Land-use Contaminant Loads and Mitigation Costs

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A Technical Paper

Motu Economic and Public Policy Research

May 2017

Document information

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Disclaimer

This technical paper is issued alongside Motu Working Paper 17-xx: "Modelling the potential impact of New Zealand's freshwater reforms on land-based Greenhouse Gas emissions". All errors, omissions, and opinions expressed are the responsibility of the authors.

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 ISSN 1176-2667 (Print), ISSN 1177-9047 (Online).

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1 Introduction

The National Policy Statement for Freshwater Management (NPS-FM) (MfE, 2014a) establishes the need to set and manage water resources within limits. A great deal of research has been carried out to quantify the processes, transformations and effects of contaminant loss from land to water, as well as to identify strategies to mitigate contaminant losses to freshwater (e.g. Monaghan et al. 2007; McDowell & Nash, 2012; McDowell et al 2014). However, less research has been undertaken to assess the unintended impacts of the NPS-FM on New Zealand's greenhouse gas emissions (GHG) Emissions. As a result, MPI SLMACC contracted Motu with Landcare Research, and with assistance from NIWA and AgResearch, to assess the possible impacts of freshwater reforms on NZ's land-based GHG emissions.

2 2012 Land-use map

A national-scale map of New Zealand was initially developed by Landcare Research in the mid-2000s for a project featuring the 'CLUES' model. This layer used an intersection between land-cover from the NZ Land-cover Database version 2 (LCDB2) and a 2003 version of land uses from AgriQuality's Agribase™ dataset. Once intersected, decision rules were made to create a land-use map based on the classification developed for the project (Woods et al. 2006). This map was recently updated using an intersection of LCDB2[1] (Ministry for the Environment, 2004) and Agribase™ version from March 2011. More details on these two databases are provided in Appendix A.

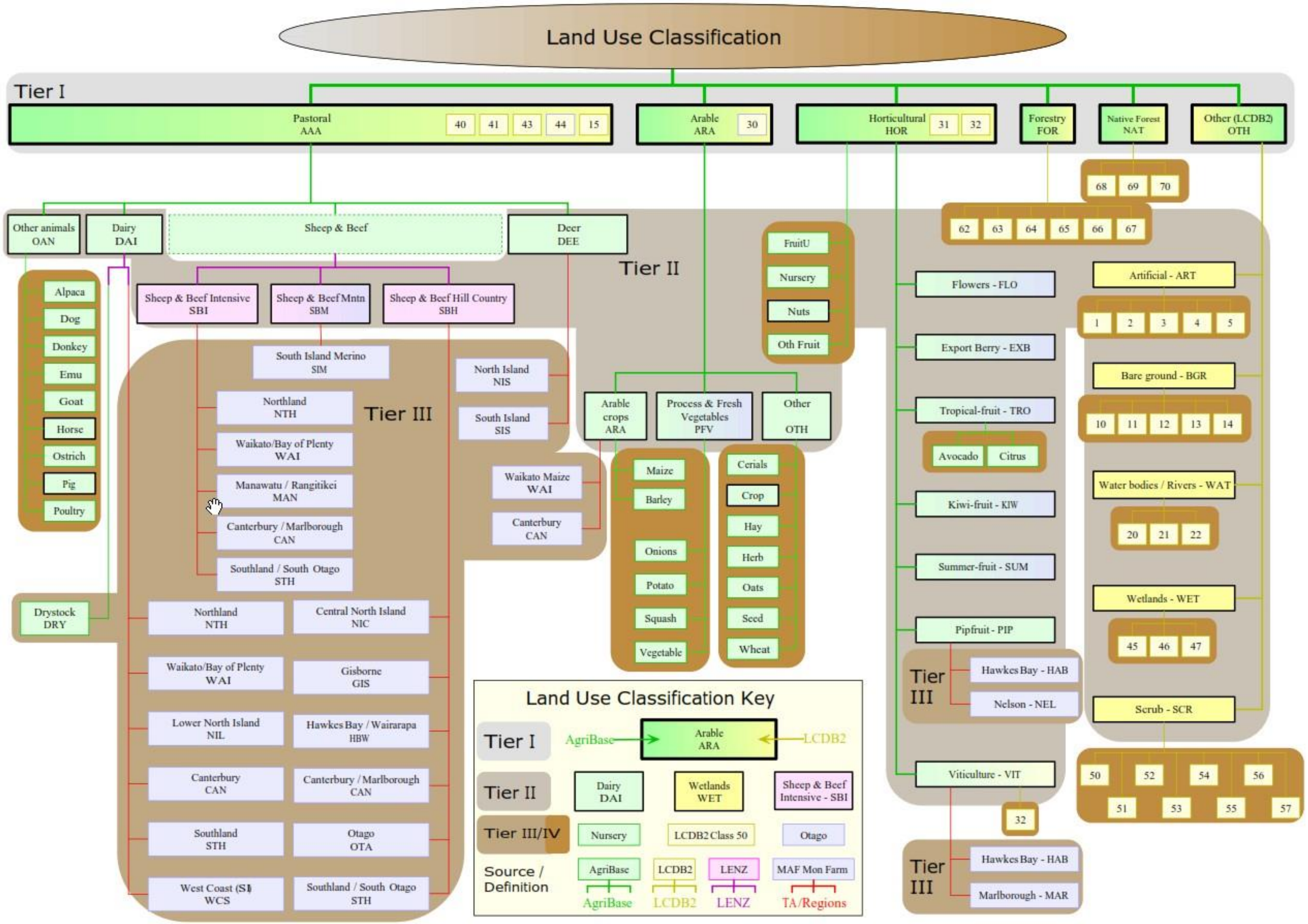
The land-use classification used a tiered approach from broad categories (e.g. pastoral, arable, horticultural, etc) to more detailed categories (e.g. dairy, maize, kiwifruit). The latest version of the land use map was re-created down to an additional tier 2 based on the most detailed information available in Agribase™. Other national-level data sets, such as the Land Environments of New Zealand (Leathwick et al. 2003) and the Agricultural Census (StatsNZ 2008), were used to distinguish further between intensive and extensive livestock farming depending on the topography of the landscape and number of animals in a given territorial authority. The high-level steps for creating the various tiers of the map are as follows:

1 At the time the 2011 land use map was created, LCDBv3 had not been released yet (available from 2012). Although there was been notable *land-use* change (e.g. sheep and beef to dairy) in some areas of New Zealand between 2002 and 2011, the *land-cover* change (e.g. exotic forestry to high exotic productive grassland) over that same time period is relatively small. Landcare Research is in the process of updating this land-use map with the latest version of Agribase™ and LCDBv4; however, this will not be completed until at least June 2016.

- **Step 1** Define the unified, virtualized geometries for each land parcel and territorial authority in New Zealand (TA) in New Zealand. Individual land parcels are initially defined using LCDB2.
- **Step 2 (Tier I):** Specify the high level land uses for each land parcel defined in Step 1 using both Agribase™ and LCDB2. This establishes whether each farm is pastoral, arable, horticultural, forestry, etc., but does not assign specific stock types or crops to the land.
- **Step 3 (Tier II):** Refine Tier I to provide additional spatial and descriptive detail by specifying the livestock and crop types for each land parcel. The first stage is to assign the most specific land uses (e.g. dairy, sheep & beef, kiwifruit, etc.) based on the Agribase™ classification. For parcels not included in Agribase™, first use LENZ to distribute the different land uses in relation to the land form (e.g. flat, rolling, etc.) and then assign the most profitable land uses to the flatter areas. Aggregate arable and horticultural crops (e.g. vegetables, viticulture) are further refined based on the relative area of each crop for a given TA using the Agricultural Production Survey.
- **Step 4 (Tier III):** Further refine Tier II to provide additional regional detail using information about MAF monitor farms (MAF 2011) and the regional statistics from the Agricultural Production Survey (see Appendix B1 for more details on this database). Note that this step is not utilised in the 2015 SLMACC modelling project.
- **Step 5 (Tier IV):** Refine further to give the highest classification of land use. This uses additional information from Agribase™ to assign other livestock (e.g. alpaca, goats, etc.) and crops (e.g. potatoes, wheat, etc.) to each parcel. This assignment is refined in each TA based on the relative area of each crop in the Agricultural Production Survey.

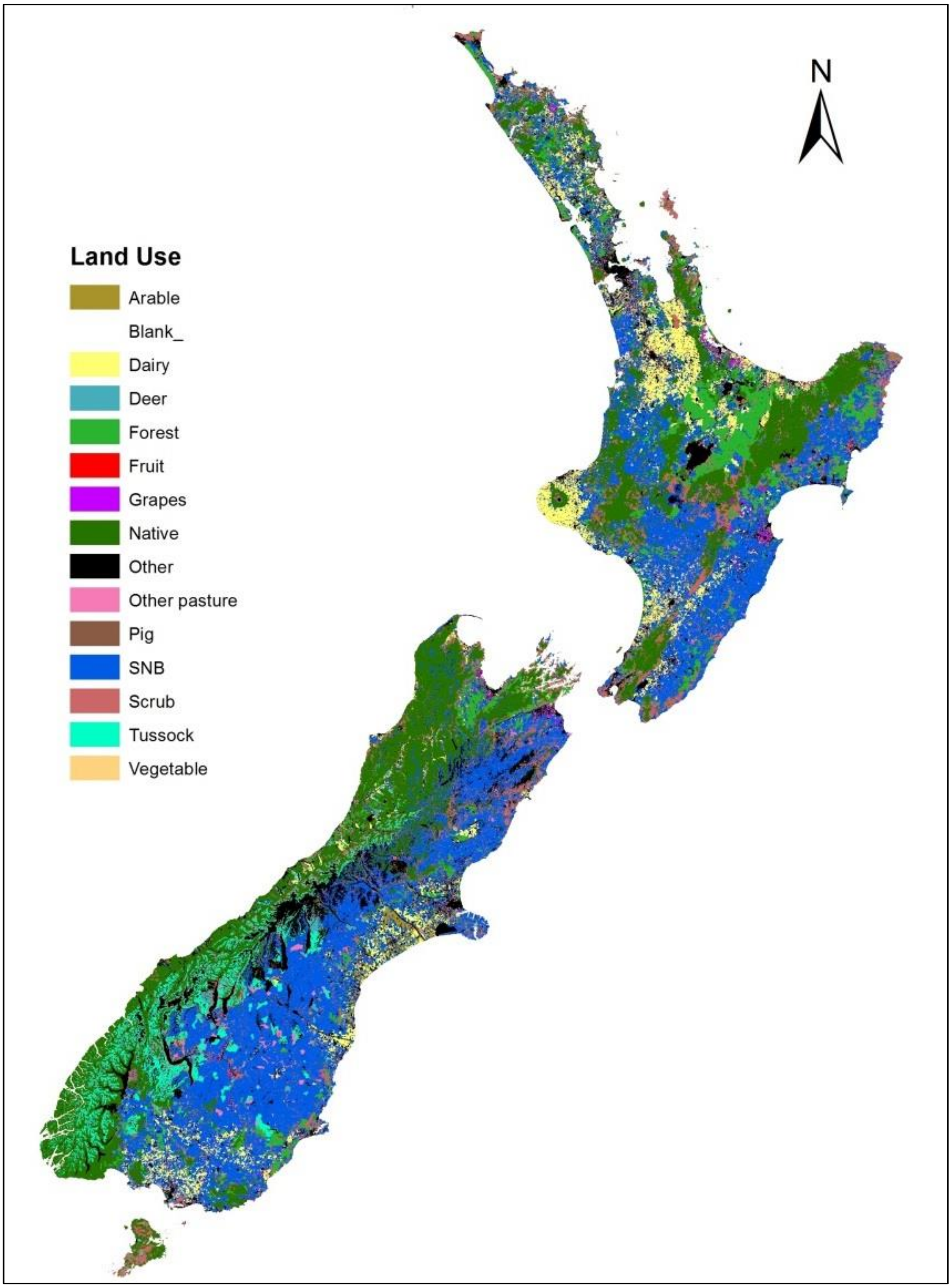
A schematic of how the classification was defined is shown in Figure 1. The full list of land uses included in the map is shown in Figure 2.

Figure 1: New Zealand land use map tier system



The land use map output is a shapefile with attributes from both LCDB2 and Agribase™, with inferences on dominant land use. We decided to use the land cover as the primary attribute. Where the land cover is grassland (high-producing or low-producing), we used the information on the dominant land use from Agribase™. Where there was no additional information from Agribase™, the classification stayed as "land area devoted to livestock" (coded "AAA"). Appendix B2 shows how some land uses included in this map were aggregated to establish a smaller classification of land uses that will be modelled in NZFARM and LURNZ for this research project. This is due to (a) the lack of nationally-comprehensive economic data available for some of the land uses, and (b) the assumption that the NPS-FM will not have a noticeable impact on some of these land uses, and therefore also not have an impact on GHG emissions. A draft map indicating the spatial distribution of 14 different land uses across New Zealand is shown in Figure B2. This map has already been incorporated into NZFARM. It has also been formatted into 1-ha and 25-ha grid cells so that it can be added to LURNZ.

Figure 2: New Zealand land use, 2011.



3 Description of key datasets for land use map

3.1 AgriBase™

AgriBase™ is a spatial dataset originally developed by the Ministry for Agriculture (MAF) in 1993, and is now curated by AgriQuality Limited. AgriBase™ provides rich detail about on-farm crops, horticultural species and animal numbers for many stock types (Sanson 2005). As farmers are encouraged to enter information on their farm on a voluntary basis (AgriQuality New Zealand 2011), the database is incomplete both in spatial coverage (not all farms are present) and in the data-fields farm owners have chosen to fill in. Furthermore, its spatial detail is limited to whole farm enterprises. This has four types of consequences, a number of which may coincide for a single farm:

1. Where a farm has more than one activity, AgriBase records what the activities are but does not record where they take place within the farm.
2. Where a farm uses both land owned by the enterprise and land leased from other owners, the AgriBase record may contain conflicting information, e.g. the sum of the areas occupied by all the plant types may differ significantly from the recorded total spatial extent of the farm.
3. Where a farmer has not filled in all the data-fields that are relevant to their farm, there will obviously be data gaps leading to uncertainty in the interpretation.
4. Where a farmer has misinterpreted the meaning of one or more data-fields, the data will appear to be inconsistent.

3.2 Land Cover Database 2 (LCDB2)

Land Cover Database 2 (LCDB2) is a thematic classification of 43 land cover and land use classes covering mainland New Zealand, near shore islands and the Chatham Islands. The first Land Cover Database (LCDB1) was completed in 2000 using SPOT satellite imagery acquired over the summer of 1996/97. LCDB2, released in July 2004, used Landsat 7 ETM+ satellite imagery acquired over the summer of 2001/02. This release also reports land cover/land use changes for the 5-year period between the two acquisitions of satellite imagery.

LCDB2 provides complete, internally consistent national coverage with a nominal spatial resolution of 1 ha, but gives no indication of what stock are present on pasture or of crop types or (with a couple of exceptions) of horticultural species.

3.3 Agricultural Production Survey (APS)

The Agricultural Production Survey is a collective term that describes both the Agricultural Production Census and the Agricultural Production Survey. The Census is undertaken every 5 years from a population of approximately 80 000 farm businesses, while the Survey is undertaken annually between Census years using a representative stratified sample of approximately 30 000 farm businesses. Statistics NZ collects and maintains APS data on behalf of MPI.

“Farm businesses” include all units identified on Statistics New Zealand's Business Frame as having agricultural activity (Statistics New Zealand 2015). This includes individuals or farming enterprises involved in livestock farming, arable farming, horticulture or forestry. The Business Frame is a list of businesses in New Zealand, based on their registration for goods and services tax (GST) with Inland Revenue. Since the compulsory registration level for GST is $60,000, there is an unknown proportion of units below this level that are excluded from the APS population (e.g. lifestyle blocks and other small farming endeavours paying <$60,000 in GST per year).

Table 1: Land use classification description

Field Name (class)	Description	SLMACC 2015 Land Use Classification
AAA	Land area devoted to livestock	Sheep & Beef (SNB)
AVOC	Avocado	Fruit
BARL	Barley (grain)	Arable
CERU	Undefined Cereals	Arable
CROU	Undefined Cropping	Arable
MAIZ	Maize (grain)	Arable
OATS	Oats (grain)	Arable
OPLA	Other Planted Types	Arable
SEED	Seed Crops (e.g. Herbage / Cereal)	Arable
WHEA	Wheat (grain)	Arable
BEF	Beef cattle numbers	Sheep & Beef
BERR	Berry fruit	Fruit
BISO	Bison numbers	Other pasture
CAM	Camelids (Alpacas and Llamas)	Other pasture
CITR	Citrus fruit	Fruit
DAI	Dairy Cattle numbers	Dairy
DEE	Deer numbers	Deer
DOG	Dogs	Other
DONK	Donkeys	Other pasture
DUCK	Ducks	Other
EMU	Emus	Other pasture
FLOW	Flowers	Vegetables
FODD	Fodder	Other pasture
HAYF	Fodder (e.g. Lucerne / green maize / hay)	Other pasture
FOR	Forestry	Forestry
FRUU	Undefined Fruit	Fruit
GOAT	Goats farmed	Other pasture
GRAZ	Grazing Other Peoples Stock	Sheep & Beef
HERB	Herbs/Medicinal Plants	Other
HORS	Horse numbers	Other pasture
KIWF	Kiwifruit Orchards	Fruit

MAN	Manuka-Kanuka	Scrub
NAT	Native Bush	Native
NURS	Nursery	Other
NUTS	Nuts	Fruit
OANM	Other Animals	Other
OFRU	Other Fruit	Fruit
OLAN	Other Land Use	Other
OSTR	Ostrich numbers	Other pasture
OTH	Idle land or planned for redevelopment	Other
PIGS	Pig numbers	Pig
PIPF	Pipfruit	Fruit
POU	Poultry birds	Other
SCR	Scrub	Scrub
SHP	Sheep	Sheep & Beef
STON	Stone Fruit	Fruit
TUSS	Tussock grassland	Tussock
ONIO	Onions (vegetables)	Vegetables
POTA	Potato (vegetables)	Vegetables
SQUA	Squash (vegetables) for export	Vegetables
VITI	Viticulture	Grapes

4 Updating LU Map to 2012 for NZFARM

In constructing a 2012 land-use basemap for NZFARM, land-cover data from the 2012 Land Cover Database 4 (LCDB4) are combined with land-use data from the most current Land Use in New Zealand (LUNZ) map. LUNZ itself combines information from the 2011 Agribase with a previous version of the LCDB.

In general, the land-use classification in the new basemap is primarily determined by LCDB4 where land cover is expected to accurately reflect land use, and it is mainly based on LUNZ use where land cover is expected to be a poor proxy for land use (e.g. in the identification of sheep-beef and dairy pasture). A map of land ownership is also used in the process: the classification differs slightly on private and public land.

We first reclassify the LCDB4 land cover categories into simplified land cover classes as shown in Table 2. This reclassification is consistent with the one used to form the land cover classes for the Land Use in Rural New Zealand (LURNZ) model (Anastasiadis et al. 2014).

A three-way intersection of the maps representing simplified LCDB4 classes, LUNZ land uses and land ownership is then taken. The analysis is performed with 1-hectare resolution versions of each map. The top panels in Table 3 and Table 4 show the land areas associated with every combination of LUNZ and simplified LCDB4 classes on private and public land, respectively. The bottom panels of each table displays the land use into which each cell from the top panel is reclassified in the NZFARM basemap. The NZFARM target land uses are colour coded.

Finally, Table 5 summarises land-use areas by ownership type in the NZFARM basemap. The final land-use areas were checked for approximate consistency with other data sources, including land area data from DairyNZ and the National Exotic Forestry Description (NEFD).

Table 2: The construction of simplified land cover classes based on the original LCDB4 classification

LCDB4 classification	LCDB4 simplified
High producing exotic grassland	Pasture
Low producing grassland	Pasture
Tall tussock grassland	Pasture
Depleted tussock grassland	Pasture
Exotic Forest	Forestry
Forest harvested	Forestry
Deciduous hardwoods	Forestry
Flaxland	Scrub
Fernland	Scrub
Gorse and/or Broom	Scrub
Manuka and/or Kanuka	Scrub
Matagouri or Grey Scrub	Scrub
Broadleaved indigenous hardwoods	Scrub
Sub-alpine scrubland	Scrub
Mixed exotic scrubland	Scrub
Short-rotation cropland	Horticulture
Orchard, vineyard and other perennial crops	Horticulture
Surface mines and Dumps	Non-productive
Sand and gravel	Non-productive
Alpine grass / herb field	Non-productive
Gravel and rock	Non-productive
Land slide	Non-productive
Permanent ice and snow	Non-productive
Lake and pond	Non-productive
River	Non-productive
Estuarine open water	Non-productive
Herbaceous freshwater vegetation	Non-productive
Herbaceous saline vegetation	Non-productive
Mangrove	Non-productive
Built-up area	Urban
Urban parkland / open space	Urban
Transport infrastructure	Urban
Indigenous forest	Indigenous forest

Table 3: The top panel shows the intersection of LUNZ with the LCDB4 simplified land cover layer on private land. Land areas shown are in hectares. The bottom panel represents the same intersection displaying the (color-coded) target land use for the NZFARM base map

				LCDB4 simplified				
LUNZ use	**Pasture**	**Forestry**	**Scrub**	**Horticulture**	**Non-productive**	**Urban**	**Indigenous forest**	**Private area**
Missing	95	15	9	10	8	1	11	149
Arable	42 801	503	110	153 197	179	462	36	197 288
Blank (sea)	3159	276	1697	54	2901	366	677	9130
Dairy	1 652 404	7566	6310	31 147	2302	763	3057	1 703 549
Deer	173 577	1390	2049	5096	124	39	320	182 595
Plantation Forest	166 325	1 260 773	36 198	2403	2269	1843	16 237	1 486 048
Fruit	9309	199	165	6742	38	122	32	16 607
Grapes	42 640	991	1124	51 203	221	1203	184	97 566
Native Bush	74 626	68 265	47 726	820	24 291	1017	1 006 433	1 223 178
Other Land Use	577 109	11 492	15 419	67 122	412 439	172 303	2684	1 258 568
Other Pasture	774 485	20 681	15 463	14 857	4949	10 899	2231	843 565
Pig	7331	62	35	2202	10	29	6	9675
Scrub	110 962	51 609	1 086 491	648	8185	1090	16 640	1 275 625
Sheep & Beef	5 895 529	81 460	97 134	115 044	15 452	1644	12 391	6 218 654
Tussock	60 688	2719	602	127	1270	11	235	65 652
Vegetable	6623	69	23	10 259	4	120	13	17 111
Private area	9 597 663	1 508 070	1 310 555	460 931	474 642	191 912	1 061 187	14 604 960

Table 3 – con't.

	LCDB4 simplified							
LUNZ use	**Pasture**	**Forestry**	**Scrub**	**Horticulture**	**Non-productive**	**Urban**	**Indigenous forest**	**Private area**
Missing	Sheep & Beef	Plantation Forest	Scrub	Arable	Other Land Use	Other Land Use	Native Bush	149
Arable	Arable	Plantation Forest	Arable	Arable	Other Land Use	Other Land Use	Native Bush	197 288
Blank (sea)	Sheep & Beef	Plantation Forest	Scrub	Arable	Other Land Use	Other Land Use	Native Bush	9130
Dairy	Dairy	Plantation Forest	Dairy	Dairy	Dairy	Other Land Use	Native Bush	1 703 549
Deer	Deer	Plantation Forest	Deer	Deer	Deer	Other Land Use	Native Bush	182 595
Plantation Forest	Sheep & Beef	Plantation Forest	Plantation Forest	Arable	Other Land Use	Other Land Use	Native Bush	1 486 048
Fruit	Fruit	Plantation Forest	Fruit	Fruit	Other Land Use	Other Land Use	Native Bush	16 607
Grapes	Grapes	Plantation Forest	Grapes	Grapes	Other Land Use	Other Land Use	Native Bush	97 566
Native Bush	Sheep & Beef	Plantation Forest	Scrub	Arable	Other Land Use	Other Land Use	Native Bush	1 223 178
Other Land Use	Other Land Use	Plantation Forest	Scrub	Arable	Other Land Use	Other Land Use	Native Bush	1 258 568
Other Pasture	Other Pasture	Plantation Forest	Other Pasture	Other Pasture	Other Pasture	Other Land Use	Native Bush	843 565
Pig	Pig	Plantation Forest	Pig	Pig	Pig	Other Land Use	Native Bush	9675

Scrub	Scrub	Plantation Forest	Scrub	Scrub	Scrub	Other Land Use	Native Bush	1 275 625
Sheep & Beef	Sheep & Beef	Plantation Forest	Sheep & Beef	Sheep & Beef	Sheep & Beef	Other Land Use	Native Bush	6 218 654
Tussock	Tussock	Plantation Forest	Tussock	Tussock	Tussock	Other Land Use	Native Bush	65 652
Vegetable	Vegetable	Plantation Forest	Vegetable	Vegetable	Other Land Use	Other Land Use	Native Bush	17 111
Private area	9 597 663	1 508 070	1 310 555	460 931	474 642	191 912	1 061 187	14 604 960

Table 4: The top panel shows the intersection of LUNZ with the LCDB4 simplified land cover layer on public land. Land areas shown are in hectares. The bottom panel represents the same intersection displaying the (color-coded) target land use for the NZFARM basemap

	LCDB4 simplified							
LUNZ use	**Pasture**	**Forestry**	**Scrub**	**Horticulture**	**Non-productive**	**Urban**	**Indigenous forest**	**Public area**
Missing	14	1	14	1	8	1	8	47
Arable	2743	162	15	3350	71	134	1	6476
Blank (sea)	671	131	996	3	1354	196	2229	5580
Dairy	36 620	346	280	573	305	176	278	38 578
Deer	55 283	70	746	127	2346	3	149	58 724
Plantation Forest	15 802	550 805	12 544	125	1366	618	10 743	592 003
Fruit	252	3	16	88	2	21	2	384
Grapes	15 775	212	975	1208	207	239	416	19 032
Native Bush	46 035	29 173	66 256	150	19 331	354	5 265 550	5 426 849
Other Land Use	102 211	3765	16 827	1491	1 230 302	35 230	6094	1 395 920
Other Pasture	149 456	2392	3587	647	3579	3287	565	163 513
Pig	186	11	0	52	0	0	1	250
Scrub	52 128	8585	1 145 255	134	28 670	387	23 806	1 258 965
Sheep & Beef	2 053 582	5599	41 290	3759	102 561	389	6413	2 213 593
Tussock	874 908	397	16 367	106	135 936	30	6129	1 033 873
Vegetable	727	7	53	345	46	13	21	1212
Public area	3 406 393	601 659	1 305 221	12 159	1 526 084	41 078	5 322 405	12 214 999

Table 4 – con't.

	LCDB4 simplified							
LUNZ use	**Pasture**	**Forestry**	**Scrub**	**Horticulture**	**Non-productive**	**Urban**	**Indigenous forest**	**Public area**
Missing	Sheep & Beef	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	47
Arable	Sheep & Beef	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	6476
Blank (sea)	Sheep & Beef	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	5580
Dairy	Sheep & Beef	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	38 578
Deer	Deer	Plantation Forest	Deer	Deer	Deer	Other Land Use	Native Bush	58 724
Plantation Forest	Sheep & Beef	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	592 003
Fruit	Other Land Use	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	384
Grapes	Other Land Use	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	19 032
Native Bush	Sheep & Beef	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	5 426 849
Other Land Use	Other Land Use	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	1 395 920
Other Pasture	Other Pasture	Plantation Forest	Other Pasture	Other Pasture	Other Pasture	Other Land Use	Native Bush	163 513
Pig	Pig	Plantation Forest	Pig	Pig	Pig	Other Land Use	Native Bush	250

Scrub	Scrub	Plantation Forest	Scrub	Scrub	Scrub	Other Land Use	Native Bush	1 258 965
Sheep & Beef	Sheep & Beef	Plantation Forest	Sheep & Beef	Sheep & Beef	Sheep & Beef	Other Land Use	Native Bush	2 213 593
Tussock	Tussock	Plantation Forest	Tussock	Tussock	Tussock	Other Land Use	Native Bush	1 033 873
Vegetable	Other Land Use	Plantation Forest	Scrub	Other Land Use	Other Land Use	Other Land Use	Native Bush	1212
Public area	3 406 393	601 659	1 305 221	12 159	1 526 084	41 078	5 322 405	12 214 999

Table 5: Land-use areas by land ownership in the 2012 NZFARM basemap. The colour coding corresponds to that used in the bottom panels of Table 3 and Table 4

NZFARM land use	Private area	Public area	Total area
Dairy	1 692 163	0	1 692 163
Sheep & Beef	6 367 364	2303 077	8 670 441
Other Pasture	809 754	157 269	967 023
Deer	180846	58 502	239 348
Pig	9578	238	9816
Plantation Forest	1 544 268	601 659	2 145 927
Scrub	1 271 137	1 324 163	2 595 300
Tussock	62 687	1 027 317	1 090 004
Arable	266 517	0	266 517
Fruit	16 216	0	16 216
Grapes	94 967	0	94 967
Vegetable	16 905	0	16 905
Native Bush	1 061 187	5 322405	6 383 592
Other Land Use	1 211 371	1420 369	2 631 740
Total	14 604 960	12 214 999	26 819 959

5 CLUES-based determination of contaminant loads

The aim of this component of the study was to use the existing catchment model CLUES2 (Catchment Model for Land use and Environmental Sustainability) (Woods et al. 2006; Semadeni-Davies et al. 2011, 2012) (to assess the loads of contaminants entering streams, summarised by Freshwater Management Unit (FMU). This involved running CLUES for a 'current' land use, extracting loads for each land-use by REC subcatchment, and then summarising the results by the larger FMU polygons.

5.1 Brief description of CLUES

CLUES determines mean annual loads of total nitrogen (TN), total phosphorus (TP), suspended sediment, and *E. coli* for each stream in the national REC (River Ecosystem Classification) stream network (Snelder et al. 2010). For pastoral land-uses, the 'generated' load of TN and TP are determined as a function of broad enterprise type (e.g. Dairy) and other catchment attributes such as rainfall and subcatchment-average slopes using a simplified version of the OVERSEER farm nutrient loss model (version 6.1, http://www.Overseer.org.nz). TN loads from horticulture and cropping are determined from equations summarising results of SPASMO model runs for

2 https://www.niwa.co.nz/freshwater-and-estuaries/our-services/catchment-modelling/clues-%E2%80%93-catchment-land-use-for-environmental-sustainability-model

selected enterprise types, as described in Woods et al. (2006). Nutrient loading for other land-use types is determined by calibrating yields to measured loads using the SPARROW catchment model software (Elliott et al. 2005) (http://water.usgs.gov/nawqa/sparrow), which includes factors for drivers such as rainfall and soil drainage. For TP, a further source proportional to the estimated sediment generation is added, to account for TP associated with mass erosion (Elliott et al. 2005). Sediment sources are determined according to erosion terrain classification and land cover, and drivers of slope and rainfall ((Elliott et al. 2008). Sources of *E. coli* are based on source coefficients for pasture and non-pasture, adjusted for rainfall and soil drainage, and calibrated to measured loads. Point sources of TN, TP, and *E. coli* are also incorporated into the model.

CLUES also accumulates contaminants down the stream network including accounting for loss of contaminants (for example, by settling in lakes), and also includes methods for determining concentrations. Those aspects of CLUES are not relevant to the current study, which only addresses contaminant generation rather the loading in streams or concentrations.

This study was based on the most recent version of CLUES (Version 10.1), which incorporates updates in parameter values from model-recalibration.

5.2 Application for the current study

Land use for the current study was based on NZFARM land-use layers provided by Landcare Research (described elsewhere in the report). The mapping NZFARM to CLUES land use classes are shown in Table 6. NZFARM Sheep & Beef was split into three CLUES classes (SBINTEN, SBHILL, SBHIGH) as described in Woods et al. (2006).

Table 6: Mapping from NZFARM land use classes to CLUES representative classes

NZFARM land use class	**CLUES land use class**
Arable	MAIZE
Dairy	DAIRY
Deer	DEER
Plantation Forest	PLANT_FOR
Fruit	KIWIFRUIT
Grapes	GRAPES
Native Bush	NAT_FOR
Other Land Use	OTHER
Other Pasture	UNGR_PAST
Pig	OTHER_ANIM
Scrub	SCRUB
Sheep & Beef	SBINTEN,SBHILL,SBHIGH
Tussock	TUSSOCK
Vegetable	POTATOES

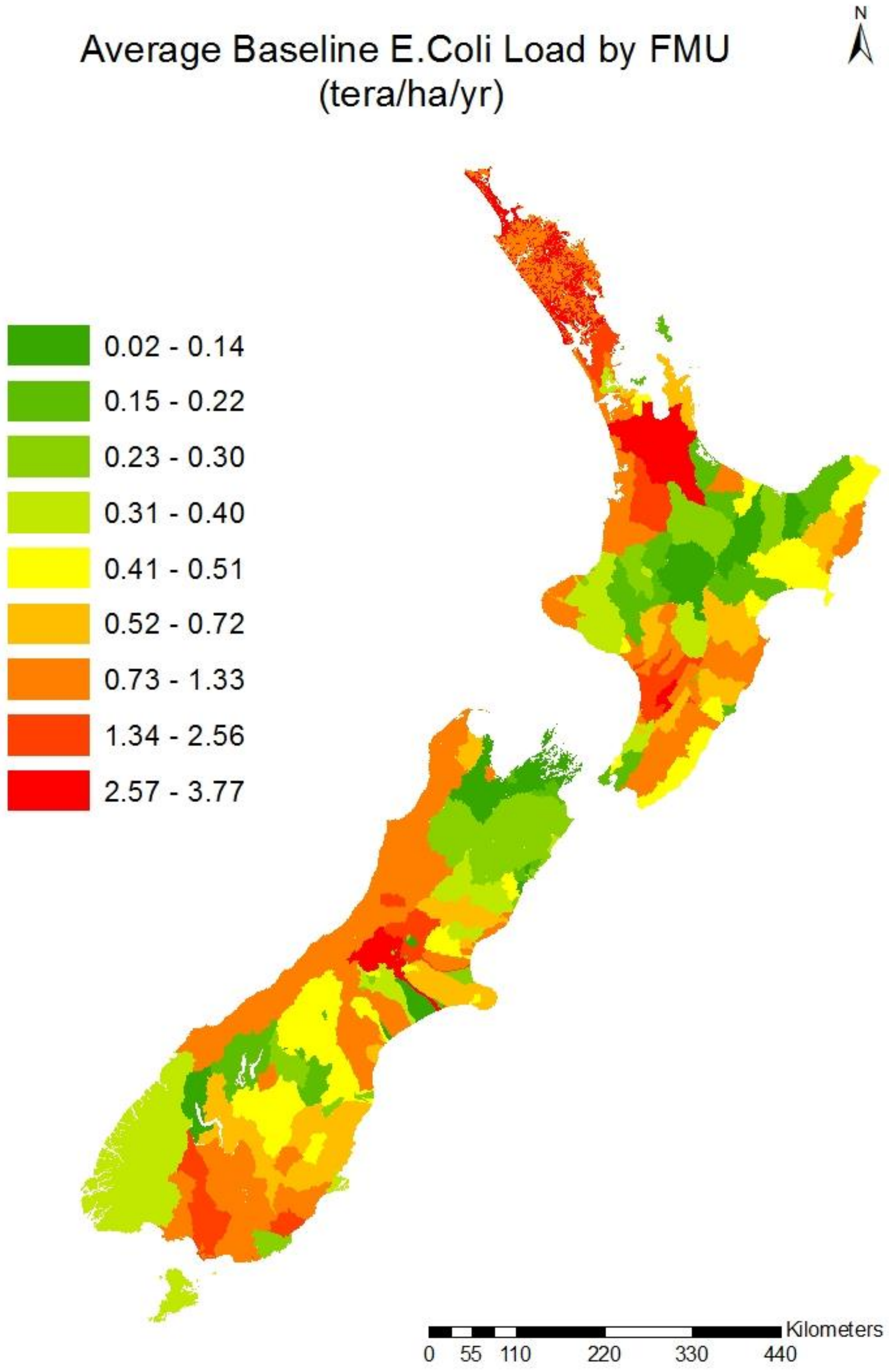
Slope, rainfall, soil drainage, soil order, and point sources were taken from CLUES default values.

In the standard CLUES model, the component of P associated with mass erosion is considered as a separate source term not associated with a particular land use. For the current study, this source was apportioned to forested (including scrub) and non-forested areas assuming a 5.1-fold greater loss per unit area for non-forested areas for this term. This ratio is consistent with the CLUES erosion model.

The load for each land-use and REC subcatchment was extracted from CLUES model outputs (using an in-house version of CLUES to enable separation by land-use). The load for each land use within each Freshwater Management Unit (FMU, as supplied by Landcare Research) was then determined by summing the loads from the subcatchments within the FMU. If an REC subcatchment was split by and FMU boundary, the loads from the REC subcatchment were apportioned to the relevant FMUs according to the proportions of the REC subcatchment. In some cases, such as areas abutting the coast, the FMU has no REC subcatchment, so the above method would give zero load. To account for this, we determined the yield (load per unit area) for those parts of the FMU that are covered by the FMU, and this yield could be used to approximate the load for the full FMU assuming that the same yield applies.

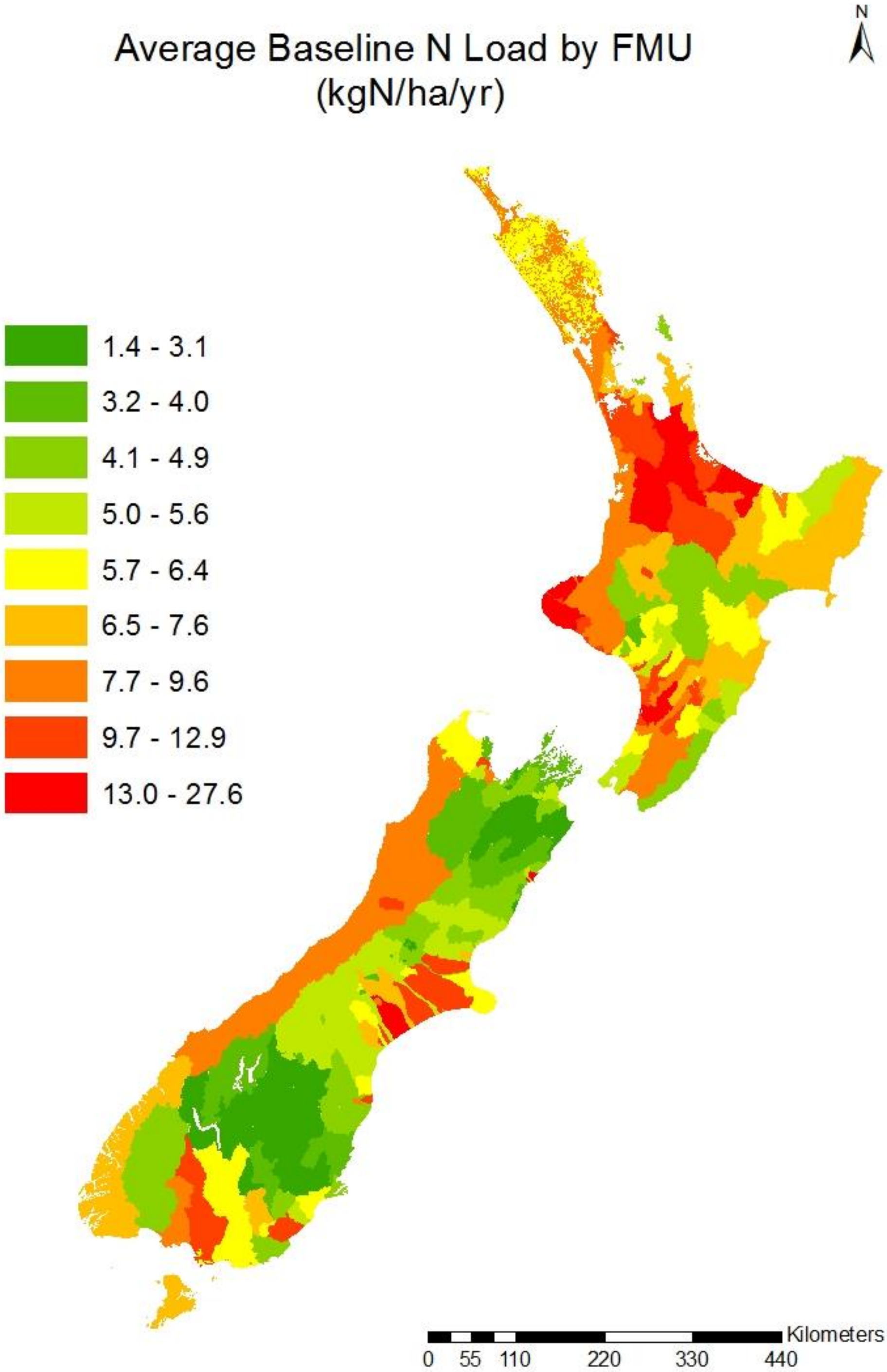
Tables of yield and load by land use (along with point sources) for each FMU are provided in a separate excel file. These are mapped from Figure 3 - Figure 6.

Figure 3: *E. coli* baseline loads (tera/ha/yr) for each water management area.



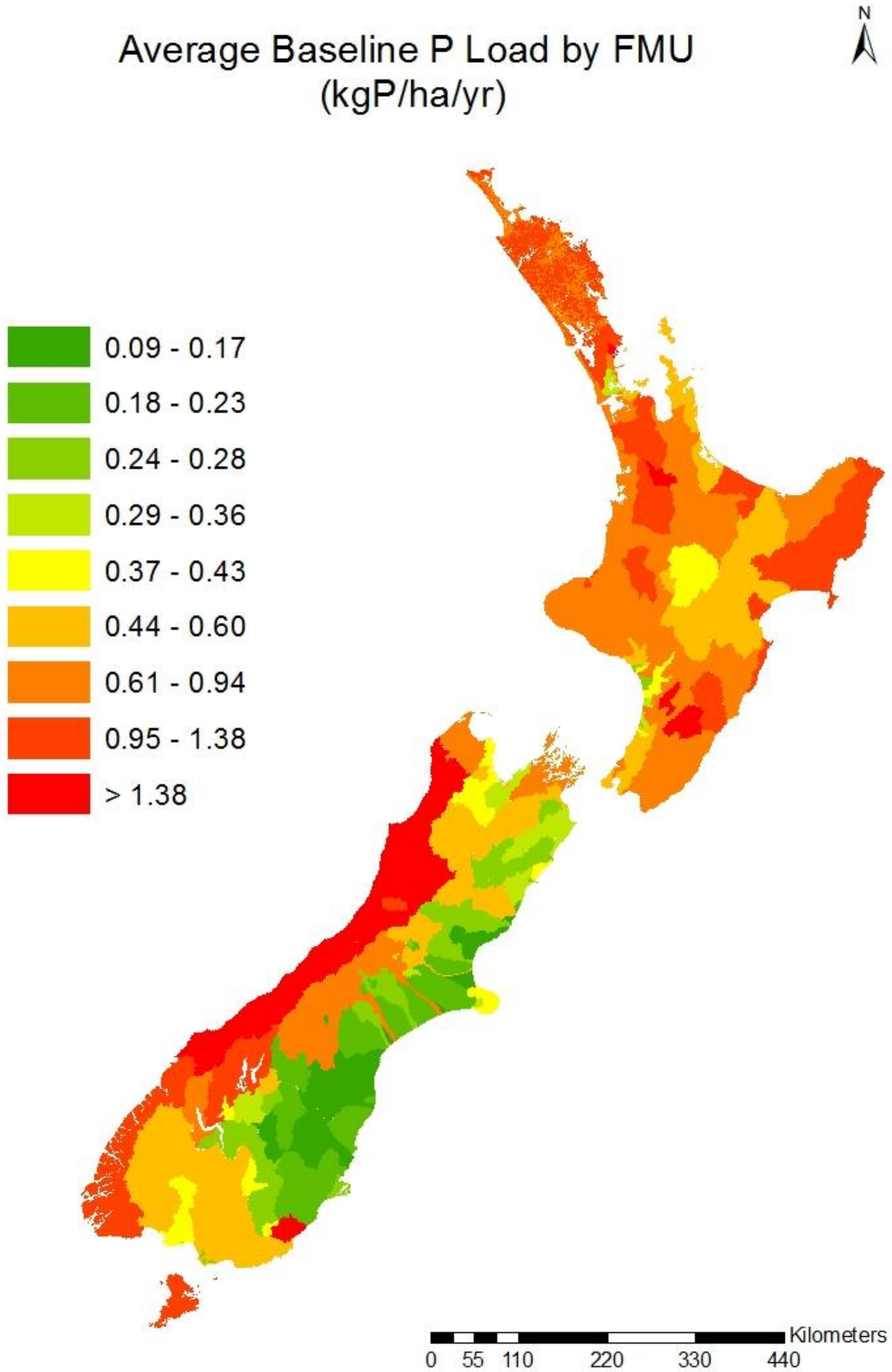
Note: FMU is used to refer to the range of different management areas across the country

Figure 4: Nitrogen baseline loads (kgN/ha/yr) by water management area



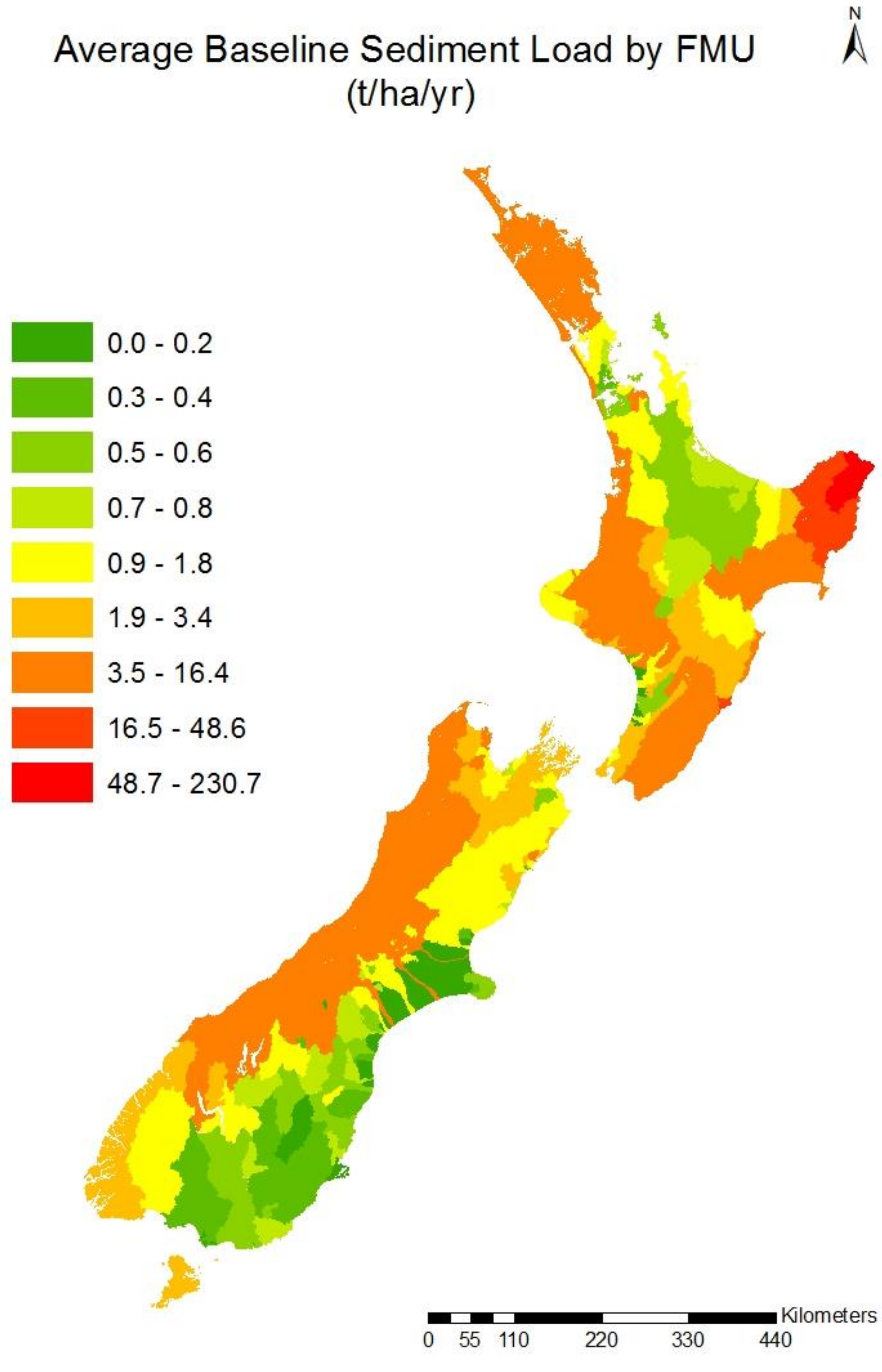
Note: FMU is used to refer to the range of different management areas across the country

Figure 5: Phosphorus baseline loads (kgP/ha/yr) by water management area



Note: FMU is used to refer to the range of different management areas across the country

Figure 6. Sediment baseline loads (t/ha/yr) by water management area



Note: FMU is used to refer to the range of different management areas across the country

6 Details on mitigation cost estimates

6.1 Overview

The National Policy Statement for Freshwater Management (NPS-FM) (MfE 2014a) establishes the need to set and manage water resources within limits. A great deal of research has been carried out to quantify the processes, transformations and effects of contaminant loss from land to water, as well as to identify strategies to mitigate contaminant losses to fresh water (e.g. McDowell & Nash 2012; Monaghan et al. 2007; McDowell et al. 2014). This research has focused on mitigation from implementing technology (e.g., feed pads) as well as conducting better management practices (e.g. reduced fertiliser application).

For this project, we reviewed and collected data on the cost and effectiveness for a wide-range of options to mitigate nitrogen (N), phosphorus (P), sediment (S), *E.coli* (E), and greenhouse gas emission (GHG) from a range of land uses. These include dairy, sheep & beef (S&B), deer, arable cropping, and horticulture. Mitigation options were quantified as an individual practice or technology, or as a set of options referred to as mitigation bundles. Cost figures are reported as both annualized costs ($/ha/yr) as well as relative change in net farm returns, while reductions in diffuse pollution from the contaminants/emissions are listed in relative terms due to the wide variance in baseline rates that can vary through factors such as stocking rate, soil type, slope, fertiliser rate, etc.

We have typically focused on mitigation estimates that came from models, literature or research programmes that originated in New Zealand. The relative effectiveness of N and P mitigation options were often reported in the literature as being estimated using the OVERSEER model, while S, E, and GHG mitigation estimates were reported as using a variety of methods.

6.2 Methods

In this report, we construct mitigation cost figures to help estimate the impacts that implementing the NPS-FM nationally will have on New Zealand's GHG emissions. These curves will be incorporated in to spatial economic land use model that have been designed to estimate the effects of potential policies and pathways to meeting an agri-environmental policy objective by estimating cost-effective ways to implement land use and land management change (Daigneault et al, 2015). The model is parameterised to track GHG emissions and several contaminants that can affect the quality of freshwater from a wide-range of land uses as well as a few land management options such as fencing streams, planting riparian buffers, and reducing stock. The key addition from this project will be to update and improve the cost and effectiveness figures for mitigation options that can be tracked in the model.

We collected several mitigation options for reducing nitrogen, phosphorus sediment and *E. coli* loads in the New Zealand. Additional details on some of the wetland mitigation were provided by expert option (e.g. Chris Tanner of NIWA was consulted about the wetland mitigation options). The specific costs include initial capital, ongoing and periodic maintenance, and opportunity costs from taking land out of production. An overview of the individual mitigation options considered is listed in Table 7. See McDowell et al. (2013) for more details on each option, including factors limiting uptake and co-benefits.

Table 7: Summary of individual mitigation options

Option	Description	Cost Component		
		Opp	**Capital**	**Maint**
Stream bank Fencing	Construct fences to exclude stock from permanent waterways		X	X
Riparian buffers	Fence streams with 5m buffer that is planted with grass and native vegetation.	X	X	X
Wetland Construction	Modification of landscape features such as depressions and gullies to form wetlands and retention bunds	X	X	X
Alum	Apply to pasture and cropland to decrease P loss in runoff			X
Low Solubility P	Apply low water soluble fertiliser to reduce P loss in runoff			X
Sediment Traps	Stock pond or earth reservoir constructed at natural outlet of zero-order catchment	X	X	X
Variable Rate Irrigation	Optimise water and nutrient application according to local pasture and crop requirements		X	X
Feed Pads	Constructed area to keep animals off paddock for specified time	X	X	X
Restrictive Grazing	Remove animals from pasture at certain times and/or extend housing period.	X	X	X
Nitrification Inhibitors	Apply dicyandiamide (DCD) or alternative inhibitor to reduce nitrate		X	X
Space-Planted Trees	Trees planted on slopes to retain soil and prevent erosion	X	X	
Reduce Fertiliser	Lower fertiliser application rates and/or adjust timing	X		
Reduced Tillage	Adjust tilling practices and timing to reduce the time land is bare during the growing cycle.	X		
Zero Tillage	Eliminate crop disturbance from tilling	X		
Cover Crops	Plough crops into soil between harvest and sowing periods		X	X
Full afforestation	Convert part or all of farm to pine plantation or native bush	X	X	X
Mitigation Bundle	Includes a combination of the practices listed above. Often more effective, albeit at a higher cost	X	X	X

Costs are likely to vary over time and practice, particularly for mitigation options that include high capital costs. Thus, we converted these costs to an annual figure so that they can be directly comparable with the costs already included in the baseline net farm revenue calculation. Initial capital and periodic maintenance costs are annualised over 25 years using a discount rate of 8%. Annual maintenance and opportunity costs are assumed to accrue on a yearly basis and thus are directly subtracted from the base net farm revenue figure. These base figures are discussed in the next section.

For the NZFARM baseline, production yields, input costs, and output prices come from several sources (MPI SOPI 2013a, b; Lincoln University Budget Manual 2013), and have been verified with agricultural consultants and enterprise experts. All figures are listed in 2012 New Zealand Dollars (NZD). Nutrient losses for pastoral enterprises are estimated using the OVERSEERv6 nutrient budgeting tool, while estimates for other enterprises are derived from the literature (e.g. Lilburne et al. 2010; Parfitt et al 1997). GHG emissions are derived using national GHG inventory methodologies (MfE 2014b). Erosion figures are based on methods from Ausseil et al. (2013), while *E.coli* figures were estimated using the CLUES model (Elliott et al. 2005). Note that many of the figures for the freshwater contaminants will change once we update the model with new load estimates from the CLUES model, which is currently being updated with a land-use map that was developed as part of this project.

6.3 Baseline practices

We use baseline or no mitigation estimates from the national-level NZFARM model as a basis for which to estimate opportunity costs and relative impacts of each mitigation practice.3 These baseline practices assume 'typical' management practices for a given land use (e.g. dairy farms already have a nutrient management plan). The mean estimates for each major land use is reported in Table 8. As these are listed as national averages, each figure actually has a distribution around it due to variances in factors such production, financial returns, land use capability class, climate, region and more.

3 N.B. These estimates are based on a 2012 land-use map that is in the process of being updated for this project. Thus, some of the figures may change between now and when the project is finalised.

Table 8: Mean New Zealand net farm revenue and contaminant losses by land use (per ha per yr)

Land Use	Net Farm Revenue ($)	GHG (kg)	Nitrogen (kg)	Phosphorus (kg)	Sediment (t)	*E.Coli* (tera)
Dairy	3418	6.4	38.0	0.8	4.2	4.1
Sheep & Beef	127	2.0	10.2	0.5	12.4	4.0
Deer	995	0.8	2.3	0.5	6.2	0.6
Other Pasture	96	1.5	7.5	0.4	8.9	2.9
Arable	1650	1.0	20.0	0.4	0.9	0.2
Horticulture	5597	1.5	12.7	0.1	2.6	1.6
Forestry	514	–11.3	2.0	0.2	3.2	0.4
Other	3	–0.5	1.4	0.1	2.7	2.0
All land	431	0.4	8.7	0.4	7.3	2.8

6.4 Individual mitigation options

In this section, we report the findings from the main set of individual mitigation options reported in the literature. These are presented by key land use: dairy, S&B, deer, arable cropping, and horticulture. A list of the sources consulted to develop these estimates is listed in Section 3.

Table 9: Individual mitigation options cost and effectiveness (% from no baseline)

Mitigation Option	Annualised Cost ($/ha/yr)	EBIT	N Loss	P Loss	Sediment	*E.Coli*	GHG
			Dairy				
Effluent Management	$24	−0.7%	−4%	−30%	0%	0%	0%
Riparian Planting	$71	−2.1%	−56%	−66%	−75%	−60%	−3%
Fencing Streams	$137	−4.0%	−13%	−15%	−70%	−60%	0%
Wetlands	$68	−2.0%	−10%	−45%	−65%	−55%	0%
Alum	$34	−1.0%	0%	−26%	0%	0%	0%
Low Solubility P	$48	−1.4%	0%	−10%	0%	0%	0%
Sediment Traps	$68	−2.0%	0%	−15%	−80%	−50%	0%
Variable Rate Irrigation	$58	−1.7%	−10%	0%	0%	0%	0%
Feed Pads	$171	−5.0%	−15%	−15%	0%	−10%	0%
Restrictive Grazing	$513	−15%	−36%	−30%	−40%	−10%	−10%
Nitrification Inhibitors	$137	−4.0%	−25%	0%	0%	0%	−17%
Space-Planted Trees	$34	−1.0%	0%	−20%	−70%	0%	−5%
			Sheep & Beef				
Riparian Planting	$26	−21%	−56%	−50%	−75%	−60%	−10%
Fencing Streams	$32	−25%	−13%	−15%	−70%	−60%	0%
Wetlands	$25	−20%	−10%	−45%	−65%	−55%	0%
Alum	$64	−50%	0%	−26%	0%	0%	0%
Sediment Traps	$25	−20%	0%	−15%	−80%	−50%	0%
Low Solubility P	$25	−19.4%	0%	−10%	0%	0%	0%
Nitrification Inhibitors	$0	0.0%	−25%	0%	0%	0%	−15%
Restrictive Grazing	$14	−11%	−16%	−20%	−10%	−10%	−6%
Space-Planted Trees	$6	−5%	0%	−20%	−70%	0%	−6%
			Deer				
Riparian Planting	$37	−3.7%	−51%	−50%	−82%	−60%	−13%
Fencing Streams	$40	−4.0%	−13%	−15%	−70%	−60%	0%
Wetlands	$30	−3.0%	−10%	−45%	−65%	−55%	0%
Space-Planted Trees	$20	−2.0%	0%	−20%	−70%	0%	−6%
Nitrification Inhibitors	$0	0.0%	−7%	−9%	0%	0%	−3%
			Arable Cropping				
Riparian Planting	$11	−0.7%	−51%	−50%	−75%	−60%	−4%
Reduce Fertiliser by 15%	$22	−1.3%	−7%	0%	0%	0%	−5%
Reduced Tillage	$141	−8.6%	−2%	−25%	−25%	0%	−4%
Zero Tillage	$171	−10%	−10%	−50%	−25%	0%	−20%
Cover Crops	$409	−25%	−60%	−25%	−10%	0%	−20%
			Horticulture				
Riparian Planting	$62	−1.1%	−51%	−50%	−75%	−60%	−4%
Limit N per application	$90	−1.6%	−4%	0%	0%	0%	0%
10% reduction in N	$1,679	−30%	−10%	0%	0%	0%	−3%
Cover crops	$347	−6.2%	−5%	−25%	−25%	0%	−10%
Altering tillage practice	$0	0.0%	−5%	−25%	−25%	0%	−4%

6.5 Mitigation Bundles

In recent years, catchment-scale modelling of the effect of management practices to reduce diffuse-source pollution has focused on including a set of mitigation that are packaged as a 'bundle' of options that would likely be introduced on the farm at the same time (e.g. Everest 2014; Vibart et al. 2015). These bundles are typically defined as:

- M1: relatively cost-effective measures with minimal complexity to existing farm systems & management
- M2: mitigation that is less cost-effective than M1, but with capital costs and/or large system change
- M3: management options with large capital costs and/or are relatively unproven

These bundles are also often modelled as being implemented sequentially. That is, M2 also includes the practices in M1, while M3 includes practices from M1 and M2. Examples of practices that are included in each of these bundles are listed in Table 10. Note that a bundle will not necessarily include all of these practices, but rather a mix that achieves a similar reduction in contaminants for a given annualized cost per ha.

Table 10: Mitigation bundle practices

Mitigation Bundle	Management Option
M1	Installation of soil moisture monitoring gear and VRI on existing centre pivots. Adjust cropping fertiliser rates and types to best suit plant requirements and timings Limit each urea application Variable Rate Fertiliser Gibberellic Acid to substitute some spring and autumn nitrogen on pastures Apply nitrate inhibitors Optimise Stocking Rates Implement best management practices for infrastructure use and maintenance Optimum Olsen P Low solubility P fertiliser Laneway runoff diversion Effluent management Stock exclusion/fencing
M2	Modify irrigated area to include centre pivots/laterals fitted with Variable Rate Irrigation technology Variable Rate application of liquid urea Wetlands and/or sediment traps Tile drain amendments Reduce nitrogen fertiliser applications Riparian planting Enhance animal productivity via introducing cows with greater genetic merit Dairy farms to install covered feed pads and required effluent systems

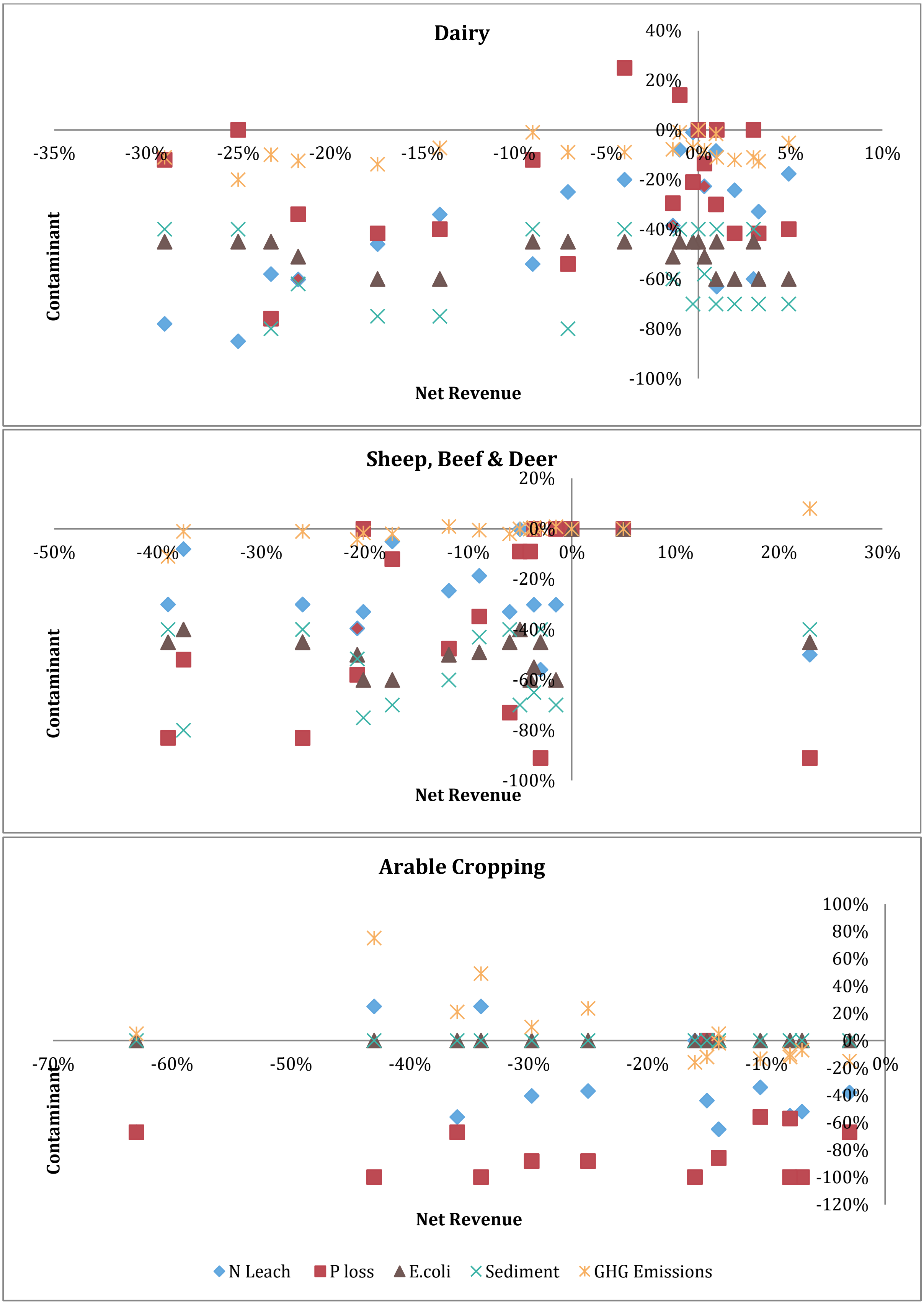
M3	Further reduce nitrogen fertiliser applications Reduce stocking rates All cows wintered off paddock, possibly in barns Restricted grazing of pasture and cropland Apply alum to pastures and crops Increase effluent area No winter feed crop yields over 14 t/ha.

Figure 7 shows scatter plots indicating the relative cost and effectiveness of mitigation bundles taken from the following studies:

- Parsons et al. (2015): Rotorua Lakes catchment, Bay of Plenty
- Everest (2014): Hinds catchment, Canterbury
- Vibart et al. (2015): Southland region
- Monaghan et al. (2016): New Zealand

In all cases, the effectiveness of each bundle was tracked for most, but not all of the 5 types of contaminants/emissions (N, P, S, E, GHG) that we are interested in. As a result, we estimated the relative effectiveness for the 'missing' contaminants by using the figures from the individual practices discussed in the previous section of this report. For example, Vibart et al. (2015) did not estimate the effects of practices on mitigating S and E, but as their bundles included options such as stock exclusion and constructing wetlands, we were able to use that information to fill in the blanks. To the best of our knowledge, no studies have been conducted to develop mitigation bundles for horticultural crops (see Agribusiness 2014a,b).

Figure 7: Relative change in net revenue v. contaminant (% change from baseline) for modelled mitigation bundles.



The mean, max, and min values for impacts to net revenue and the different contaminants and emissions of the mitigation bundles for each land use is listed in Table 11. The mean values are the figures that we will initially include in economic land use model that will be used in the next stage of the project to estimate the possible effects of the NPS-FM on GHG emissions. A few things to note from the mitigation bundle figures:

- The M1 bundles are indeed relatively low-cost (mean of 0–11% reduction in net farm revenue) but present a wide range of effectiveness for the different contaminants
- The arable cropping bundles did not include any mitigation that could reduce S or E. This may not be huge issue for this land use, but we will have to wait for the updated CLUES modelling to confirm
- As many of these mitigation bundles were developed to just focus on N and/or P, they often do not have a large effect on GHG emissions
- The figures that do have a larger effect on GHGs include de-stocking, DCDs, or additional trees or vegetation
- Implementing some mitigation bundles could actually lead to an increase in GHGs. This is particularly the case for more advanced mitigation for sheep, beef, & deer, and arable cropping.

Table 11: Cost and effectiveness of mitigation bundles by land use

		Dairy			**Sheep, Beef, & Deer**			**Arable Cropping**		
		M1	M2	M3	M1	M2	M3	M1	M2	M3
Net Revenue	Min	−4%	−9%	−29%	−26%	−38%	−39%	−16%	−43%	−63%
	Mean	0%	−1%	−22%	−9%	−12%	−21%	−11%	−25%	−30%
	Max	3%	5%	−14%	−4%	23%	−3%	−3%	−7%	−8%
Nitrogen	Min	−60%	−63%	−85%	−33%	−50%	−56%	−55%	−65%	−67%
	Mean	−23%	−38%	−60%	−19%	−25%	−40%	−34%	−37%	−41%
	Max	−1%	−18%	−34%	0%	−5%	−30%	0%	25%	25%
Phosph	Min	−42%	−54%	−76%	−83%	−91%	−91%	−100%	−100%	−100%
	Mean	−14%	−30%	−34%	−35%	−48%	−58%	−56%	−88%	−88%
	Max	25%	0%	0%	0%	0%	0%	0%	−67%	−67%
E.coli	Min	−60%	−60%	−60%	−60%	−60%	−60%	0%	0%	0%
	Mean	−51%	−51%	−51%	−49%	−50%	−50%	0%	0%	0%
	Max	−45%	-45%	−45%	−40%	−40%	−45%	0%	0%	0%
Sediment	Min	−70%	−80%	−80%	−70%	-80%	−75%	0%	0%	0%
	Mean	−58%	−60%	−62%	−43%	−60%	−52%	0%	0%	0%
	Max	−40%	−40%	−40%	0%	−40%	−40%	0%	0%	0%
GHG	Min	−12%	−13%	-20%	−2%	−2%	−11%	−16%	−7%	−12%
	Mean	−8%	-8%	−12%	0%	1%	−4%	−13%	24%	10%
	Max	−2%	−1%	−7%	1%	8%	0%	−10%	75%	49%

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