same Gis SB1
Can SB1	Canterbury	Pallic/Brown	400/800	Easy Hill	5	87
Can SB1	Canterbury	Pallic/Brown	400/800	Steep Hill	7	12119
Can SB2	Canterbury	Recent	400/800	Flat	2	2764
Can SB2	Canterbury	Recent	400/800	Rolling	3	12890
Can SB2	Canterbury	Recent	400/800	Easy Hill	5	62
Can SB3	Canterbury	Recent	400/800	Flat	2	same as Can SB2
Sou SB1	Southland	Pallic/Brown	1000/1300	Flat	2	10012
Sou SB1	Southland	Pallic/Brown	1000/1300	Rolling	3	60288
Sou SB2	Southland	Pallic/Brown	800/1000	Flat	2	846
Sou SB2	Southland	Pallic/Brown	800/1000	Rolling	3&4	22609
Farm	Region	Soil	Rainfall	Topography	LUC	
Wai D2	Waikato	?	900/1400	?	?	
Wai D5	Waikato	?	900/1400	?	?	
BoP D4-5	Bay of Plenty	?	1000/1800	?	?	
BoP D6	Bay of Plenty	?	1000/1800	?	?	
Can D3	Canterbury	?	irrigated	?	?	No trees
Can D4	Canterbury	?	irrigated	?	?	No trees
Sou D3	Southland	?	800/1300	?	?	
Sou D4	Southland	?	800/1300	?	?	

The Scion sheep and beef farm areas used as the basis for calculating productivity, costs and revenues were selected using the following spatial data sets:

Step 1. All farms that are identified as Sheep & Beef selected from Agribase database. https://www.nlrc.org.nz/resources/datasets/agribase. Access to this spatial data base is on a one off fee to purchase the data at that date in time. Scion purchased this spatial data set in April 2016.

Step 2. Farms identified were then selected for each region specified. This Region dataset is available from koordinates (see link below) this is the definitive set of regional council boundaries for 2012 as defined by the Local Government Commission and/or the territorial authorities themselves but maintained by Statistics New Zealand. https://koordinates.com/layer/4240-nz-regional-councils-2012-yearly-pattern/

Step 3. Each regional farm was then selected for soil. The soil data was selected from the soil fundamental data layers (available from koordinates see link below). Selections were based on prominent soil occurring within a LRI unit using the New Zealand soil classification (NZSC) field. https://lris.scinfo.org.nz/layer/79-fsl-new-zealand-soil-classification/

Step 4. Rain fall ranges in each area was selected using NIWA national climate maps – These are maps of average annual rainfall that have been produced for all of New Zealand, based on the 30-year period 1981–2010. These spatial data sets are available on request and payment from NIWA. For more info see https://www.niwa.co.nz/climate/research-projects/national-and-regional-climate-maps

Step 5. LUC class areas were selected using NZLRI Land Use Capability spatial layer. Data available from https://lris.scinfo.org.nz/layer/76-nzlri-land-use-capability/
The New Zealand Land Resource Inventory (NZLRI) is a national database of physical land resource information. It comprises two sets of data compiled using stereo aerial photography, published and unpublished reference material, and extensive field work:

1. An inventory of five physical factors (rock type, soil, slope, present type and severity of erosion, and vegetation). A 'homogeneous unit area' approach is used to record the five physical factors simultaneously to a level of detail appropriate for presentation at a scale of 1:50,000.
2. A Land Use Capability (LUC) rating of the ability of each polygon to sustain agricultural production, based on an assessment of the inventory factors above, climate, the effects of past land use, and the potential for erosion. The NZLRI covers the country in 11 regions, each with a separate LUC classification.

The first edition NZLRI provides national coverage from mapping between 1973 and 1979 at a scale of 1:63,360. A limited revision regional upgrade of the north Waikato area was completed at a scale of 1:63,360 in 1983. Second edition NZLRI regional upgrades at a scale of 1:50,000 have been completed for Northland, Wellington, Marlborough and Gisborne-East Cape. Third edition NZLRI layers contained a restructured polygon attribute table to allow the core NZLRI to complement the newly created fundamental soil layers with minimal duplication.

Results of this analysis are presented in Table A1. Of note is that four farm types had no corresponding area while another two had less than 100 ha. For example, LUC 5 is uncommon nationally and was not found in Waikato or the East Coast. Consensus opinion was that forests were not compatible with irrigated dairy land on the Canterbury Plains due to the irrigators. Commercial forestry is a marginal proposition on the plains due to the low growth rates and risk of wind damage, although trees have traditionally played an important role in protecting stock and soils from wind.

The farm areas identified were used as the basis for estimating the potential carbon sequestration and profitability of radiata pine afforestation. This was modelled as an alternative to the conservative ETS lookup tables, and the approach uses spatial datasets to ensure that estimates are representative of the land actually available.

In this process:

- FIF identifies and accumulates 25m x 25m cells within farm boundaries within each farm type.
- For each cell, FIF determines the total stand carbon at the end of a 28 year rotation of the selected radiata pine regime. Four default regimes are available: pruned, structural, carbon and biomass. For this exercise we have assumed a structural regime.
- For each farm within a farm type, FIF reports the minimum, maximum and mean stand carbon at age 28, as well as the number of cells and the area. It is therefore possible to extract productivity measures for other sub-classes (e.g. mean sequestration rate on the worst and best 20% of area).
- FIF calculates the NPV of carbon net revenues using a conservative approximation. Rather than earning credits up until harvest then paying an immediate liability (due to harvest) and an ongoing liability (based on residue decay and wood product lifespans), the calculation assumes that credits are claimed and sold up to the value of half of the end of rotation carbon stock, with no future liabilities. Revenues are earned at a constant rate over the 28 year rotation with a constant annual cost of $60 incurred to cover the administration costs (registration, filing returns) and field measurement.
- The carbon NPV calculated is much less than would be calculated if credits are sold as they are earned and a liability paid back at harvest, but the approach avoids the risk of carbon price being higher when liability payments are due. Accounting up to half of the final rotation stock is approximately equivalent to accounting up until the long-term average over two rotations.
- FIF calculates the NPV of non-carbon net revenues using spatial data sets for establishment, tending, harvest and transport costs. MPI log prices were used.

For each farm type (row) a number of metrics have been estimated for different afforestation options. MPI’s ETS lookup tables have been used to provide estimates for indigenous forest and radiata pine. These are conservative estimates but provide a low cost option for landowners who can avoid the expense of establishing plots. FIF has been used to provide specific estimates for the farm type areas identified. Two alternatives are given:

- Mean sequestration rate from establishment until the year of harvest.
- Mean Sequestration rate assuming only half the total sequestration is claimed and sold. Carbon annuities presented are based on this approach, which avoids the risk from selling credits up until the year of harvest then having to pay a liability.

The data includes:

Indigenous forest:

a) Sequestration rate (t CO_2 ha^{-1} year^{-1}) assuming ETS Lookup table
b) Annuity from carbon revenues ($ ha^{-1} year^{-1}) assuming national ETS Lookup table

Radiata pine:

a) Sequestration rate (t CO_2 ha^{-1} year^{-1}) assuming ETS Lookup table.
b) Annuity from carbon revenues ($ ha^{-1} year^{-1}) assuming regional ETS Lookup tables.
c) Mean Sequestration rate (t CO_2 ha^{-1} year^{-1}) over 28 years assuming FIF productivity estimate. This addresses the question of farm emissions offset during the growing phase of a forestry crop’s first rotation.

d) Mean Sequestration rate assuming only half the total sequestration is claimed and sold. This acknowledges harvest liabilities and approximates sequestration up to the long-term average carbon stock.
e) Annuity from carbon revenues ($ ha^{-1} year^{-1}) assuming only half credits are sold. This assumes a carbon price of $15/t CO_2 and a constant annual compliance cost of $60 ha^{-1} (which in present value terms is similar to actual registration and compliance costs at five-yearly intervals).
f) Annuity from timber revenues for a 28 year rotation ($ ha^{-1} year^{-1}).

Note: Sequestration values are calculated from carbon stock changes only – this is not a full lifecycle analysis and does not account for emissions from fossil fuels used in forest management, or "avoided emissions" through the use of wood biomass for energy.

1.1 Forestry Profitability Calculation Assumptions

All data on costs and prices are an estimate at a generic/national level. These may not represent site specific costs precisely.

Data was extracted for each sub-catchment for a blanket cover (excluding urban, water bodies and DoC areas) of *Pinus radiata* structural (framing) regime (thinned to 500 stems ha^{-1} from initial planting of 900 stems ha^{-1}), with a rotation length of 28 years.

A discount rate of 8% was used as it broadly represents the range of discount rates used currently by forest growers for forest market valuations.

Prices for timber (Table A3.2) were based on an average price for each grade over 16 quarters (June 2012 – June 2015, inclusive) taken from MAF and Agrifax indicative domestic radiata pine log prices [1].

Table A3.2. Regime, log grades and carbon price

Regime	Discount Rate	Timber $/tonne	Carbon $/NZU
Structural (framing) regime (thinned to 600 spha from initial planting of 900 spha)	8%	S1 – $105 S2 – $100 S3 – $97 Pulp – $50	$15

For each regime the Net Present Value (NPV) of forestry in perpetuity was determined using discounted cash flow analysis. The minimum unit of area was a 25 x 25 cell (625 m^2).

Table A3.3. Data used to estimate the financial return

Costs (C)	Revenues (R)
Establishment (years 1,2,3 $/625m^2)	Timber ($/tonne)
Silviculture (Thinning, year 7 $/625m^2)	
Access road* construction ($/km)	
Internal landings ($/625m^2)	Carbon ($/NZU)
Internal road construction ($/625m^2)	
Harvesting ($/tonne)	
Transport# ($/tonne/km)	
ETS compliance ($/625m^2)	

1m^3 of *Pinus radiata* timber = 1 tonne

Modelling plantation forest establishment and management costs

The cost of establishing a new plantation forest involves purchasing and planting the crop, and the control of weeds to allow maximum tree growth during the crop establishment period. Establishment costs were adjusted to allow for slope class and included planting, releasing and site preparation. Thinning costs were also adjusted for hindrance.

Estimating within plantation forest landing and road costs

Modelling the cost of landings and roads was undertaken using landing and road density estimates. The density at which landings and roads occur within a forest was assigned to slope classes 0-10, 10-20, and >20 degree slope (Table A3.4).

Classification of landing density (L_{den}) was estimated from maximum haul distance (*MHD*) associated with rubber-tyred ground-based (0-10 degree slope), tracked ground-based (10-20 degree slope), and hauler (>20 degree slope), with estimated maximum haul distances of 325 m, 350 m, and 370 m, respectively.

Table A3.4. Landing and road densities developed across slope classes.

Slope (°)	Landing density (ha landing^{-1})	Road density (km ha^{-1})
0-10	10.6	0.062
10-20	12.3	0.057
>20	13.7	0.054

Road density used the same slope classification as landing density, but was calculated using:

$$R_{den} = (MHD * 2 / L_{den}) / 1000 \qquad (1)$$

The spatial datasets developed and used to estimate landing costs were grouped into three soil classes based on difficulty of earthworks, and into three slope classes (Table 3).
Landing construction costs were based on expert knowledge and published reports [2] (Richardson 1989). Landing construction times were derived by soil type and slope, and costs were calculated using 2011 machine costs.

For the estimation of internal road costs, a simplified version of impedance cost was developed from three slope classes, 0-5, 5-15, and >15 degree and four classes of erosion [3] (Bloomberg, et al., 2011).

Landing density (Table A3.4) was used to calculate the number of landings required for each slope class area within each forest. The costs associated with these landing densities where portioned to the number of landings required per cell (625 m2) within each slope class.

Slope classes in Table A3.4 were also used to estimate the road density requirements on a km ha^{-1} within a forest (Equation 1). The construction cost was then used to estimate the realistic cost of road construction within forests on a per cell basis assigned across the slope and ESC classes.

Calculation of harvesting costs

Harvesting costs (H_{cost}) were given to forests using slope classes for the North and South Islands by assigning the Agrifax value (Table A3.5). The stems per hectare to be harvested were converted to stems per 625 m^2 cell and given the Agrifax value associated with harvesting costs. Harvesting cost was calculated using:

H_{cost} = *Yield* * Agrifax value (2)

Table A3.5. Estimated logging cost ($ per tonne) by terrain/system and location

Slope	Island	Extraction type	Agrifax value ($)
0-10	North Island	Flat Ground-based	21
10-15	North Island	Tracked Ground-based	26
15-20	North Island	Steep Tracked	30
>20	North Island	Hauler	39
0-10	South Island	Flat Ground-based	26
10-15	South Island	Tracked Ground-based	26
15-20	South Island	Steep Tracked	31
>20	South Island	Hauler	33

Calculating transport costs

The calculation of transport costs from the farm location to the closest destination (port, saw mill, processing plant) was undertaken on a distance basis. The total tonnage of timber produced from each cell located on the farm was multiplied by distance in kilometres and the cost of transport, estimated to be $0.22 per km.

Development of productivity surfaces

The productivity surfaces for *Pinus radiata* [4,5,6] (Palmer et al., 2009; 2010a and 2010b) was developed by combining advanced statistical techniques with mapping technology to predict 300 Index and Site Index for any location in New Zealand. The 300 Index is an index of volume mean annual increment, and Site Index measures height at a reference age. The maps of Site Index and 300 Index were developed using growth measurement data from trees in 1,146 permanent sample plots in radiata pine stands planted between 1975 and 2003. The data was combined with a number of climate, land use, terrain and environmental variables to predict forest productivity under a range of conditions. For more details refer to Palmer et al. 2009 [4].

A purpose written python routine calculates volumes of each log grade in cubic metres ha^{-1} for a structural regime, from the 300 Index and Site Index surfaces in association with regression model coefficients. A similar routine calculates annual carbon sequestration surfaces in tonnes of CO_2.

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4. Appendix IV – Enterprises

Table A4.1: Details (annual data) of the Waikato region dairy systems, including support land.

Region:	Waikato	Waikato
Farm area platform (ha)[1]	150.5	159.9
Farm area support (ha)[1]	11.1	30.6
Peak cow numbers[1]	420	477
Stock rate (cows/ha)[1]	2.79	2.98
Lactation length (days)[1]	233	240
Fertiliser inputs (kg N /ha)[1]	113	134 kg N
Cow wintering strategy[3]	pasture + feedpad for supplements	on farm
Variants: Rainfall[2]	900 - 1400	900 - 1400
Variants: Soil type[2]	Brown; Allophanic	Brown; Allophanic
Variants: Slope[2]	Flat and rolling	flat
Crop block		
Crop type[3]	maize silage	maize silage
Crop consumed (t DM)[3]	65	376
Assumed crop yield (t DM/ha)[4]	20	20
Grazing months[3]	fed as supplement (winter and shoulders)	fed as supplement (winter and shoulders)
Support block (including area for young stock)		
Crop type[3]	Baleage	Baleage
Crop consumed (t DM)[3]	65	376
Assumed crop yield (t DM/ha)[4]	15	15
Area for young stock[3]	0	0
Production (kg MS/y)[1]	137,340	188,415
Production (kg MS/cow/y)[1]	327	395
Production system	2	5

[1]DairyBase; [2]Spatial information; [3]Expert opinion; [4]DairyNZ (2012)

Table A4.2: Details of the dairy enterprises in the Bay of Plenty (BoP) region, including support land.

Region:	BoP	BoP
Farm area platform (ha)[1]	142.8	131.5
Farm area support (ha)[1]	28.3	26.2
Peak cow numbers[1]	439	387
Stock rate (cows/ha)[1]	3.1	2.94
Lactation length (days)[1]	251	252
Fertiliser inputs (kg N /ha)[1]	130	122
Irrigation (mm/y)	0	100-200
Irrigation area (% platform)[1]	-	14%
Cow wintering strategy	pasture + feedpad for supplements	pasture + feedpad for supplements
Imported supplements: by-product (t)	600 t PKE	None
Variants: Rainfall[2]	1000-1800	1000-1800
Variants: Soil type[2]	Brown; Pumice; Recent	Pumice; Recent
Variants: Slope[2]	flat and rolling	flat and rolling
Crop block		
Crop type[3]	maize silage	maize silage
Crop consumed (t DM)[3]	262	119
Assumed crop yield (t DM/ha)[4]	20	20
Grazing months[3]	fed as supplement (winter and shoulders)	fed as supplement (winter and shoulders)
Support block (including area for young stock)		
Crop type[3]	Baleage	Baleage
Crop consumed (t DM)[3]	262	119
Assumed crop yield (t DM/ha)[4]	15	15
Area for young stock[3]	0	0
Production (kg MS/y)[1]	198,428	154,413
Production (kg MS/cow/y)[1]	452	399
Production system	4/5 (high)	3

[1]DairyBase; [2]Spatial information; [3]Expert opinion; [4]DairyNZ (2012)

Table A4.3: Details of the dairy enterprises in the Canterbury region, including support land.

Region:	Canterbury	Canterbury
Farm area platform (ha)[1]	220.0	211.1
Farm area support (ha)[1]	55.7	60.3
Peak cow numbers[1]	780	752
Stock rate (cows/ha)[1]	3.5	3.56
Lactation length (days)[1]	257	258
Fertiliser inputs (kg N /ha)[1]	233	241
Irrigation (mm/y)	400-600	400-600
Irrigation area (% platform)	100%	100%
Cow wintering strategy	on crop late May- early Aug	on crop late May- early Aug
Variants: Rainfall[2]	400-800	400-800
Variants: Soil type[2]	Recent (stony); Brown; Gley	Recent (stony); Brown
Variants: Slope[2]	flat	flat
Crop block (rotating)		
Crop type[3]	Kale	Kale
Crop consumed (t DM)[3]	159	275
Assumed crop yield (t DM/ha)[4]	15	15
Grazing months[3]	May- Aug	May- Aug
Support block (including area for young stock)		
Crop type[3]	Baleage	Baleage
Crop consumed (t DM)[3]	129	649
Assumed crop yield (t DM/ha)[4]	14	14
Grazing months[3]	Sent to platform and winter crop	Sent to platform and winter crop
Area for young stock[3]	16	24
Production (kg MS/y)[1]	318,240	324,864
Production (kg MS/cow/y)[1]	408	432
Production system	3	4

[1]DairyBase; [2]Spatial information; [3]Expert opinion; [4]DairyNZ (2012)

Table A4.4: Details of the dairy enterprises in the Southland Region.

Region:	Southland	Southland
Farm area platform (ha)[1]	239.1	213.3
Farm area support (ha)[1]	111.8	96.8
Peak cow numbers[1]	660	638
Stock rate (cows/ha)[1]	2.76	2.99
Lactation length (days)[1]	253	261
Fertiliser inputs (kg N /ha)[1]	140	146
Cow wintering strategy	off farm 2 months	cows off farm in June and on feedpad (1h/d) from July to Oct
Imported supplements by-product (t DM)	3t brewers grain	4t brewers grain + 354t PKE
Variants: Rainfall[2]	800-1300	800-1300
Variants: Soil type[2]	Brown; Pallic	Brown; Pallic
Variants: Slope[2]	flat	flat
Crop block (rotating)		
Crop type[3]	Swedes	Swedes
Crop consumed (t DM)[3]	264	126
Assumed crop yield (t DM/ha)[4]	13	13
Grazing months[3]	June-July	June-July
Support or runoff block 2 (including area for young stock)		
Crop type[3]	Pasture silage	Pasture silage
Crop consumed (t DM)[3]	94	184
Assumed crop yield (t DM/ha)[4]	12	12
Grazing months[3]	Sent to platform and winter crop	Sent to platform and winter crop
Area for young stock[3]	25	25
Production (kg MS/y)[1]	279,180	279,444
Production (kg MS/cow/y)[1]	423	438
Production system	3	4

[1]DairyBase; [2]Spatial information; [3]Expert opinion; [4]DairyNZ (2012)

Table A4.5: Details of the dairy goat enterprise for the Waikato region, including support land from Ganche et al. (2015).

Region:	Waikato
Farm area platform (ha)	40
Farm area support (ha)	7
Perennial pasture	Ryegrass +White clover and Lucerne (65/35)
Peak numbers	600
Stock rate (doe/ha)	15
Lactation length (days)	289
Effluent system	Daily spray from sump; mostly solid spreading
Fertiliser inputs (kg N/ha)	150
Structures	Housed in barn year round
Imported supplements by-product (t)	3t Dried distillers grain
Variants: rainfall	900-1400
Variants: Soil type	Brown; Allophanic
Variants: slope	Flat to rolling
Support block	
Crop type	Maize grain
Prior land use	maize
Planting month	October
area (ha)	7
Production (kg MS/y)	45000
Production (kg MS/doe/y)	75
System	Fresh forages-based

Table A4.6: Details of the sheep and beef enterprises in the Waikato and Bay of Plenty (BoP) regions.

Region:	Waikato	Waikato	BoP
Effective area (ha)[1]	251	586	345
Crop area (ha)[1]	22	0	0
Sheep SU[1]	585	2627	1560
Cattle SU[1]	2047	1962	1823
Overall SU/ha[1]	10.5	7.8	9.8
Sheep:cattle ratio[1]	22	57	46
Variants: Soil type[2]	Brown; Gley	Brown; Allophanic	Pumice
Variants: rainfall[2]	900-1400	900-1400	1000-1800
Fertiliser inputs (kg/ha)[1]	12.4 kg N; 19 kg P	6.5 kg N; 15 kg P	10 kg N; 18 kg P
Irrigation (mm)	-	-	-
Variant: Slope[2]	Easy hill to hard hill	Hard hill	easy hill and hard hill
Class[3]	5	3	4

[1] Beef + Lamb 2015a; [2]Spatial information; [3]Beef + Lamb farm classes (Beef + Lamb 2015b)

Table A4.7: Details of the sheep and beef enterprises in the Manawatu and Gisborne regions.

Region:	Manawatu	Manawatu	Gisborne	Gisborne
Effective area (ha)[1]	922	195	944	375
Crop area (ha)[1]	7	4	5	9
Sheep SU[1]	4630	1286	4187	1942
Cattle SU[1]	2297	741	3154	1374
Overall SU/ha[1]	7.5	10.4	7.8	8.8
Sheep:cattle ratio[1]	67	63	57	59
Variants: Soil type[2]	Brown	Pallic; Brown	Brown	Brown
Variants: rainfall[2]	800-1400	800-1401	800-1400	800-1401
Fertiliser inputs (kg/ha)[1]	5 kg N/; 9 kg P	5 kgN/ha; 13 kg P/ha	4 kg N/ha; 10 kg P/ha	6 kg N/ha; 11 kgP/ha
Variant: Slope[2]	easy hill and hard hill	Rolling, easy hill (20/40/40)	easy hill and hard hill (50/50)	easy hill and hill (50/50)
Class[3]	3	5	3	4

[1] Beef + Lamb 2015a; [2]Spatial information; [3]Beef + Lamb farm classes (Beef + Lamb 2015b)

Table A4.8: Details of the sheep and beef enterprises in the Canterbury region.

Region:	Canterbury	Canterbury	Canterbury
Effective area (ha)[1]	7929	394	427
Crop area (ha)[1]	12	13	177
Sheep SU[1]	7481	2097	1864
Cattle SU[1]	2193	1124	1292
Overall SU/ha[1]	1.2	8.2	7.4
Sheep:cattle ratio[1]	77	65	59
Variants: Soil type[2]	Pallic; Brown	Recent	Recent
Variants: rainfall[2]	400-800	400-800	400-800
Fertiliser inputs (kg/ha)[1]	2 kg N; 2 kg P	8 kg N; 8 kgP/ha	10 kg N; 4 kg P
Variant: Slope[2]	hill and steep	flat; rolling; hill (50/37/13)	flat
Class[3]	1	6	8

[1] Beef + Lamb 2015a; [2]Spatial information; [3]Beef + Lamb farm classes (Beef + Lamb 2015b)

Table A4.9: Details of the sheep and beef enterprises in the Southland region.

Region:	Southland	Southland
Effective area (ha)[1]	230	527
Crop area (ha)[1]	10	4
Sheep SU[1]	2500	3372
Cattle SU[1]	222	811
Overall SU/ha[1]	12	8.0
Sheep:cattle ratio[1]	92	81
Variants: Soil type[2]	Pallic; Brown	Pallic; Brown
Variants: rainfall[2]	1000-1300	800-1000
Fertiliser inputs (kg/ha)[1]	9 kg N; 15 kg P	8 kg N/ha; 11 kg P/ha
Variant: Slope[2]	flat and rolling	flat and rolling
Class[3]	7	6

[1] Beef + Lamb 2015a; [2]Spatial information; [3]Beef + Lamb farm classes (Beef + Lamb 2015b)

Table A4.10: Details of the deer enterprise in the Southland region from Wall (Pers. Comm 2015).

Region:	Southland
Effective area (ha)	285
Crop area (ha)	16
Perennial pasture	Perennial ryegrass + white clover
Sheep SU	1995
Cattle SU	570
Deer SU	1710
Overall SU/ha	15.0
Variants: Soil type	Pallic; brown
Variants: rainfall (mm)	1000-1400
Fertiliser inputs N and P	only to crop DAP 250 kg/ha Nov; Urea 100 kg/ha Jan
Imported supplements	None
Variant: Slope	50% flat, 40% easy rolling, 10% hill

Table A4.11: Details of the Horticultural enterprises to be modelled for the Bay of Plenty region

Region:	Bay of Plenty	Bay of Plenty	Bay of Plenty
Crop	Kiwifruit	Kiwifruit	Avocado
Management	Integrated	Organic	
Sward management	herbicided rows pasture (mowed)	full pasture (mowed)	full pasture (mowed)
Pruning management	mulched (twice)	mulched (once)	mulched
Fertiliser inputs			
Foliar sprays	10-20 kg/ha Low Biuret Urea (twice)	-	100 kg/ha Low-Biuret Urea + 0.5% Magnesium Sulphate in >1500 l/ha (as required June-Aug) Zinc and Boron foliar sprays at critical stages of flowering as required
Ground fertilisation	450 kg/ha CAN total (300 kg/ha in August, 150 kg/ha in November)	600 kg/ha Fishmeal	30 kg/ha Potassium nitrate (August)
	175 kg/ha Muriate of Potash (August)	100 kg/ha Muriate of Potash	Lime as required to adjust pH (Sept)
	350 kg/ha Sulphate of Potash (August)	200 kg/ha Sulphate of Potash	200 kg/ha Gypsum (Sept)
	200 kg/ha 30% Serpentine Super (August)	600 kg/ha Biophos	400 kg/ha single Superphosphate (Sept)
	225 kg/ha Kieserite (August)	200 kg/ha Kieserite	75 kg/ha Kieserite + 25 kg/ha Zinc Sulphate (Sept)
	(5 t/ha Compost)	10 t/ha Compost	100 kg/ha Cuttings Avocado Regular Tree Mix (monthly from September to March)
	(400 kg/ha Lime)	3 t/ha Vermicast	50 kg/ha Potassium Nitrate (May)
Irrigation system	None	None	None
Crop Yield	40-50000 kg/ha @ 16.5% DM (cultivar-dependent)	28-34000 kg/ha @ 16.5% DM (cultivar-dependent)	12000 kg/ha
Variants: soil type	Allophanic, Pumice	Allophanic, Pumice	Allophanic, Pumice
Variants: rainfall	1100 - 1650	1100 - 1650	1100 - 1650

Table A4.12: Details of the Horticultural enterprises to be modelled for the Gisborne region.

Region:	Gisborne
Model enterprise	Viticulture
Crop	Vinegrapes (Chardonnay)
Sward management	full pasture (mowed)
Pruning management	Pruning in June, mulched
Foliar sprays	-
Irrigation system	-
Yield	15 t/ha @ 12% MC content
Variants: soil type	Recent, Gley
Variants: rainfall	800-1100

Table A4.13: Details of the arable crop rotation for the Manawatu region.

Region:	Manawatu
Crop rotation	Potatoes - Barley - Lettuce - Green oats
Crop 1	Potatoes
Planting	October
Cultivation	Intensive cultivation
Fertiliser inputs	500 kg/ha Nitrophoska total (split)
Irrigation system	as required (travelling irrigator)
Harvest	April
Yield	50-60 t/ha
Crop 2	Barley
Planting	April
Cultivation	Minimum tillage
Fertiliser inputs	600 kg/ha DAP (split application 60:40) 630 kg/ha CAN in January
Irrigation system	None
Harvest	January
Yield	8-10 t/ha
Crop 3	Lettuce
Planting	February
Cultivation	Discing
Fertiliser inputs	840 kg/ha Nitrophoska Blue TE banded dresssing
Irrigation system	as required (travelling irrigator)
Harvest	April
Yield	32 t/ha FW
Crop 4	Green oats
Planting	May
Cultivation	Minimum tillage
Fertiliser inputs	-
Irrigation system	None
Harvest	September
Yield	sprayed, ploughed in
Variants: soil type	Recent, Brown, (Gley)
Variants: rainfall	800-1100

Table A4.14: Details of the arable crop rotation for the Gisborne area.

Region:	Gisborne	Gisborne
Model enterprise	Vegetable Cropping	Arable cropping
Crop rotation	Summer Broccoli - Winter lettuce	Grain maize-Squash
Crop 1	Summer broccoli	Grain maize
Planting	October	October
Cultivation	Minimum tillage	Minimum tillage
Fertiliser inputs	150 kg/ha Sulphate of ammonia (pre-planting)	250 kg/ha Cropmaster 20 at planting
	300 kg/ha Potash Gold (at planting)	250 kg/ha Urea side dressing
	150 kg/ha CAN side dressing	
Irrigation system	30 mm every 14 days as required - travelling boom irrigator	None
Harvest	February	May - June
Yield	10 t/ha	12 t/ha @ 18-24% MC
Crop 2	Winter lettuce	Squash
Planting	April	October
Cultivation	Minimum tillage	Intensive cultivation
Fertiliser inputs	400 kg/ha Nitrophoska Blue at planting	200 kg/ha Cropmaster 20 at planting
	80 kg/ha Urea side dressing	200 kg/ha Urea side dressing (November)
Irrigation system	None	as required per soil water balance
Harvest	September	February - March
Yield	25 t/ha @ 7% DM	15 t/ha @ 35% MC
Variants: soil type	Recent	Recent
Variants: rainfall	800-1100	800-1100

Table A4.15: Details of the arable crop rotations for the Canterbury region.

Region:	Canterbury	Canterbury
Crop rotation	Maize-Wheat-Kale-Triticale	Barley - Oats + Italian ryegrass - Barley
Crop 1	Maize silage	Barley
Planting	October	October
Cultivation	Intensive cultivation	Intensive cultivation
Fertiliser inputs	240 kg/ha Nitrophoska at sowing 50 kg N/ha (urea) at sowing 100 kg N/ha (urea) during growth	150 kg/ha CropMaster 15 at sowing 50 kg N/ha (split)
Irrigation system	centre pivot	centre pivot
Harvest	March-April	January
Yield	23 t DM/ha	16 t DM/ha
Crop 2	Wheat	Oats + Italian Ryegrass
Planting	March	February-March
Cultivation	Intensive cultivation	Minimum tillage
Fertiliser inputs	160 kg/ha CropZeal20N at sowing	200 kg/ha CropZeal20N at sowing 50 kg N/ha (split)
Harvest	October	October
Yield	6 t DM/ha	7 + 0.3 t DM/ha
Crop 3	Kale	Barley
Planting	October	October
Cultivation	Intensive cultivation	Intensive cultivation
Fertiliser inputs	240 kg/ha DAP + 15 kg/ha Boronate at sowing 200 kg N/ha (urea) during growth	150 kg/ha CropMaster 15 at sowing 50 kg N/ha (urea, twice during growth)
Harvest	March - April	January
Yield	21 t DM/ha	16 t DM/ha
Crop 4	Triticale	
Planting	–March - April	
Cultivation	Intensive cultivation	
Fertiliser inputs	160 kg/ha CropZeal20N at sowing	
Harvest	September - October	
Yield	4 - 5 t DM/ha	
Variants: soil type	Brown, Pallic, Recent	Brown, Pallic, Recent
Variants: rainfall	500-800	500-800

Table A4.16: Details for the arable cropping rotations for the Waikato region.

Crop rotation	Maize-Annual Ryegrass	Potatoes-Onion-Carrots-Squash-Oats&Rye-Barley-Oats&Rye
Crop 1	Maize silage	Potatoes
Planting	October	September
Cultivation	Discing	Intensive cultivation
Fertiliser inputs	200-300 kg/ha DAP at planting 200-300 kg/ha Urea side dressing	200 kg N/ha at planting 100 kg N/ha side dressing (split)
Irrigation system	None	Centre Pivot
Harvest	March	March
Yield	22-26 t/ha @ 32-38% DM	50 t/ha
Crop 2	Annual ryegrass	Onion
Planting	April	June
Cultivation	Direct Drill	Intensive cultivation
Fertiliser inputs	50 kg/ha Urea (after each grazing)	50 kg N/ha evenly spaced throughout growth 50 kg N/ha 40 kg N/ha (urea)
Irrigation system	None	as required
Harvest	September-October	December - January
Yield	10 - 13 t/ha	45 t/ha
Crop 3		Carrots
Planting		May
Cultivation		Intensive cultivation
Fertiliser inputs		120 kg N/ha (split) 40 kg P/ha
Harvest		October
Yield		60 t/ha
Crop 4		Squash
Planting		November
Cultivation		Minimum tillage
Fertiliser inputs		80 kg N/ha at planting
Harvest		March
Yield		25 t/ha @ 35% MC
Crop 5		Oats & rye
Planting		April
Cultivation		Direct drill
Harvest		June
Yield		ploughed in
Crop 6		Barley
Planting		July
Cultivation		Direct drill
Fertiliser inputs		370 kg/ha CAN October 370 kg/ha CAN November
Harvest		February
Yield		7 t/ha
Crop 7		Oats & rye
Planting		March
Cultivation		Direct drill
Irrigation		None
Harvest		July
Yield		ploughed in
Variants: soil type	Brown, Allophanic	Brown, Allophanic, Granular
Variants: rainfall	900-1400	900-1400

Table A4.17: Details for the arable cropping rotations for the Southland region.

Region:	Southland	Southland
Model enterprise	Arable cropping	Vegetable cropping
Crop rotation	Forage brassica-Cereals-Potatoes	Potatoes-Carrots
Crop 1	Kale	Potatoes
Planting	December	August
Cultivation	Direct drill	Intensive cultivation
Fertiliser inputs	50 kg/ha triple superphosphate	200 kg N/ha
	150 kg/ha Urea	100 kg N/ha side dressing (twice, spaced out 6 weeks)
	150 kg/ha Urea	
Irrigation system	None	None
Harvest	May	March
Yield	13 t/ha DM	45 t/ha
Crop 2	Barley	Carrots
Planting	June	May
Cultivation	Direct drill	Intensive cultivation
Fertiliser inputs	370 kg/ha CAN October	120 kg N/ha (split) 40 kg P/ha
	370 kg/ha CAN November	
Harvest	February	October
Yield	6 t/ha	60 t/ha
Crop 3	Oats & rye	
Planting	March	
Cultivation	Direct drill	
Fertiliser inputs	-	
Harvest	July	
Yield	ploughed in	
Crop 4	Potatoes	
Planting	August	
Cultivation	Intensive cultivation	
Fertiliser inputs	200 kg N/ha	
	100 kg N/ha side dressing (twice, split)	
Harvest	February - March	
Yield	45 t/ha	
Variants: soil type	Brown, Pallic	Brown, Pallic
Variants: rainfall	800-1300	800-13000

Table A4.18: Details of the Radiata based Forestry enterprises to be modelled for the Bay of Plenty and Gisborne region.

Region:	Bay of Plenty/Gisborne	Bay of Plenty/Gisborne	Bay of Plenty/Gisborne
Crop	Radiata Clearwood	Radiata Framing	Radiata Pulp
Rotation length (yr)	28	28	25
Planting density (spha)	833 - 1100	833 - 1100	1000 - 1300
Cultivation	Dependent on topography, soil, veg cover, area. But could include: Deep ripping, rotary slashing, root-raking, roller or blade crushing, windrowing	Dependent on topography, soil, veg cover, area. But could include: Deep ripping, rotary slashing, root-raking, roller or blade crushing, windrowing	Dependent on topography, soil, veg cover, area. But could include: Deep ripping, rotary slashing, root-raking, roller or blade crushing, windrowing
Fertiliser inputs	n/a	n/a	n/a
Herbicide application	Pre plant mid-autumn 1 or 2 releases	Pre plant mid-autumn 1 or 2 releases	Pre plant mid-autumn 1 or 2 releases
Pruning management	1st year 3 2nd year 5 3rd year 8	n/a	n/a
Foliar sprays	Cu for dothistroma control	Cu for dothistroma control	Cu for dothistroma control
Waste thinning	Year 7	Year 7	Year 7
Final stocking (spha)	350	450	500
Variants: soil type	Allophanic, Pumice, Recent, Brown	Allophanic, Pumice, Recent, Brown	Allophanic, Pumice, Recent, Brown
Rainfall (mm)	1100 - 1650	1100 - 1650	1100 - 1650

Table A4.19. Details of the Douglas fir (D.Fir), Eucalypt and Redwood based Forestry enterprises to be modelled for the Bay of Plenty and Gisborne region.

Region:	Bay of Plenty/Gisborne	Bay of Plenty/Gisborne	Bay of Plenty/Gisborne
Crop	D.Fir framing	Eucalypt Pulp	Redwood sawlogs
Rotation length (yr)	45	15-20	35
Planting density (spha)	1600	1100	500
Cultivation	Dependent on topography, soil, veg cover, area. But could include: Deep ripping, rotary slashing, root-raking, roller or blade crushing, windrowing	Dependent on topography, soil, veg cover, area. But could include: Deep ripping, rotary slashing, root-raking, roller or blade crushing, windrowing	Dependent on topography, soil, veg cover, area. But could include: Deep ripping, rotary slashing, root-raking, roller or blade crushing, windrowing
Fertiliser inputs	n/a	n/a	n/a
Herbicide application			Pre plant mid-autumn 1st release year 1 2nd release year 2
Pruning management	n/a	n/a	1st year 7 2nd year 9 3rd year 11
Thinning regimes	One thin age 14-16	n/a	Self-thinning
Final stocking (spha)	600	1100	400-500
Irrigation system	None	None	None
Variants: soil type	Allophanic, Pumice, Recent, Brown	Allophanic, Pumice, Recent, Brown	Allophanic, Pumice, Recent, Brown
Rainfall (mm)	1100 - 1650	1100 - 1650	1100 - 1650

5. Appendix V – Mitigation options for arable and vegetable farms

Table A5.1: List of mitigation strategies to achieve target reductions in N, P and sediment losses to water from arable cropping.

Mechanism	Rank	OVS*	Mitigation description	Comments	Information source/ Evidence	Proposed change to typical rotations in Table 2
Lower N input	1	N	Matching fertiliser applications to plant demand	Requires good understanding of development of plant demands throughout the year; also opportunity for fine scale management of spatial aspects of fertiliser placement using PA approaches	By how much can current average application rates be reduced without inferring yield losses?	Expert estimates: Grain maize -5%; Silage maize -20%; Waikato vegetable cropping as changed in Table 2
Lower N input	1a	N	Account for soil mineralisation during growth period and for nutrients retained by catch crops	Requires good understanding of nutrient mineralisation capacity of the soil throughout the year	AMN, depending on soil type and previous land use, soil can mineralise between 20 and 200 kg N/ha year; timing of mineralization mainly dependent on soil temperature and moisture	
Lower N input	1b	N	Soil testing prior to fertiliser application	May help in deciding plant requirements	Deep mineral N	
Improve N efficiency	2	Y/N	Split N fertiliser applications to match plant demand; fertigation to apply little amounts of fertiliser often	Particularly in light (high risk) soils; fertigation is possible through pivot; unirrigated crop further splitting might be difficult	Splitting can reduce N leaching (Williams et al., 2003)	Assume that monthly even application rates match plant
Improve N efficiency	3	N	Improve placement of fertiliser (broadcast or knifing of fertiliser)	Direct impact of N losses	Placement can reduce N leaching in particular for plants with sparse rooting system (Williams et al., 2003)	

Mechanism	Rank	OVS*	Mitigation description	Comments	Information source/ Evidence	Proposed change to typical rotations in Table 2
Improve P efficiency	4	Y	Manage soil P levels within acceptable productivity norms (e.g., maize 15-30 mg/L Olsen-P)	Apply P fertiliser only when soil tests indicate the need, reduced soil P levels will reduce risk of P losses in runoff		
Improve efficiency	5	N	Improve selection of fertiliser material (controlled release fertilisers; CRFs)	Requires good understanding of plant demands throughout the year and clear understanding of when the nutrient is released in dynamic environment (soil moisture and temperature)	According to FAR on-going research is promising; CRFs can reduce leaching, particularly in areas with high rainfall (Martin et al., 2001)	Rule of thumb: to make the use of CRFs economically viable, need to reduce fertiliser use by about 25%
Immobilise soil N after harvest	6	Y	Improve residue management		Contrasting results on straw incorporation (Thomsen and Christensen, 1998)	
Lock up available P in plant tissues, avoid build-up of soil N after harvest	7	Y/N	Plant ‘catch’ crops (CC) or double-sown crops and minimize fallow periods in rotations	Stabilise soils and reduce risk of runoff and erosion during high rainfall in winter	N-uptake of CC: 200-300 kg/ha; CC reduced nitrate leaching by 53% (Fraser et al., 2012)	
Improve N/P efficiency – might need additional infrastructure	8	Y	Better irrigation management: match irrigation supply with infiltration rates (will vary with soil type and condition)	Switch from boom to centre pivot, soil moisture monitoring, variable rate applications to improve water and nutrient use efficiency		
Reduced erosion risk, slower N mineralisation	9	Y	Use reduced cultivation practices, such as minimum till or direct drill	Improve aggregation of soils through plant roots, reduce mineralisation losses, on appropriate soils (and crops) – contrasting results possible (Di and Cameron, 2002; Francis, 1995)		Some changes are suggested to current management practices in Table 2

Mechanism	Rank	OVS*	Mitigation description	Comments	Information source/ Evidence	Proposed change to typical rotations in Table 2
Avoid build-up of soil N after harvest	10	Y	Optimise timing of cultivation practices (early harvest, establishment of crops in autumn or late cultivation to shorten fallow period)	Dependent on soil-type (and crop) N mineralisation after cultivation/ fallow (March much higher than for May ploughing) (Francis, 1995)		
Capture of sediment & P	11	Y	Vegetated filter strips as attenuation zones to capture surface runoff and allow sediment to settle out	Efficiency dependent on topography, vegetation in buffer, width of buffer, buffer : field ratio etc.	Not much scope?	
Efficiency gain	12	N	Wheel track ripping or furrow dyking	Heavier soils where infiltration is reduced due to compaction	Localised, not much scope?	
Efficiency gain	13	N	Use precision cropping technologies for fertiliser application (GPS guidance); Calibration of fertiliser spreader	Delivers more precise nutrient inputs, upgrade of technology needed	High scope	

*Included in current version of Overseer

Table A5.2: Typical example scenarios for arable cropping. Management in red & brackets represents proposed mitigation strategies.

Region:	Manawatu	Gisborne	Gisborne	Gisborne	Canterbury	Canterbury	Waikato	Waikato	Southland	Southland
Model enterprise	Arable cropping	Vegetable Cropping	Arable cropping	Arable cropping	Arable cropping	Arable cropping	Arable cropping	Vegetable cropping	Arable cropping	Vegetable cropping
Crop rotation	Potatoes - barley - spring onion-green oats	Summer Broccoli - Winter lettuce	Grain maize-Squash (include cover crops after both crops; e.g., annual ryegrass)	Grain maize-Grain maize	Maize-wheat-kale-triticale	Barley - Oats + italian RG - Barley	Maize-annual ryegrass	Potatoes-onion-carrots-squash-oats&rye-barley-oats&rye	Forage brassica-cereals-potatoes	Potatoes-carrots
Crop 1	Potatoes	Summer broccoli	Grain maize	Grain maize	Maize silage	Barley	Maize silage	Potatoes	Kale	Potatoes
Planting	October	October	October	October	October	October	October	September	December	August
Cultivation	IC (intensive cultivation)	MT (minimum tillage)	MT	MT	IC (MT)	IC (MT)	discing (MT or DD)	IC	DD (direct drill)	IC
Fertiliser inputs	500 kg/ha Nitrophoska total (split application: at planting & 1-2 side dressing)	300 kg/ha Potash Gold	250 (235) kg/ha Cropmaster 20	235 kg/ha Cropmaster 20	240 (200) kg/ha Nitrophoska	150 kg/ha CropMaster 15	250 (200) kg/ha DAP	200 (100) kg N/ha	50 kg/ha triple superphosphate	200 kg N/ha
		150 kg/ha CAN side dressing	250 (235) kg/ha Urea side dresssing	235 kg/ha Urea side dresssing	50 (40) kg N/ha (urea)	50 kg N/ha (urea, twice during growth)	250 (200) kg/ha Urea	100 (50) kg N/ha side dressing (twice, spaced out 6 weeks)	150 kg/ha Urea	100 kg N/ha side dressing (twice, spaced out 6 weeks)
					100 kg N/ha (urea)				150 kg/ha Urea	

Region:	Manawatu	Gisborne	Gisborne	Gisborne	Canterbury	Canterbury	Waikato	Waikato	Southland	Southland
Irrigation system	as required (travelling irrigator)	30 mm every 14 days as required - travelling irrigator	None	None	as required (centre pivot)	as required (centre pivot)	None	as required	None	None
Harvest	April	February	May - June	May	March-April	January	March	March (Feb-May)	May	March
Yield	50-60 t/ha	10 t/ha	12 t/ha @ 18-24% MC	12 t/ha @ 18-24% MC	23 t DM/ha	16 t DM/ha	22-26 t/ha @ 32-38% DM	50-60 (30-80) t/ha	13 t/ha DM	45 t/ha
Crop 2	Barley	Winter lettuce	Squash	Annual ryegrass	Wheat	Oats + Italian RG	Annual ryegrass	Onion	Barley	Carrots
Planting	April	April	October	May	March	February-March	April	June	June	May
Cultivation	MT	MT	IC (MT)	DD	IC (MT)	MT	DD	IC	DD	IC
Fertiliser inputs	600 kg/ha DAP split application 60:40	400 kg/ha Nitrophoska Blue	200 kg/ha Cropmaster 20	50 kg/ha Urea (after each grazing)	160 kg/ha CropZeal20N	200 kg/ha CropZeal20N	50 kg/ha Urea (after each grazing)	400 (200) kg/ha Nitrophoska 12:10:10	370 kg/ha CAN October	90 kg N/ha on monthly basis
	630 kg/ha CAN in Jan	80 kg/ha urea side dressing	200 kg/ha urea side dressing			50 kg N/ha (urea, twice, during growth + after grazing (Sept))		400 (200) kg/ha Nitrophoska 12:10:10	370 kg/ha CAN November	
		150 kg/ha Sulphate of ammonia side dressing						80 (0) kg/ha Urea		
Irrigation system	None	None	as required - SWB (soil water balance)	None	as required (centre pivot)	as required (centre pivot)	None	as required	none	None
Harvest	January	September	February	September-October	October	October	September-October	January	February	October

Region:	Manawatu	Gisborne	Gisborne	Gisborne	Canterbury	Canterbury	Waikato	Waikato	Southland	Southland
								(January-February)		
Yield	8-10 t/ha	25 t/ha @ 7% DM	15 t/ha @ 35% DM	8-10 t/ha	6 t DM/ha	7 + 0.3 t DM/ha	8-10 t/ha (plus twice grazed by dairy cows 2-3 t/ha)	45 t/ha	6 t/ha	60 t/ha
Crop 3	Spring Onions				Kale	Barley		Carrots	Oats & rye	Annual ryegrass (possible as cover crop)
Planting	January				October	October		May (February-May)	March	
Cultivation	discing				IC (MT)	IC (MT)		IC	DD	
Fertiliser inputs	570 kg/ha Nitrophoska Perfect				240 kg/ha DAP	150 kg/ha CropMaster 15		90 kg N/ha (split application)	-	
	350 kg/ha Nitrophoska Blue TE				200 kg N/ha (urea)	50 kg N/ha (urea, twice during growth)				
Irrigation system	as required (travelling irrigator)				as required (centre pivot)	as required (centre pivot)		None	None	
Harvest	May				June-July	January		October (October-November)	July	
Yield	14 t/ha				21 t DM/ha	16 t DM/ha		60 t/ha	ploughed in	
Crop 4	Green oats				Triticale			Squash	Potatoes	
Planting	May				September - October			November	August	
Cultivation	MT				IC (MT)			MT (IC)	IC	
Fertiliser inputs	-				160 kg/ha CropZeal20N			170 kg/ha Nitrophoska	200 kg N/ha	

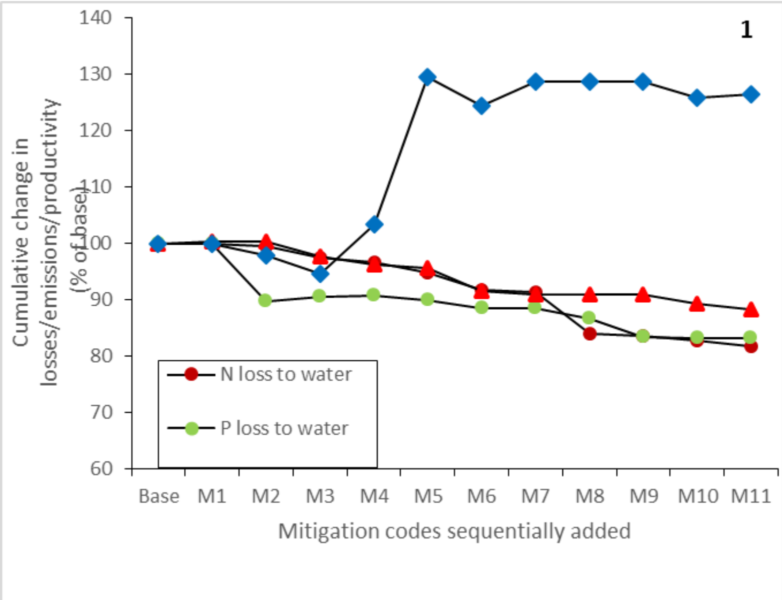
Region:	Manawatu	Gisborne	Gisborne	Gisborne	Canterbury	Canterbury	Waikato	Waikato	Southland	Southland
								(12:10:10) at planting		
									100 kg N/ha side dressing (twice, spaced out 6 weeks)	
Irrigation system	None				as required (centre pivot)			None	None	
Harvest	September				February			March	March	
Yield	sprayed, ploughed in				14 t DM/ha			25 t/ha	45 t/ha	
Crop 5								Oats & rye		
Planting								April		
Cultivation								DD		
Fertiliser inputs										
Irrigation system										
Harvest								June		
Yield										
Crop 6								Barley		
Planting								July		
Cultivation								DD		
Fertiliser inputs								370 kg/ha CAN October		
								370 kg/ha CAN November		
Irrigation system								none		
Harvest								February		
Yield								7 t/ha		
Crop 7								Oats & rye		
Planting								March		

Region:	Manawatu	Gisborne	Gisborne	Gisborne	Canterbury	Canterbury	Waikato	Waikato	Southland	Southland
Cultivation								DD		
Fertiliser inputs								-		
Irrigation system								None		
Harvest								July		
Yield								ploughed in		
Variants: soil type	Recent	Recent	Recent		Brown, Pallic, Recent	Brown, Pallic, Recent	Brown, Allophanic	Brown, Allophanic, Granular	Brown, Pallic	Brown, Pallic
Variants: rainfall	950	1080	1080		500-800	500-800	900-1400	900-1400	800-1300	800-13000
Variants: systems										

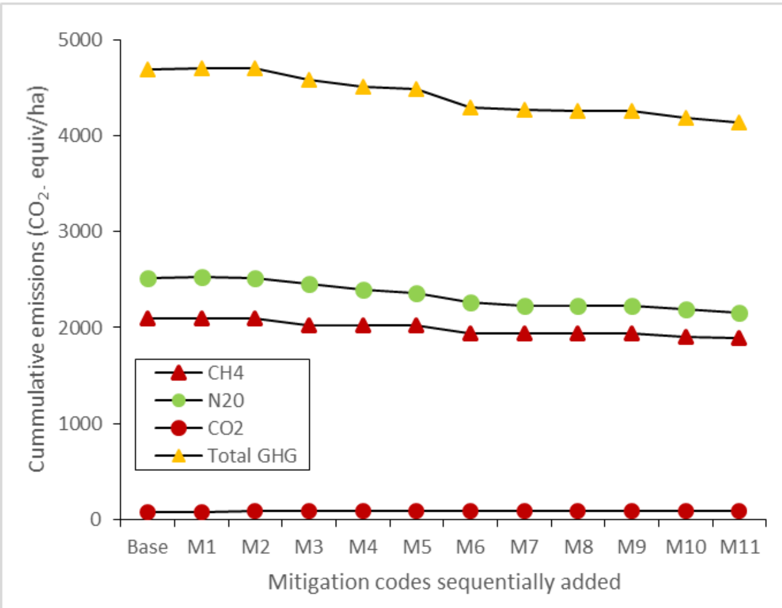
6. Appendix VI – Abatement curves for S&B sites

Cumulative percent changes in (a) emissions to air and water and farm productivity 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 19 sheep and beef system modlelled in the 6 regions

1a

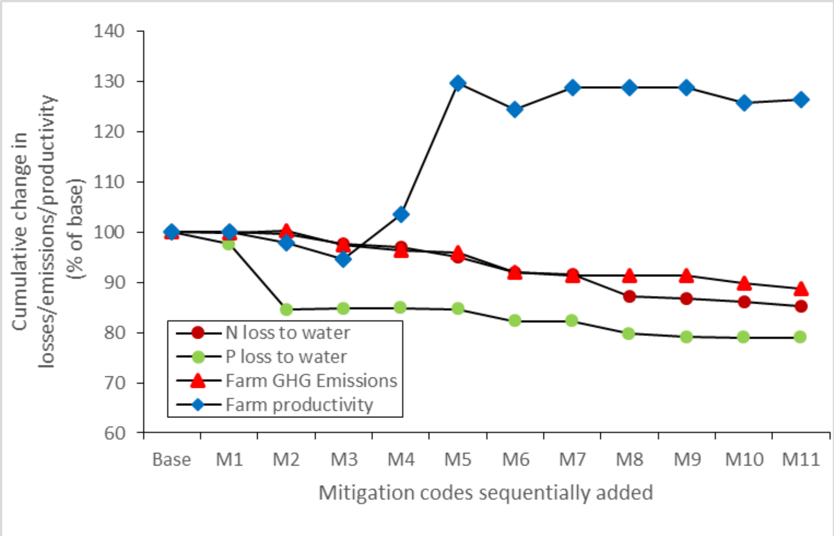


1b



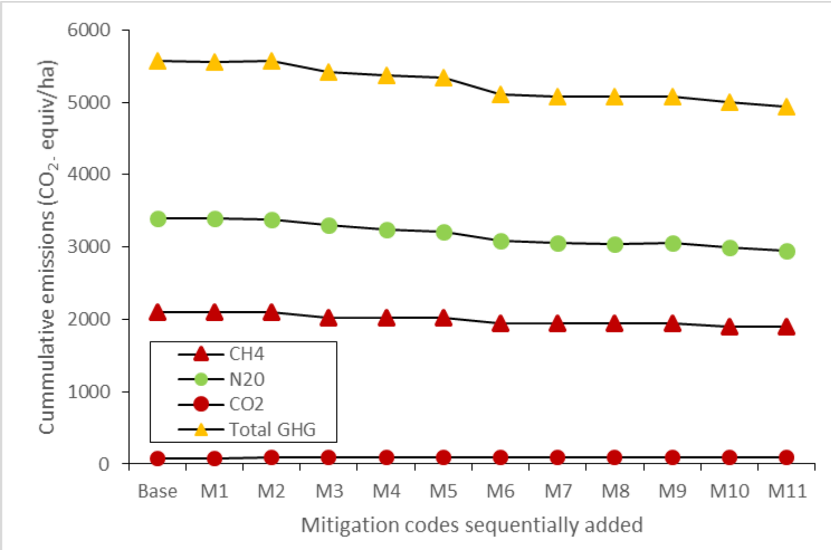
Figures A6.1a and 1b: Cumulative percent changes in (a) emissions to air and water and farm productivity and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Manawatu sheep and beef (1) system on Pallic soil with 800mm rainfall.

2a



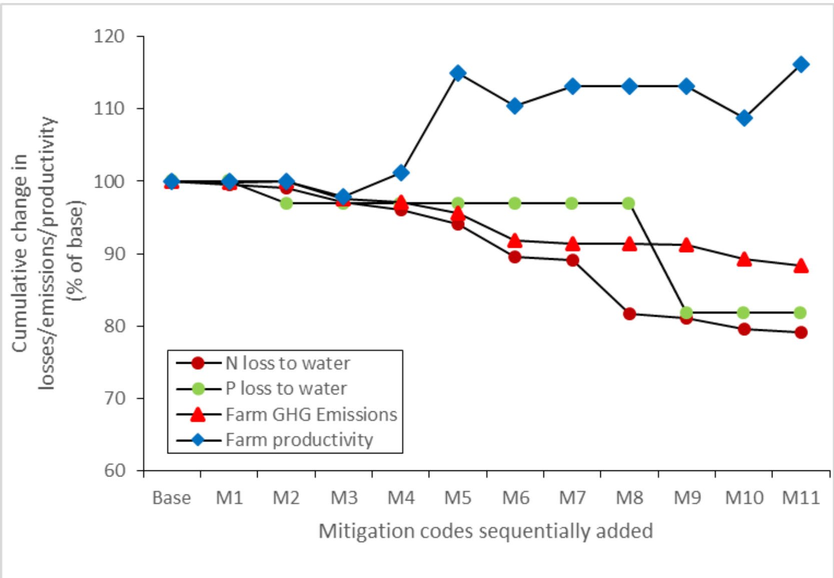
140
130
120
110
100
90
80
70
60
Cumulative change in losses/emissions/productivity (% of base)
N loss to water
P loss to water
Farm GHG Emissions
Farm productivity
Base
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
M11
Mitigation codes sequentially added

2b



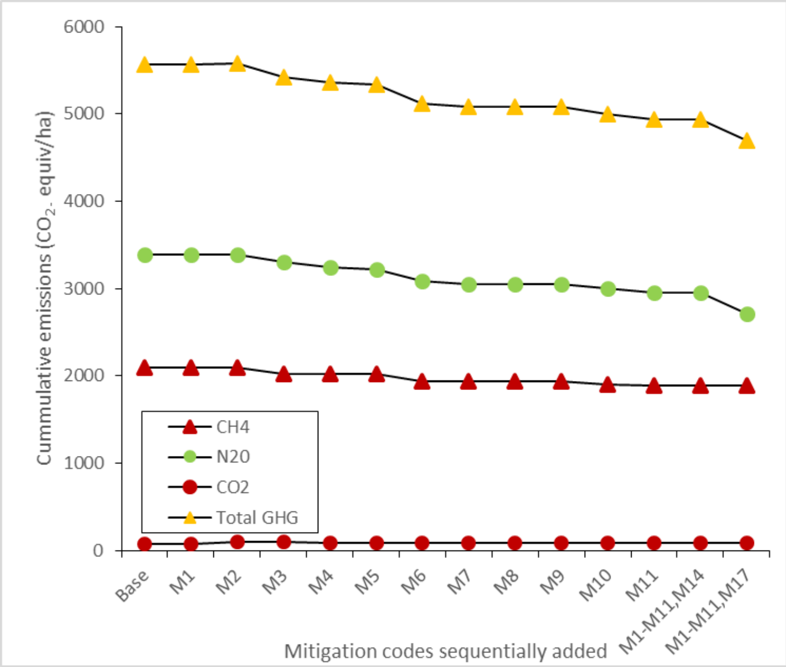
6000
5000
4000
3000
2000
1000
0
Cummulative emissions (CO_2- equiv/ha)
CH4
N20
CO2
Total GHG
Base
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
M11
Mitigation codes sequentially added

2c



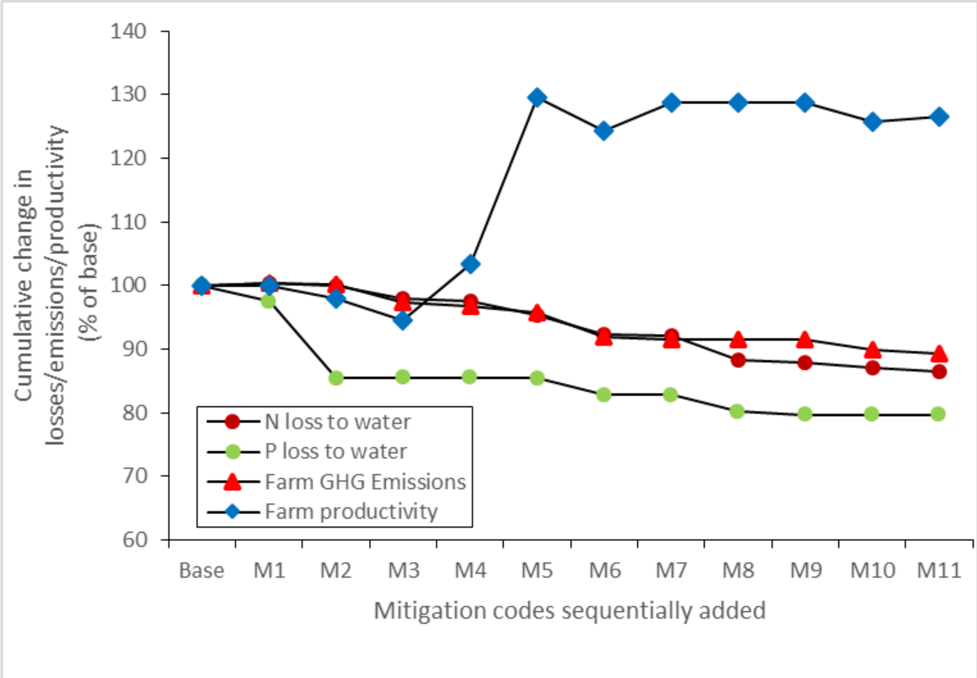
120
110
100
90
80
70
60
Cumulative change in losses/emissions/productivity (% of base)
N loss to water
P loss to water
Farm GHG Emissions
Farm productivity
Base
M1
M2
M3
M4
M5
M6
M7
M8
M9
M10
M11
Mitigation codes sequentially added

2d

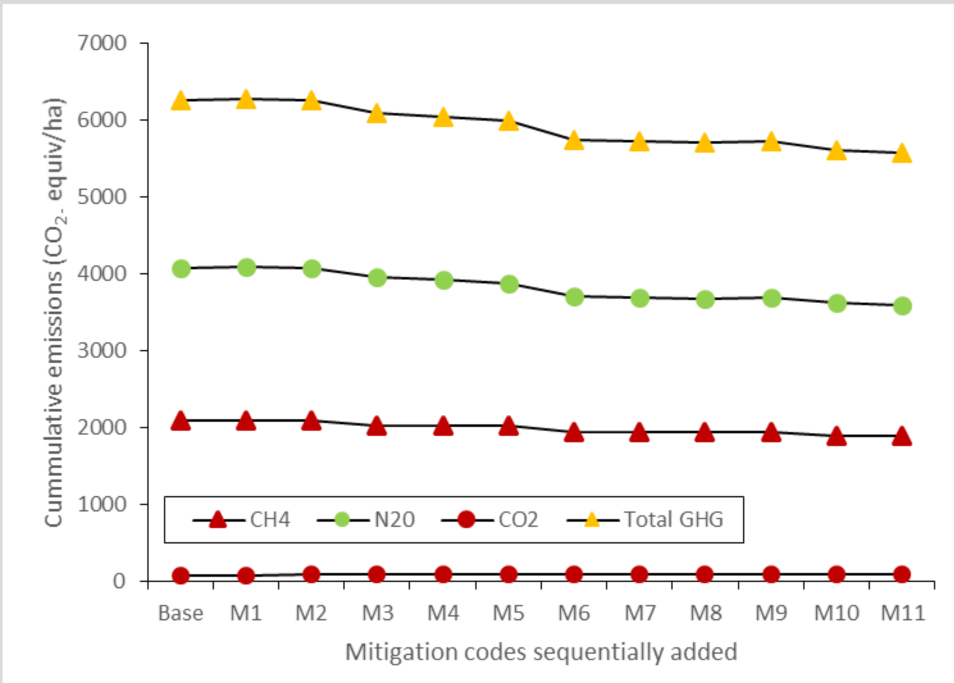


Figures A6.2a-2d: Cumulative percent changes in (a) emissions to air and water and farm productivity and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Manawatu sheep and beef (1) system on Pallic soil with 1200mm rainfall.

3a

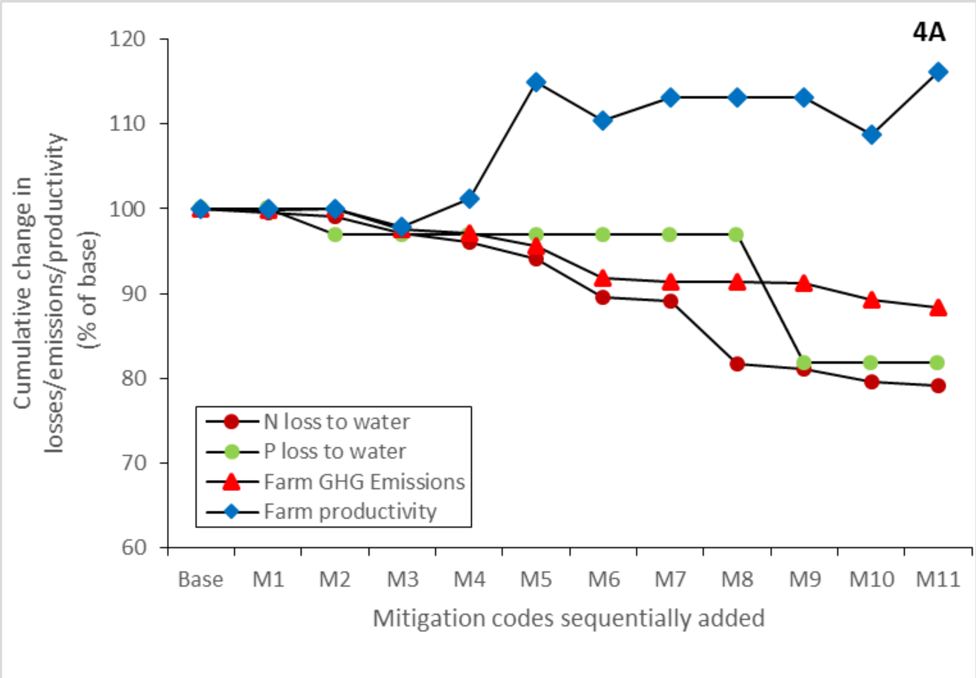


3b

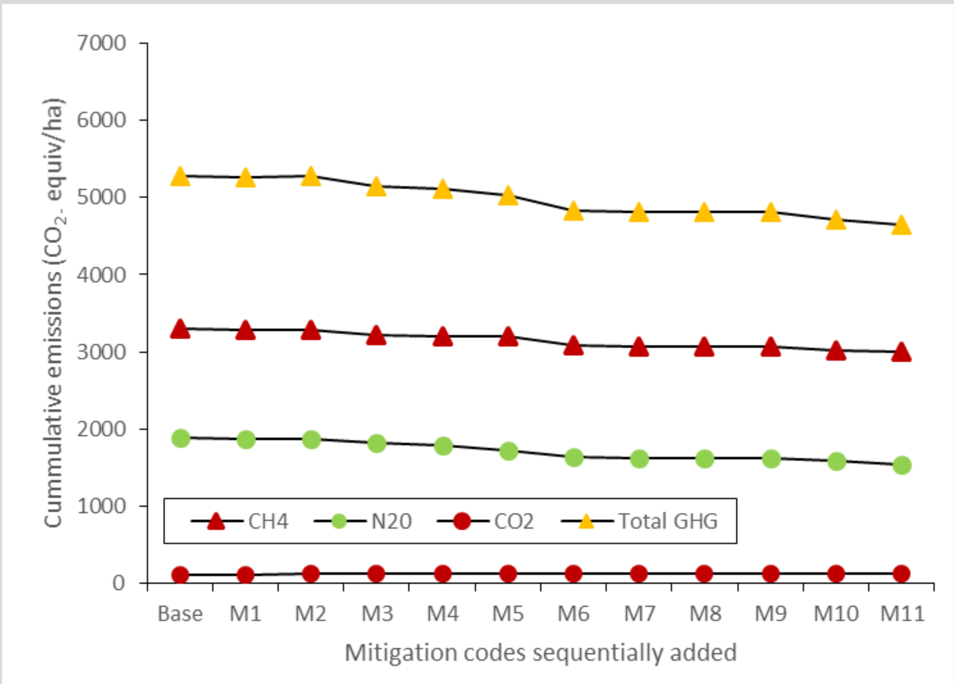


Figures A6.3a-3b: Cumulative percent changes in (a) emissions to air and water and farm productivity and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Manawatu sheep and beef (1) system on Pallic soil with 1400mm rainfall.

4a

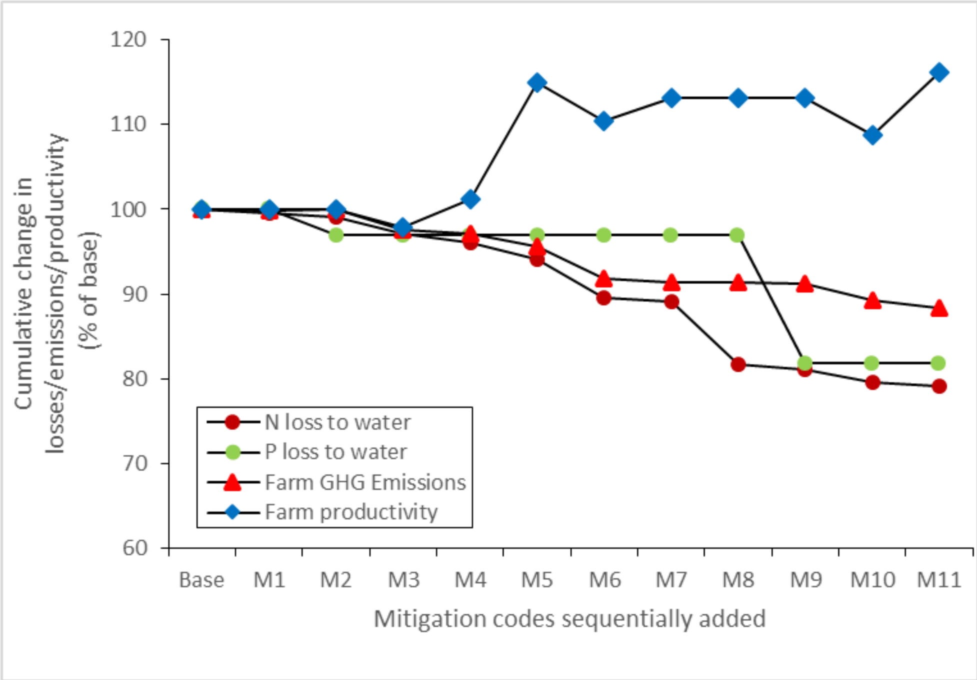


4b

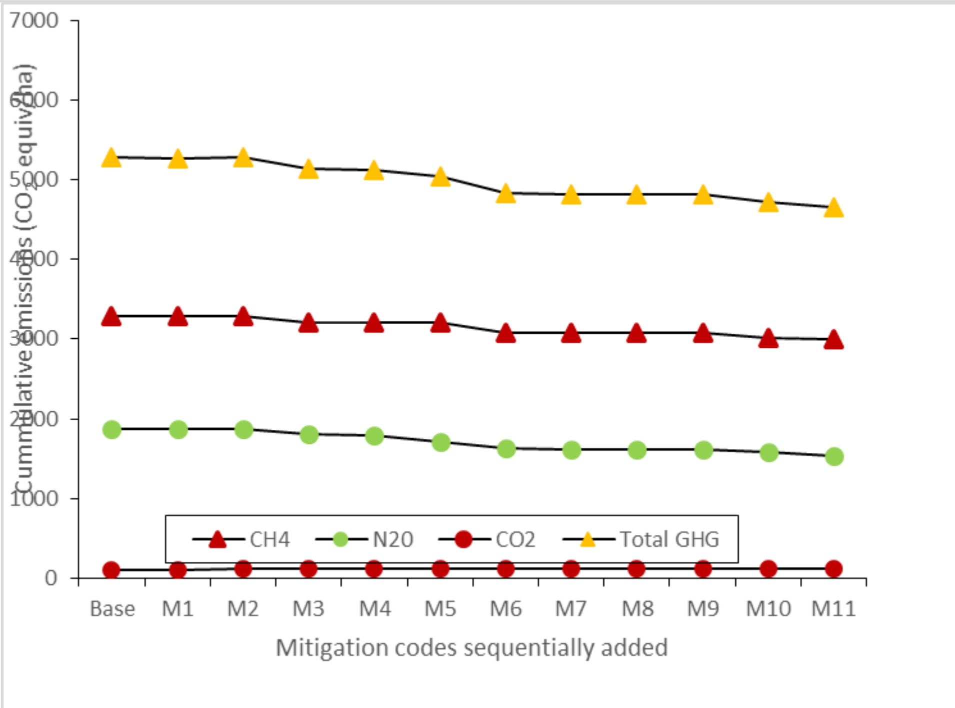


Figures A6.4a-4b: Cumulative percent changes in (a) emissions to air and water and farm productivity and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Manawatu sheep and beef (2) system on Brown soil with 800mm rainfall.

5a

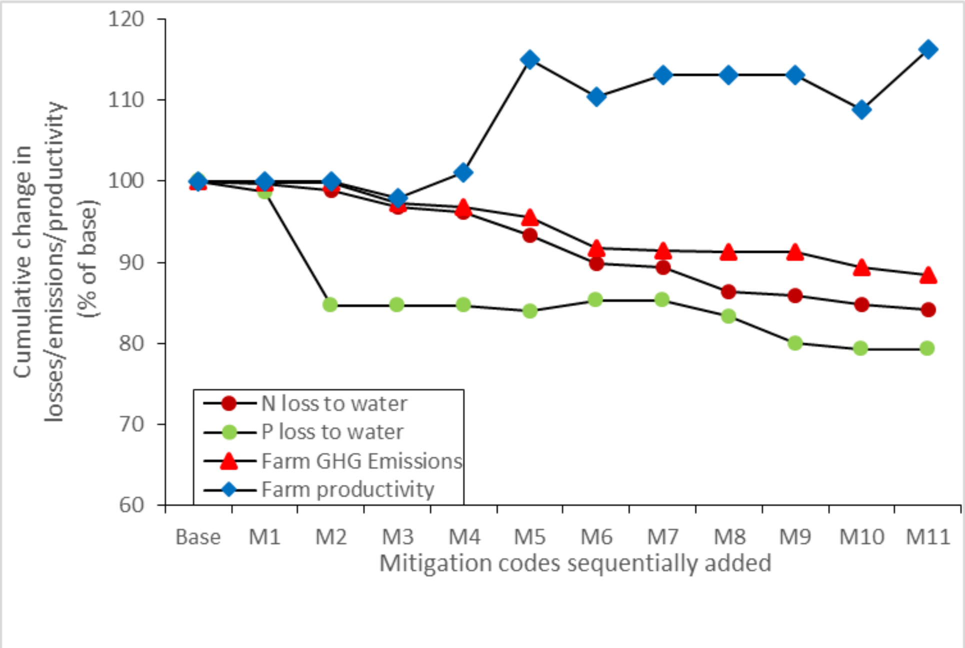


5b

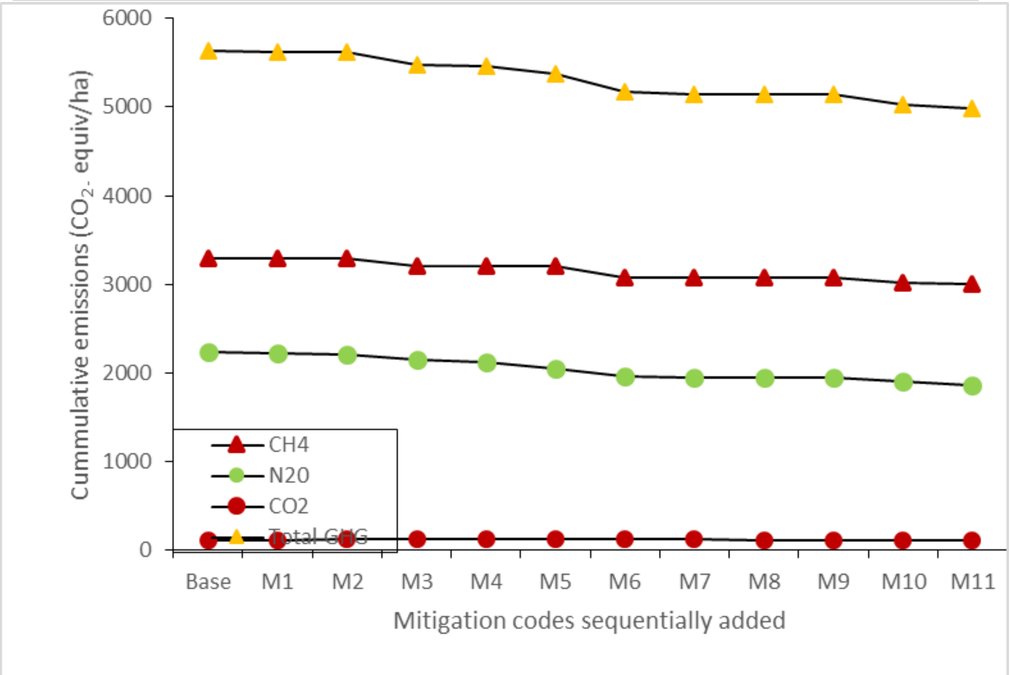


Figures A6.5a-5b: Cumulative percent changes in (a) emissions to air and water and farm productivity and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Manawatu sheep and beef (2) system on Brown soil with 1200mm rainfall.

6a

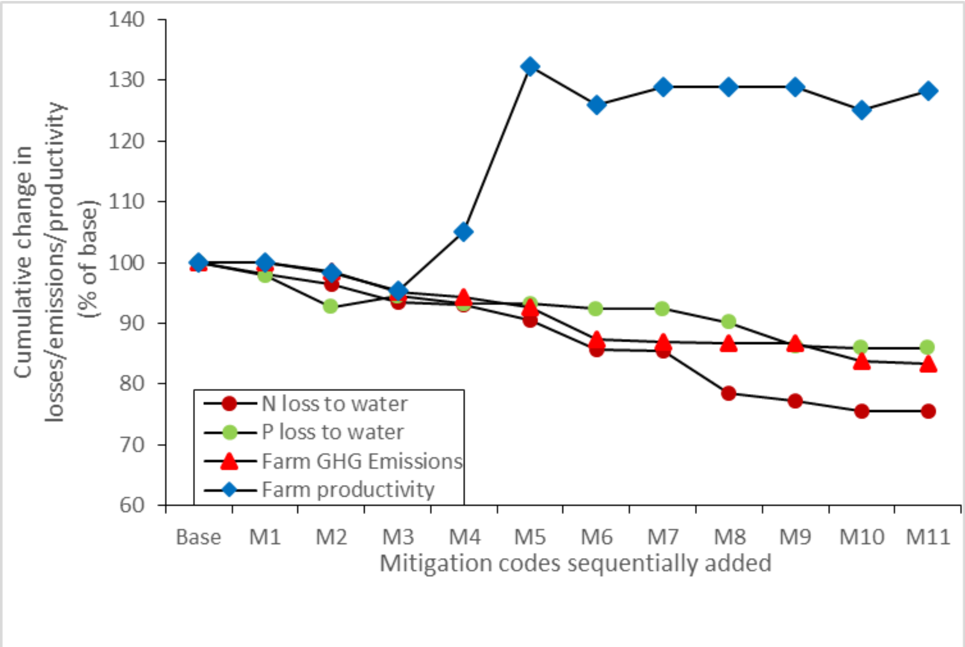


6b

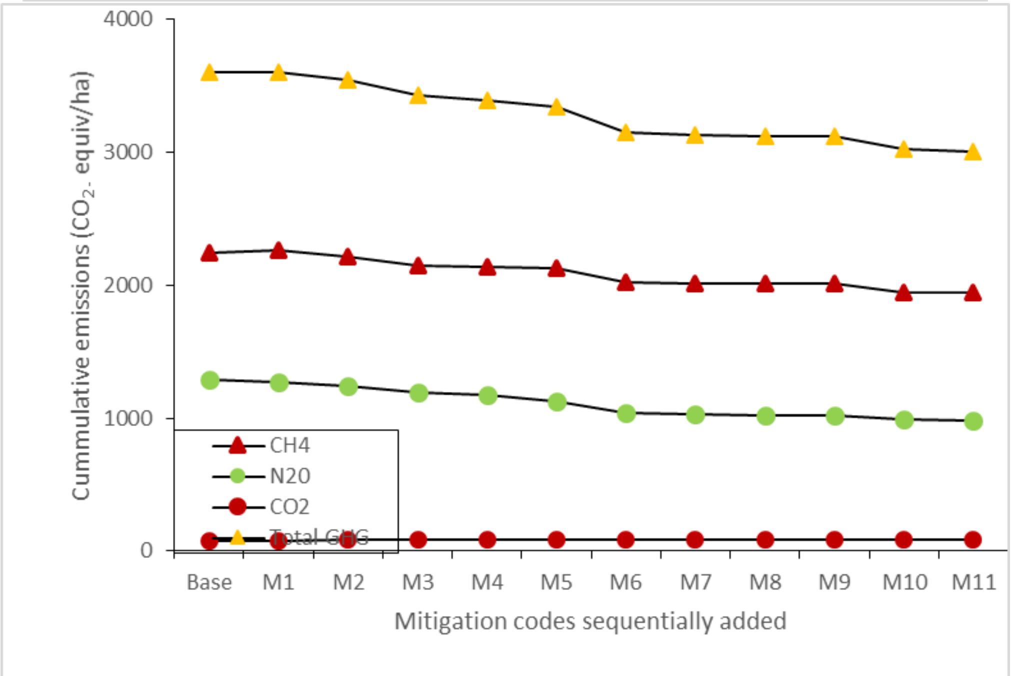


Figures A6.6a-6b: Cumulative percent changes in (a) emissions to air and water and farm productivity and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Manawatu sheep and beef (2) system on Brown soil with 1400mm rainfall.

7a



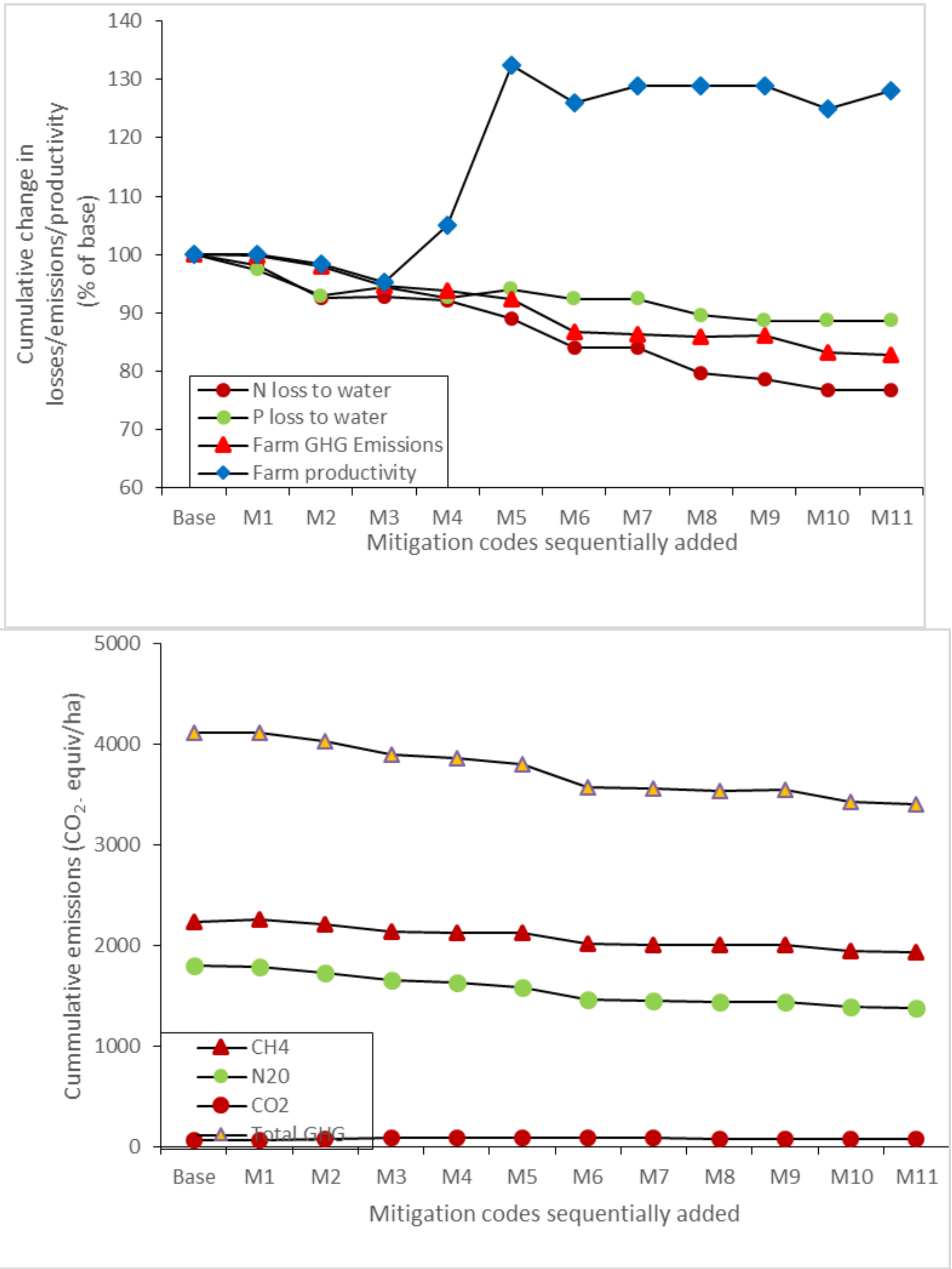
7b



Figures A6.7a-7b: Cumulative percent changes in (a) emissions to air and water and farm productivity 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 Gisborne sheep and beef (1) system on Recent soil with 800mm rainfall.

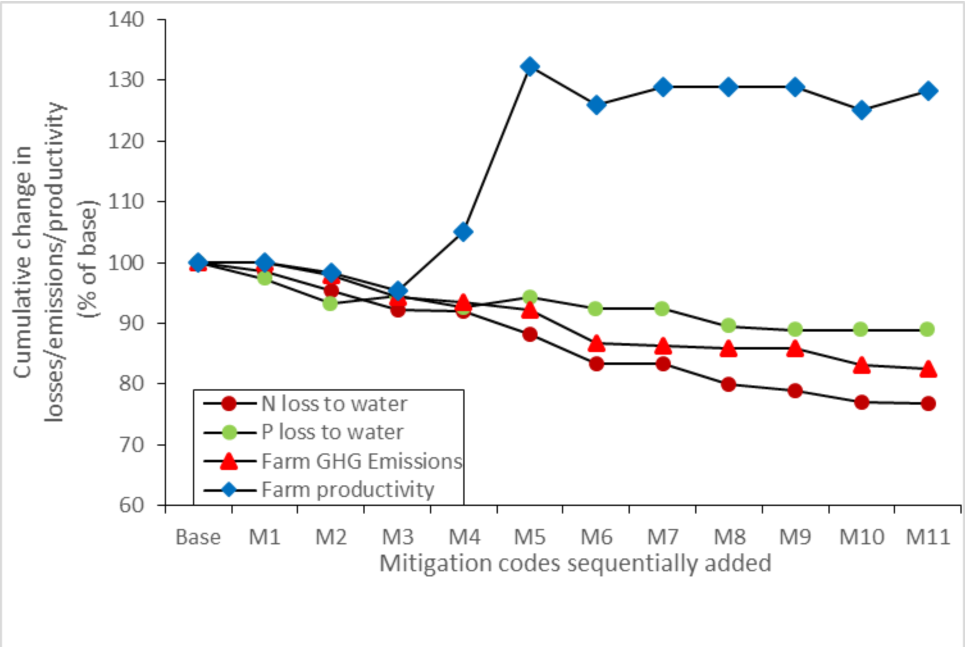
8a

8b

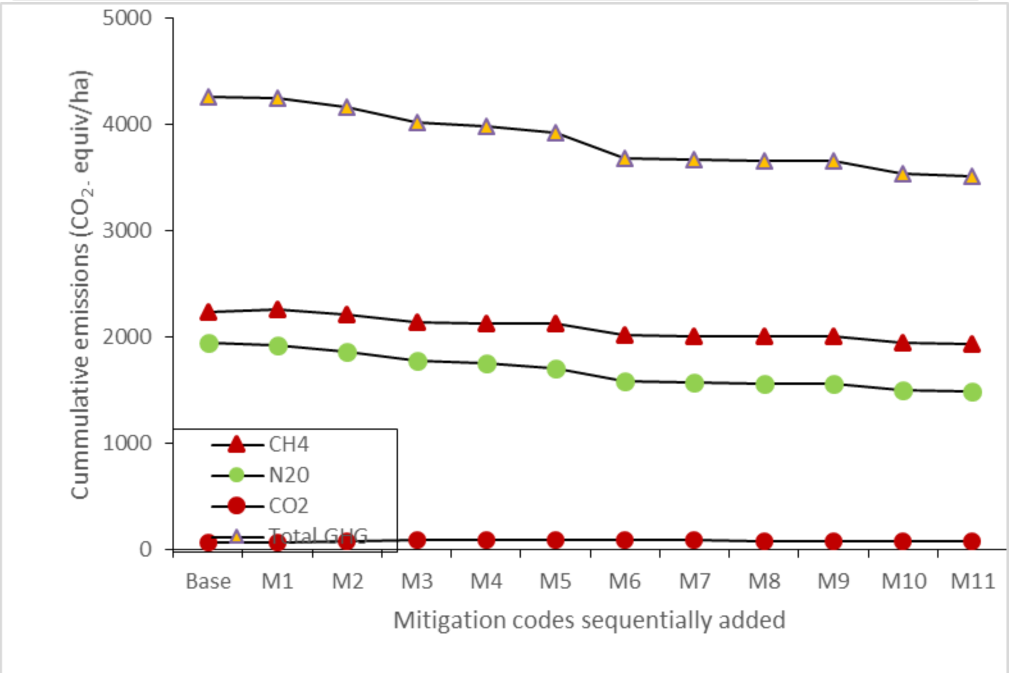


Figures A6.8a-8b: Cumulative percent changes in (a) emissions to air and water and farm productivity and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Gisborne sheep and beef (1) system on Recent soil with 1200mm rainfall.

9a

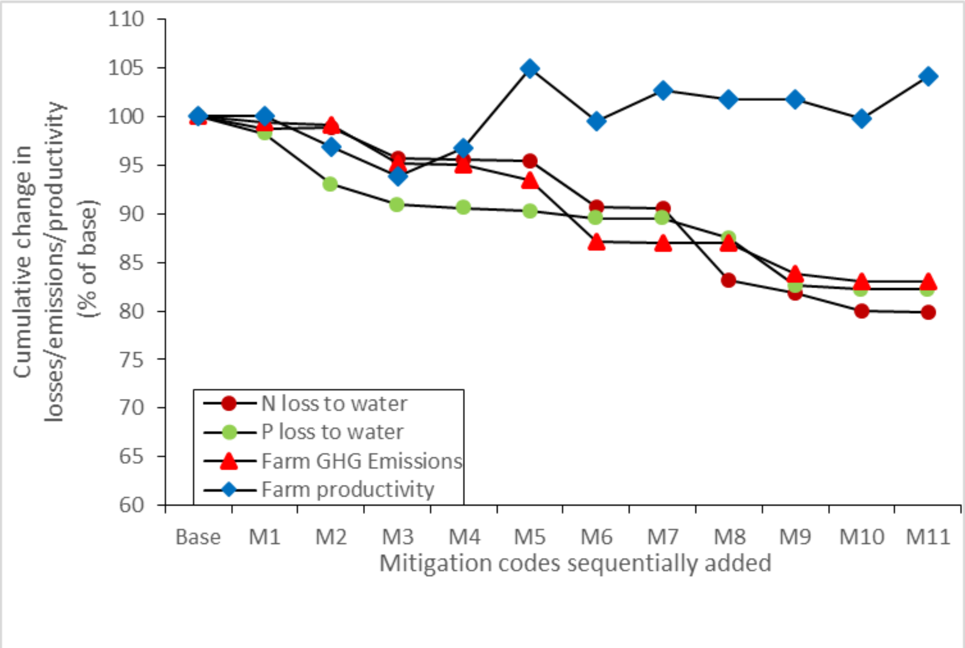


9b

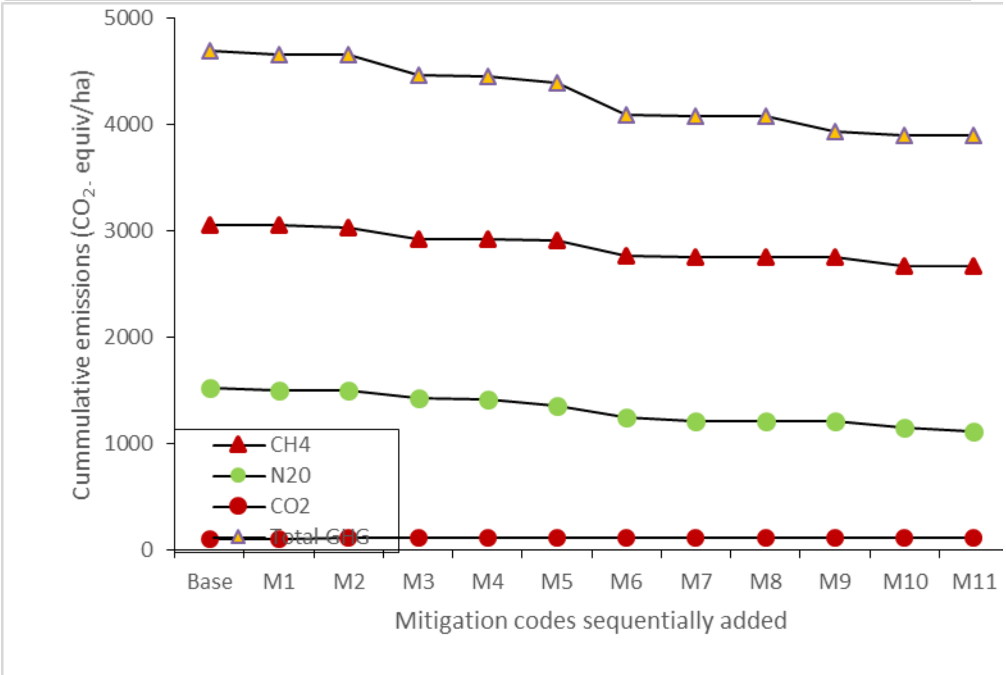


Figures A6.9a-9b: Cumulative percent changes in (a) emissions to air and water and farm productivity and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Gisborne sheep and beef (1) system on Recent soil with 1400mm rainfall.

10a

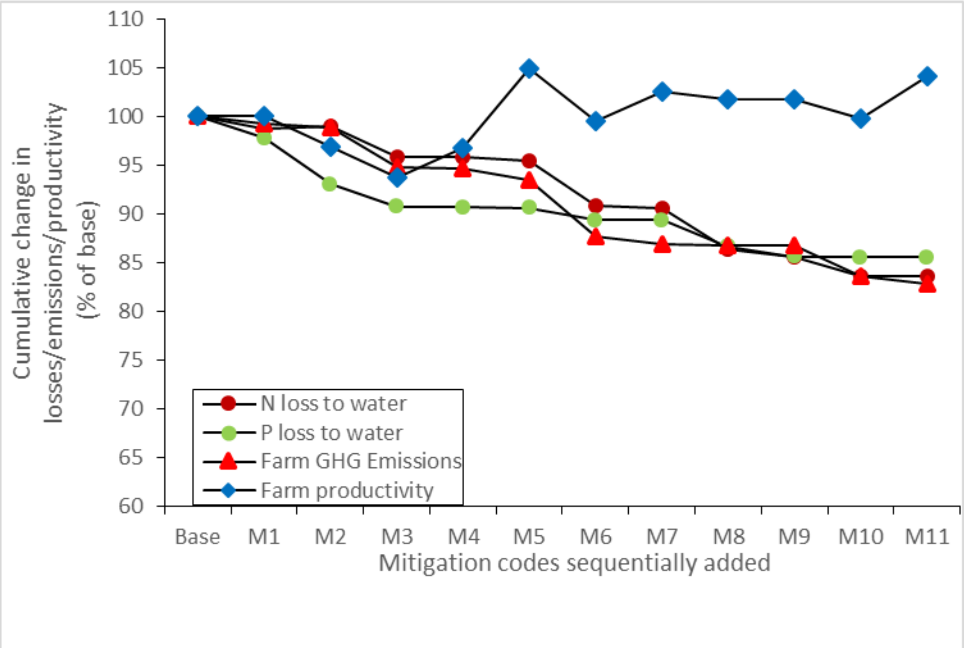


10b

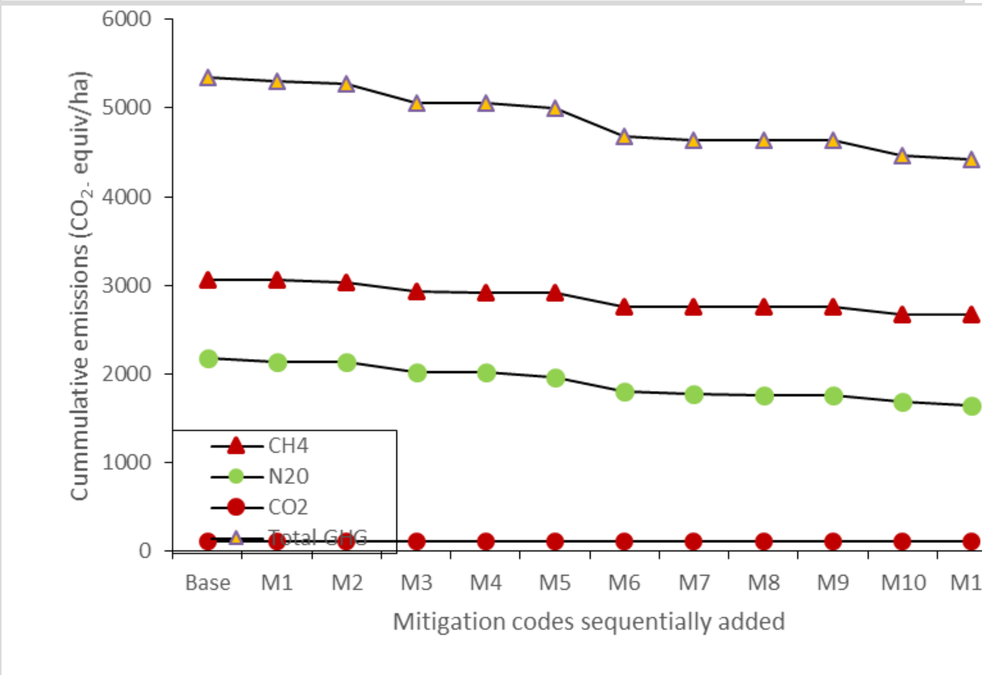


Figures A6.10a-10b: Cumulative percent changes in (a) emissions to air and water and farm productivity and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Gisborne sheep and beef (2) system on Recent soil with 800mm rainfall.

11a

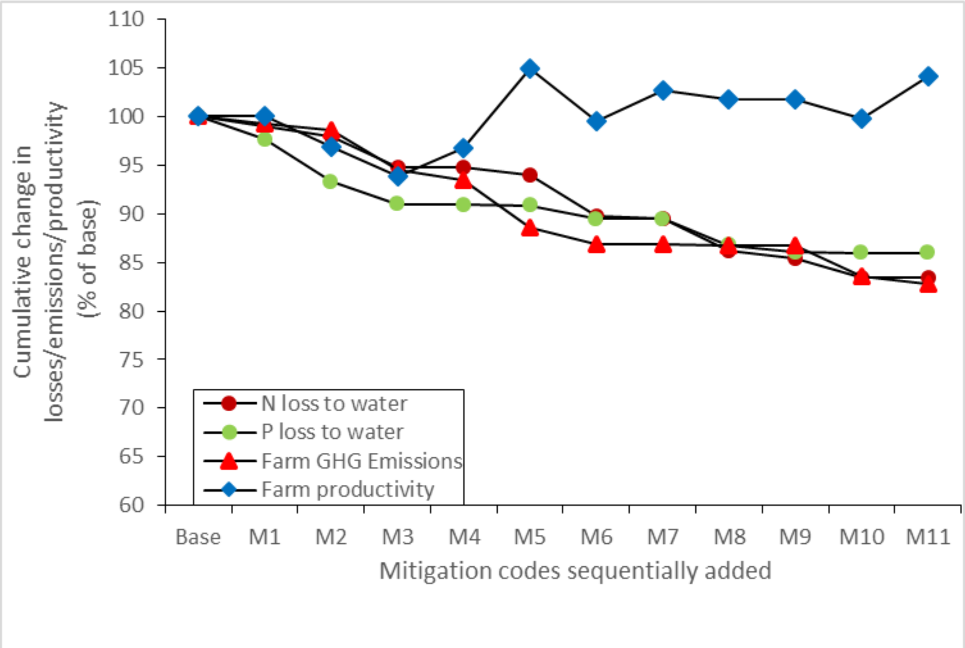


11b

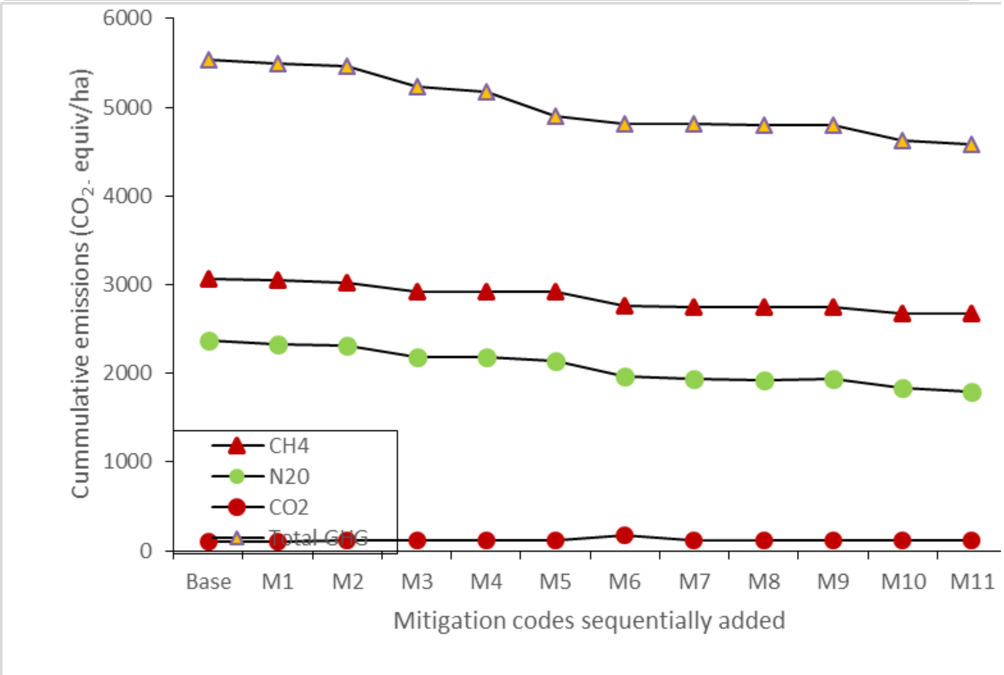


Figures A6.11a-11b: Cumulative percent changes in (a) emissions to air and water and farm productivity and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Gisborne sheep and beef (2) system on Recent soil with 1200mm rainfall.

12a

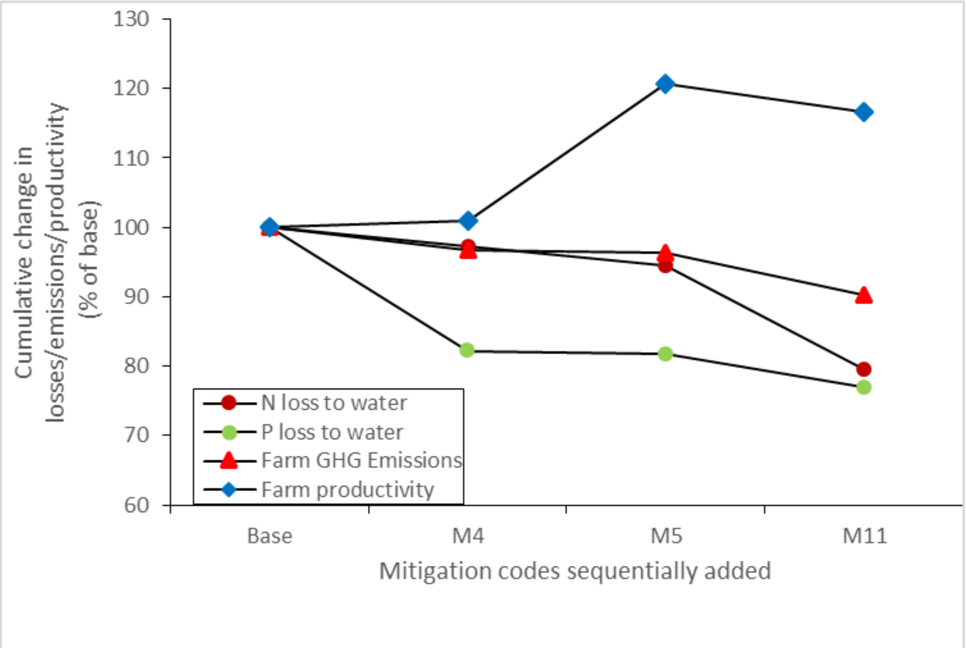


12b

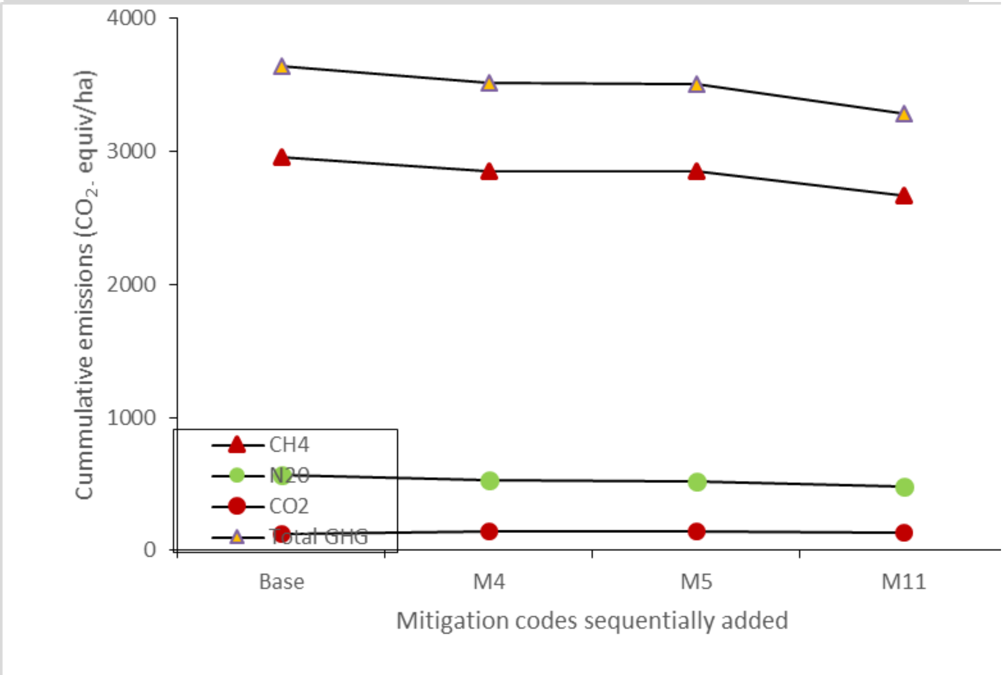


Figures A6.12a-12b: Cumulative percent changes in (a) emissions to air and water and farm productivity and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Gisborne sheep and beef (2) system on Recent soil with 1400mm rainfall.

13a

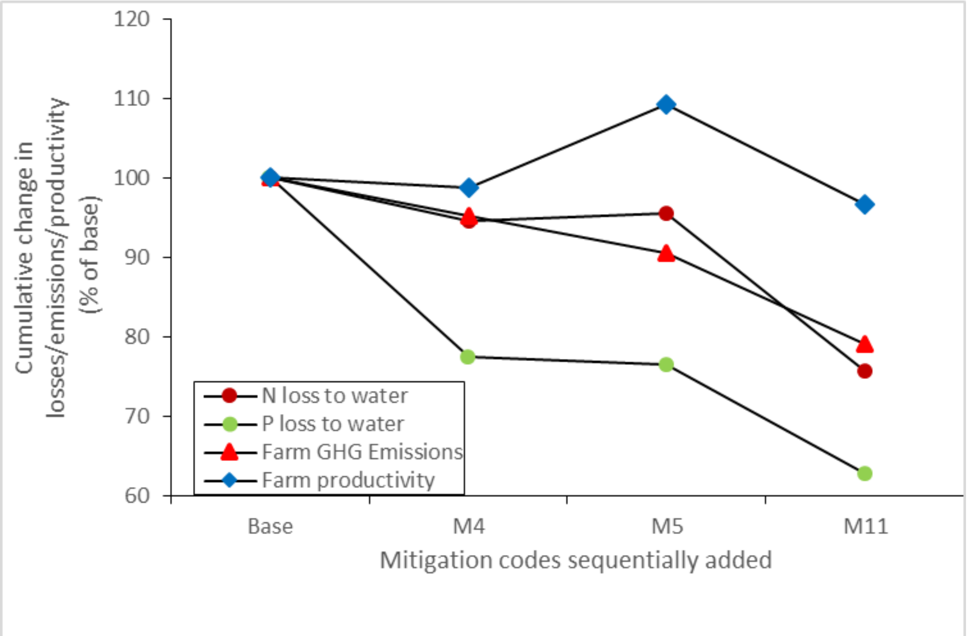


13b

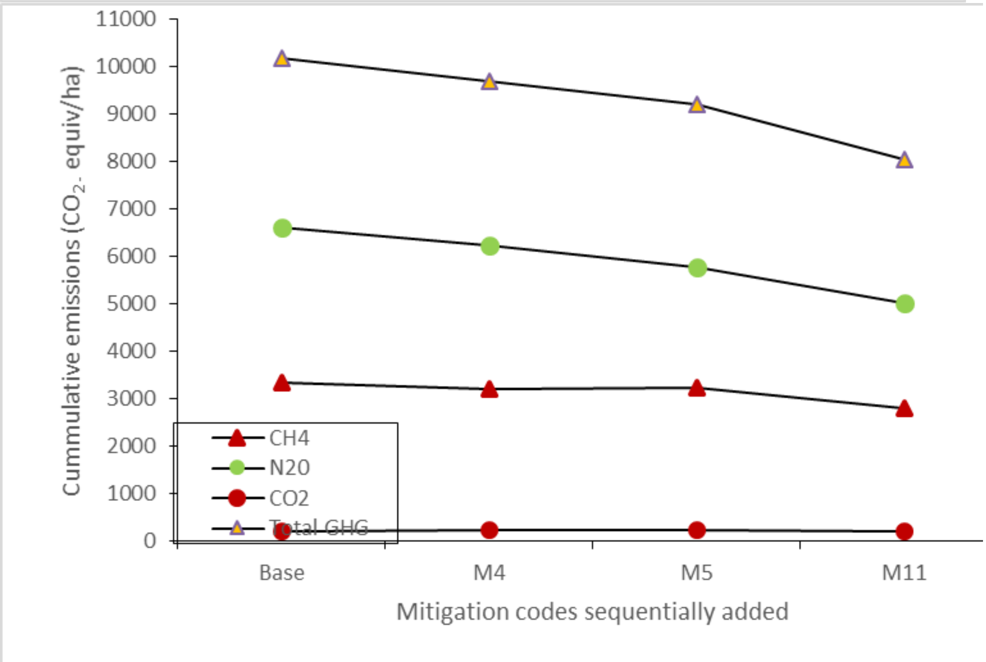


Figures A6.13a-13b: Cumulative percent changes in (a) emissions to air and water and farm productivity and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Bay of Plenty sheep and beef (1) system on Pumice soil with 1000mm rainfall.

14a

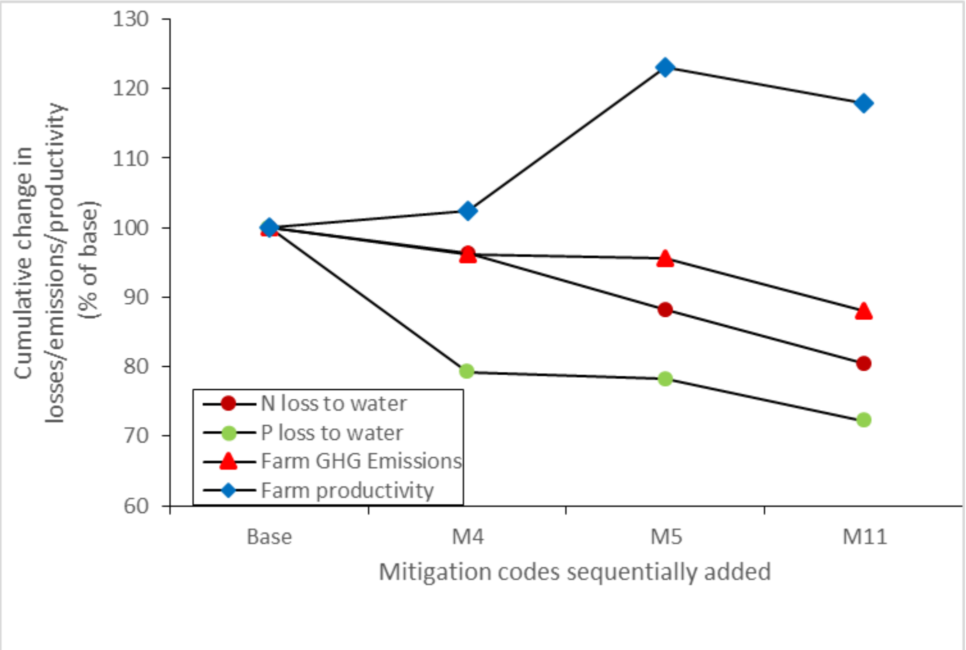


14b

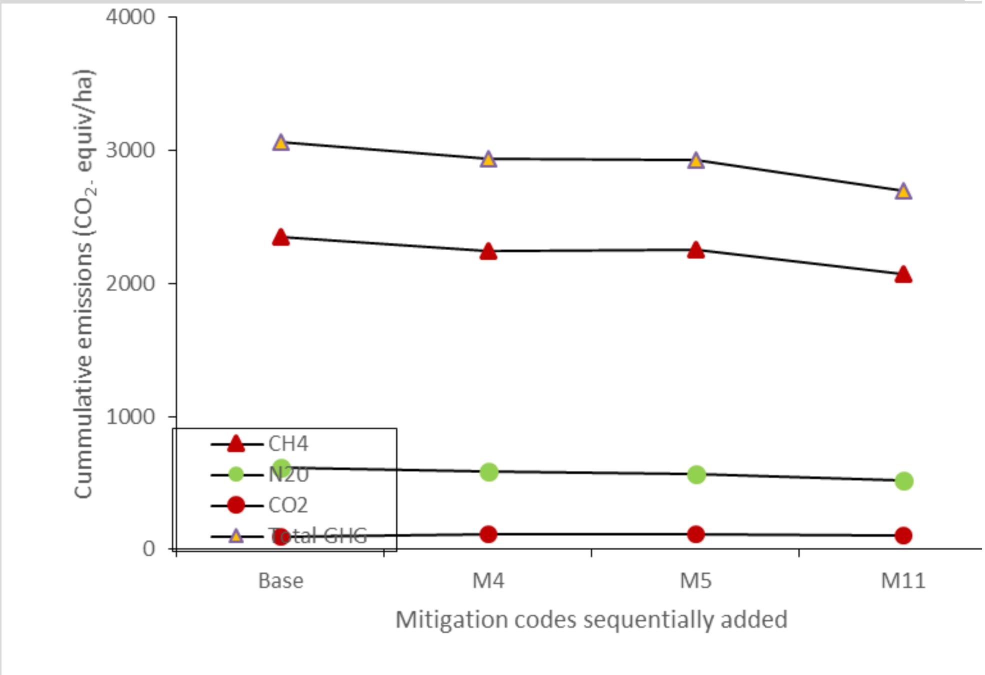


Figures A6.14a-14b: Cumulative percent changes in (a) emissions to air and water and farm productivity and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Bay of Plenty sheep and beef (1) system on Gley soil with 900mm rainfall.

15a

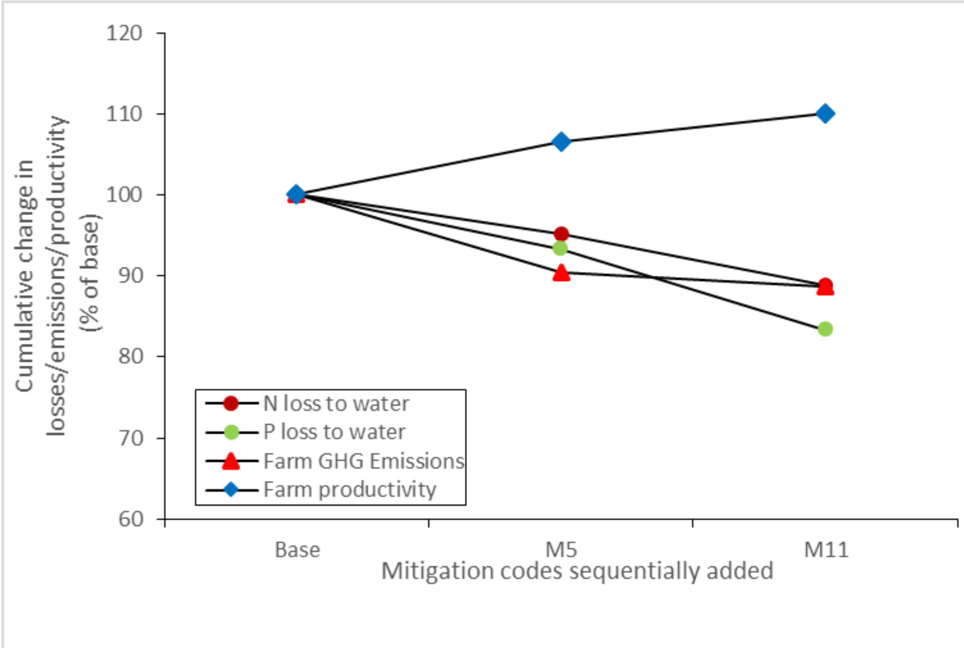


15b

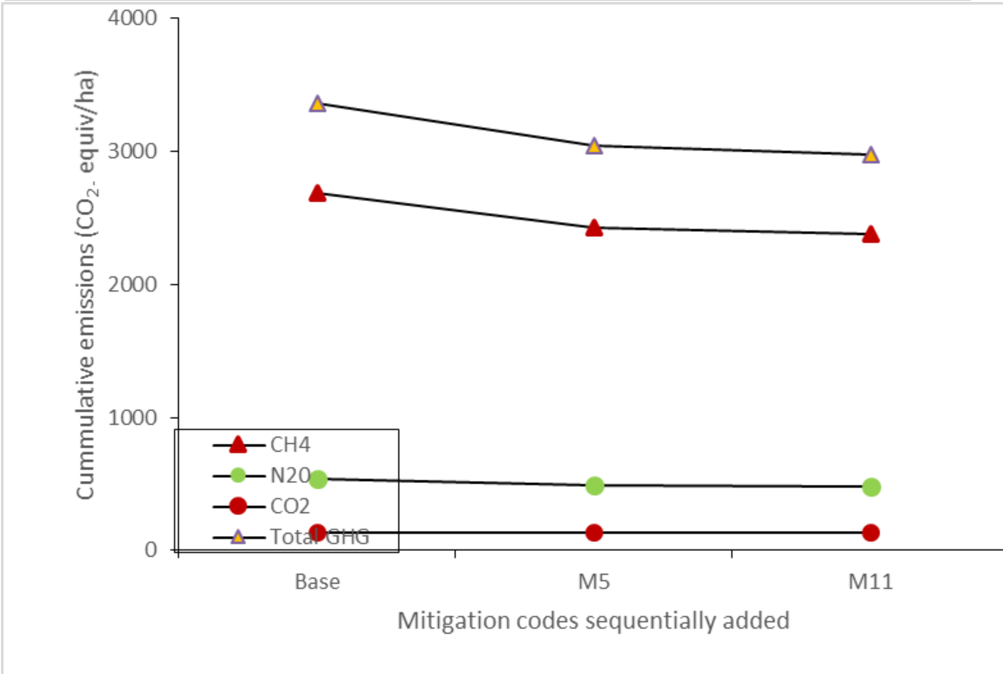


Figures A6.15a-15b: Cumulative percent changes in (a) emissions to air and water and farm productivity and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Wairarapa sheep and beef (2) system on Allophanic soil with 1400mm rainfall.

16a

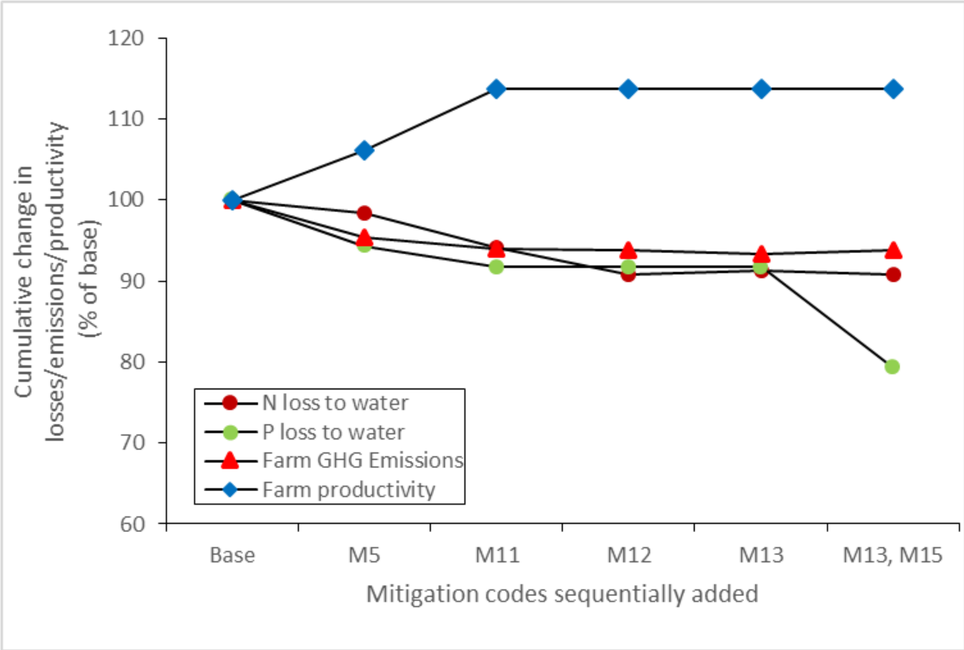


16b

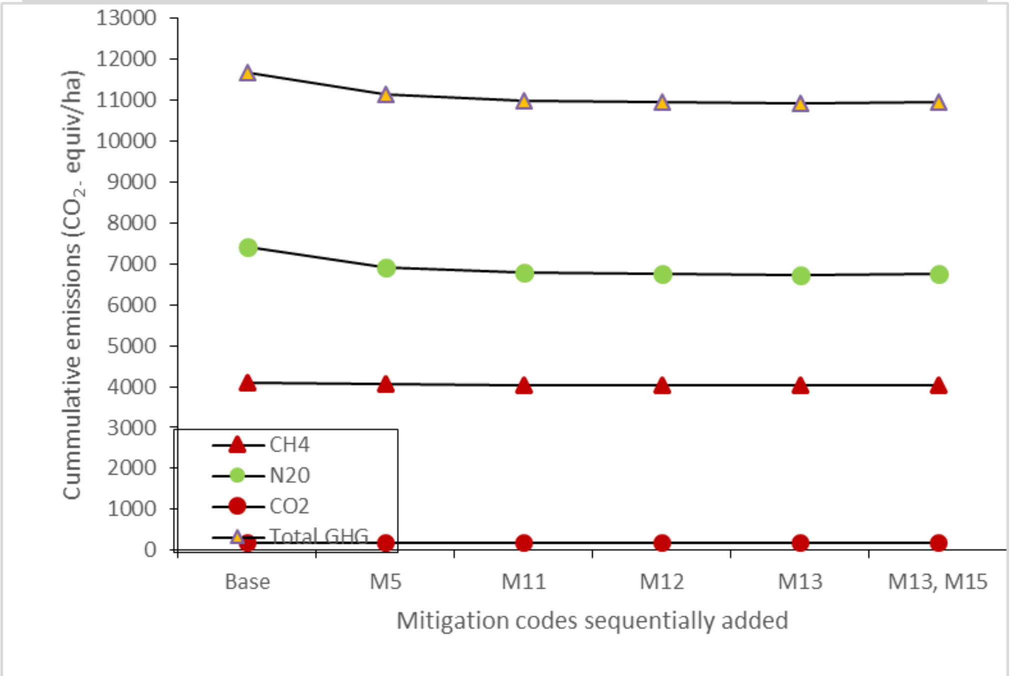


Figures A6.16a-16b: Cumulative percent changes in (a) emissions to air and water and farm productivity and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Canterbury sheep and beef (2) system on Recent soil with 800mm rainfall.

17a

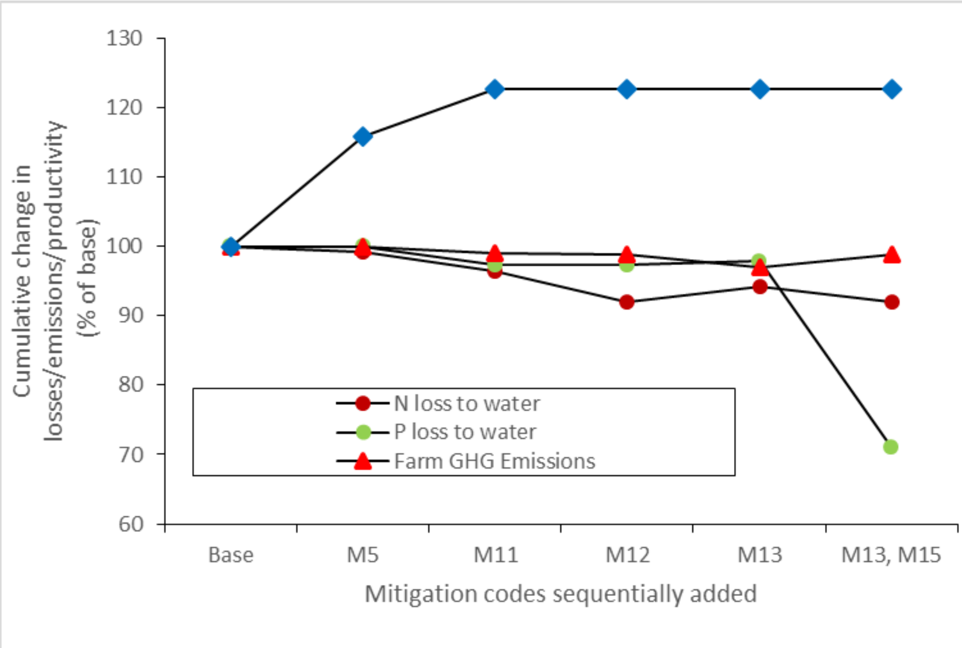


17b

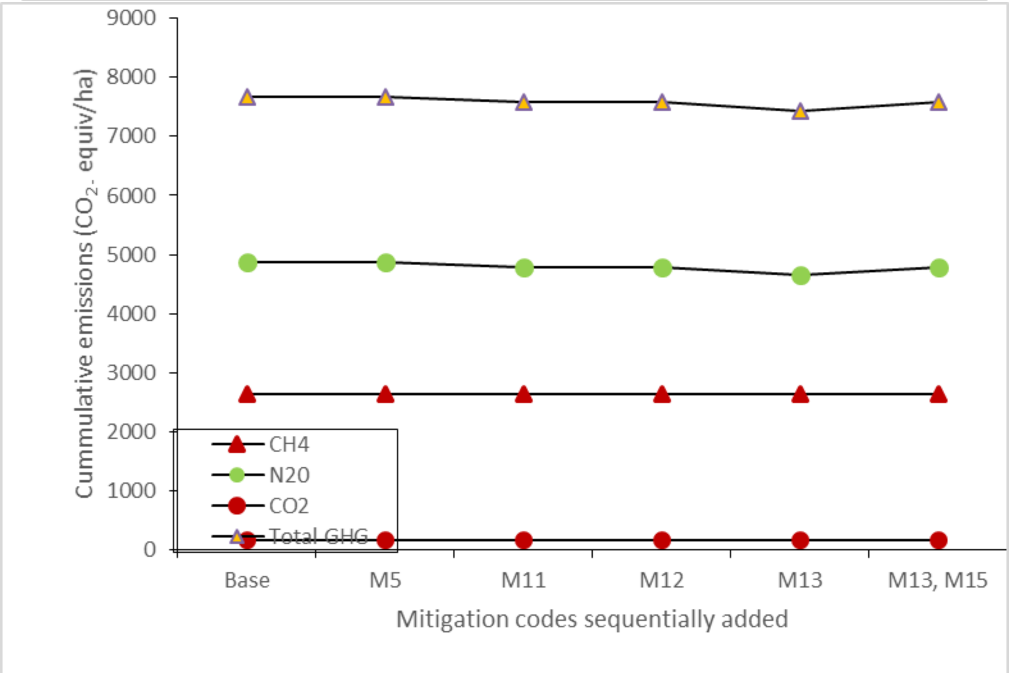


Figures A6.17a-17b: Cumulative percent changes in (a) emissions to air and water and farm productivity and (b) actual emissions of methane, nitrous oxide, carbon dioxide and totals with the stepwise introduction of mitigations and changes in enterprise, performance and practice to the Southland sheep and beef (1) system on Pallic soil with 1300mm rainfall.

18a

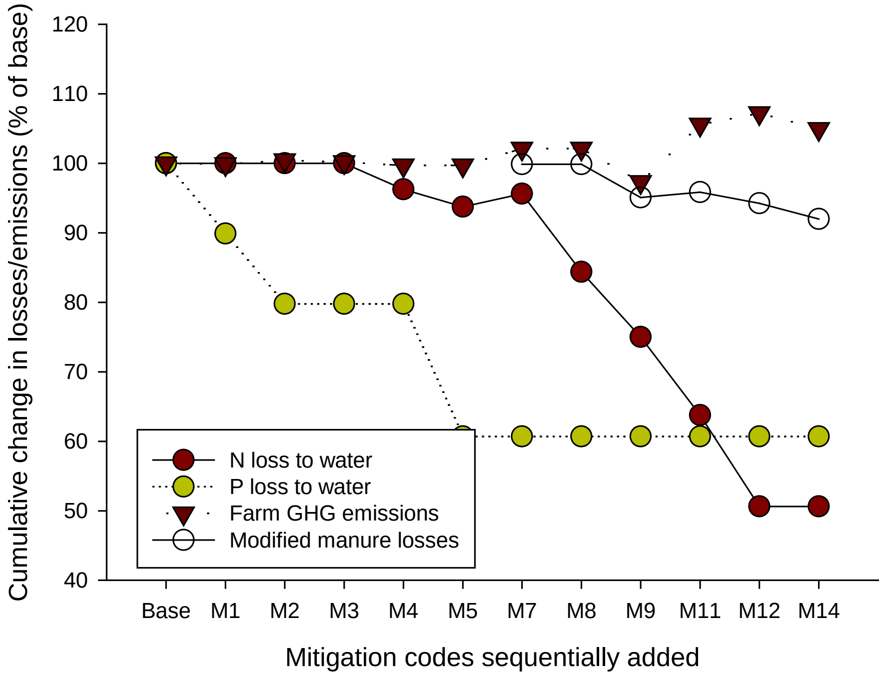


18b



Figures A6.18a-18b: Cumulative percent changes in (a) emissions to air and water and farm productivity 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 sheep and beef (2) system on Brown soil with 1000mm rainfall.

7. Appendix VII – Abatement curves for dDairy sites



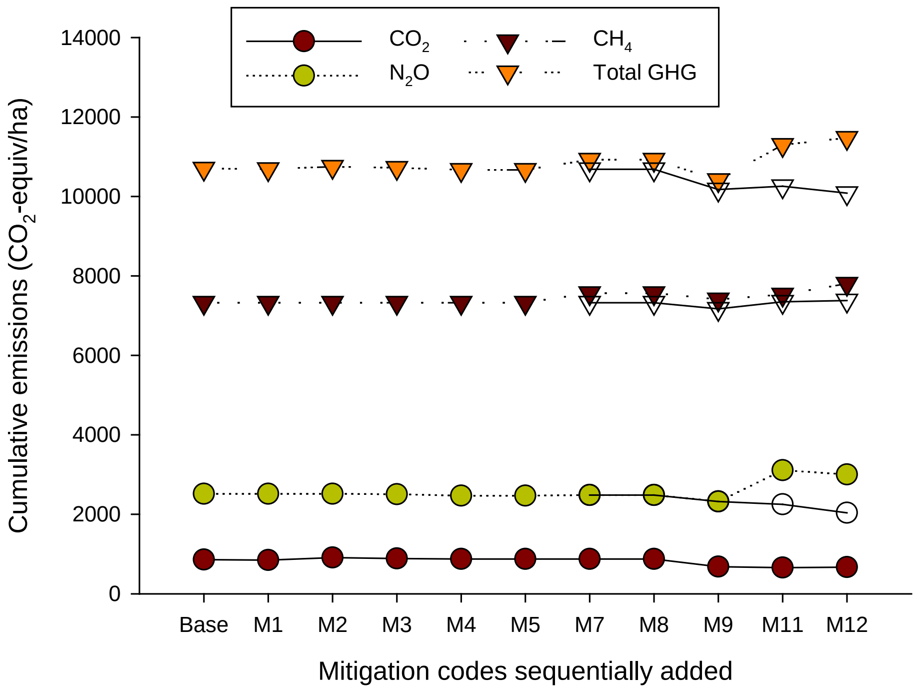


Figure A7.1. Relationship between N and P loss reductions on GHG emissions. Southland dairy farm (System 2).

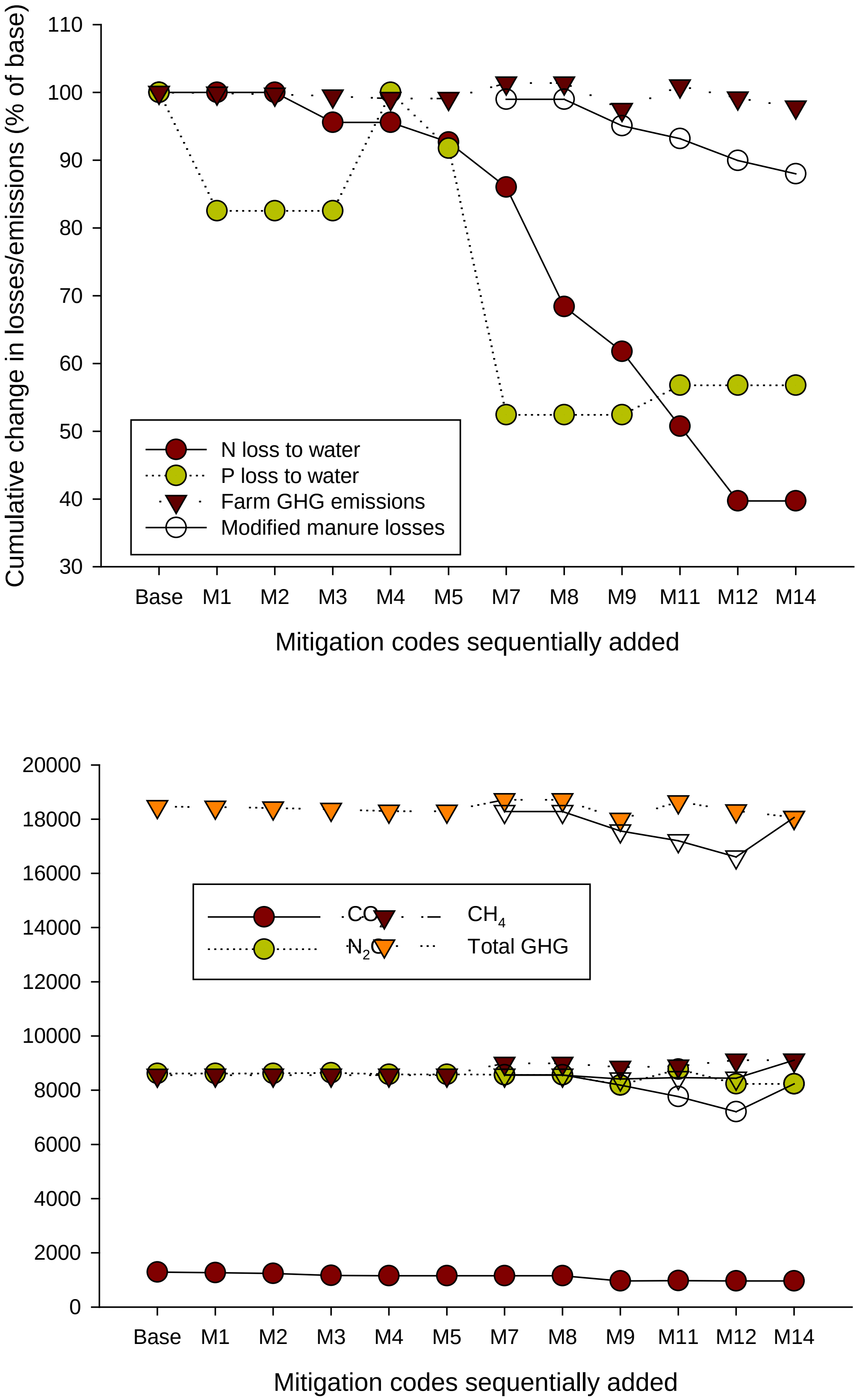


Figure A7.2. Relationship between N and P loss reductions on GHG emissions. Southland dairy farm (System 4).

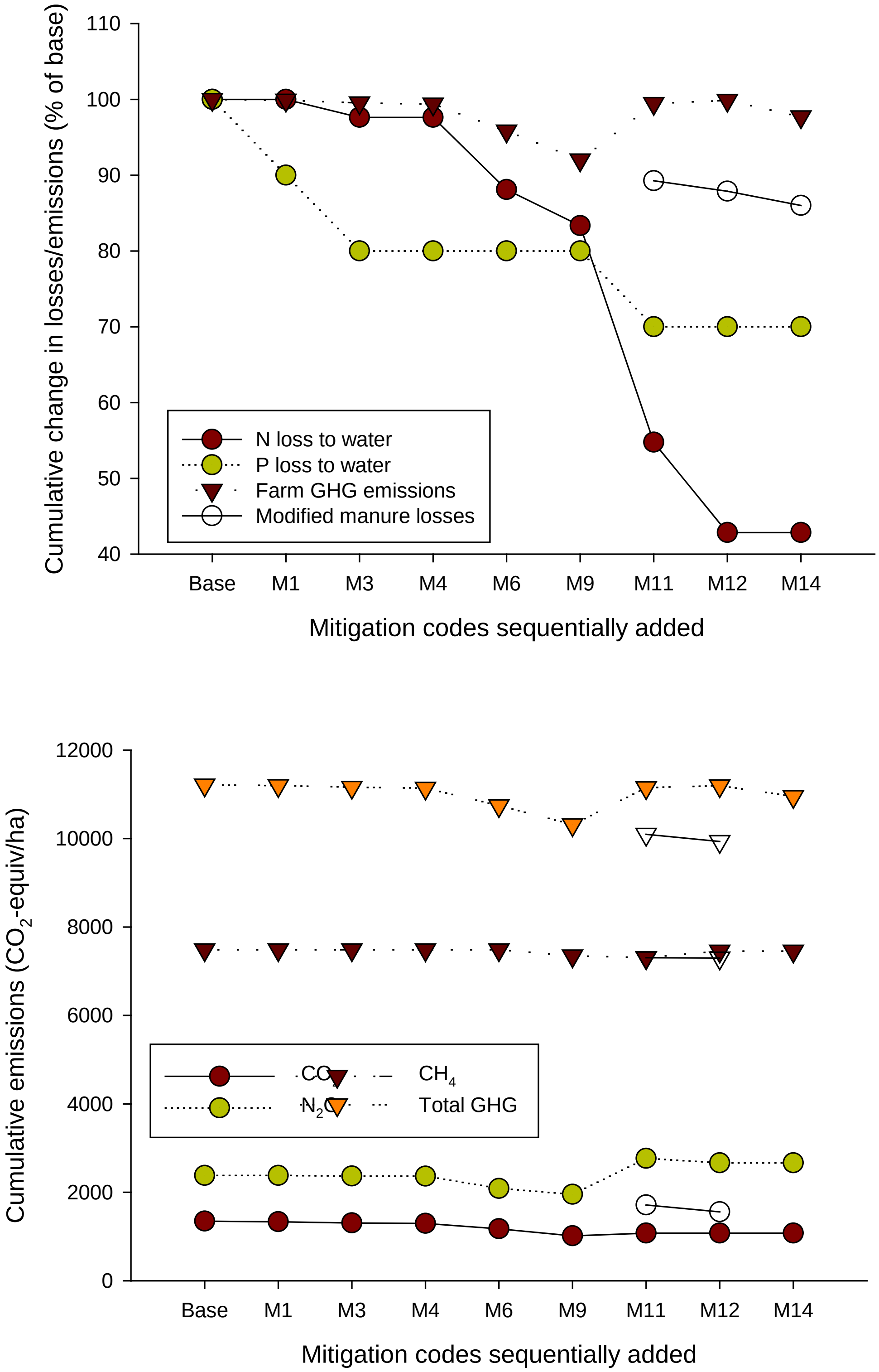


Figure A7.3. Relationship between N and P loss reductions on GHG emissions. Canterbury dairy farm (Systems 2).

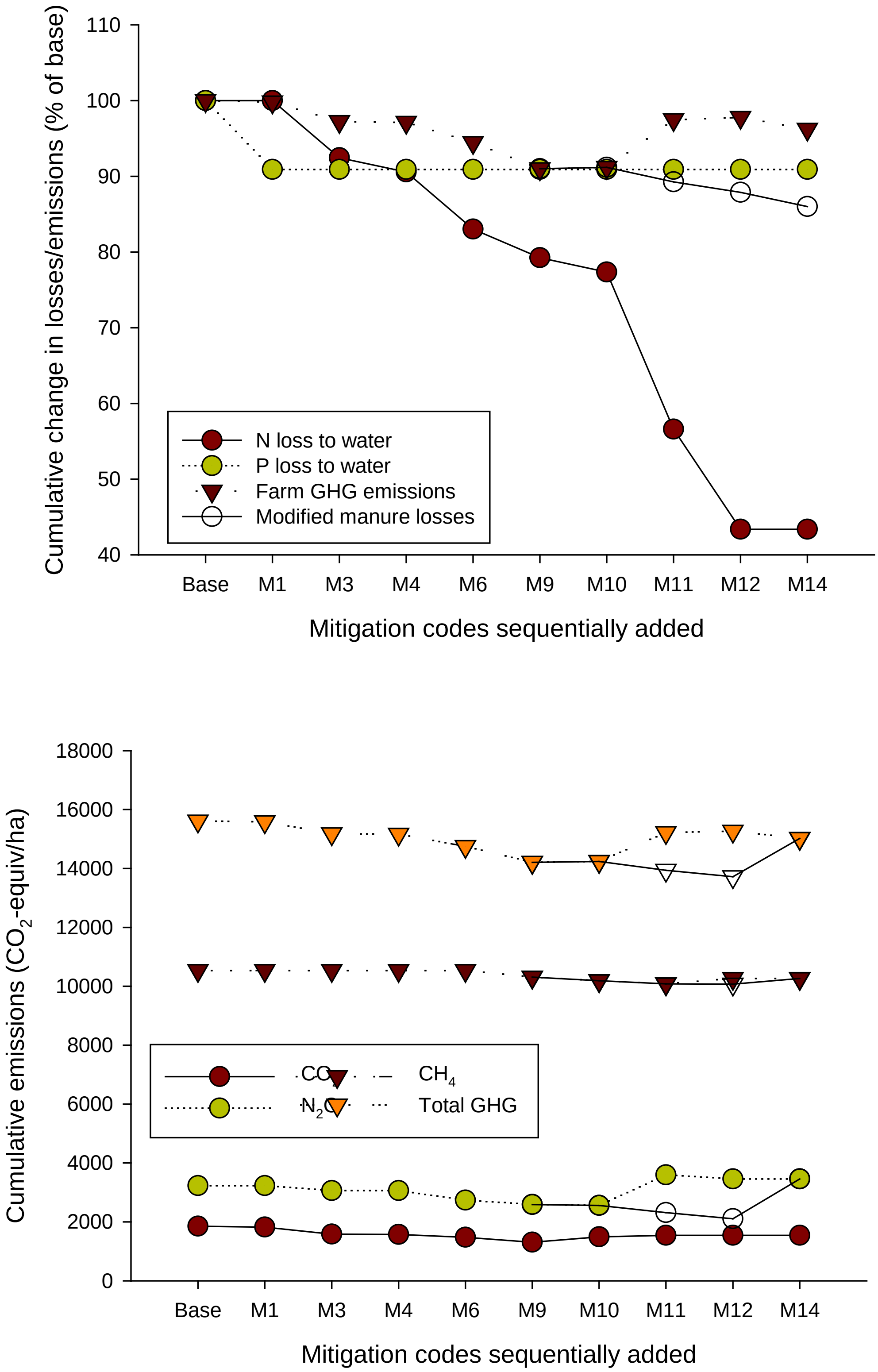
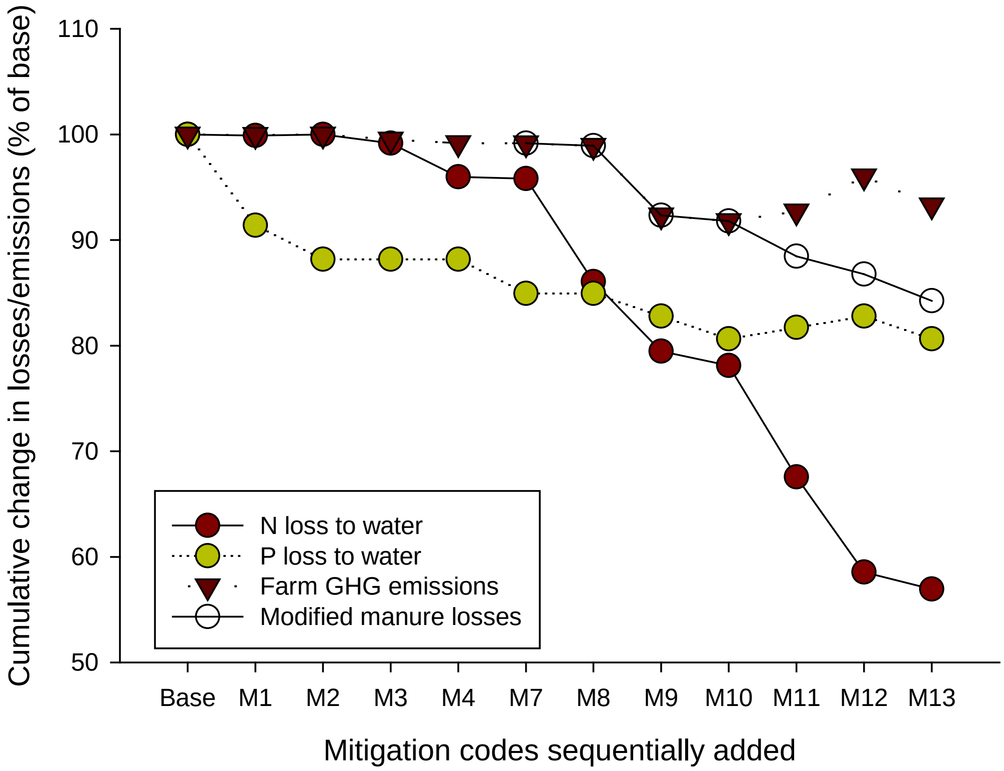


Figure A7.4. Relationship between N and P loss reductions on GHG emissions. Canterbury dairy farm (Systems 4).



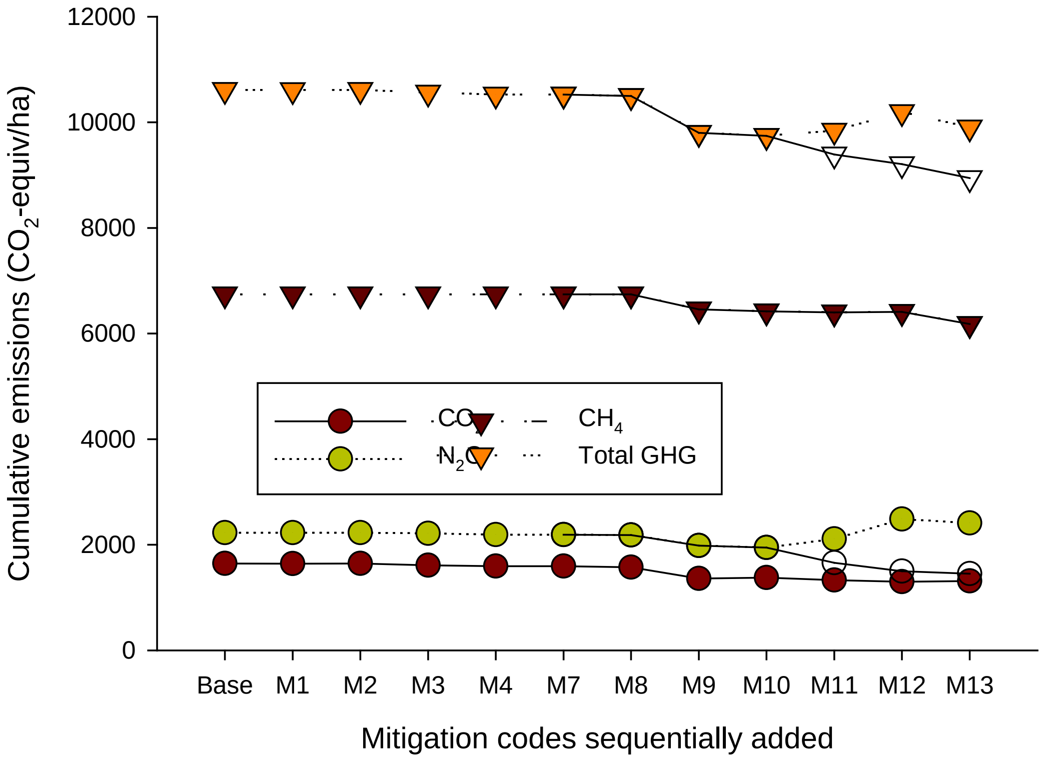
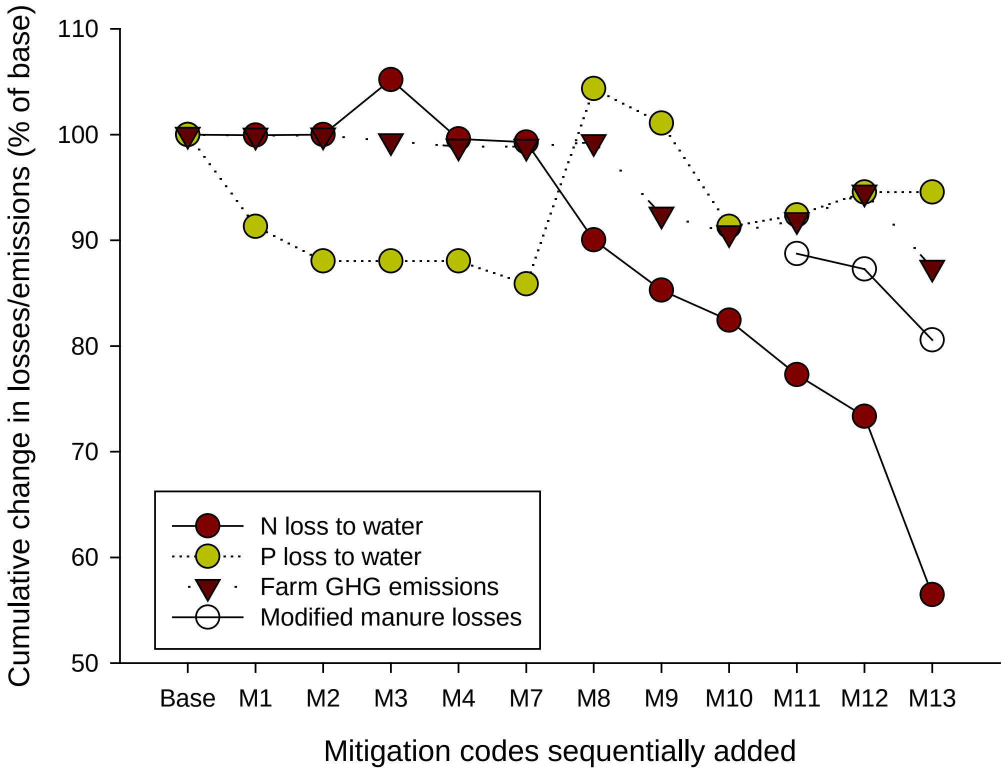


Figure A7.5. Relationship between N and P loss reductions on GHG emissions. Waikato dairy farm (System 2).



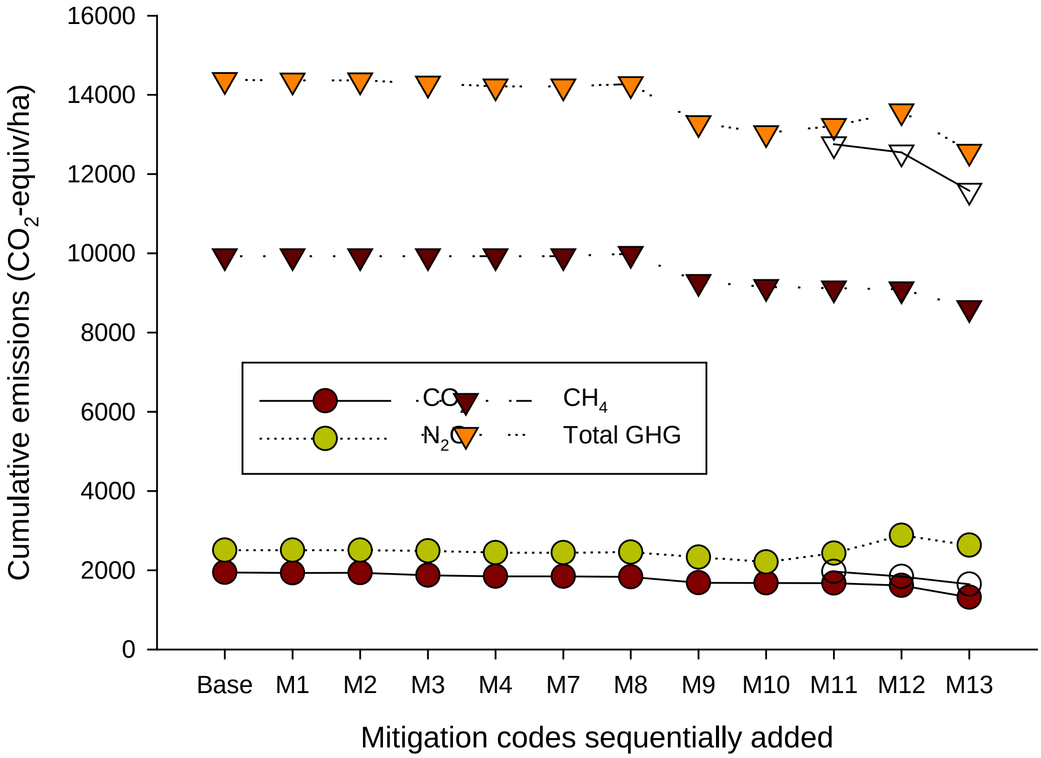


Figure A7.6. Relationship between N and P loss reductions on GHG emissions. Waikato dairy farm (System 4).

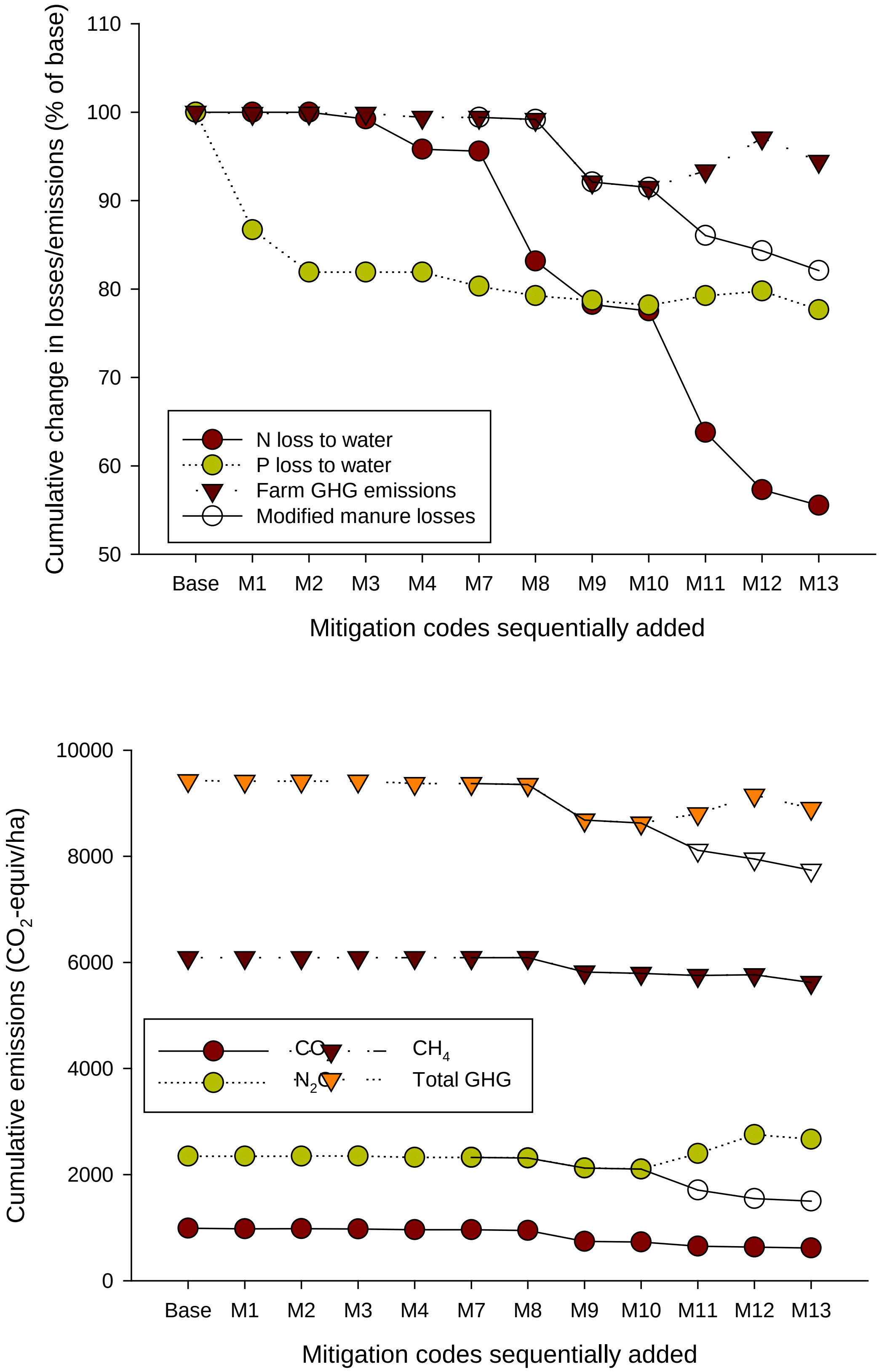
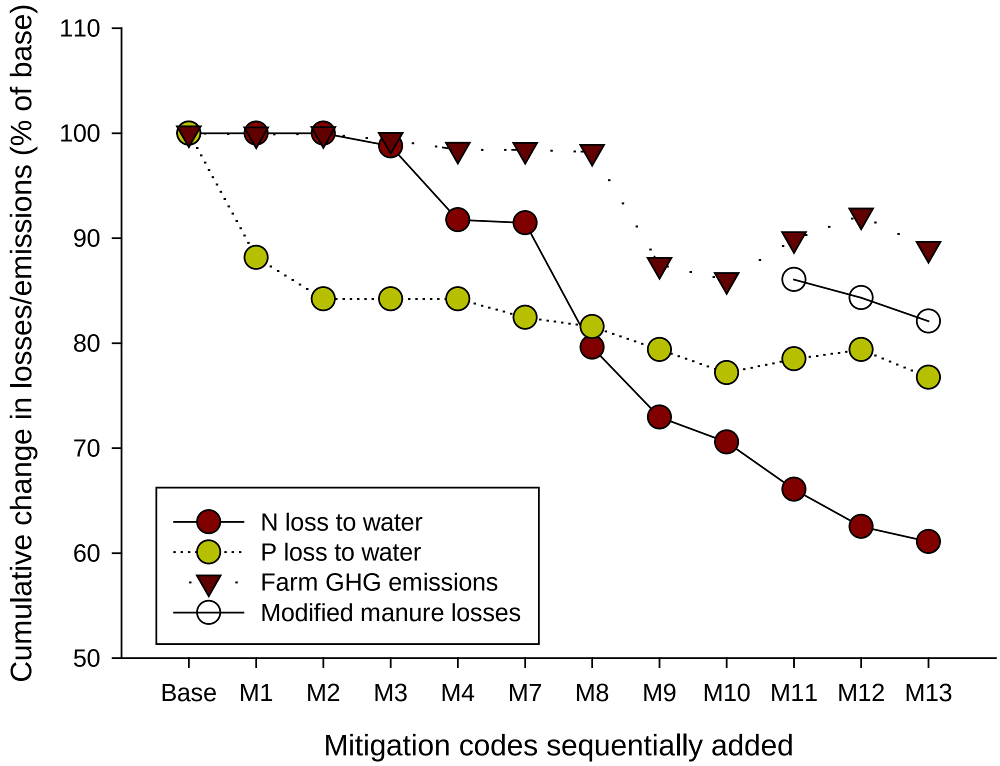


Figure A7.7. Relationship between N and P loss reductions on GHG emissions. Bay of Plenty dairy farm (System 2).



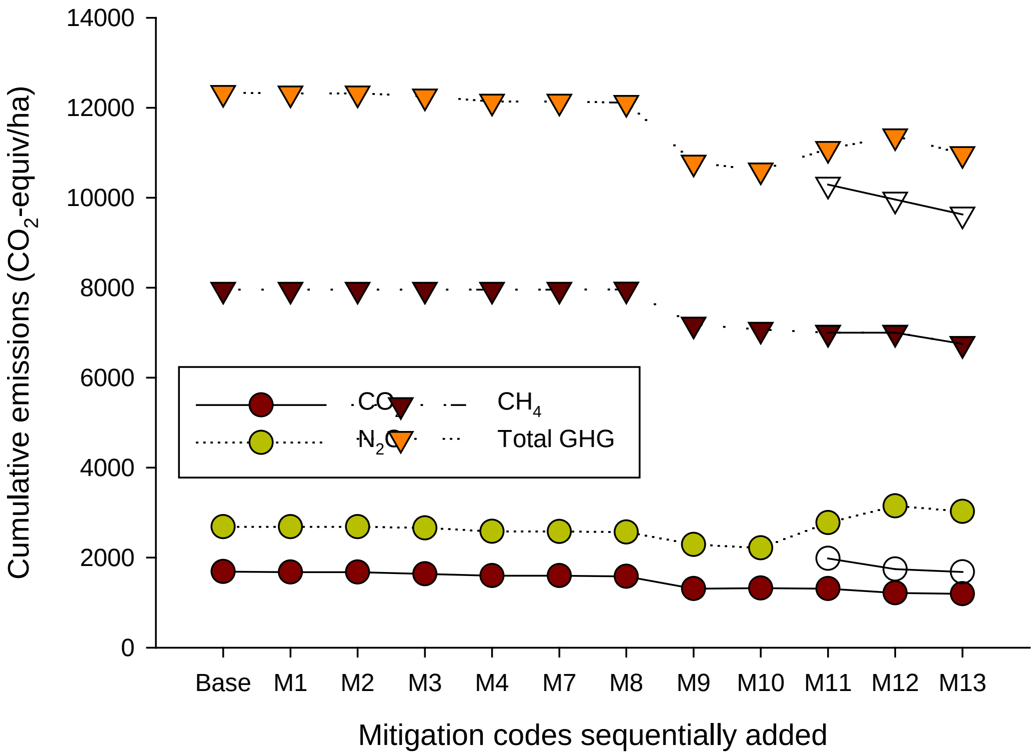


Figure A7.8. Relationship between N and P loss reductions on GHG emissions. Bay of Plenty dairy farm (System 4).