Manaaki Whenua
Landcare Research

Preparation of land use and nitrogen-loss data for the Waimakariri Zone limit-setting process

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Preparation of land use and nitrogen-loss data for the Waimakariri Zone limit-setting process

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Summary

Project and Client

Environment Canterbury require spatial data on land use and nutrient losses for use in the technical assessment of the impacts of potential scenarios of interest to the Waimakariri Zone Committee.

Objectives

Estimate nitrate losses and the drainage lost below the root zone within the Waimakariri Zone area under a series of modelled scenarios.

This report describes:

- The derivation of the base 'Current land use' layer
- Each of the key inputs to the nutrient loss model and their derivation
- The methods used to model each scenario and its associated nitrate loss estimate.

Methods

A spatial modelling approach was used to classify and combine information on land use and management practices, climate, soil type, and a table of expected nitrogen losses for each farm type, climate and soil category. This was done by developing a series of GIS (geographic information system) models to combine various data sources to map land use, and then to combine this land use map with soil and climate layers, along with the nitrogen lookup table to estimate nitrogen and drainage losses. Loss estimates were further modified to match other sources of information. Several variations of potential planning rules were simulated.

Results

Layers of land use and estimated N losses have been generated for five scenarios: Current_oldMP, Current State, Hindcast, Current Consented, and New Irrigation. In a second round of modelling a further five scenarios representing N losses under different planning rules were developed: Current Pathways, Current Pathways PC5, scenario4, draft ZIPA (Zone Implementation Programme Addendum), final ZIPA.

Recommendations

As the various assumptions and simplifications may have an impact on the accuracy of these spatial estimates of N losses, we recommend that the estimated nitrate losses for lifestyle blocks are reviewed. In addition, an uncertainty analysis would help identify other potential errors that may be significant.

1 Introduction

Environment Canterbury is working with the Zone Committee and the local community to set nutrient load and flow limits for the Waimakariri Water Management Zone comprising the Ashley, Ashley-Waimakariri and Saltwater nutrient zones (Fig. 1). Nutrient limits are a way of managing diffuse sources of nitrogen loss in the catchment. Different land use and management scenarios were used to explore what might happen as a result of different actions on environmental, economic, cultural and social well-being, and to help the community make decisions on setting appropriate limits.

This report describes the methods used to map current land use, and estimate nitrate-nitrogen (henceforth referred to as nitrate) losses from rural land use in the Waimakariri Zone area. It provides estimates of catchment nitrate losses under a range of possible future land-use change and mitigation scenarios.

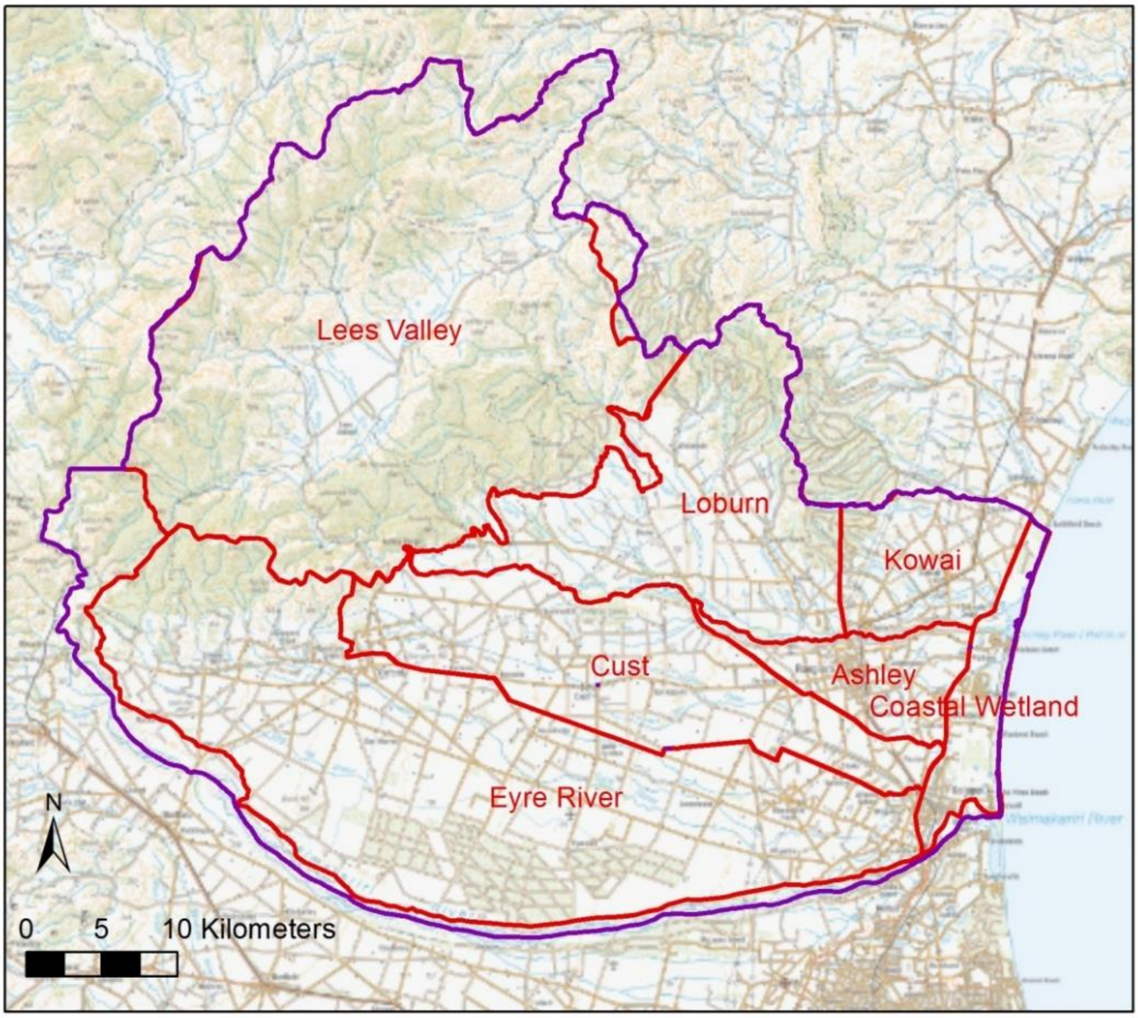

Figure 1 The boundary of the area modelled for the Waimakariri limit setting process (purple). Preliminary nutrient management zones are delineated in red.

1.1 Scope

A large-scale, multi-disciplinary technical work programme was undertaken to support and inform the Waimakariri Land and Water Solutions Programme. It included assessments of cultural health, water quality, water quantity, biodiversity, the local economy, and social/recreational conditions within the zone. These assessments were undertaken to:

- understand the current state of the zone
- estimate outcomes if current resource management practices were to continue unaltered into the future (Current Pathways Scenario)
- explore future alternatives for resource management (Alternative Pathways Scenario)
- support the Zone Committee options assessment process
- evaluate the impact of the Solutions Package on cultural, environmental, social and economic values.

This process is summarised in Figure 2.

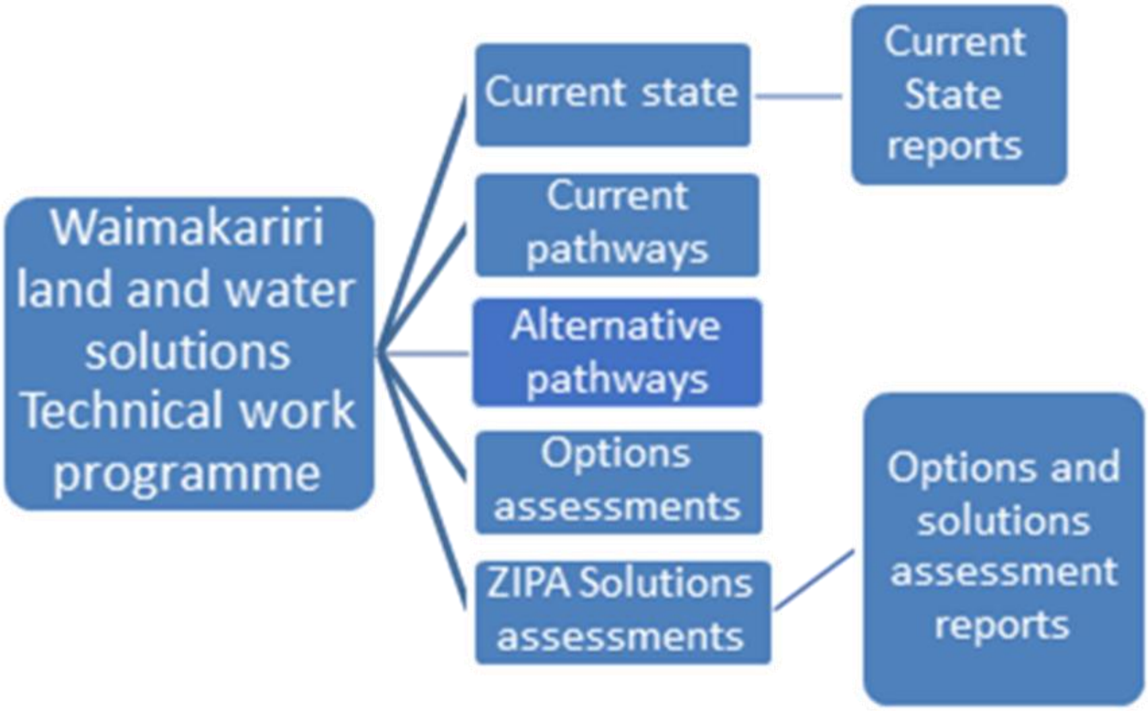

Figure 2 Roadmap for the Waimakariri Land and Water Solutions Programme.

This report is one of a series of technical reports that document key aspects of the Waimakariri Land and Water Solutions Programme. It focusses on the assessment of nitrate concentrations in groundwater and surface water in the zone and provides inputs for the technical reports on Aquatic Ecology and Biodiversity (Arthur et al. 2019), Social Assessment (Sparrow & Taylor 2019) and Economic Assessment (Harris 2019).

1.2 Report Outline

A modelling approach was used to estimate the nitrate losses and drainage lost below the root zone within the Waimakariri Zone (WZ) area. This report describes:

- The derivation of the base 'Current land use' layer
- Each of the key inputs to the nutrient loss model and their derivation
- The methods used to model each scenario and its associated nitrate loss estimate.

2 Nitrogen loss modelling

A spatial modelling approach was used to classify and combine information on land use and management practices, climate, soil type, and a table of expected nitrogen losses for each farm type, climate and soil category. This was done by developing a series of GIS (geographic information system) models to combine various data sources to map land use, and then to combine this land use map with soil and climate layers, along with the nitrogen lookup table to estimate nitrogen and drainage losses over the WZ area. The approach follows that used in both the Selwyn Waihora (Robson 2014) and South Canterbury Coastal Streams (Lilburne 2015) limit setting processes, and by the Matrix for Good Management (MGM) (Robson et al. 2015). Information about the various data sources is outlined below.

2.1 Soil

Soil data were obtained primarily from S-map[1] and supplemented by the modified Land Resource Inventory[2] where S-map coverage was incomplete. The S-map soils are classified according to the soils' water holding capacity, slope, natural drainage class and presence of an impeded layer, as described in the MGM report (Lilburne & Webb 2015). Figure 3 shows the spatial pattern of the soil classes according to the dominant soil sibling within a polygon.

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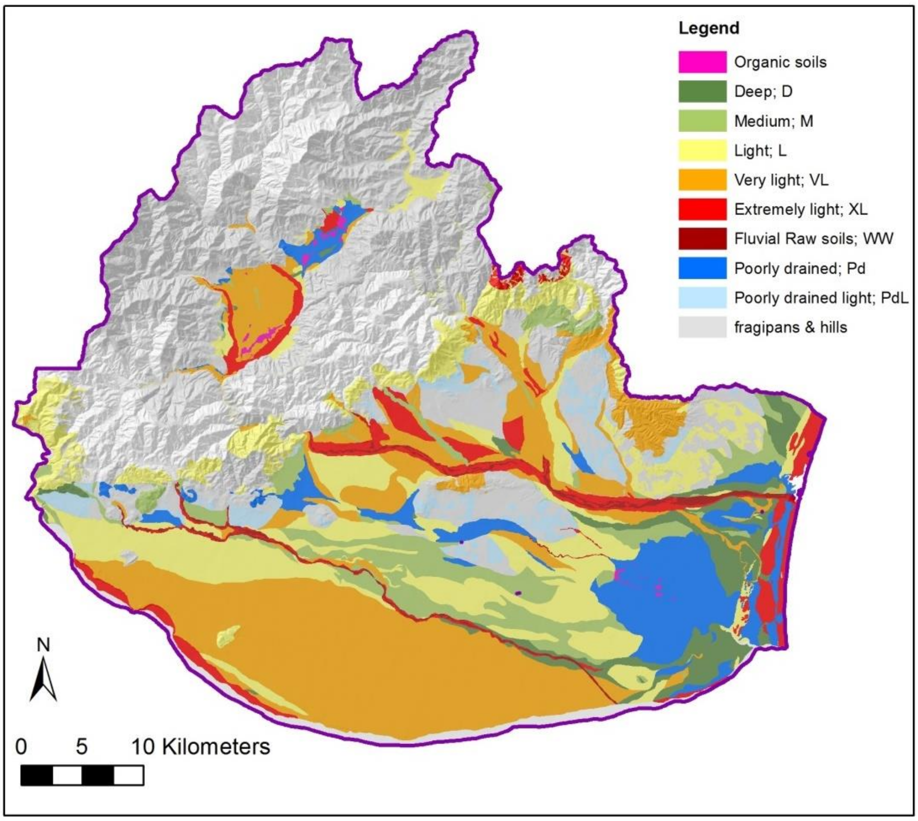
[1] S-map: http://smap.landcareresearch.co.nz

[2] https://apps.canterburymaps.govt.nz/lrisupport/



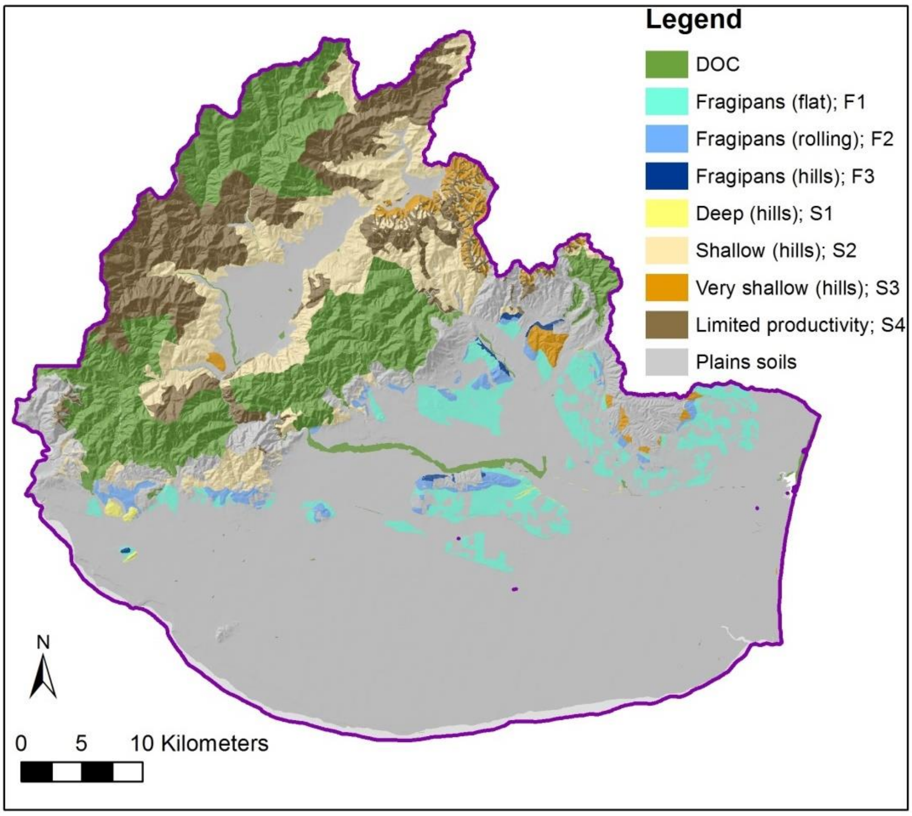


Figure 3 MGM Soil classes in the Waimakariri zone modelling area. The upper map shows the soils on the plains (except soils with an impeded layer). The lower map shows the soils with an impeded layer and those on the hills (excluding DOC estate).

2.2 Climate

The climate layer was clipped from the MGM climate layer (Lilburne & Webb 2015). This, in turn, is derived from a cluster analysis based on NIWA layers of mean long term rainfall, temperature and potential evapo-transpiration. There are 9 climates within the Waimakariri zone (Fig. 4). Table 1 contains the mean climate properties used for each climate zone.

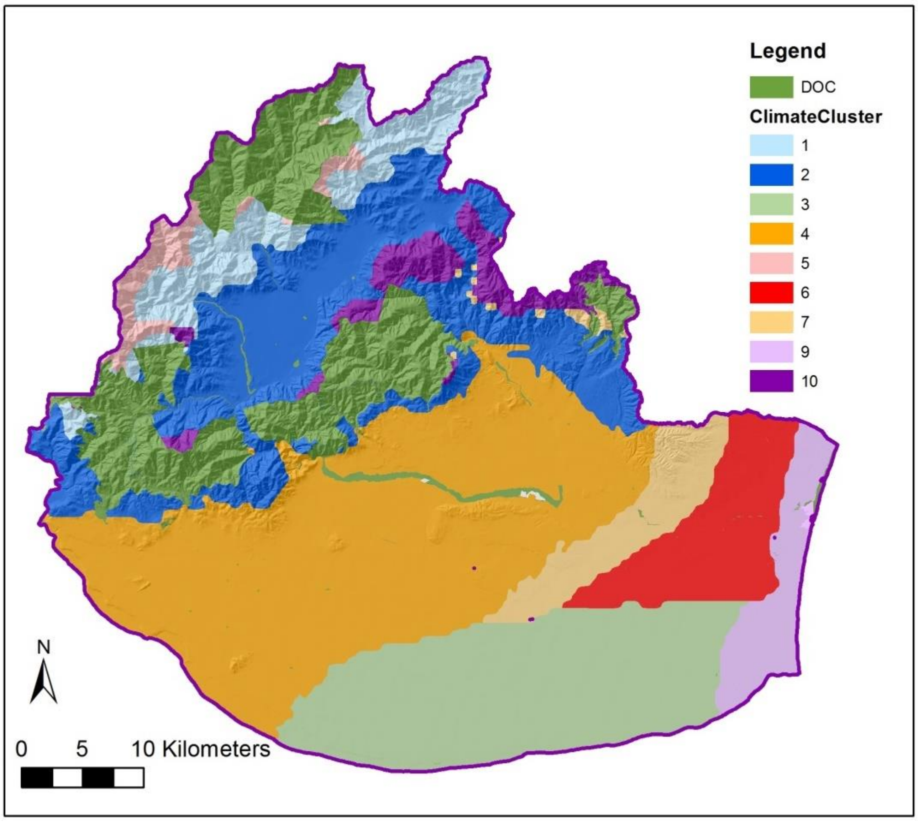


Figure 4 MGM climate clusters within the Waimakariri zone (excluding DOC estate).

Table 1 MGM climate clusters and their mean properties

MGM Climate zone	Mean rainfall (mm/yr)	Mean temperature (°C)	Mean PET (mm/yr)
1	1345	8.7	654
2	1040	9.8	744
3	656	11.7	888
4	897	11.3	858
5	1389	6.1	466
6	651	11.4	798
7	755	9.5	740
9	554	10.7	752
10	768	8.4	617

2.3 Generating the farm land use map

2.3.1 Overview

The land use/management layer used in the modelling was based on a land use layer generated according to the methods described in Hill et al. (2012). This approach uses AgriBase™ data (AsureQuality 2016) as the primary source of data, supplemented by the Land Cover Database, Department of Conservation (DOC) conservation estate boundary information, an irrigation layer (Brown 2016), and topographic data.

AgriBase™ is the only comprehensive source of property-scale land use data that is available for the whole region. This dataset is supplied to Environment Canterbury every 6 months (subject to funding). Agribase data that were supplied in April 2016 were used in this project. The AgriBase™ dataset is compiled from a voluntary survey of rural landowners who specify the dominant land use on their property, along with details of the type and area of all land uses, including crop type and area, type and number of stock.

The land cover database (LCDB4v1), provided by Landcare Research (2015), was used to characterise the small amount of land for which where there was no useful Agribase™ information. It is a land cover layer derived from satellite imagery captured in 2012/13. In addition to the LCDB classes, an additional class (golf courses) was sourced from topographic data from Land Information New Zealand.

The 2016 DOC estate boundary was obtained from koordinates.com. All conservation land was assumed to be native forest/scrublands/tussock except for DOC land with a grazing concession which was treated as being farmed.

The irrigation layer was sourced from the Aqualinc irrigation layer as was available in April 2016. This includes information on the spatial area and the irrigation type.

Combining Agribase™, LCDB, the irrigation layer, the DOC estate boundaries, and topographic data as described by Hill et al. (2012) resulted in a draft 'baseline' land use layer of Land Use and Water Quality (LUWQ). In this, each farm enterprise has a single numeric code (lu_scen) indicating its main land use, even where there are other, less significant activities also carried out within the farm.

The draft land use layer was then modified/corrected (in ascending order of precedence so that each correction overwrites any earlier corrections) by:

- ECan's dairy effluent consents database
- land use identification from ECan's lifestyle layer
- farm type corrections provided from ECan field work and the farmer reference group
- the boundary of DOC land.

Full details of these modifications are described below.

2.3.2 Processing steps

Environment Canterbury's Land Use and Water Quality (LUWQ) layer was clipped to the boundary of the Waimakariri study site, and this was used as the base data layer. Further data sources were used to update and augment this layer as follows:

1. All DOC land, other than DOC grazing concessions, was given a Farm_ID of 'DOC' so that it was not considered as active farmland.
2. Areas of urban/built-up areas, rivers/lakes/ponds and sand/rock/gravel.were masked out of the N-Loss analysis These were given a Farm_ID of 'MASKED'.
3. Some farm enterprises, particularly those in the hill country, include land that is not realistically capable of intensive use and high production, so relatively low N-Loss could be expected. We defined these areas to be where the LRI Land Use Capability (LUC) class is 7 or 8, or where the LUC is 5 or 6 and the slope is steeper than 15 degrees. The area of productive land (i.e. the land not in these LRI classes) was calculated for each farm.
4. LCDB v4.1 was used to fill in some gaps where there was no farm type from Agribase and no valid lu_scen number for certain farms – these appeared to be specific errors in the LUWQ layer relating to three LCDB classes 33 – Orchard, vineyard and other perennial crops; 43 – Tall tussock grassland; and 44 – Depleted grassland.
5. Environment Canterbury's dairy effluent consents database was used to identify properties that must be dairy farms. Any farm having one or more effluent consents was given a dairy farming lu_scen number if it did not already have one.
6. Environment Canterbury's Lifestyle Study layer (Mojsilovic 2016) was used to identify lifestyle blocks. Some are already labelled as such in Agribase, but there has been a huge amount of land use change toward lifestyle blocks in recent years, and the ECan layer is more up-to-date and comprehensive.
7. Several properties in ECan's lifestyle layer were, in fact, inside urban areas. We used a rule that, if the property was smaller than 1 ha in size and was in a Residential or Business Zone, it would be considered part of the masked-out urban areas, rather than being treated as a lifestyle property with its own N-Loss rate.
8. There were a few properties with a farm type of Lifestyle in Agribase that were not present in ECan's lifestyle layer. Those smaller than 10 ha were kept as lifestyle, but those larger were re-coded to an appropriate farming lu_scen number, depending on their class in LCDB v4.1. This was done because we wished to model them as having N-Loss rates appropriate to their farming activities rather than using the lifestyle N-Loss rate.
9. ECan provided corrections to the land use designation of certain farms based on field work, advice from farmers, and visual assessment of recent images. The corrections were of three types: (a) the farm had no current Farm_ID or Agribase data, so the correction was provided as a new polygon – with land use designation – which we added into our land use layer; (b) the farm had a current FARM_ID, and we replaced the Agribase land use with ECan's new land use designation; (c) ECan's correction identified the farm as now being split into several different enterprises, so we split the

farm area using polygons provided by ECan and labelled the new sub-farms with suffixes following the original Farm_ID.

10 Ngāi Tahu's large Eyrewell dairy farming property was split into two categories on the basis of their annual monitoring report (PDP 2016): those parts of the farm that have so far been developed, and those areas that are currently still in forestry.

11 The data source used for designating the final lu_scen value was recorded in the 'origin_update' column. These origins could be Agribase, Golf, LCDB (these first three come through from the LUWQ layer), or DOC, DOCGrz (DOC Grazing Concessions), LCDB4, LIFESTYLE (from ECan's lifestyle layer), MATTD (from ECan fieldwork and advice), or NTAHU (from PDP (2016)).

12 As supporting information, we calculated percentage area of each farm in pasture, crop, or winter forage, using the agricultural land use maps of North et al. (2015). These maps provide a paddock-based land use identification, so all the paddocks within the farm enterprise boundary were included in the percentages for that farm.

13 Dairy farms were separated into two levels of milk solid production based on soil, with the lower level for soils with a class of poorly drained. This separation was based on information from the Waimakariri farmer reference group.

14 Cropping farms with more than 50% of the farm in winter forage were reassigned to be Sheep & Beef classes. Cropping farms with less than 5% area of winter forage were assumed to be pure cropping farms (no stock).

15 Each of the lu_scen farm types was assigned to the closest MGM farm type.

At the conclusion of these steps a base layer representing Current land use (as at 2015) was generated (Fig. 5). This was then used as a base from which to generate land use layers for various scenarios as described in section 0. The final set of land use/management types used in the current scenario is given in Table 2.

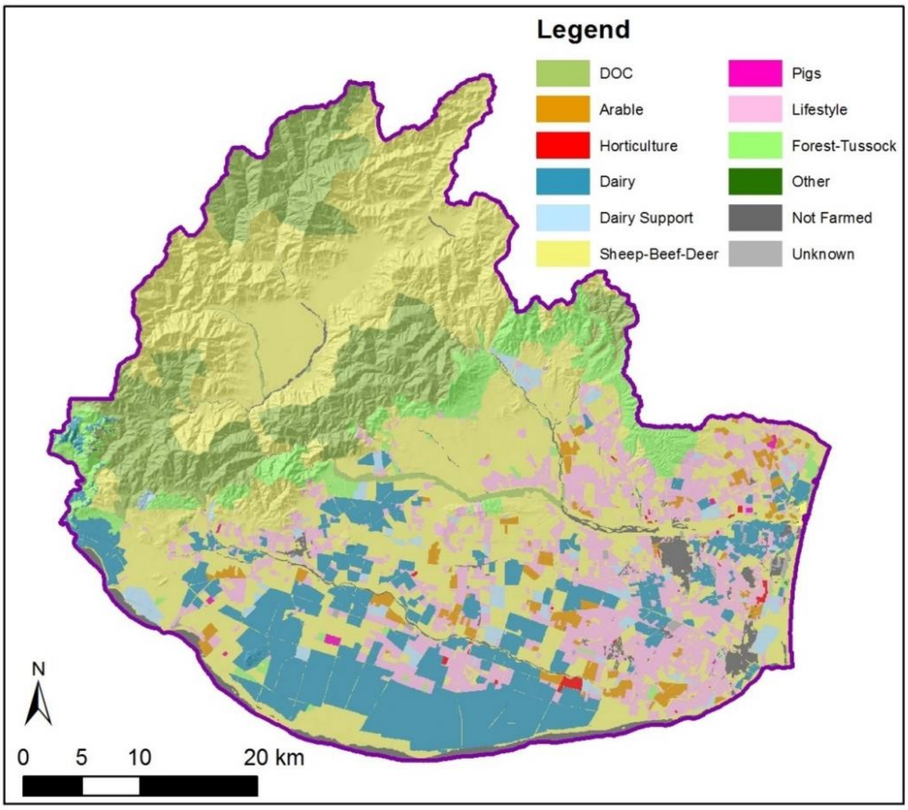


Figure 5 Land use in 2015.

Table 2 List of farm types used in the Waimakariri land use scenarios and their MGM equivalent

Lu_scen code	MGM farm type	Description
102	40% Std_For Gra Spray G + 60% SBD07	Arable mixed grazing spray irrigated
105	40% Std_For Gra Dry G + 60% SBD01	Arable mixed grazing dryland
103	Std_For Gra Spray G	Arable seasonal grazing spray irrigated
106	Std_For Gra Spray G	Arable seasonal grazing dryland
110	Std arable Ret Dry NoG	Arable dryland
111	Std arable Ret Spray NoG	Arable spray irrigated
132	Std+For_Roo+Gre Ret Dry	Arable + Veg dryland
135	Std+For+Roo+Gre Ret Spray	Arable + Veg spray irrigated
201	IntensVeg Ret Spray NoG	Vegetables spray irrigated
221	IntensVeg Ret Dry NoG	Vegetables dryland
202	n/a	Viticulture
210	n/a	Apples
211	n/a	Berry fruit
301	SBD26	Sheep Low Intensity spray irrigated
302	SBD20	Sheep Low intensity dryland
402	SMML_Pivot	Dairy med supplement, low production, spray irrigated
404	SMML_WinOnKale_Pivot	Dairy med supplement, low production, winter on, spray irrigated
420	SMML_Rain	Dairy med supplement, low production, dryland
421	SMML_WinOnKale_Rain	Dairy med supplement, low production, winter on, dryland
422	SMMM_Pivot	Dairy med supplement, med production, spray irrigated
423	SMMM_WinOnKale_Pivot	Dairy med supplement, med production, winter on, spray irrigated
424	SNML_WinOnPasture_Rain	Dairy no supplements, low production, winter on, dryland
425	SNML_WinOnPasture_Pivot	Dairy no supplements, low production, winter on, spray irrigated
450	SBD44	Dairy Support dryland
451	SBD50	Dairy Support spray irrigated
501	SBD12	Beef spray irrigated
502	SBD06	Beef dryland
551	SBD11	Deer spray irrigated
552	SBD05	Deer dryland
601	SBD07	Sheep and Beef
602	SBD09	Sheep and Beef
650	n/a	Sheep and beef hill country
801	n/a	Native forestry
802	n/a	Exotic forestry (from developed land)
803	n/a	Exotic forestry (form undeveloped land)
901	n/a	Pigs
981	4SU + 7 kg N (septic tank)	Lifestyle
985	n/a	Golf course

2.3.3 Current land use statistics

Summaries of the areas and numbers of farms in the WZ are presented in Tables 3 – 6. Note that only land within the zone area is included in this analysis. This means that farms that extend beyond the zone boundary are larger than is reflected in these tables.

Table 3 Summary of farm area and number within the Waimakariri zone area

	Area (ha)	Count
Farms (smaller than 5 ha)	14,522	4990
Farms (5 ha or larger)	182,769	2,308
DOC estate	34,831	
Masked out areas (urban, etc.)	7,239	
Unknown[a]	588	33
Total land use area	239,949	

[a]Land that was not associated with AgriBase™ landownership information. This includes much of the road network (where the LCDB layer was of insufficient resolution and so recorded it as agricultural land uses), unmanaged land along the rivers, as well as farms where the landowner has not completed the AgriBase™ survey.

Table 4 Count of farms by farm size and land use type within the Waimakariri zone according to the baseline land use layer (dominant land use)

	Hectares							
	<5	**5–10**	**10–15**	**15–20**	**20–25**	**25–30**	**>30**	**Total**
Arable	2	4	11	8	4	3	39	71
Dairy				2	3		99	104[3]
Dairy support	9	4	2	2	1	2	45	65
Sheep, Beef, Deer	30	14	68	43	52	23	317	547
Forestry	3	5	14	7	9		37	75
Horticulture	9	10	2		3	1	2	27
Lifestyle	4,935	1,041	185	114	100	16	8	6,399
Pigs	2	1	1	1	2	1	2	10
Total	**4,990**	**1,079**	**283**	**177**	**174**	**46**	**549**	**7,298**

[3] Note that what is counted as a single dairy farm may comprise multiple dairy platforms

Table 5 Area (ha) of Scenario 1 land use type by soil type

	WW,XL	VL	L	M	D	PdL	Pd	F1-F3	O	S1-S4	unknown	Grand Total
Arable	88	526	1,533	1,087	622	0	300	704	0	4	6	4,872
DairyFarm	395	19,186	6,051	2,447	813	1,139	2,860	0	0	0	77	32,969
DairySupport	505	1,380	751	537	445	22	760	458	33	176	4	5,070
Sheep-Beef-Deer	7,434	17,595	11,294	6,332	2,195	611	5,332	12,879	414	44,622	1,009	109,719
Forest-Tussock	772	3,617	8,609	705	242	809	60	4	0	277	11	15,106
Horticulture	2	123	22	48	198	4	23	0	0	0	0	418
Lifestyle	655	5,760	8,397	2,698	2,988	3,599	4,763	0	0	0	4	28,865
Pigs	0	136	35	37	48	7	10	0	0	0	0	273
DOC	1,301	123	45	69	9	79	14	1	0	0	33,191	34,831
NotFarm	1,497	452	506	449	636	16	484	68	0	214	2,917	7,239
Unknown	70	61	102	22	39	1	258	33	0	1	0	588
Grand Total	**12,719**	**48,959**	**37,346**	**14,430**	**8,236**	**6,287**	**14,863**	**14,147**	**447**	**45,296**	**37,220**	**239,949**

Table 6 Area (%) of Scenario 1 land use type by soil

	WW,XL	VL	L	M	D	PdL	Pd	F1-F3	O	S1-S4	unknown	Grand Total
Arable	0.0%	0.2%	0.6%	0.5%	0.3%	0.0%	0.1%	0.3%		0.0%	0.0%	2.0%
DairyFarm	0.2%	8.0%	2.5%	1.0%	0.3%	0.5%	1.2%				0.0%	13.7%
DairySupport	0.2%	0.6%	0.3%	0.2%	0.2%	0.0%	0.3%	0.2%	0.0%	0.1%	0.0%	2.1%
Sheep-Beef-Deer	3.1%	7.3%	4.7%	2.6%	0.9%	0.3%	2.2%	5.4%	0.2%	18.6%	0.4%	45.7%
Forest-Tussock	0.3%	1.5%	3.6%	0.3%	0.1%	0.3%	0.0%	0.0%		0.1%	0.0%	6.3%
Horticulture	0.0%	0.1%	0.0%	0.0%	0.1%	0.0%	0.0%					0.2%
Lifestyle	0.3%	2.4%	3.5%	1.1%	1.2%	1.5%	2.0%				0.0%	12.0%
Pigs		0.1%	0.0%	0.0%	0.0%	0.0%	0.0%					0.1%
DOC	0.5%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		0.0%	13.8%	14.5%
NotFarm	0.6%	0.2%	0.2%	0.2%	0.3%	0.0%	0.2%	0.0%		0.1%	1.2%	3.0%
Unknown	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%		0.0%	0.0%	0.2%
Grand Total	**5.3%**	**20.4%**	**15.6%**	**6.0%**	**3.4%**	**2.6%**	**6.2%**	**5.9%**	**0.2%**	**18.9%**	**15.5%**	**100.0%**

2.4 Generating the nutrient loss estimates

A lookup table of nitrate loss rates for the Waimakariri area was derived using a combination of values from the MGM (Robson et al. 2015) and the LUT (Lilburne et al. 2013) for farm types not covered by MGM. The MGM values are based on the latest version at the time of preparation of the Overseer Nutrient Budget model (OVERSEER), in this case version 6.2.2. A series of adjustments were made to lower these losses to better match water quality measurements and agricultural statistics. As the MGM classes did not include farms with sufficiently low stocking rates, these adjustments included accounting for lower N losses from ineffective areas on farms and from low-producing sheep and beef hill country. These are described below.

2.4.1 Land cover adjustment for ineffective areas

Effective and ineffective areas on agricultural land were distinguished, with the latter being masked and assigned a low nitrogen loss. This step was only applied within arable, horticultural, dairy, sheep, beef & deer, and dairy support land. Data sources used to identify non-effective areas of farms included: Land Cover Database (LCDB) v4, irrigation status, and the Global Forest Change 2014 layer (Hansen et al. 2013).

The nitrogen losses were not altered for irrigated land, or high producing grassland, crop, and fruit LCDB land covers. Additionally, any land experiencing forestry loss, having either harvested exotic forest LCDB cover, or with loss detected by Global Forest Change 2014 layer, was excluded from the ineffective land mask.

2.4.2 Semi-improved and unimproved land adjustment

Nitrogen loss from semi-improved and unimproved grazing farmland, taken as low producing grasslands & tussock grasslands LCDB land covers, was estimated using the linear regression meta-models developed for sheep/beef/deer farms from the large MGM dataset (Snow et al. 2016). The regression models estimate nitrogen losses by using a small number of inputs: soil, climate, stocking rate, % of beef stock, and a forage cropping area.

For the semi- and unimproved land, the APSIM model estimates of dry matter production were reduced by 1/2 to reflect lower production associated with the cover. Other inputs assumed 100% sheep and no winter forage cropping area.

The motivation for using the MGM regression approach for the low production land was the assessment that, at the very low stocking rates, the OVERSEER® block-level estimate of nitrogen losses is insensitive to stocking rate changes.

Diffuse nitrogen losses for lifestyle blocks were estimated using the MGM regression equations for sheep, beef, and deer land use, using low stocking rates (4 RSU/ha). An additional point-source discharge for each property was applied, reflecting presence of a septic tank (7.0 kgN per property[4]).

2.4.3 Farming intensity adjustment

Following a preliminary analysis of the estimated diffuse nitrogen loads against the available surface and groundwater quality data (see Etheridge and Hanson, 2019 for a detailed discussion), we validated the modelled farming intensity against other sources. When aggregated up to the study area level and compared against the available district-level metrics, the selected MGM farm systems tended to overestimate the expected livestock intensity. To achieve a closer reconciliation between the two estimates, we lowered the intensity of the modelled livestock farming systems.

The modelled estimate of the livestock inventory was compared with an inventory estimated from projecting the district stock count data in the Statistics NZ Agricultural Census tables. The modelled dairy production was also compared with the 2015/2016 production statistics published for the district (LIC & Dairy NZ2016).

At the study area level, we estimated the modelled intensity by extrapolating and totalling a metric of representative MGM farm types, e.g. stocking rate and milk solids production, across the land use map. Lifestyle properties were not included in the stock inventory of the land use map. In other words, we assumed that lifestyle properties contain a negligible proportion of the stock in the Statistics NZ census.

Table 7 summarises the estimated livestock inventories and the effect of these adjustments. Our modelled sheep, beef & deer land use is likely to include dairy support, while the Statistics NZ data are cleanly grouped by stock classes, and in it, the dairy support will be fully accounted against its dairy group.

Table 7 Summary of district stock inventory for dairy and sheep, beef and deer estimated from two data sources: Statistics NZ agricultural census and from the land use map generated for modelling nitrogen load, expressed in revised stock units (rounded to nearest 1000s)

	Statistics NZ estimate	Land use map estimate	Ratio	Land Use map after adjustments	Adjusted Ratio
Dairy & Dairy Support	807,000	884,000	0.91	685,000	1.18
Sheep, Beef & Deer	440,000	769,000	0.57	527,000	0.83
Total	**1,246,000**	**1,653,000**	**0.75**	**1,212,000**	**1.03**
RSU/ha	9.1	12.0		8.8	

[4] Derived from Loe (2012), Estimating nitrogen and phosphorus contributions to water from discharges that are consented and permitted activities, Environment Canterbury Report No. R12/18, ISBN 978-1-927195-80-2

To reconcile the stock inventory data, we applied a linear factor of 0.70 to the modelled stocking rate of the dryland sheep, beef & deer farms. The stock reduction factor was translated to a change in N loss rates using the linear meta-models in Snow et al. (2016). To reconcile the modelled and reported district-level milk production data, we weighted the medium production dairy MGM farm types with a lower production variant.

A comparison with OVERSEER results from two farm files edited by the farmer reference group indicated comparable nitrate loss estimates.

2.5 Mapping nitrogen loss

Two layers are generated: nitrate mass, and drainage below the root zone. Masked areas, including urban land, and rural areas with unknown land use are assigned default values (Table 8). As the two sources of lookup loss rates are derived using different soil and climate classifications, these were cross-referenced in accordance with the values listed in Table 9. When dairy loss rates were not available for all climate zones and soils, the N loss rates for the nearest equivalent climate zone/soil were used.

Table 8 Default values used in the nitrate lookup tool (as applied in the Waimakariri process)

	Drainage (mm/yr)	Nitrate (mg/L)	Nitrate (kg/ha)
Masked areas: urban, riverbeds, parks etc.	100	2	2
Farms with unknown land use	350	6	21

Table 9 Soil and climate match between MGM and LUT

Type	MGM soil/climate zone	Equivalent LUT soil/climate zone
Soil	O	D
Soil	WW	XL
	F1-F2	D,M,L,VL,XL,Pd,PdL
	F3, S1-S4	–
Climate	2	850 mm/yr (Hororata)
	3	650 mm/yr (Lincoln)
	4	850 mm/yr (Hororata)
	6	750 mm/yr (Darfield)
	7	750 mm/yr (Darfield)
	8	650 mm/yr (Lincoln)
	9	650 mm/yr (Lincoln)

Figure 6 shows the estimate nitrate losses below the root zone for the current land use under good management practice (GMP) and Figure 7 averages these within each farm enterprise.

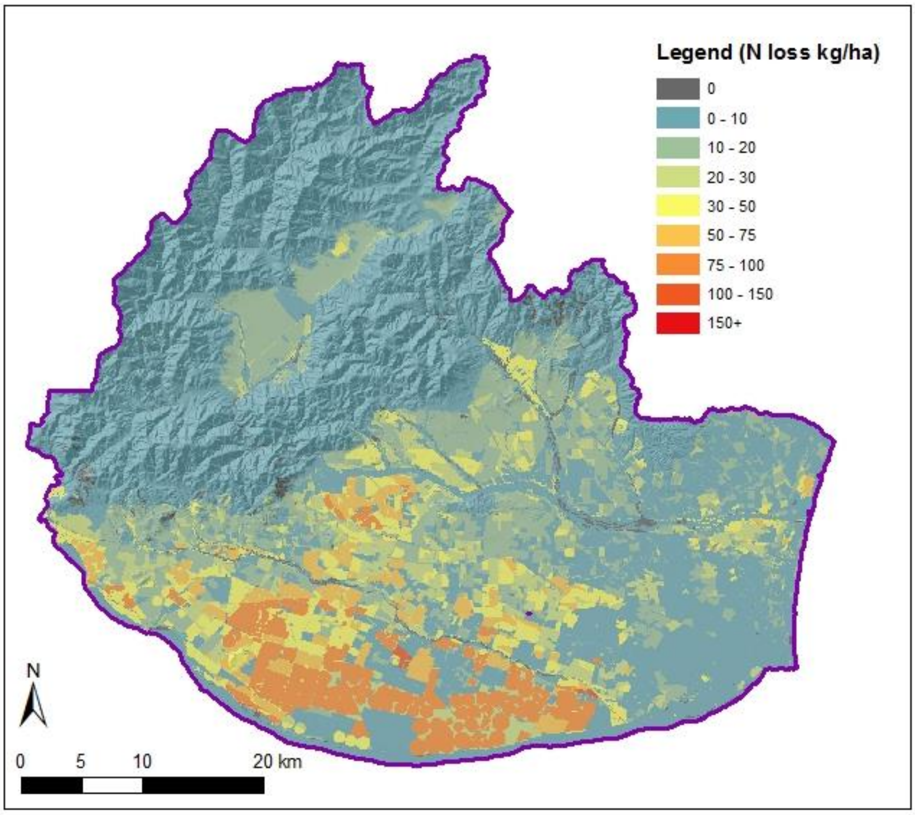


Figure 6 N losses below the root zone under current land use (under GMP).

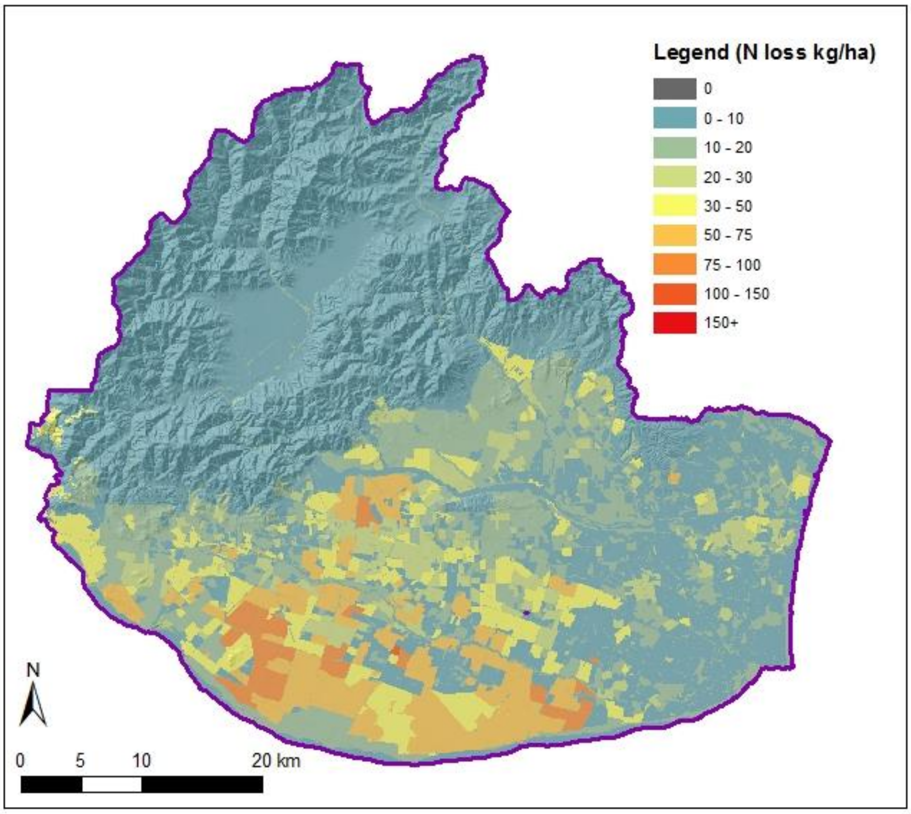


Figure 7 N losses below the root zone under current land use (under GMP) averaged over each farm.

Table 10 summarises the N losses by dominant land use and farm size, and Table 11 shows the number of farms by dominant land use and level of N losses.

Table 10 Total N losses (t/yr) by dominant land use and farm size

Total N (t/yr)	Farm size in hectares									
	<5	5–10	10–15	15–20	20–25	25–30	30–40	40–50	>50	Total
Arable	0	0.3	1.7	1.5	1.6	1.4	3.6	3.0	87.5	100.7
Dairy				1.1	2.9		1.7	3.4	1,866.0	1,875.1
Dairy support	0.1	0.5	0.5	0.9	0.8	0.8	9.7	8.1	159.6	181.0
Sheep, Beef, Deer	0.5	1.8	10.4	9.9	17.7	12.0	34.7	47.2	1,074.5	1,208.6
Forestry	0.0	0.1	0.3	0.3	0.4		0.5	0.8	25.8	28.2
Horticulture	0.4	0.7	0.2		0.8	0.2	0.4		10.1	12.8
Lifestyle	60.5	44.5	11.9	10.9	11.7	2.3	1.3		0.3	143.2
Pigs	0.1	0.1	0.7	0.4	0.9	1.4			6.8	10.4
DOC										8.4
Unknown										4.5
Not Farmed										16.4
Total N losses										3,595.4

Table 11 Count of farms by level of mean N losses and land use

Count of farms	N losses (kg/ha/yr)										
	<5	5–10	10–15	15–20	20–25	25–30	30–40	40–50	50–60	60–80	>80
Arable	1	21	13	21	2	6	6	1			
Dairy			4	10	11	4	12	14	11	31	7
Dairy support	4	13	8	5	2	5	15	2	3	4	4
Sheep, Beef, Deer	50	102	128	98	57	56	43	4	9		
Forestry	71	4									
Horticulture		17	2	1	3	2			1	1	
Lifestyle	4146	2021	232								
Pigs		1	2	2	2				3		
DOC	1										
Unknown		2		3	28						
Not Farmed	1										
Total Count	4274	2181	389	140	105	73	76	21	27	36	11

3 Scenarios – part 1

A set of land use/nitrate loss scenarios were developed as follows

Current_oldMP	Land use reflecting farm types in 2015 under pre-GMP (current) management practice. Also known as CMP – Current Management Practice.
Current State	Land use reflecting farm types in 2015 under good management practice. Also known as GMP - Good Management Practice
Hindcast	Reflecting farm types and nitrate losses from the 1980s
Current Consented	Assuming current land use and nitrate losses under GMP + the Ngai Tahu farm is fully developed into irrigated dairy. Also known as Current consented at GMP
New Irrigation	Assuming an additional 500 ha of irrigation in the Lees Valley, 3,500 ha in the Loburn area and 8,750 ha on the plains.

3.1 Current State scenario

The current state scenario nitrate losses are presented in section 2.5.

3.2 Current oldMP scenario

The current, or pre-good-management-practice state was simulated by applying percent changes to the nitrate loss estimates under the Current State (GMP) scenario. These applied percent changes are estimated from the relative effect of Matrix of Good Management GMP modelling proxies on the root zone losses, using a sample of representative OVERSEER® nutrient budgets. We note that this sample may not reflect the type of farm system and the level of uptake of good management practices in the study area. The relative effects of GMP modelling proxies for individual farms were averaged into broad land use classes (cropping, dairy, dairy support, sheep & beef), and these average percent changes were applied to the GMP modelling data as outlined below. The resulting N losses are depicted in Figure 8.

A For all dryland & irrigated land on farms not intersecting the Waimakariri Irrigation Limited (WIL) command area:

- Data used to estimate the average effect of GMP: The sample of representative farms consisted of MGM industry survey farms, and the effects of the GMP proxies, as % differences, are reported in the OVERSEER® update addendum to Robson et al. (2015).
- The relative change was applied to N losses (kg/ha) in the Current State scenario. The loss rates of dairy, and sheep and beef farm types were multiplied by the percent changes of 15, 25, and 8 percent respectively.

B For irrigated land on farms intersecting the WIL command areas:

- Data used to estimate the average effect of GMP: The sample consisted of the representative irrigated farm OVERSEER nutrient budgets used in calculating the consented nitrogen loads for the WIL scheme. The files were run through the GMP proxies on the Farm Portal.
- Using the Farm Portal GMP proxies and the above data, we estimated the average percent effect of GMP on both the nitrogen root zone loads and drainage depths across the land use groups.
- To simulate management practice prior to good management practice (GMP) based on the above analysis, modifiers of 50, 60, and 140 percent were applied to nitrogen root zone loads for cropping, dairy, and sheep and beef land uses respectively. In addition, to simulate the effect on drainage, modifiers of 90, 80, and 90 percent were applied to the estimated OVERSEER drainage volumes for cropping, dairy, and sheep and beef farm types respectively.
- Extrapolated to the scheme command area, the estimated effect of GMP proxies on the representative sampling of OVERSEER files used in consenting the scheme nitrogen load is dominated by the improvements in water use efficiency introduced by the irrigation proxies. This leads to large increases in both loads and drainage, but minimal changes in the average nitrogen concentrations in the drainage waters.

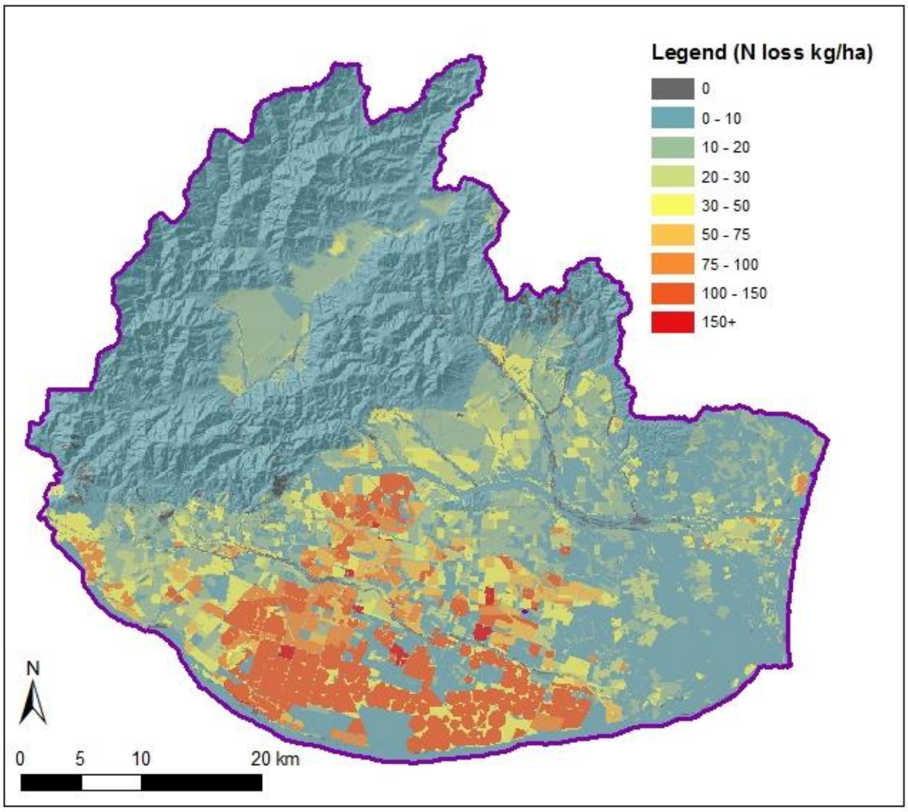


Figure 8 N losses below the root zone under current land use pre GMP (Current_oldMP).

3.3 Hindcast scenario

The development of rules for a historical land use map was based on the narrative information in Mary Sparrow's history of land use in the region, and by comparing the 1986 North Canterbury catchment board Waimakariri resource survey map with the MGM soils map (of N loss categories) (Table 12).

Stocking rates/ha have generally increased from 1994 (and from the 1970s with back calculation estimates based on Ag census stats 1969–70 and 70–71 for Ashley, Rangiora, Eyre, Oxford counties). Using very coarse SU and areas – SU/ha in 1970 was approximately 0.61 of 2012. In early 1980s this is assumed to be at 0.7. This intensity factor is applied to the MGM nitrate loss rates. For cropping, a factor of .8 is applied – this assumes some decrease in intensity but adjusted up for long fallows (Mary Sparrow, pers. comm.). Figure 9 shows the land use, Figure 10 maps the nitrate loss below the root zone.

Table 12 Rules for deriving the 1980 hindcast land use and associated nitrate loss rates

Area	Intensity modifier	Farm type	MGM farm code and lu_scen number for Irrigated farms	MGM farm code and lu_scen number for Dry farms
Hills (S1-S4, F3)	0.7	low intensity (low pasture)		SDB00 650
F1, F2, VL, XL, WW	0.7	low intensity (low pasture)		603
D, PD (areas 1, 2, 3, 4, 5)	0.8	mixed farming intensive cropping cereals – vegetables)	Std+For+Roo+Gre Ret Spray 132	Std+For+Roo+Gre Ret Dry 135
M, L, PD (areas 6, 7, 8, 9)	0.7	Arable mixed grazing	102	105
PD (excluding areas 1-9)	0.7	Dairy no supplement, low production, Winter on	SNML_WinOnPasture_Pivot 425	SNML_WinOnPasture_Rain 424
Forestry areas as indicated on Waimakariri resource survey map	1	Exotic forestry		803

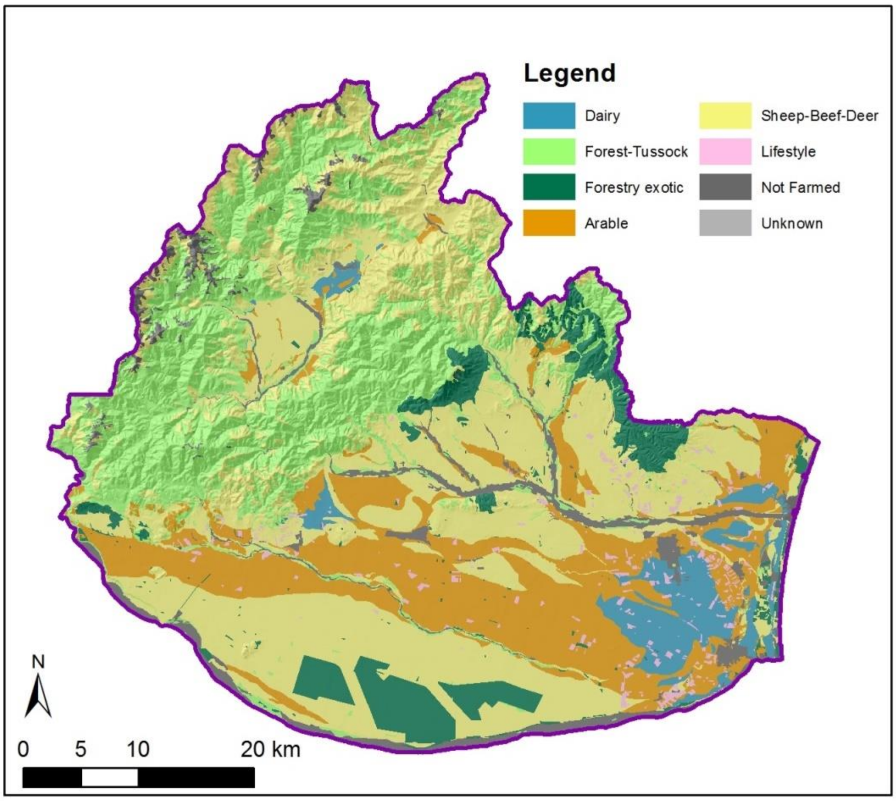


Figure 9 Estimate of land use in the 1980s based on some simple rules.

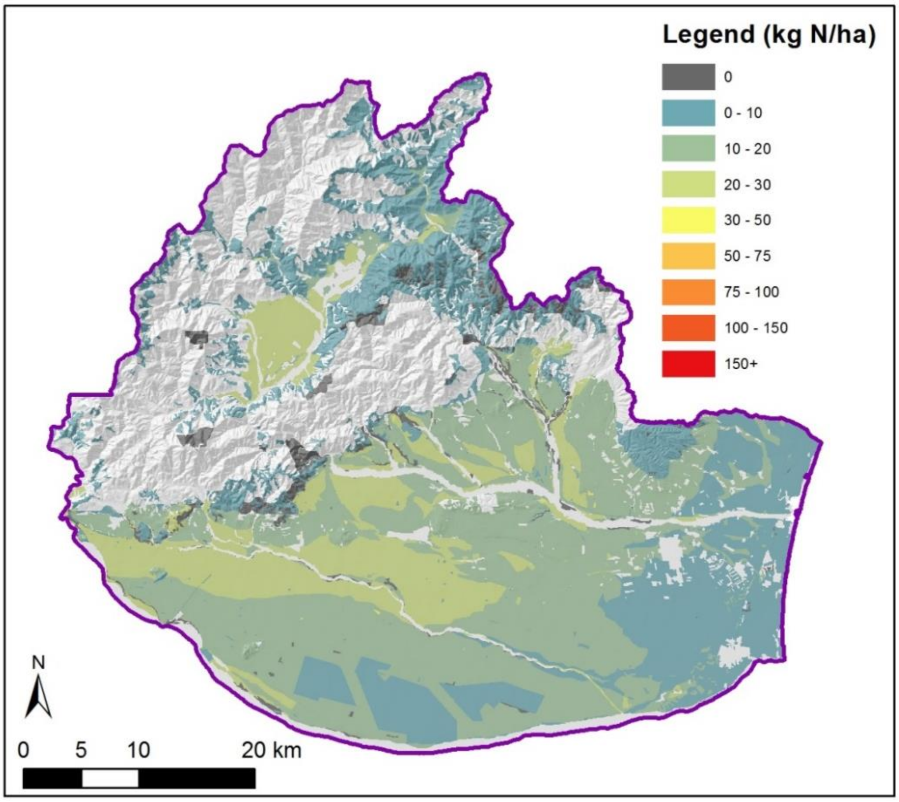


Figure 10 Estimated N losses from land use in 1980.

3.4 Current Consented scenario

This scenario builds on the current 2015 land use and finishes the conversion of the Ngai Tahu Eyrewell farm from forestry to irrigated land under dairy. The land uses are shown in Figure 11, and the resulting N losses in Figure 12. This scenario is also known as Current consented at GMP.

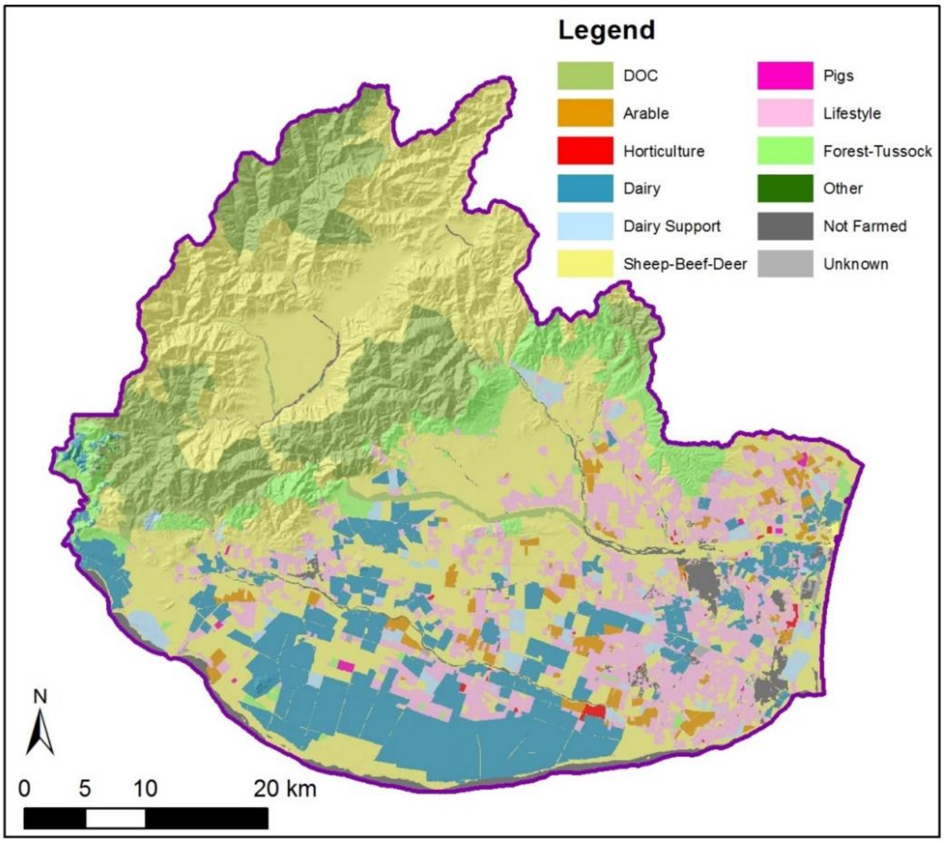


Figure 11 Land use under the Current Consented scenario.

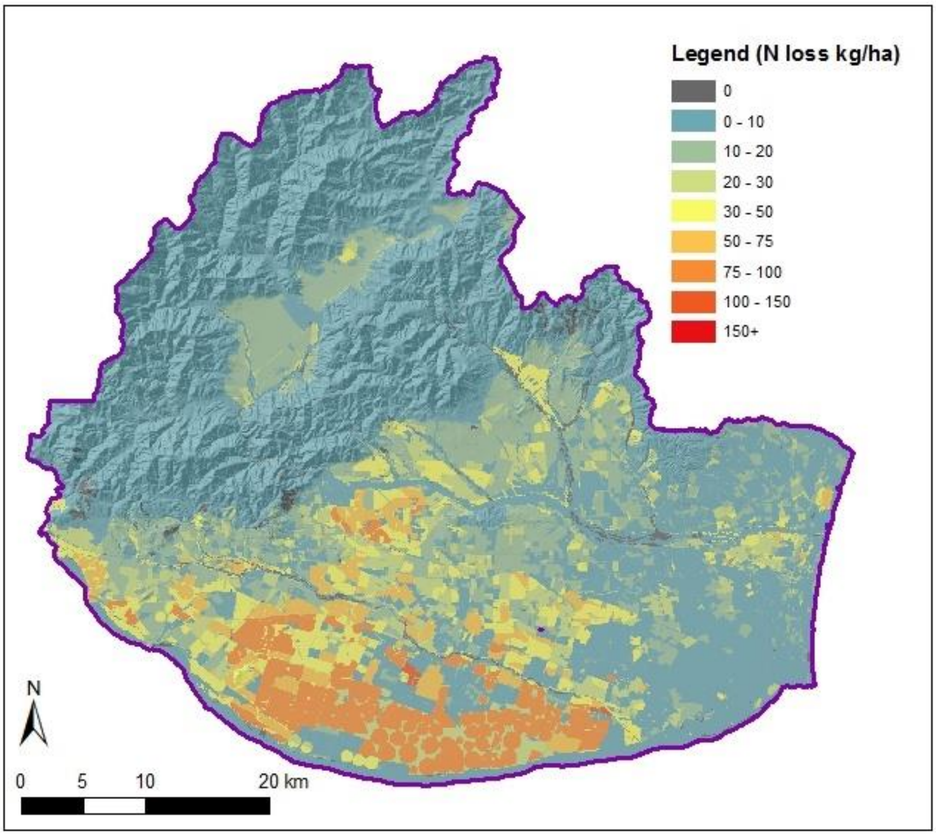


Figure 12 N losses below the root zone under the Current Consented scenario.

3.5 New irrigation scenario

A future scenario with additional irrigation was created by taking the Current Consented land use and changing selected dryland blocks to be irrigated. Existing paddock boundaries were maintained – and blocks of land less than 5 ha were not converted, except the Lees Valley, where this minimum size was < 50 ha. Thus, one block of 550 ha in the Lees Valley was converted to irrigated dairy support, all of the suitable dryland area in the Loburn area was selected (3,304 ha) and 8,736 ha were randomly selected within the plains area. The Loburn and plains area were converted to a 50:50 mix of dairy support and dairy. The GMP loss rates were applied to this land use scenario. Figure 13 shows the areas of additional irrigation; Figure 14 shows the nitrate loss below the root zone under the new irrigation scenario.

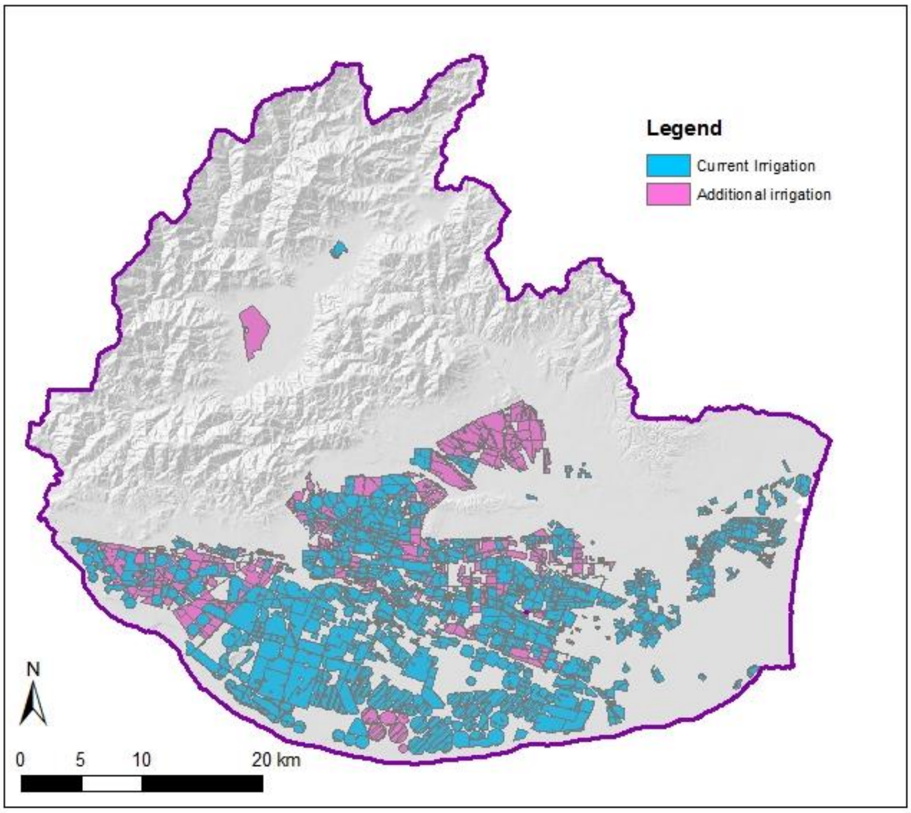


Figure 13 Map showing the area of new irrigation.

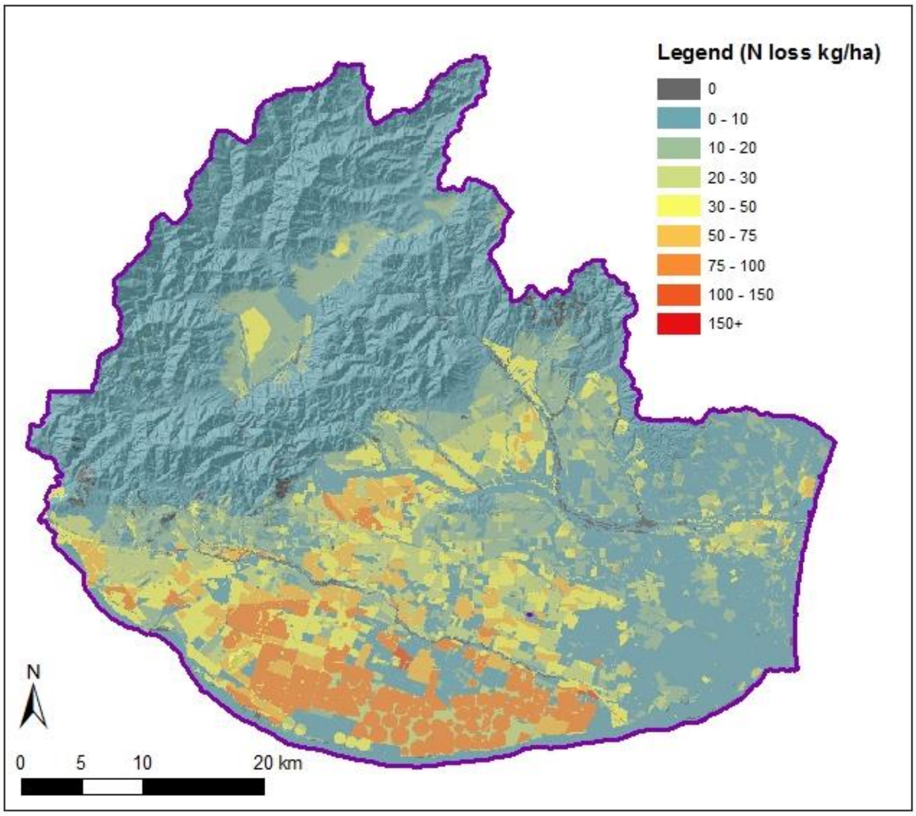


Figure 14 N losses (kgN/ha) below the root zone under the New Irrigation scenario.

3.6 Summary of nitrate losses

A summary of the nitrate losses by sub catchment area for the above scenarios is presented in Table 13. Note that the N load adjustments, detailed in section 2.4, were not applied to the Hindcast layer so this scenario was not included in this table.

Table 13 Total nitrate losses (t/yr) by sub catchment under four scenarios

	Current oldMP	Current State	Current Consented	New Irrigation
Ashley	85.8	74.8	74.8	75.4
Coastal wetlands	53.4	46.9	46.9	46.9
Cust	807.3	529.5	529.5	577.8
Eyre	3,198.5	2130.8	2,204.4	2,288.3
Kowai	88.9	81.4	81.4	81.6
Lees Valley	319.4	297.4	297.4	306.7
Loburn	374.8	348.3	348.3	392.2
Blank	96.9	86.3	86.3	86.9
Total Waimakariri Zone	**5,024.9**	**3,595.4**	**3,669.0**	**3,855.8**

4 Scenarios – part 2

In 2018, a further set of scenarios were developed (Table 14), each with a variant of the rules governing the permitted increases in winter forage. Table 15 provides the details of the rules for permitted increases under each scenario. Farms less than 1 ha in size do not intensify.

Table 14 Additional scenarios modelled in November 2018

Current Pathways	The updated Current Consented land use scenario with the additional intensification of land up to 50% of Plan Change 5 rules.
Current Pathways PC5	The same as Current Pathways but with 100% uptake of the Plan Change 5 rules. Also known as PC5PA.
Scenario 4	The updated Current Consented land use scenario with additional intensification according to the Scenario 4 variant of the Plan Change 5 winter grazing rules.
Draft ZIPA	The updated Current Consented land use scenario with additional intensification according to the draft Waimakariri Zone Implementation Programme Addendum (ZIPA) variant of the Plan Change 5 winter grazing rules.
Final ZIPA	The updated Current Consented land use scenario with additional intensification according to the final ZIPA variant of the Plan Change 5 winter grazing rules.

Table 15 The winter forage allowance for permitted activities for each scenario

Option	Winter grazing allowances based on property size (ha)				
	< 5	5–10	10–100	100–1,000	>1,000
Current Pathways (PC5)	No consent	No consent	10 ha	10%	100 ha
Scenario 4	No consent	No consent	7.5 ha	7.5%	75 ha
Draft ZIPA	No consent	5%	5%	5%	50 ha
Final ZIPA	No consent	5 ha		5%	50 ha

4.1 Current consented – updated scenario

Several corrections were made to the base Current Consented layer described in section 3.4. The main correction involved separating land with no farm identifier into farm blocks and unfarmed land, e.g. roads, and then assigning appropriate nitrate loss estimates to each. Table 16 lists the updated farm counts and Figure 15 shows nitrate losses averaged over each property.

Table 16 Count of farm enterprises by type in the updated Current Consented layer, and the difference with the original version

Enterprise type	Count	Change
Arable	77	-6
Dairy	103	+1
Dairy support	65	0
Sheep, Beef, Deer	587	+40
Forestry	76	-1
Horticulture	27	0
Lifestyle	6,399	0
Pigs	10	0
Total	**7,344**	

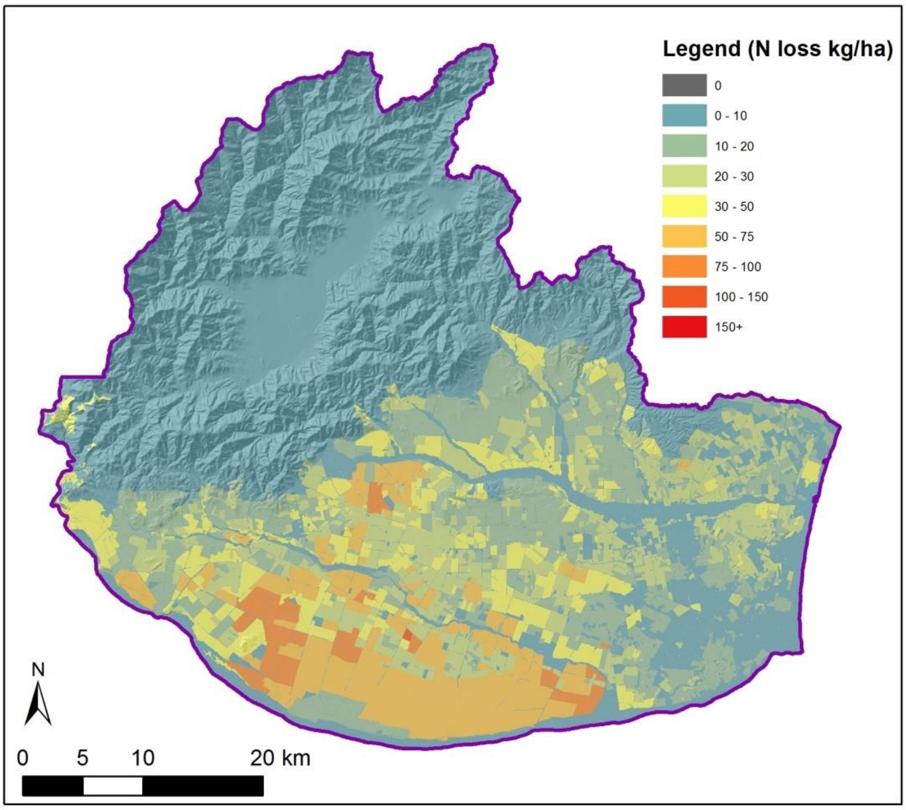


Figure 15 Updated map of Current Consented nitrate losses averaged by farm enterprise.

4.2 Current Pathways PC5 layer scenario

This scenario models what might happen if land owners (under current consented land use) were to intensify according to the Plan Change 5 (PC5) rules relating to the different zones.

In red zones, permitted activities can have up to 50 ha of irrigated land including an increase of up to 10 ha of new irrigation since Feb 2016, and the maximum area of the property used for winter grazing must be less than 10 hectares for any property less than 100 hectares in area; or 10% of the area of the property, for any property between 100 hectares and 1,000 hectares in area; or 100 hectares, for any property greater than 1,000 hectares in area.

In orange zones, permitted activities can have up 50 hectares irrigated with water and up to 10 hectares of winter grazing for any property less than 100 hectares in area; or 10% of the area of the property for any property between 100 hectares and 1,000 hectares in area; or 100 hectares, for any property greater than 1,000 hectares in area.

The following steps were taken to simulate these PC5 rules:

- Clip all input data sets to the extents of the two study sites using the relevant Nutrient Allocation Zone (NAZ) boundaries. Exclude DOC land and areas with no Farm-ID from the analysis.

- Use the forage maps of North et al. (2015a, b) and the irrigation data described above to quantify the current area of winter forage and irrigation within each farm boundary.
- Assess the area of land within each farm boundary that could realistically support high N-Loss activities, based on land-use capability class and slope.
- Assess whether each farm would currently be 'consented' or 'permitted' under the PC5 rules, determine any extra area of winter forage and/or irrigation permitted properties would be allowed under these rules, and estimate the consequent N losses. Carry this out for each of the red and orange zone rules.

We clipped the properties that extended beyond the red and orange zones within the Waimakariri zone to the outer red/orange boundary and applied the rules to these truncated areas (potentially to the advantage of the property owner). The internal boundaries, i.e. between red and orange zones, were treated differently – the area of the whole farm was used rather than the truncated area. Then the red and orange zone rules were applied to the component parts of the farm. This approach simulates a single consent and avoids giving any advantage to the farms that contained both orange and red zones. Figure 16 shows the N losses below the root zone assuming full uptake of permitted intensification under the PC5 rules.

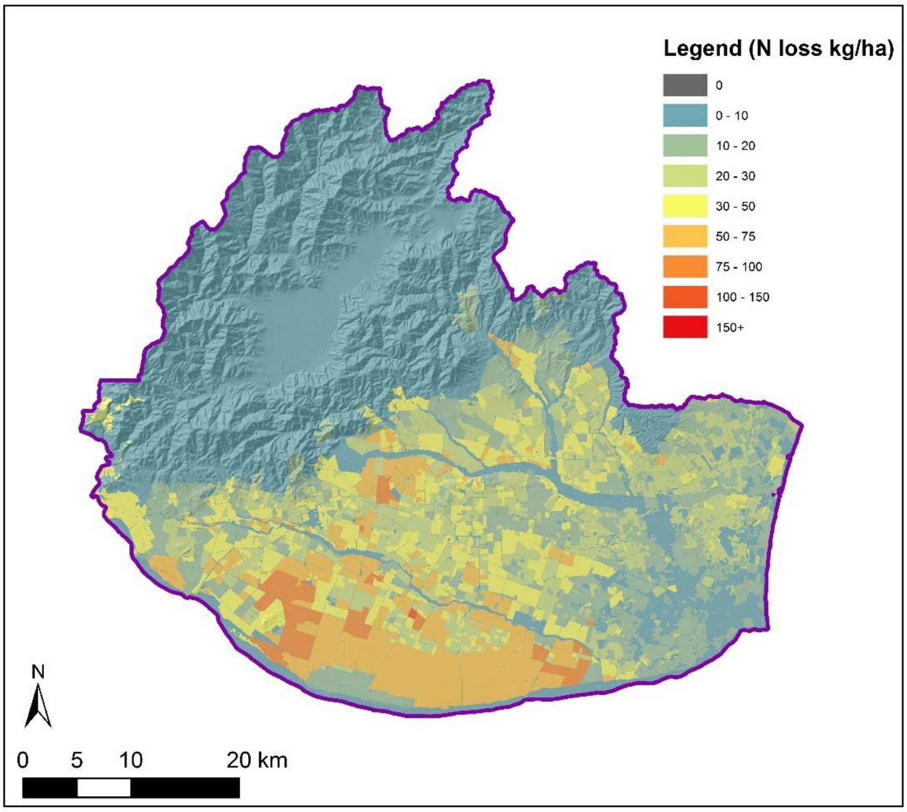


Figure 16 N losses below the root zone under the Current Pathways PC5 scenario.

4.3 Current Pathways layer scenario

This scenario is very similar to the Current Pathways PC5 scenario except that the additional intensification is limited to 50% of uptake of the Plan Change 5 (PC5) rules. This was simulated as each farm taking up half of its plan change 5 intensification allowance.

4.4 Scenario 4 layer

This scenario is very similar to the Current Pathways PC5 scenario except for the farm size thresholds (Table 15). Farms up to 10 ha need no consent. Those between 10 and 100 ha can intensify up to 7.5 ha, those between 100 and 1,000 ha can intensify up to 7.5% of the farm and those over 1,000 ha can intensify to a maximum of 75 ha.

4.5 Draft ZIPA layer scenario

This scenario is very similar to the Current Pathways PC5 scenario except for the farm size thresholds (Table 15). Farms up to 5 ha need no consent. Those between 5 and 1,000 ha can intensify up to 5% of the farm and those over 1,000 ha can intensify to a maximum of 50 ha.

4.6 Final ZIPA layer scenario

The final ZIPA scenario is based on the Current Consented scenario, and allows intensification on farms up to 5 ha in size without consent, farms between 5 and 100 ha can intensify up to 5 ha, those between 100 and 1,000 ha can intensify up to 5% of the farm and those over 1,000 ha can intensify to a maximum of 50 ha.

In addition, dairy platform farms within the Nitrate Priority Management Area (NPMA) are to reduce their baseline GMP N losses by 15% and other consented land must reduce by 5%. Outside of the NPMA, no reductions beyond GMP are required. Reductions are limited to a floor of 20 kg/ha/yr, i.e. nitrate limits for consented land owners who are required to reduce their N losses will be set to the higher of the reduced load and 20 kg/ha/yr.

Two versions of this scenario were simulated, with 50% and 100% uptake of the permitted intensification rules respectively. Figure 15 shows the map of nitrate losses under the provisions of the ZIPA where 100% uptake of the intensification rules is assumed.

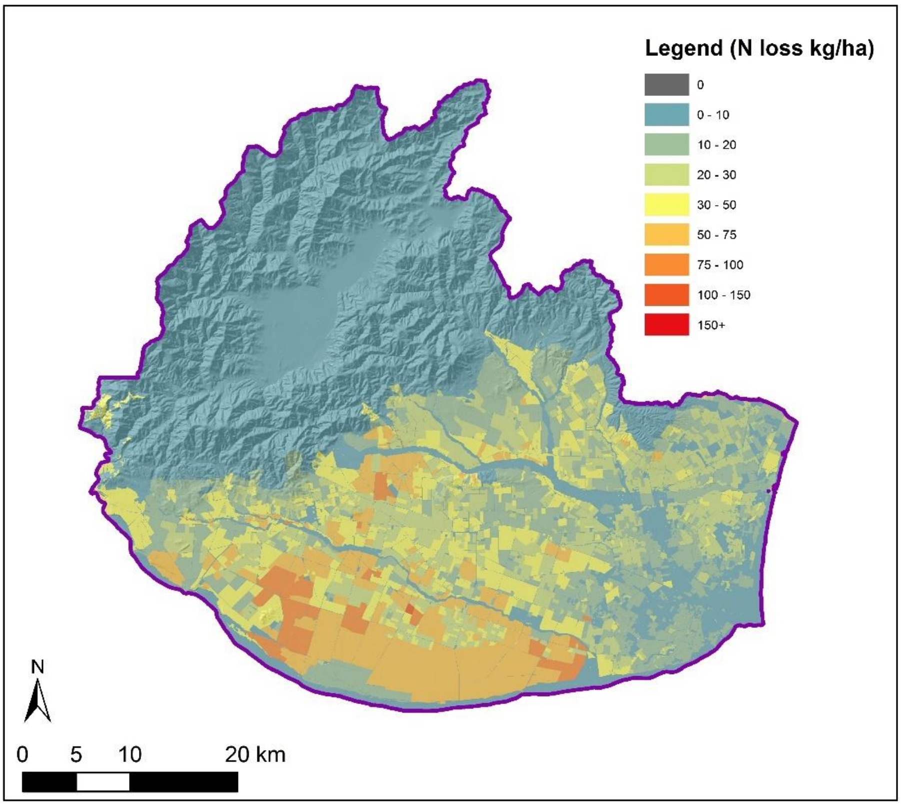


Figure 17 Nitrate losses below the root zone under the ZIPA scenario (100% uptake of the intensification rules). Includes the reductions in losses from consented farms in the NPMA (with a floor of 20 kg/ha).

4.7 Summary of nitrate losses

Total N losses by farm type are summarised in Table 17 for each of the scenarios described above.

Table 17 Total nitrate losses (t/yr) by farm type under the various scenarios

Farm type	Total area (ha)	Current Pathways	Current Pathways PC5	Scenario4		Draft ZIPA		Final ZIPA	
%PA uptake assumption		50	100	50	100	50	100	50	100
Arable	5,382	114	125	119	124	118	121	116	123
Dairy	32,714	1,949	1,956	1,952	1,955	1,950	1,952	1,727	1,953
Dairy support	5,069	181	205	191	201	188	194	184	197
Sheep, Beef, Deer	97,444	1,077	1,328	1,180	1,284	1,137	1,198	1,145	1,237
Forestry	21,341	34	81	53	71	45	56	48	61
Horticulture	418	13	15	14	15	14	14	13	15
Lifestyle	28,864	582	687	634	687	618	654	634	687
Pigs	273	10	11	11	11	11	11	11	11
DOC	34,831	8	8	8	8	8	8	8	8
NotFarmed	12,750	26	26	26	26	26	26	26	26
Unknown	588	10	12	11	12	11	11	11	11
Total	**239,674**	**4,004**	**4,452**	**4,198**	**4,393**	**4,125**	**4,246**	**3,922**	**4,329**

5 Uncertainty

There are a number of uncertainties in the methodology for estimating nitrate losses below the root zone. While all the input layers are the best available at the time, each is likely to have some errors or detail that is not captured. For example:

- The soil layer specifies the dominant soil type within soil survey polygons that are nominally mapped to 1:50,000 scale. There will be small pockets of other soils within the soil survey polygons that cannot be mapped at that scale. The soil mapping is largely derived from expert analysis of aerial photography, with some fieldwork. Thus, there may be some interpretation, classification or processing errors.
- The climate layer (Lilburne & Webb 2015) is based on interpolated layers of three climate variables each of which varies in accuracy.
- The AgriBase™ land use layer is derived from survey data as provided by landowners. There may be inconsistency in the way landowners have interpreted and completed the survey, or errors in data processing.

In addition, multiple-use land, including leasehold land, adds another complexity. Dairy support land is not well identified by the AgriBase™ survey; however, the area of dairy support can be checked in that it should be consistent with the area of dairy farms, and with adjusting the dairy farm type (winter on vs winter off) accordingly. The AgriBase survey is a 5-year rolling one, which means that the data are between 1 and 5 years out of date. The match with MGM farm types is another source of error that has been mitigated to some extent by comparing farm type production levels with regional productivity statistics and testing the land use maps with the farmer reference group. The irrigation information is derived from a visual analysis of aerial photography and will have some errors. All MGM farm types assume pivot irrigation so N loss rates may be underestimated for other spray irrigation systems.

The lookup table is derived from farm-scale modelling. As commented earlier, the values are (i) limited by the narrow range of farm types, climate and landforms used in the modelling, and (ii) include some unresolved inconsistencies. There will also be uncertainties in the inputs used to characterise each farm system, along with functional errors in the models themselves. The key model for the arable and pastoral land uses is OVERSEER® (version 6.2.2) using farm systems developed by the Matrix of Good Management project (Environment Canterbury 2014). This project established a comprehensive, robust and consistent set of nutrient loss estimates based on industry-agreed good management practice. This did not include life style blocks so these estimates are considered to be less robust. Other land uses were modelled by SPASMO (Soil Plant Atmosphere System Model) as described in Lilburne et al. (2013).

Generation of the new irrigation scenario involved a random selection process to select land parcels that are converted to another land use. In real life, a different set of land parcels might undergo conversion, which might result in a slightly lower or higher total loss depending on the underlying soil types.

An uncertainty analysis of the model of subcatchment nitrate losses helps with understanding the significance of these inherent uncertainties in the input data and the models that underpin the lookup table. A preliminary expert assessment of the magnitude of the errors was undertaken by Etheridge et al. (2018). They derived confidence intervals for the estimated loads of three nitrate management areas, and identified some soil-climate and farm type combinations that were considered to be less reliable.

6 Recommendations

Given the extent of the lifestyle blocks in the Waimakariri zone area, we recommend that the estimated nitrate losses for lifestyle blocks are reviewed. An uncertainty analysis would help identify other potential errors that may be significant.

Once a proposed scenario is agreed as the basis for nutrient limits for the Waimakariri Zone, the methods used to generate the target loads for the sub-catchments for this agreed scenario should be reapplied with nutrient loss estimates from the latest release of OVERSEER® – to ensure that the derived target load and consequent nutrient discharge allowance are compatible with the farm-scale nutrient budgets that land managers might be required to produce for compliance purposes. This would also help minimise the impact of data input and model errors.

7 Acknowledgements

We are grateful for the helpful review and editing comments by Leo Fietje and Stella Belliss.

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Appendix 1 – Data sources used

For land use mapping:

- Environment Canterbury Land Use and Water Quality layer – includes farm boundaries and farm type from Agribase (AsureQuality 2015) and the Landcover Database (LCDB v4). The process of generating this layer is described by Hill et al. (2012).
- Aqualinc irrigation layer for Waimakariri (Brown 2016).
- DOC Public Conservation Areas (2016 data), and DOC Grazing Concessions.
- Environment Canterbury's Dairy Effluent Consents Database.
- NZLRI Land Use Capability (Newsome et al. 2008).
- Waimakariri Lifestyle Study (Mojsilovic 2016).
- Farm type corrections, provided by Matt Dodson (Environment Canterbury) on differences from Agribase – observations from field work, inspection of imagery, and information from land managers and other experts.
- Agricultural land use map (per-paddock) for Waimakariri district in winter 2013 and summer 2012/13 (North et al. 2015).

For nitrogen loss modelling:

- MGM climate, soil, farm systems and matrix nitrate loss rates (Robson et al. 2015).
- The prior lookup table for land uses not covered by MGM (Lilburne et al. 2013).