

**BEFORE THE ENVIRONMENT COURT
AT WELLINGTON**

**I TE KŌTI TAIAO O AOTEAROA
TE WHANGANUI-A-TARA ROHE**

IN THE MATTER	of the Resource Management Act 1991
AND IN THE MATTER	of appeals under Clause 14 of Schedule 1 of the Resource Management Act 1991 against the decision of the Manawatū-Whanganui Regional Council on Proposed Plan Change 2 to the One Plan ("PC 2")
BETWEEN	TE RŪNANGA O RAUKAWA (ENV-2021-WLG-00020) NGĀTI TURANGA (ENV-2021-WLG-00021) ANDREW DAY (ENV-2021-WLG-00022) WELLINGTON FISH AND GAME COUNCIL (ENV-2021-WLG-00023) Appellants
AND	MANAWATŪ-WHANGANUI REGIONAL COUNCIL Respondent

**EVIDENCE IN CHIEF OF ALEC DONALD MACKAY
FOR THE WELLINGTON FISH AND GAME COUNCIL
(Table 14-2)**

Dated: 6 November 2023

Counsel:
Sarah Ongley
Barrister
PO Box 8213
NEW PLYMOUTH
Telephone: 0274 467 917
Email: sarah@ongley.co.nz
www.bankchambers.co.nz

1. QUALIFICATIONS AND EXPERIENCE

- 1.1 My full name is Alec Donald Mackay. I have a Doctor of Philosophy (PhD) degree in Soil Science from Massey University, Palmerston North, New Zealand. I also hold a Bachelor of Agricultural Science Honours Degree from Massey University.
- 1.2 I have worked as a Post-Doctoral Scientist in the Agronomy Department of Purdue University, Indiana, US (1982-84), Research Scientist, DSIR Grasslands, Palmerston North (1985-90) Research Scientist/Officer-in-charge, DSIR Ballantrae Hill Country Research Station (1990-92); Research Scientist/Officer in Charge, AgResearch Ballantrae Hill Country Research Station (1992-95) and Research Scientist and Programme Leader, AgResearch Grasslands (1996-2007).
- 1.3 My current position is as a Principal Scientist in the Land Use Function and Evaluation Team, Digital Agriculture, based on the Grasslands campus in Palmerston North. The current focus of my research is on (i) exploring the relationship between farm production and the environment, with a particular focus on the impacts of land use on those soil properties (e.g., nutrient fertility, physical condition, biology and organic matter) and processes that regulate the soil's supporting, provisioning and regulating services, (ii) impact of predicted future climates on primary production, and (iii) ongoing interest in farm planning.
- 1.4 I have more than 30 years' experience in land evaluation and planning, including as one of the principal developers of Beef + Lamb NZ Land and Environment Plan (LEP) Tool Kit, Project Green (www.projectgreen.co.nz) and Soils Underpinning Business Success (SUBS). SUBS is an education package, which was developed to assist land managers gain simple, easily learned skills for describing and mapping their own soils.
- 1.5 I am a Fellow and Life member of the New Zealand Society of Soil Science and a Past President. I have published more than 140 research publications and more than 240 conference papers. Over the last 30 years I have been involved in supervision of 20 post-graduate students.

- 1.6 I have had active involvement in the Sustainable Land Use Initiative (SLUI) with Horizons Regional Council since its conception in September 2004, and have provided Horizons ongoing expertise as a member of the SLUI advisory group. I was involved in the development of the water quality component of the One Plan first notified in 2007, and in the subsequent hearings (giving evidence for Manawatū-Whanganui Regional Council). In that context, I was principally involved the development of the natural capital based approach for nutrient allocation.

2. CODE OF CONDUCT FOR EXPERT WITNESSES

- 2.1 I confirm that I have read the Environment Court's Code of Conduct for Expert Witnesses as contained in the Environment Court's Practice Note 2023. I have complied with the Code when preparing this written statement and will do so when I give oral evidence before the Court. The data, information, facts and assumptions I have considered in forming my opinions are set out in this statement to follow. The reasons for the opinions expressed are also set out in the statement to follow. Unless I state otherwise, this evidence is within my sphere of expertise, and I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

3. PURPOSE AND SCOPE OF EVIDENCE

- 3.1 I have been asked by the Wellington Fish and Game Council (**Fish & Game**) to give evidence on the development of Table 14-2 in the Manawatū-Whanganui (**Horizons**) One Plan (**One Plan**). I comment on the part Good Management Practices (**GMPs**) and Best Management Practices (**BMPs**) played in the development of the Table and in the management of water quality outcomes in the One Plan.

4. DOCUMENTS AND MATERIALS REFERENCED

- 4.1 In producing this statement of evidence, I have reviewed the following statements of evidence filed on behalf of the Manawatū-Whanganui Regional Council:
- 4.1.1 Professor David Horne; and
 - 4.1.2 Dr James Hanly.

- 4.2 In attach to my evidence, the following documents that provide background to the development of the One Plan's Table 14-2:
- 4.2.1 Appendix 1: Section 42A Report to Council-level Hearings Panel hearing submissions on the Proposed One Plan (Alec Mackay)
 - 4.2.2 Appendix 2: Supplementary Evidence to Council-level Hearings Panel hearing submissions on the Proposed One Plan, March 2010 (Alec Mackay).
 - 4.2.3 Appendix 3: Farm Strategies for Contaminant Management - A report by SLURI, the Sustainable Land Use Research Initiative for Horizons Regional Council March 2007 (includes Appendix 6 *"Defining nutrient (nitrogen) loss limits within a water management zone on the basis of the natural capital of soil"*).
 - 4.2.4 Appendix 4: Implementation of FARM Strategies for Contaminant Management Further questions - A report by SLURI, the Sustainable Land Use Research Initiative for Horizons Regional Council July 2008.
 - 4.2.5 Appendix 5: *"Notes on the derivation of One Plan Table 14.2"* prepared by Barry Gilliland, Senior Policy Analyst, Horizons Regional Council 1 November 2017.
 - 4.2.6 Appendix 6: Rebuttal Evidence of Peter Harold Taylor prepared for declaration proceedings before the Environment Court (20 January 2017).¹

5. EVIDENCE

- 5.1 My evidence covers the background to the development of Table 14-2 in the One Plan and the part GMPs and BMPs played in the development of the Table and in the management of water quality outcomes in that Plan.

¹ Refer Decision [2017] NZEnvC 37 ENV-2016-WLG-000038.

5.2 In the development of the One Plan, Horizons considered a number of options for management nitrogen to water including:

- capping and managing down;
- placing limits on intensive land use;
- benchmarking;
- nutrient use efficiency;
- input-based controls;
- best management practices;
- Nitrogen (**N**) allocation based on land area; and
- N allocation based on the natural capital of the soil within a catchment.

5.3 Discussion of these options is contained in my Section 42A evidence (Appendix 1), in reports attached as my Appendices 2, 3 and 4 and in a further report *“FARMS test farms project - Testing the One Plan approach to contaminant management linking the FARM Strategy to the SLUI Whole Fam Plan design”* 20 February 2008.²

5.4 Of these options, four were explored in greater detail:

- | | |
|-----------|--|
| Option 1: | Capping current production systems and nitrogen losses - regardless of N losses from individual farms. |
| Option 2: | Placing a limit on the losses of nitrogen from intensive land uses - restrict any further intensification or require mitigation practices as an integral part of any ongoing land development. |
| Option 3: | Calculate a nitrogen leaching loss limit for land - in each catchment to deliver on the water quality outcome. |
| Option 4: | Allocate a nitrogen loss limit based on the natural capital of the soils (recognising not all soils are the same) in each catchment to deliver on the water quality outcome, recognising the differences in the productive of soils. |

² <https://www.horizons.govt.nz/publications-feedback/one-plan-documents/technical-reports> link - A Report by SLURI to Horizons Regional Council (20 February 2008).

- 5.5 The analysis was as follows (again drawing on my Section 42A evidence and these background reports).
- 5.5.1 Option 1 Stopped any future decline, favoured existing intensive land users, and disadvantaged landowners that had not fully developed land. It was considered to risk locking in the current land use patterns and had the potential to limit future land use change.
 - 5.5.2 Option 2, like 1, had a focus on limiting/controlling N loss by regulating land use. It was considered to have required a tight definition of intensification and a detailed description of each land use.
 - 5.5.3 Options 3 and 4 did not target a land use, intensity of use, or place a limit on production. Both offered approaches for developing policy linked directly to the underlying natural biophysical resources of the land in a catchment. Option 3 would have had one nitrogen loss limit value for all the land in a catchment.
 - 5.5.4 Option 4 recognised that not all land is the same in a catchment, or farm. In fact soils can vary enormously in natural capital. This option would allocate a nitrogen loss limit based on the biophysical potential of natural capital of the soils in a catchment. This option could be used in all catchments.
- 5.6 **Option 4 was favoured.** In the absence of a method for calculating a soil's natural capital, information from the extended legend of the LUC worksheets' "*attainable potential livestock carrying capacity*" was used as a proxy for the soil's natural capital.
- 5.7 Two factors were considered in deriving the N loss allocation based on the natural capital. If the goal of the policy was to encourage the most efficient land resource use with the least environmental impact, the N leaching loss limit should be weighted towards those soils with the greatest natural capital. If an imperative of policy was to retain land use options on soil with little natural capital, the weighting of the N leaching limit would need to be increased on those soils. This was in recognition that as the natural capital

of the soil declines, the land use options also decline, as does the range and cost competitiveness of mitigation options.

- 5.8 Option four was ultimately advanced and forms the background to the development of Table 14-2 in the One Plan.
- 5.9 I have been provided with a copy of “*Notes on the derivation of One Plan Table 14.2*” authored by Mr Gilliland, Horizons Regional Council (Appendix 5). I have been informed these notes were prepared following Declaration proceedings in 2017 and provided to Fish & Game.³ Although I was not involved in the preparation or discussion of those notes, they provide a more recent summary of the way Table 14.2 was developed.
- 5.10 Peter Taylor presented evidence to the Environment Court during the One Plan hearings in 2012, for Horizons, that assessed the ability of dairy farms to comply with Table 14-2 cumulative nitrogen leaching maximum (CNLM)’s.⁴ That history is well summarised by Mr Taylor’s later evidence (20 January 2017 – my Appendix 6). Mr Taylor’s evidence during the One Plan hearings, in 2012, was based on the “*FARM Strategy Test Farms*”. Of these 18 farms, it was estimated that 28% were able to meet Table 14-2 Year 1 CNLMs without applying additional N loss mitigation practices (i.e., more mitigation than practiced at the time of assessment) and 22% of these farms would be able to meet the Year 20 CNLMs. It was estimated that if high to medium cost-effective N loss mitigation practices were applied, 78% of the 18 farms could meet the Year 1 CNLMs and 61% could achieve the Year 20 CNLMs.
- 5.11 Mr Taylor’s evidence to the Environment Court (2012) in relation to these FARM Strategy Test Farms, was that “*for the majority of these farms achieving these reductions would be relatively easy. For two farms it would be possible but with some difficulty and for three farms very difficult*”.
- 5.12 This indicated more than GMP/BMP would be required for some farms. This is not well aligned with Professor Horne’s evidence, which states:⁵

Overseer was always a means to an end in the original PC2, which recognised that water quality was only going to improve as a consequence

³ Decision [2017] NZEnvC 37 ENV-2016-WLG-000038.

⁴ Evidence of Peter Taylor 20 January 2017 (my Appendix 6) at [20].

⁵ EIC Horne at [17]. Refer also EIC Horne at [53]: “*As I discussed above, the implementation of GMPs/BMPs was always the central focus of the One Plan, as encapsulated in Dr Monaghan’s original evidence.*”

of behaviour change by farmers, which is to say, the adoption of GMP/BMPs. Hence the emphasis on identifying the suite of Good Management Practices (GMPs) Best Management Practices (BMPs) at that time.

- 5.13 The evidence that preceded the Environment Court's decision on the One Plan⁶ was on a far more refined analysis than simply focusing on the implementation of GMP/BMP's.
- 5.14 Professor Horne's evidence attaches as his Attachment A, *Section 42A Report of Dr Ross Martin Monaghan on behalf of Horizons Regional Council* (August 2009). This however was only part of the evidence that formed the background to Table 14-2 (and the approach of the One Plan). I agree with Professor Horne's statement that adoption of GMP/BMP's is important, but it also needs to be acknowledged (as did my section 42A Report at the time) that the range and cost competitiveness of mitigation options differs depending on the natural capital of land (i.e., a distinction between land capability classes) and without specific targets for N then GMP/BMP's would not deliver the required outcomes.
- 5.15 There was recognition at that time that best practice nutrient management, along with nutrient budgeting and planning, mitigation technologies, industry initiatives (e.g. Clean Streams Accord) and Environmental Management Systems (EMS), all had the potential to reduce losses of sediment, P, and faecal material and with the inclusion of specific targets nitrogen. Many of these management (mitigation) practices (in Appendices 3 & 4) are evaluated extensively in the FARMs test farm project.⁷
- 5.16 In the FARMs test farm project a wider range of promising contaminant minimisation options were evaluated in terms of potential effectiveness, cost, and practicality. The nitrogen loss limits in Table 14.2 were used as targets to assess the effectiveness of reducing nitrogen leaching losses. Whereas progress can be made in reducing the losses of some contaminants through the adoption of the GMP/BMP, and this reflected in water quality outcomes, relying on GMP/BMP for achieving the required reductions to improve water quality outcomes is more difficult.

⁶ *Day v Manawatu Wanganui Regional Council* [2012] NZEnvC 182; [2012] NZEnvC 285.

⁷ Above-cited footnote 2.

5.17 My section 42A Report at the time stated in relation to Option 4:⁸

The major strength of this approach is that in calculating the N leaching loss limit it considers the whole catchment and is not prescriptive. It is not linked to current land use, but rather linked to the underlying land resources in the catchment. The approach does not target a land use or intensity of use, and it does not place limits on inputs; rather it allocates N leaching loss limits to each LUC unit based on the biophysical potential of the natural capital of the soils. It treats farms with the same land resources in the same manner, regardless of current use. It disadvantages high input, highly productive farms on soils with little inherent natural capital (e.g., sand country, gravels, and steep land soil) to limit nitrogen leaching, even when BMPs have been followed. (Emphasis)

5.18 Therefore, I consider generic statements that the One Plan focussed only on land use practice improvements (BMPs/GMPs), are selective and potentially misleading.

5.19 I note a recent study looking at the uptake of best management practices on dairy farms to catchment water quality improvement over a 20-year period, best practice reduced phosphorus (P), E coli and sediment concentrations but not nitrogen (N) concentrations,⁹ stating:¹⁰

Step changes in the concentrations of water quality contaminants were detected over the 20-year period which were broadly consistent with the catchment-scale implementation of targeted on-farm BMPs including: improved effluent management (land application, storage, including the capture of effluent from off paddock infrastructure), a transition from flood to spray irrigation and wintering practices. While the implementation of BMPs has helped to improve several water quality metrics, some national water quality thresholds were not being met meaning that more actions are required to achieve further improvements.

Alec Donald Mackay

⁸ At [38], Section 42A Report of Dr Alec Mackay on behalf of Horizons Regional Council (refer Appendix 1).

⁹ McDowell, RW., Macintosh, KA., Depree, C., 2023. *Linking the uptake of best management practices on dairy farms to catchment water quality improvement over a 20-year period*. Science of The Total Environment 895 <https://doi.org/10.1016/j.scitotenv.2023.164963>

¹⁰ Above-cited at 5. *Conclusions*. Refer also Abstract "... These data indicate that extension advice and on-farm practice change have helped to improve overall water quality over time. Nevertheless, recent regulatory threshold values for some contaminant concentrations are not being met, meaning that more actions are required, over and above the BMPs implemented".

Appendix 1

Section 42A Report to Council-level Hearings Panel hearing submissions on the
Proposed One Plan (Alec Mackay)

BEFORE THE HEARINGS PANEL

**IN THE MATTER of hearings on
submissions concerning
the Proposed One Plan
notified by the
Manawatu-Wanganui
Regional Council**

**SECTION 42A REPORT OF DR ALEC DONALD MACKAY
ON BEHALF OF HORIZONS REGIONAL COUNCIL**

1. INTRODUCTION

My qualifications/experience

1. My full name is Alec Donald Mackay. I have a Doctor of Philosophy (PhD) degree in Soil Science from Massey University, Palmerston North, New Zealand. I also hold a Bachelor of Agricultural Science Honours Degree from Massey University.
2. I have worked as a Post-Doctoral Scientist in the Agronomy Department of Purdue University, Indiana, US (1982-84); Research Scientist, DSIR Grasslands, Palmerston North (1985-90); Research Scientist/Officer-in-charge, DSIR Ballantrae Hill Country Research Station (1990-92); Research Scientist/Officer in Charge, AgResearch Ballantrae Hill Country Research Station (1992-95); and Research Scientist and Programme Leader, AgResearch Grasslands (1996-2007).3. My current position is as a Principal Scientist and Programme Leader in the Climate, Land and Environmental Group of AgResearch, based on the Grasslands campus in Palmerston North. The current focus of my research is on exploring the relationship between farm production and the environment, with a particular focus on the impacts of land use on those soil properties (eg. physical integrity of organic matter content) and processes that regulate the soil's supporting, provisioning and regulating services. Developing approaches for valuing the soil's natural capital and ecosystem services is a new science domain. Research also extends to land management, including active involvement in the Sustainable Land Use Initiative (SLUI) with Horizons Regional Council; an approach to resource management based on development of natural capital; whole farm planning (ie. Meat & Wool New Zealand's Land and Environment Plan (LEP) Tool Kit; and environmental planning and reporting through Project Green (www.projectgreen.co.nz), which aims to develop a minimum, voluntary New Zealand standard for sustainable production for sheep, beef cattle, deer and goat supply. I was a principal in the development of the SUBS (Soils Underpinning Business Success) education package, which was developed to assist land managers gain a few simple, easily learned skills for describing and mapping their own soils.
3. Since 2004 I have been a member of the Sustainable Land Use Research Initiative (SLURI), a cross-organisational group that aims to provide scientific information on soils and land use.
4. I am a Fellow of the New Zealand Society of Soil Science and the Immediate Past President. I have published more than 80 research publications, more than 140

conference papers and more than 30 significant client reports, and over the last 15 years I have been involved in supervision of 18 post-graduate students.

5. I have provided expertise to Horizons since its establishment, through being heavily involved in the development of the Sustainable Land Use Initiative (SLUI) and more recently through assisting in developing the Farmer-Applied Resource Management Strategy (FARMS) for nutrient management. I have also been retained by Horizons on an ongoing basis to continue the development (eg. on-farm monitoring programme) and evolution (eg. refinements to the Whole Farm Plan template) for use in SLUI and FARMS.
6. I have read the Environment Court's practice note Expert Witnesses – Code of Conduct, and agree to comply with it.

My role in the Proposed One Plan

7. I have provided expertise to Horizons in the development of the Sustainable Land Use Initiative (SLUI) since its conception in September 2004 and in the development of the water quality component of the Proposed One Plan.

Scope of evidence

8. My evidence focuses on nutrient allocation regimes and is in three parts:
 - i. The case for using an approach based on natural capital for a nutrient allocation regime.
 - ii. The science behind the natural capital approach.
 - iii. Refinements to the natural capital approach.
11. The evidence draws heavily on two reports prepared by the Sustainable Land Use Research Initiative (SLURI) cross-organisational team for Horizons:
 - i. Farm Strategies for Contaminant Management (Clothier *et al.*, 2007). This report covers an investigation of the sources of diffuse Nitrogen (N) and Phosphorus (P) losses from the dominant land uses contributing to N and P loadings in Horizons' Water Management Zones (WMZs). The report established what the target best management practices (BMPs) are for sheep and beef, and dairying to ensure that water quality in Horizons' WMZs move towards their quality criteria. It examined a number of options: grandparenting (ie. the capping of farm N leaching losses at levels based on emissions from current land use or the average of

emissions from land use in previous years), limiting intensive land uses, allocation of an N-loss limit per hectare, and allocation of an N-loss limit based on the soil's natural capital) for defining an N leaching loss limit that could underpin a nutrient allocation regime; and

- ii. Implementation of FARM strategies for Contaminant Management. Further questions (Mackay *et al.*, 2008). This report includes an analysis of the impact that information used at differing levels (ie. Class, Subclass and Unit) in the extended legends of the Land Use Capability (LUC) worksheets has on the calculation of the N leaching loss limits and the N loading in the river. It also examines mitigation options available for reducing N leaching losses beyond the root zone change within each LUC class, and investigates the N leaching loss limits required to achieve the water quality standard in the Upper Manawatu and Mangatainoka Rivers as detailed in the Proposed One Plan, Schedule D, Table D.17. It also reports on the appropriateness of a single table for N leaching loss limits for all catchments.

2. EXECUTIVE SUMMARY OF EVIDENCE

The Case For Using An Approach Based On Natural Capital For A Nutrient Allocation Regime

12. The allocation of an N-loss limit based on the soil's natural capital was identified as the option that best met the dual requirements for continued economic growth and ongoing flexibility in land use in Horizons' Region, while meeting water quality targets. This approach was subsequently adopted and formed the basis for the N-loss limit contained in Rule 13-1 in the Proposed One Plan (POP). The natural capital based approach recognises that land is a finite resource and that land-based industries are the basis of our economic wellbeing. The approach captures all the land within a Water Management Zone (WMZ) that contributes to the water quality outcome. It is portable beyond the target catchments, providing land owners with timely messages on resource management.

The dual requirements for continued economic growth and ongoing flexibility in land use in the Region while meeting water quality targets.

13. There is a finite area of land available for primary production locally, regionally and globally. Highly productive soils require centuries to develop under natural conditions and in New Zealand such highly productive soils are limited to 1.28 million hectares or 5% of total area. There are significant future opportunities for continued growth in the

Region's land-based sectors and these benefits would flow on to the wider New Zealand economy, through increased exports. An integral and underlying part of any policy initiative to protect water must be retaining the ability for future economic growth and flexible land use options. For example, a policy that placed a moratorium on the expansion of intensive farming practices and a limit on N leaching losses from less intensive farming systems in the Upper Manawatu catchment would limit the potential expansion of irrigated sheep and beef farming, dairying, cropping, horticulture, and commercial vegetable growing in the catchment. By limiting land use options for individual producers, such a policy would raise issues of equity, in addition to restricting industry growth strategies, and rural and regional development. The likely effects of taking this approach can be calculated in the following example, using dairying as an example of an intensive farming system: by utilising the same mix of Land Use Capability (LUC) classes currently used by the existing dairy industry in the Upper Manawatu catchment, the area under dairying could be increased from 20,000 ha to more than 40,000 ha. Assuming an average stocking rate of 2.5 cows per ha, with each cow producing 340 kg of milk solids per year and a payout of \$5 per ha, the additional 24,800 ha under dairying would inject an additional \$105 million into the regional economy.

14. Increased production (eg. milk solids and stock live weight per hectare) and efficiency gains (eg. cows or stock units per labour unit and lambs per ewe) have been the basis for the ongoing success, profitability and competitiveness of the pastoral industry in New Zealand over the last 50 years. Increased farm size has been the other key strategy that has enabled producers to remain profitable. These strategies are not likely to change in the foreseeable future, thus forcing producers to continue to search for additional efficiency gains. This will result in them having to continue pushing their businesses beyond current production levels and beyond the inherent carrying capacity of their land holdings, through additional inputs such as N fertiliser, irrigation and supplementary bought-in feed.
15. Retention of growth and land use options is therefore critical to the future viability of the Region's land-based industries. At the same time, the "do nothing" option with regards to N leaching losses will further accelerate the current trends in increasing N leaching from farms and the resulting decline in water quality in the already affected Water Management Zones. More catchments will be put at risk. The objective of improving water quality therefore cannot be achieved unless N leaching losses are addressed.

What options are available for addressing N leaching losses to water bodies?

16. Potential options for addressing N leaching losses to water bodies were evaluated against the criteria used to assess the natural capital based approach. These included: placing limits on intensive land use, benchmarking, nutrient use efficiency, input-based controls, best management practices, grandparenting (ie. the capping of farm N leaching losses at levels based on emissions from current land use or the average of emissions from land use in previous years) and N allocation based on land area. The following discussion is limited to options for addressing N losses and does not address P losses. The need for specific targets for N and not for P can be explained by comparing the chemistry and behaviour of the two nutrients in soil.
17. **Placing limits on the N leaching losses from existing intensive land uses only:** This offers an option for preventing further decline in water quality, providing -there is no further expansion of intensive land uses or increases in N losses from the less intensive land uses in the catchment. It rewards those landowners with the largest N leaching losses and protects the capital investments contributing to those N leaching losses, if used as the basis for the allocation of the N loss limit. It puts at risk the capital investments of landowners not currently generating significant N losses, but with the opportunity to do so. This approach would also disadvantage landowners who had been actively conserving N.
18. In addition to a moratorium on any further expansion of intensive land uses and any increase in N losses from less intensive land uses, both of which would have to be monitored, a strategy would have to be developed for reducing N leaching losses from farms within the priority catchments, where N loadings in the water body are above the standard. The approach is linked to current land use and, as a consequence, may not necessarily encourage the best use of the land resources in the catchment for the required water quality outcomes. It has the potential to seriously reduce future land development and land use change.
19. **Benchmarking each sector:** This approach would enable landowners and the land-based industries to identify their individual and collective contributions to the current N loading and to monitor changes over time. This would provide an early indicator of future environmental impacts and could be used to quantify the impact of current environmental best practices on N loadings, while making available information that might be required to meet any market requirements related to nutrient management. The concept of benchmarking the 'typical' or 'average' farm within a sector and then

working towards a planned reduction of N leaching losses brings with it challenges. To be effective, benchmarking will require the establishment of an N loss allocation for each sector in each catchment and a mechanism for changing that allocation when land use changes. The approach is linked to current land use and, as a consequence, may not necessarily encourage the best use of the land resources in the catchment for the required water quality outcomes. It has the potential to seriously reduce future land development and land use change.

20. Operationalizing the **Nutrient use efficiency** approach would require each producer in a catchment to have a “target or limit”. This brings with it a significant number of challenges, including establishing the initial N allocation for each sector and then to each landowner in that sector; and in reallocating and recalculating N use efficiencies to accommodate land use change between existing and new land uses within the catchment.
21. **Input-based controls:** Many inputs could be controlled to limit the risk of N leaching losses to the environment. While these are relatively easy to describe and quantify, there are a number of major technical difficulties when assessing effectiveness. Chief among these is predicting effectiveness from farm to farm, and verification of the level of implementation of any input controls.
22. **Best practices nutrient management:** Along with nutrient budgeting and planning, mitigation technologies, industry initiatives (eg. Clean Streams Accord) and Environmental Management Systems (EMS), best practices nutrient management has the potential to reduce losses of sediment, P, and faecal material and with the inclusion of specific targets, N from intensive agriculture. Many of these practices are listed in the FARM strategy.
23. **Grandparenting:** The capping of farm N leaching losses at levels based on emissions from current land use or the average of emissions from land use in previous years (eg. the last 3-5 years) would immediately stop any further increase in N leaching and any further decline in water quality, assuming no lag. Existing landowners would be limited to their historic N leaching losses, enabling them to continue their existing land uses without requiring additional N rights. On that basis there would be no upfront costs and, as far as practicable, the viability of existing land uses would not be significantly compromised. However, using N leaching losses calculated as part of the grandparenting process as the basis for the subsequent allocations has significant disadvantages. It recognises landowners with the largest N leaching losses and protects the capital investments contributing to those losses, while putting at risk the capital

investments of landowners not currently generating significant N losses, but with the opportunity to so. This approach would also disadvantage landowners who had been actively conserving N, for example by using Best Management Practices (BMPs).

24. The major weaknesses with grandparenting as an approach if it becomes the basis for the subsequent allocation of the N loss limit, is it does not consider the future and locks in current land use. It fails to recognise that land is a finite resource and fails to assess land use options in the catchment against the desired water quality outcomes. It also puts the future viability of all farms at risk, by failing to allow growth options and flexibility in land use.
25. **N allocation based on land area:** The average N leaching loss permissible for each of the 129,638 hectares in the Upper Manawatu Water Management Zone in the Proposed One Plan in Year 1, would be 13.2 kgN/ha below the root zone. If all the land resources in the catchment were the same (ie. they had the same natural capital and were providing the same ecosystems services to the community), all land owners would receive the same N-limit allocation per hectare. This would be a very simple, effective and equitable approach for all landowners in the catchment. It would negate the need to develop policy for each land use and would address the major challenge identified with all the other approaches, ie. setting the initial N-limit allocation.
26. However, the flat N-limit allocation approach has a major disadvantage because it fails to recognise differences between land types. Landscapes in the Upper Manawatu catchment range from flat to rolling to steep and by treating all land the same, the flat N allocation approach fails to recognise these differences. Within landscapes (ie. flat, rolling hills) the characteristics of the soils vary greatly in their inherent productive capacity and versatility. They represent a large component of the natural capital on which New Zealand's economy and environment depends. Contrary to popular belief, the area of versatile and elite soils represents less than 5% of New Zealand's soils while more than 65% of the country's soils have at least one physical limitation to productivity under pastoral uses. Common features of many soils derived from alluvium, loess, volcanic materials, coastal sands or in eroding hill and steep lands are their young age, weakly developed soil structure, poor drainage, limited water-holding capacity and limited nutrient/pollutant absorption capacity. This would suggest that treating all land the same would fail to recognise that some soils are capable of producing more, and hence are of greater value to the economy, than others which are less productive and more fragile.

27. The market recognises differences in the inherent natural capital of a soil, with land containing the more versatile and elite soils commanding higher prices. Land values are a product of current economic conditions, product prices, and the potential for future production gains, which are the sum of the soils' natural capital (eg. texture, organic matter content, soil depth, etc) and added capital (eg. technologies that address N and P deficiencies, low pH and toxicities through to technologies such as drainage, irrigation and flood control schemes to assist in water regulation, and infrastructure, including buildings, tracks and fences).
28. In addition to differences in productive capacity, soils vary in their ability to absorb nutrients, pesticides and wastes. Soils form the critical link between the atmosphere, a land use and water quality by regulating the time span between rain falling on the land and reaching streams, rivers and aquifers. Not only does the soil store and transmit enormous quantities of water, but it also acts as a renovator and sink for pollutants. High nutrient absorption capacity and pollutant assimilation are related to the Cation Exchange Capacity (CEC) and organic matter content of a soil (SOM), both of which increase the soil's capacity to absorb and assimilate chemical and organic inputs. Soils with high natural capital have high absorption capacity and primary production potential, and minimal adverse environmental impacts. Soils with lower natural capital, such as shallow and stony or sandy soils, have limited ability to store nutrients and water. Shallow or sandy soils require more frequent irrigation and additional nutrients for crop production to compensate for losses and inefficiencies. On these soils, there are greater risks that soluble nutrients and pesticides will pass beyond the reach of plant roots and adversely affect water quality.
29. Rather than assuming all land in a catchment is the same, an alternative approach is to recognise differences between soils and allocate the N-limit based on the soils' natural capital.

3. THE SCIENCE BEHIND THE NATURAL CAPITAL APPROACH

30. This is a new approach for which direct methods for calculating a soil's natural capital are still in development. Dominati *et al.* (2009) proposed a draft framework for classifying and measuring soil natural capital and ecosystem services, based on current understanding of soil forming processes, soil taxonomy and classification, soil processes, and the links between climate and land use.
31. In the absence of a method for calculating a soil's natural capital, a proxy that serves as a useful alternative is the ability of the soil to sustain a legume-based pasture that fixes

N biologically under optimum management and before the introduction of additional technologies. A legume-based pasture is a self-regulating biological system with an upper limit on the amount of N that can be fixed, retained, cycled, and made available for plant growth. The legume pasture dry matter base provides one indicator of the underlying productive capacity of the soil, taking into account the influence of new plant germplasm and the use of phosphorus, sulphur and potassium fertilisers, lime inputs, trace elements and technologies to control pests and weeds. It reflects the underlying capacity of soil to retain and supply nutrients and water, and the capacity of the soil to provide an environment to sustain legume and grass growth under the pressure of grazing animals.

32. Estimates of the potential productive capacity of a legume-based pasture fixing N biologically under a “typical sheep and beef farming system” for each Land Use Capability (LUC) unit in New Zealand are listed under “attainable potential carrying capacity” in the extended legend of the Land Use Capability worksheets, which are based on the capability for long-term sheep and beef livestock production.
33. Using the productivity indices (ie. attainable potential carrying capacity) listed in the extended legend of the LUC worksheets for calculating the natural capital of soils is a new application of the information in the extended legend. It reflects the evolving nature of sustainable land management, with the necessity to set limits on emissions from land to both air and water (in this case emissions to water, and specifically nitrate leaching losses beyond the root zone). It also demonstrates the potential utility of the information in the extended legend to advance sustainable land management. An attraction of the approach is that the extended legend of the LRI is already established as the basis for land development and evaluation, and the information in the extended legend is available throughout the New Zealand.
34. The N leaching loss limit for a given land unit can be calculated using the potential animal stocking rate that can be sustained by a legume-based pasture fixing N biologically, under optimum management and before the introduction of additional technologies. Using the land units listed in the extended legend of the LUC worksheets’ “attainable potential livestock carrying capacity” as a proxy for the soil’s natural capital, stocking rates were transformed to pasture production and used in the OVERSEER® nutrient budget model to calculate N leaching losses under a pastoral use.
35. For soils on LUC Classes I and II land, the calculated N leaching loss was 30 kgN/ha and 27.4 kgN/ha, respectively; this decreased to 23.5 kgN/ha and 17.5 kgN/ha for soils

on LUC Classes III and IV land, respectively.

36. If all the soils in the Upper Manawatu catchment were farmed at 90% of their potential as listed in the extended legend, and assuming a transmission coefficient of 0.5 for all land classes, the N loading in the river would be 921 tonnes annually. This is higher than the river's current N loading. When the potential production is limited to 75% on all LUC classes, the resulting N load in the river is very close to the present loading (Table 3). A significant amount of the most intensively farmed Class II and Class III land in the Upper Manawatu catchment currently would be operating at above 75% of potential, while a significant area of the Class IV and Class VII land would be operating at below 75% of potential.
37. The driver for N leaching loss limits can be changed from resources efficiency to one that recognises the necessity to add greater flexibility to landscapes that have little natural capital and lack versatility in either land use options and/or mitigation strategies. The trade-off between resource efficiency and retention of land use options is examined further in the last section of this evidence.
38. The major strength of this approach is that in calculating the N leaching loss limit it considers the whole catchment and is not prescriptive. It is not linked to current land use, but rather linked to the underlying land resources in the catchment. The approach does not target a land use or intensity of use, and it does not place limits on inputs; rather it allocates N leaching loss limits to each LUC unit based on the biophysical potential of the natural capital of the soils. It treats farms with the same land resources in the same manner, regardless of current use. It disadvantages high input, highly productive farms on soils with little inherent natural capital (eg. sand country, gravels and steep land soil) to limit N leaching, even when BMPs have been followed.
39. In catchments that have no existing water quality problems, landowners can be provided with an indication of the level of production and associated N leaching loss that would be permissible before mitigation practices would have to become an integral part of ongoing farming practices.

4. REFINEMENTS TO THE NATURAL CAPITAL APPROACH

40. The evidence in this section addresses a series of specific questions on the calculation of the N loss limit and the implications of this for the N loading in the river.

How does the LUC model change if differing levels of detail are used?

41. The net result of utilising more detailed landscape and rainfall data in the calculation of N leaching loss limits is a more accurate picture of the contribution of each land unit to N leaching and N loading in the river. This could be used to provide greater detail to assist landowners in the calculation of their N-loss limit and for making adjustments to Table 13.2 of the Proposed One Plan. Using the Upper Manawatu catchment as an example, the calculated N leaching loss at the LUC class, LUC subclass and LUC unit level, using the average rainfall value for the catchment, produced the same N loadings in the river when summed for the whole catchment. However, there were large differences in contribution to N leaching losses at the subclass level and particularly at the unit level, compared with the average for the class. This is highlighted in Figure 2 of the report by Mackay *et al.* (2008).
42. Use of an average rainfall value in the calculation of the N leaching loss will tend to overestimate losses for landscapes receiving less than the average rainfall, and underestimate losses from the higher rainfall zones in the catchment that have the same level of fertility and stocking rate. When additional soil information (eg. drainage class) and slope information (ie. flat, rolling, hill, steep), along with rainfall beyond the average for the catchment (eg. in 200 mm bands across the catchment) are included in the calculation of the N leaching loss, the contribution from each LUC unit changes further (see Figure 2 of Mackay *et al.*, 2008), as does the N loading to the river (see Figure 3 of Mackay *et al.*, 2008).

Flat and rolling landscapes with hill and steep land

43. As a general rule for flat and rolling landscapes within a catchment that also include hill and steep land, adding more detailed biophysical information, while assuming the same attenuation factor from land to river for all land units, will reduce the calculated N leaching loss and loadings into the river from soils. This is a consequence of the inclusion of less versatile soils (identified by more detailed mapping), use of actual rainfall (which is often lower than the catchment's average rainfall) and low slope classes. Inclusion of soil drainage classes would either increase or reduce the calculated N leaching losses.

44. As a general rule for hill and steep landscapes within a catchment that also include flat and rolling country, adding more detailed biophysical information, while assuming the same attenuation factor from land to river for all land units, will increase the N leaching loss and loadings into the river from soils. This is a consequence of the inclusion of more versatile soils (identified by more detailed mapping), use of actual rainfall (which is often higher than the catchment's average rainfall) and higher slope classes.
45. The findings of the FARMS test farm project (Manderson & Mackay, 2008) evaluated the effect of using the New Zealand Land Resource Inventory (NZLRI), which contains land information at the 1:50,000 scale, with that obtained by an on-farm survey, which could be at scales less than 1:5,000. It is worth noting that there is inherently more uncertainty in the available information about soils on hill and steep land, suggesting that landowners with these landscapes should consider more detailed mapping before making a decision on the scale at which to calculate their N leaching loss limit. Dr Andrew Manderson covers this issue in detail in his evidence.

How do mitigation options change with Land Use Capability Class?

46. To address this question it is first necessary to introduce the following concepts with respect to the behaviour of soils within each Class and the effects, on production levels and the environment, of production technologies developed to overcome "limitations to use".

The ability to realise and sustain the productive potential of soils

47. Agricultural production on elite and versatile soils (Classes I and II) with high natural capital requires lower levels of inputs (eg. fossil fuels, fertilisers and irrigation water) per unit of output than soils with little natural capital.
48. Under particular land uses, soils with limited natural capital can attain a similar level of productivity to soils with high natural capital. For example, shallow soils under irrigation can attain the same levels of pasture production as versatile soils. The productive capacity of soils on LUC Classes I and II, and on LUC Classes III and IV (through the use of feed pads and stand-off areas when soils are wet), is not generally constrained by the physical limitations of the soils. However, the physical integrity of soils found on Classes VI and VII will often define the upper limits of production.

The environmental impact of a soil operating at its natural potential

49. Emissions (eg. N leaching losses) will be higher on coarse textured, weakly developed, stony soils and soils on slopes, compared with elite soils. This rule will not be universal, because there will be trade-off. As a generalisation, the amount of product per unit of input will be greater, and the emissions resulting from the added production will be less, on an elite soil (ie. high natural capital) when comparing all soils at the same level of potential.

Production beyond the soil's natural capital

50. A number of very effective technologies are available (eg. cultivation, drainage and irrigation) to lift the productive capacity of soils on flat and rolling landscapes beyond their natural capital compared with soils found in hill country and steep land. There are also more technologies (eg. feed pads and N fertiliser) that are available for sustaining production to compensate for the lack of natural capital of soils on flat and rolling landscapes. The cost of technologies generally increases, as does their production benefit, as the natural capital of a soil declines.

Mitigating nitrogen losses in soils operating beyond their natural productive capacity

51. Technologies (eg. cultivation, drainage and irrigation) used as substitutes for a lack of productive capacity (eg. weakly developed soil structure and limited water available to plants) of soils will lead to increased N loss, through a combination of increased production and greater leaching volumes. The number and efficacy of mitigation options for compensating for the limited capacity of soils to retain N in the topsoil horizons decline as the natural capital of soils becomes more limited. Soils on which production technologies have their biggest impact on production levels will also be those landscapes that provide the greatest challenge in mitigating N leaching losses.

Relationship between N loss mitigation options and the natural capital of soil grouped by LUC class

52. The number of options for mitigating N losses decreases as the producer moves from soils in LUC Classes I and II to those in Class III and greater. The absolute cost of mitigation (eg. application costs) and/or the cost of mitigation as a function of production and income from land increases as the limitations to use increase. From a purely

biophysical stance, landowners on elite soils have no limitations to use and hence flexibility in their choice of land uses. Landowners on elite soils have a full range of options to mitigate N losses whereas on all other soils there are fewer effective options available. As the natural capital of the soil declines, the available land use options decline, along with the range and cost competitiveness of the mitigation options.

53. If the question is limited to, “What is the most efficient use of resources with the least environmental impact?” the N leaching loss limit should be weighted towards those soils with the greatest natural capital.
54. If the goal is to sustain rural communities into the future, a case for allocating higher N loss limits to soils with little natural capital would be required. This would be designed to retain the limited land use options and flexibility available to landowners on these landscapes.

Catchment level outcomes of Table 13.2 of the Proposed One Plan

What would the values have to look like to achieve the absolute standard in this timeframe?

55. Using the Upper Manawatu catchment as an example, the N loss limit permissible to achieve the river’s long-term water quality target, as set in Schedule D, Table D.17 of the Proposed One Plan, of 358,000 kg N is under 6 kg N/ha if all land is treated the same and assuming an attenuation of 0.5 from land to water. Bringing that analysis back to the initial water quality targets set for Year 1 of the Proposed One Plan for the Upper Manawatu River (859,000 kg N) and again treating all land the same, the N leaching loss limit for each hectare would be 13.2 kg N/ha, again assuming an attenuation of 0.5 from land to water in each catchment.

Is achievement of the absolute water quality standard achievable by management on farm using available best management practice?

56. On-farm management using best management practices available could not achieve the long-term water quality target set in the Proposed One Plan for the Upper Manawatu River of 358,000 kg N (ie. under 6 kg N/ha if all land is treated the same and assuming an attenuation of 0.5 from land to water). Attempting to achieve the absolute water quality standard would cause massive upheaval, because it would require radical changes to current land uses. The only land uses that could continue unchanged would

be land under native or exotic forest, scrubland and extensive sheep and beef. For intensive livestock, radical and unrealistic changes would be required.

Is it appropriate to have a single table for nitrogen loss limits for all catchments? If not then why not?

57. Adjustments would be required in the N loss values in the Table in recognition of the differences in the areal extent of soils and rainfall between catchments and the impact this will have of N loadings. The structure of Table 13.2 would remain the same, as would the catchment management planning process.

Are the values in Table 13.2 of the Proposed One Plan appropriate for conversion to intensive land uses as well as in target catchments, in reference to FARMS test farms?

58. In the first instance, the N loss limit values in Table 13.2 of the Proposed One Plan for the target catchments would be appropriate for defining thresholds for land being converted to an intensive land use in landscapes outside the target catchments. As the proportion of land under intensive land use expanded a catchment management plan would need to be developed to ensure the required water quality outcomes are achievable and at the same time retaining ongoing growth and land use options.

5. EVIDENCE

What are the options for addressing N leaching losses to water bodies?

59. My evidence is in three parts.
- A. The case for using an approach based on natural capital approach for a nutrient allocation regime.
 - B. The science behind the natural capital approach.
 - C. Refinements to the natural capital approach.
60. The evidence draws heavily on two reports prepared by the Sustainable Land Use Research Initiative (SLURI) cross-organisational team for Horizons:
- i. Farm Strategies for Contaminant Management (Clothier *et al.*, 2007). This report covers an investigation of the sources of diffuse Nitrogen (N) and Phosphorus (P) losses from the dominant land uses contributing to N and P loadings in Horizons' Water Management Zones (WMZs). The report established what the target best management practices (BMPs) are for sheep and beef, and dairying to ensure

that water quality in Horizons' WMZs move towards their quality criteria. It examined a number of options: grandparenting (ie. the capping of farm N leaching losses at levels based on emissions from current land use or the average of emissions from land use in previous years), limiting intensive land uses, allocation of an N-loss limit per hectare, and allocation of an N-loss limit based on the soil's natural capital) for defining an N leaching loss limit that could underpin a nutrient allocation regime; and

- ii. Implementation of FARM strategies for Contaminant Management. Further questions (Mackay *et al.*, 2008). This report includes an analysis of the impact that information used at differing levels (ie. class, subclass and unit) in the extended legends of the Land Use Capability (LUC) worksheets has on the calculation of the N leaching loss limits and the N loading in the river. It also examines mitigation options available for reducing N leaching losses beyond the root zone change within each LUC class, and investigates the N leaching loss limits required to achieve the water quality standard in the Upper Manawatu and Mangatainoka Rivers as detailed in the Proposed One Plan, Schedule D, Table D.1. It also reports on the appropriateness of a single table for N leaching loss limits for all catchments.

A. THE CASE FOR USING A NATURAL CAPITAL APPROACH FOR A NUTRIENT ALLOCATION REGIME

61. The allocation of an N-loss limit based on the natural capital of soils was identified in the report by Clothier *et al.* (2007) as the option that best met the dual requirements for continued economic growth and ongoing flexibility in land use in the Region, while meeting water quality targets. This approach was subsequently adopted and formed the basis for the N loss limit contained in Rule 13-1 in the Proposed One Plan. The natural capital based approach recognises that land is a finite resource and land-based industries are the basis of the Region's economic wellbeing. The approach retains ongoing flexibility in land use and management options for the targeted water quality outcome. It encourages the most efficient use of the Region's natural resources, again for the targeted water quality outcome, while allowing for a trade-off between resource efficiency and retention of farm businesses on less versatile landscapes. It does not prescribe a land use or place limits on inputs. The approach captures all the land within a Water Management Zone (WMZ) that contributes to the water quality outcome. It is portable beyond the priority catchments and sends important messages (ie. it does not reward the biggest polluter, does not penalise conservative behaviours and does not disadvantage owners of undeveloped land) and timely signals (eg. it establishes a target

for mitigation practices and defines a threshold above which the capital investment in increasing production must be extended to mitigation technologies, including significant modifications to farm design).

62. Globally, humans use about 8.7 billion hectares of land. About 3.2 billion hectares are potentially arable, of which a little less than half is used to grow crops. The remaining 1.7 billion hectares of potentially arable land, along with most non-arable land, function as pasture, forest and woodland. Land degradation is widespread and the overall pace of degradation has accelerated in the past 50 years. Productivity has declined substantially on approximately 16% of agricultural land in developing countries, especially on crop land in Africa and Central America, pasture in Africa, and forests in Central America. Almost 75% of Central America's agricultural land has been seriously degraded, as has 20% of Africa's and 11% of Asia's. Gardner (2000) reports that the decline in the global area harvested for grain, combined with the increase in world population, has steadily reduced the area of grain harvested per capita from 0.2 ha in 1965 to 0.11 ha in 1999. Grains supply more than half the calories and protein eaten directly by humans. Thus grain growing area tracks the resource base of the dominant component of the global food supply. It has been estimated that the minimum per capita arable land area needed for an adequate diet is 0.5 hectare under a modest level of inputs (Lal & Pierce, 1991). The land-to-people ratio argument is further compounded by the serious and global problem of soil degradation. This all points to land as a finite resource, and that should be considered in any decision that is likely to affect its use.

The dual requirements for continued economic growth and ongoing flexibility in land use in the Region while meeting water quality targets.

63. There is a finite area of land available for primary production regionally, nationally and globally. Highly productive soil requires centuries to develop under natural conditions. Our most productive soils have taken thousands of years to form, with the most versatile soils (LUC Classes I and II) in New Zealand limited to 1.277 million ha or 5% of total area (Mackay, 2008). In a report prepared for Horizons on future growth, Agriculture New Zealand (Anonymous, 2005) highlighted the opportunity for continued growth in the Region's land-based sectors. These benefits would not be limited to Horizons' Region but would flow through to the wider national economy, through increased exports. An integral and underlying part of any policy initiative to protect water must be the retention of options for land development and land use. For example, a policy that placed a moratorium on the expansion of intensive farming practices and a limit on N leaching losses from less intensive farming systems in the Upper Manawatu catchment would

limit the potential expansion of irrigated sheep and beef farming, dairying, cropping, horticulture, and commercial vegetable growing in the catchment.

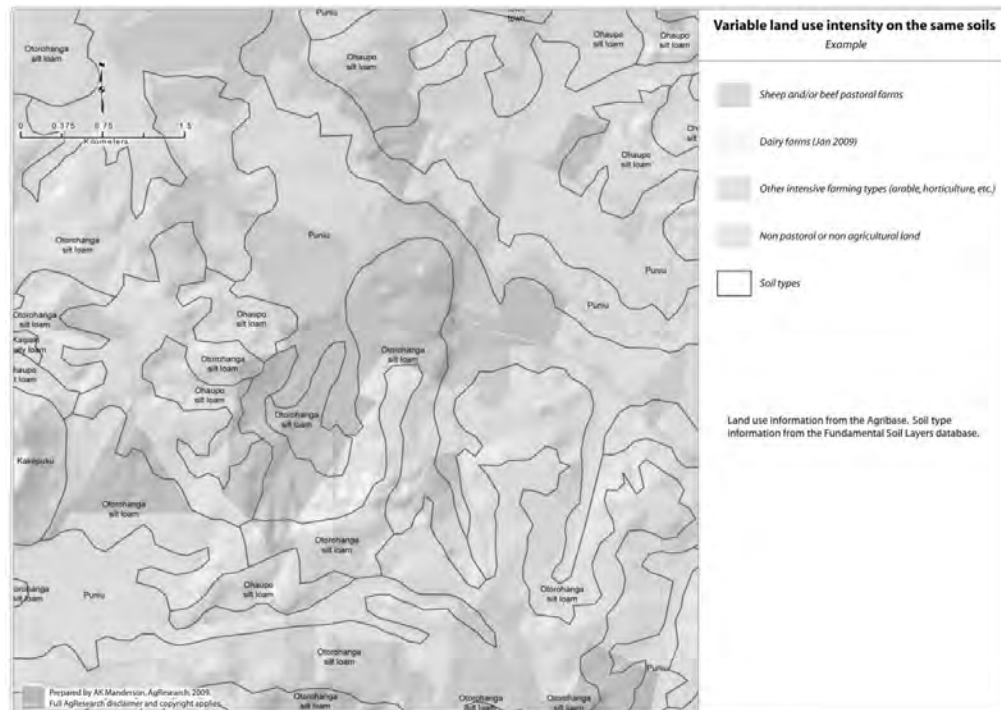


Figure 1. Land with the same natural capital under different land uses.

64. It would also limit land use options for individual producers (Figure 1), which raises issues of equity, restrict the scope of industry growth strategies (Figure 2a) and constrain rural community development and the regional economy (Figure 2b).

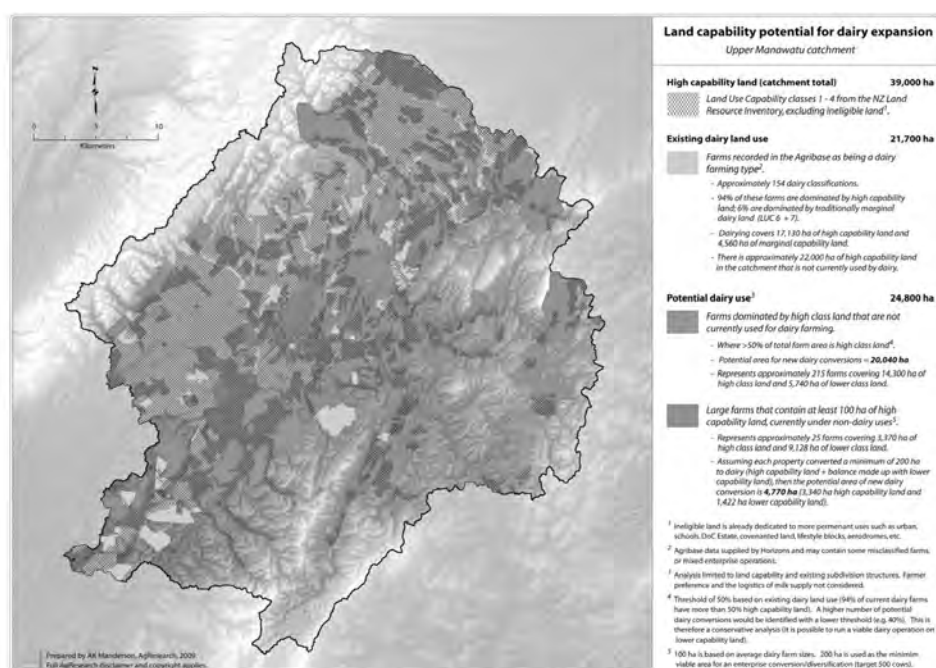


Figure 2a Existing (pink) and potential (light and dark green) extent by area of dairying in the Upper Manawatu catchment (NB: this assumes utilisation of all the Land Use Capability (LUC) classes in the catchment currently used for dairying.)

65. Figure 1 shows the implications for individual landowners of a moratorium on the expansion of intensive farming practices and a limit on N leaching losses from less intensive farming systems. Low intensity sheep and beef farms can be seen among intensive land uses on similar land classes, but if N leaching losses from current land uses on similar soils were used as a basis for a nutrient allocation regime, these properties with less intensive land use would be disadvantaged because they would effectively lose the potential for intensification already enjoyed by their neighbouring enterprises.
66. Utilising the same LUC class mix currently used by the existing dairy industry in the Upper Manawatu catchment, the area under dairying as an example of intensive farming system could be increased from 20,000 to more than 40,000 ha (Fig.2a). Assuming an average stocking rate of 2.5 cows per ha, with each cow producing 340 kg milk solids (MS) per year and a payout of \$5.00 per ha, the additional 24,800 ha under dairying would inject an additional \$105 million into the regional economy.

67. This lost opportunity is not limited to the Upper Manawatu River catchment. All the Region's priority WMZs would be affected by a moratorium on the expansion of intensive farming practices and a limit on N leaching losses from less intensive farming systems (Figure 2b). To provide an indication of the scale of the impact, 891 of the 2,652 farms within the priority zones identified as having high capability land are dairy farms; this leaves 1,761 non-dairy pastoral farms that have a high capability for potential dairy conversion. Extending that analysis beyond the priority WMZs would see that number jump again.
68. Farm Strategies for Contaminant Management (Clothier *et al.*, 2007), a study conducted for Horizons by SLURI, established the contribution of non-point source N loading from dairying and sheep and beef farming in the Upper Manawatu catchment. In that study the N loading in the Upper Manawatu River from the average dairy farm was found to be 15.4 kg/ha/yr. For sheep and beef the N loading was a much smaller 3.9 kg/ha/yr. More than 90% of the total N in the river is from these two non-point sources, with dairying contributing about half of the loading, despite only representing 16.3% of land use in the catchment, whereas sheep and beef cover 77.3% of the catchment area.
69. The N leaching loss from below the root zone in the Upper Manawatu catchment, calculated using the OVERSEER nutrient budget model, was found to be 31 kgN/ha for the average dairy farm and 7 kgN/ha for the average sheep and beef farm (Clothier *et al.*, 2007). Using an N transmission coefficient of 0.5 for both, dairying and sheep and beef operations, a direct link could be made between land use and management decisions as these influence N losses and loadings in the river. With that link it is possible to examine the impact of ongoing intensification of pasture-based agriculture on water quality and also to examine the benefits of adopting mitigation practices (Dr Brent Clothier's evidence provides more details).

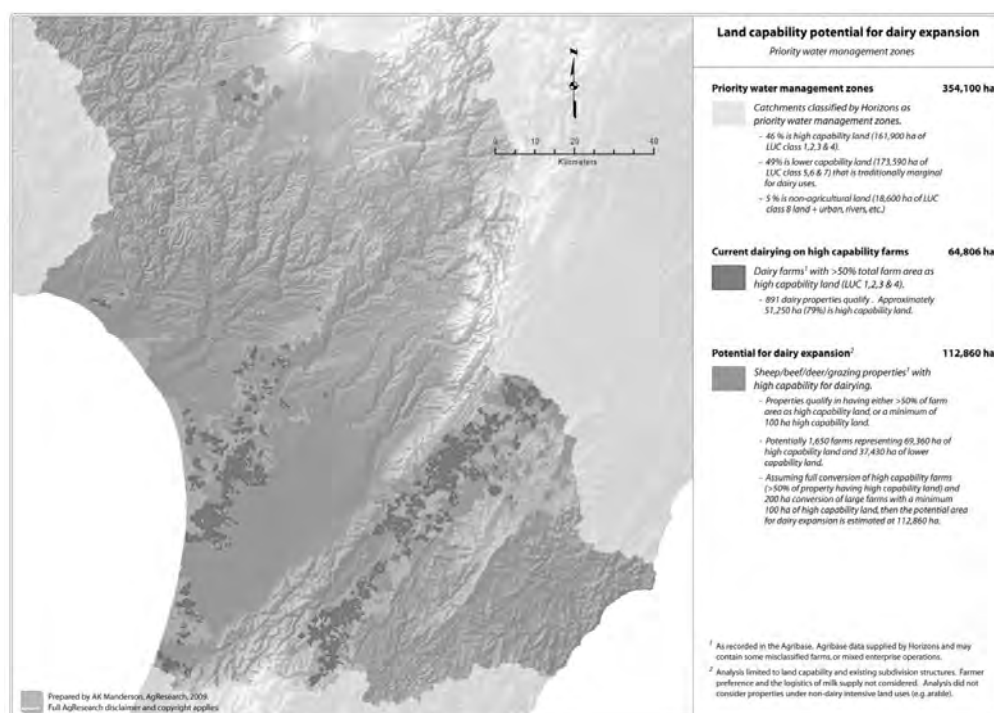


Figure 2b. Implications of a moratorium on the expansion of intensive farming practices and a limit on N leaching losses from less intensive farming systems on potential future expansion of intensive land uses in the Region's priority Water Management Zones

70. If dairy farms were to intensify to achieve an average of 1,200 kg milk solids (MS) per ha⁻¹ the leaching loss of N is predicted to be 49 kg-N ha⁻¹ yr⁻¹; this would result in a 33% increase in N-loading in the Manawatu River coming from the Hopelands sub-catchment.
71. If the average sheep/beef farming stocking rate increased to 12.2 stock units (SU) per ha⁻¹, which is a possible scenario over the next decade, the leaching loss of N is predicted to be 9 kg-N ha⁻¹ yr⁻¹. This would lead to N-loading in the river increasing by about 8.4%.
72. The Upper Manawatu catchment has 31,580 ha of land better than Class III with only 20,534 ha currently used for dairying. If dairying were to expand to all Class III or better lands, the N loading at Hopelands, emanating from the entire catchment would increase by 17.8%. This assumes the average N leaching loss from each dairy farm was 31 kgN/ha/yr and current management practices prevailed. If there were also

simultaneous production increases in dairy and sheep and beef, this number would be even bigger. This indicates that to do nothing is not an option.

73. Production (eg. milk solids per ha, liveweight per ha) and efficiency gains (eg. cows or stock units per labour unit, lambs per ewe) has been the basis for the ongoing success, profitability and competitiveness of the pastoral industry in New Zealand over the last 50 years. Increasing farm size has been the other key strategy used by producers to remain profitable. These strategies are not likely to change in the foreseeable future, thus forcing producers to continue to search for additional efficiency gains and to continue to have to push their businesses beyond current production levels and beyond the inherent carrying capacity of their land holdings, through additional inputs (eg. N fertiliser, irrigation, bought-in feed). (Dr Roger Parfitt's evidence provides additional information on previous and future industry growth strategies and the implications for emissions). Retention of growth and land use options is therefore critical to the future viability of the Region's land-based industries. At the same time, the "do nothing" option with regards to N leaching losses will further accelerate the current trends in increasing N leaching from farms and the resulting decline in water quality in the already affected WMZs. More catchments will be put at risk. The objective of improving water quality therefore cannot be achieved unless N leaching losses are addressed (Anonymous, 2007a). Therefore, the "do nothing" option will not achieve the objective of improving water quality. Additionally, the emergence of, or suggestion of legislation aimed at setting limits or thresholds on N loss above which mitigation is required suggests that to do nothing is no longer an option.
74. Horizons is one of a number of regional councils around New Zealand proposing to address farm nutrient losses through Regional Plan rules. For example, Variation 5 to the Environment Waikato Regional Plan contains new policy and rules to manage land use in the Lake Taupo catchment. The new rules serve to cap the amount of N leached from farmland, with the cap based on the previous history of N loss from each farm (ie. grandparenting). Rules in Environment Bay of Plenty's Proposed Regional Water and Land Plan, particularly Rule 11, propose to cap farm nutrient (N and P) losses at levels based on mid-2001 to mid-2004 land use. The basis of Rule 11 is that farmers cannot intensify land use unless they can keep nutrient losses within the 2001-2004 emissions. In the South Island, Environment Canterbury intends over time to move to a zone-based approach to groundwater quality and Environment Southland proposes to address non-point source discharges to achieve a 10% improvement in water quality by 2015.

What options are available for addressing N leaching losses to water bodies?

75. The options described and discussed in the report prepared by the SLURI team for Horizons Regional Council Farm Strategies for Contaminant Management (Clothier *et al.*, 2007) are expanded upon here to include benchmarking, nutrient use efficiency and best management practices, in addition to grandparenting and limiting intensive land uses. Each approach was evaluated against the criteria used to assess the natural capital based approach described earlier. The following discussion is limited to options for addressing N losses and does not address P losses.
76. The need for specific targets for N but not for P can be explained by comparing the chemistry of the two nutrients in soil and how they enter water. Phosphorus is a specifically sorbed anion tightly held by the soil, while nitrate-N is a weakly sorbed anion and, as a consequence, is easily leached. In grazing systems the loss of N is due to leaching of nitrate, originating from urine patches, down through the soil to below the roots. This occurs mainly during the period of the year (usually May to September) when net drainage occurs. The amount of nitrate-N leaching losses from a grazed pasture is a function of the number of animal urine patches, which increases with higher animal production and stocking rates (Ledgard, 2001). Best management practice, as it currently stands, does not place a limit on the number of animals or the number of urinations. Hence, as animal numbers and production increase, so do N leaching losses, even under best management practices. With the exception of soils (eg. cracking clays) that demonstrate preferential flow, P loss occurs largely via surface run-off. Phosphorus is lost in two forms, soil-bound and dissolved-P, with the former often the dominant (60-90%) mechanism in less intensively farmed hill catchments. In comparison with N losses, the quantities of P lost are smaller and a significant proportion of the P lost on an annual basis can occur during single-storm events (Parfitt *et al.*, 2009).

Placing limits on the N leaching losses from existing intensive land uses only

77. Placing a limit on the N leaching losses from existing intensive land uses only offers an option for stopping further decline in water quality, assuming no lag and no further expansion of intensive land uses or increases in emissions from the less intensive land uses in the catchment. Clothier *et al.* (2007) provide some indication of the impact this policy approach might have on water quality in the Upper Manawatu catchment.

78. In the short-term, significant reductions in the N loading in the Upper Manawatu River could be achieved by a focus on intensive dairy operations, as existing mitigation options offer the potential to reduce N losses on the average dairy farm by up to one third (Clothier *et al.*, 2007). While this approach offers a short-term policy option for Horizons, it is based on the assumption that there will be no further conversion of sheep and beef to more intensive land uses (eg. cropping, commercial vegetable growing and dairying), despite significant scope for land use change, or any further intensification of the sheep and beef sector. All of these have the potential to increase the N leaching losses and N loading in the river.
79. The focus on existing intensive land uses is closely aligned to the grandparenting option, if the N leaching losses calculated as part of the process were to become the basis for subsequent N limits or allocation of the public utility (N assimilation capacity of surface water body). It recognises and rewards the landowner with the largest N leaching loss and protects the capital investments contributing to that N leaching loss. It puts at risk the capital investments of landowners not currently generating significant N losses, but who have the opportunity to intensify production and thereby increase N losses. It also disadvantages landowners who had actively conserved N, for example by using BMPs, and it does not consider the best uses of the other natural resources within the catchment. For example, no assessment of the efficiency of utilisation of the land resources within the catchment against the current and desired water quality outcomes is considered. Rather than provide guidance to landowners outside the priority catchments who have the potential to exacerbate the current N loss challenge, it sends the wrong messages.
80. In addition to a moratorium on any further expansion of intensive land uses and any increase in N losses from less intensive land uses, both of which would have to be monitored, a strategy would be required for reducing N leaching losses from farms within the priority catchments where N loadings in the water body are above the standard.
81. The approach is linked to current land use and, as a consequence, may not necessarily encourage the best use of the land resources in the catchment for the required water quality outcomes. It has the potential to seriously reduce future land development and land use change.

Sector benchmarking

82. Benchmarking each sector would enable landowners and the land-based industries to identify their individual and collective contributions to the current N loading and to monitor changes over time. This would provide an early indicator of future environmental impacts and could be used to quantify the impact of current environmental best practices on N loadings, while making available information that might be required to meet any market requirements related to nutrient management. Benchmarks of N and P losses from typical farms in key agro-ecosystems, using the OVERSEER nutrient budgeting model, are being used within the environmental programme of the Pastoral 21 sector group to first quantify the contribution to the current environmental problem and then to assess the effectiveness of mitigation tools developed in other parts of the programme. The Dairy Industry Strategy for Sustainable Environmental Management (Dairy Environment Review Group, 2006) was designed to benchmark N and P losses for current typical dairy practice, and over a 10-year period mitigation solutions would be developed to reduce N losses by 50% and P losses by 50-80%.
83. The concept of benchmarking the 'typical' or 'average' farm within a sector and then working towards a planned reduction of N leaching losses brings with it challenges. To be effective, benchmarking will require the establishment of an N loss allocation for each sector in each catchment and a mechanism for changing that allocation when land use changes. A mechanism for setting allocations for new land uses would also be required. If the initial N leaching loss limit for each sector and each farm within a sector is allocated on the basis of the initial benchmarking exercise, it does not consider the most efficient use of the resources in the catchment for the required water quality outcome. It has the potential to seriously reduce future land development and land use change

Nutrient use efficiency

84. There are numerous types of nutrient use efficiency and they can be expressed in a number of different ways, including: 1) input based (produce N/total input N); 2) output based (eg. kg N leached/kg product; kg N leached/\$ effective farm surplus); and 3) effective on-farm land area used (eg. kgN/ha) (Wedderburn, 2008).
85. Tillman *et al.* (2008) have devised an nutrient efficiency index, which they define as the ratio of financial return per unit of N leached, calculated by dividing the amount of N leached in kg/ha by milk solid (MS) production in tonnes/ha. The authors refer to the index as an environmental efficiency index, though it is more correctly described as a

production efficiency index. Tillman *et al.* (2008) suggest that the approach would be deemed to be more palatable, and offer more flexibility to farmers, than imposing an N cap. They indicate that it would allow easy comparison between farms and enable farmers to gauge their performance relative to other farmers. Such an index, according to Tillman *et al.* (2008) would be easy for a regional council to implement and monitor, as all the required information is readily available. The approach provides industry with an indicator that could be used to encourage adoption of practices that increase the efficiency of N use within the farm system, conserve N, and have the potential to reduce N losses to the wider environment. It offers an approach for gauging the production efficiency of the business in producing milk against the loss of N (fertiliser N + legume N + mineralised N) from the pasture as nitrate in leachate.

86. At this stage in its development as an approach, it does not consider the influence of soil type, climate, feed source and a wide range of other management practices that are likely to impact on nutrient use efficiency. Failure to incorporate some of these factors will heavily favour specific farm systems in specific environments. At the extreme, the most efficient nutrient use system would be a cut-and-carry system with animals housed on a pad and with all effluent collected and processed. Farms on high class soils would also be advantaged by the approach. Landowners on soils with limited natural capital and high rainfall would be seriously disadvantaged.
87. The nutrient use efficiency approach, used alone, offers little utility. This can best be illustrated by comparing two dairy producers: Farm 1, producing 800 kg MS/ha and leaching 25 kg N/ha (nutrient use efficiency of 32 kg N/1,000 kg MS); and Farm 2, producing 1,200 kg MS/ha and leaching 37.5 kg N/ha (nutrient use efficiency of 32 kg N/1,000 kg MS). While the N use efficiency is the same for both scenarios, milk production is 50% higher and N leaching loss 48% higher on Farm 2. For the nutrient use efficiency approach to be effective as a tool in effecting change in water quality Tillman *et al.* (2008) recognised that *“it would require each dairy farmer in a catchment to have a target or a limit”*.
88. Operationalizing the N use efficiency approach for managing catchment N outcomes brings with it a significant number of challenges. It would require imposing an N use efficiency requirement on all farms in all the primary industries using land within a catchment (eg. <25 kgN/1,000 kg MS, <15kgN/250kg lamb carcass, <15kgN/65 kg wool, <15kgN/1,000 kg potatoes, etc). A mechanism would be required for establishing the initial N allocation to each sector and then to each landowner in that sector. It would also require developing a mechanism that could re-allocate and recalculate N use

efficiencies to accommodate land use change between existing and new land uses within the catchment.

89. Allowance would also have to be made for differences in soils and rainfall within the catchment, otherwise farm systems on specific soil types and in specific climates, both of which impact on N leaching, would be heavily favoured or disadvantaged. The approach would also have to be tailored to individual catchments, because along with changes in the water quality targets will come changes in climate, landscape and land use, all of which will influence the N leaching losses and N use efficiencies.
90. If the initial allocation of the N leaching loss limit is based on emissions from current land-based businesses in the catchment, the issues raised with the use of options for limiting intensive land use, benchmarking and grandparenting also apply.

Input-based controls

91. Many inputs could be controlled to limit the risk of N leaching losses to the environment. While these are relatively easy to describe and quantify, there are a number of major technical difficulties when assessing effectiveness. Chief among these is predicting effectiveness from farm to farm, and verification of the level of implementation of any input control.
92. Further, imposing rigid input-based controls (eg. no-till cultivation only, no N fertiliser inputs in May-July, zero grazing in June) will vary in effectiveness. This is because each farm system is a unique assemblage of resources (eg. land, water, enterprises and human capacity), is found in a unique spatial location, and is responding continuously to a range of drivers including climate and markets. Farms are complex system that are constantly trading-off between short-term and long-term economic, environmental and social goals. All of these will influence the outcome. The impact of imposing input-based controls on individual business would be highly variable. For example, it could limit the ability of producers to develop and implement the most cost-effective mitigation strategies compatible with their farm system. It could impose restrictions unnecessarily (eg. for a livestock farmer operating within acceptable limits). To be effective, an input-based approach will need to be tailored for different climate zones, landscapes, land uses and specific enterprises. It would also require a mechanism for addressing land use change, and some type of trigger before the input control is invoked (eg. using >50 kgN/ha/yr, stocking rate, etc). These modifications make this approach less attractive, especially when weighed against the intended outcomes.

93. Verification of adherence to the input-based specifications (eg. timing of N fertiliser application, maximum stocking rate and number of cultivation passes) brings with it challenges in both policy and quantification of effectiveness.

Best management practice

94. Best practices nutrient management, nutrient budgeting and planning, mitigation technologies, industry initiatives (eg. Clean Streams Accord) and Environmental Management Systems (EMS) have the potential to reduce the losses of sediment, P and faecal material and with the inclusion of specific targets, N, from intensive agriculture. These can have specific targets for N loss. The need for specific targets for N but not for P was explained earlier.
95. The Primary Sector Water Partnership has produced a plan of action for the sustainable management of freshwater resources. Its aim is that by 2013, 80% of the nutrients applied to the land are managed through quality assured nutrient management plans and budgets. A secondary aim is that by 2016, 1.7 million hectares of intensively farmed land will focus on improved environmental outcomes through operating nutrient budgets and nutrient management plans within their broader farm management plans. At this stage, the latter goal contains no specific targets or thresholds for nutrients. BMPs therefore have limited utility until N leaching loss targets are included. Addition of N loss limits to BMPs, as currently proposed by the horticultural industry to address N leaching losses from commercial vegetable operations, offers the pastoral industry an approach for addressing the current weakness of BMPs.

Grandparenting

96. Grandparenting is the capping of farm N leaching losses at levels based on emissions from current land use or the average of emissions from land use in previous years (eg. the last 3-5 years). It immediately stops any further increase in N leaching and any further decline in water quality, assuming there is no lag.
97. Grandparenting limits all landowners to their historic N leaching loss. Existing landowners can continue their existing land uses without needing to obtain additional N rights. On that basis there is no upfront cost. It also ensures that as far as practicable, the viability of existing land uses is not significantly compromised. These factors, along with the degree of certainty of achieving the outcome, appear to have been important

elements in the choice of this allocation option by Environment Waikato to address N leaching into Lake Taupo (Anonymous, 2007b).

98. However, using N leaching losses calculated as part of the grandparenting process as the basis for the subsequent allocations has significant disadvantages. It recognises landowners with the largest N leaching losses and protects the capital investments contributing to those losses, while putting at risk the capital investments of landowners not currently generating significant N losses, but with the opportunity to so. This approach would also disadvantage landowners who had been actively conserving N, for example by using Best Management Practices (BMPs). In effect there are “windfall gains” for the worst polluters and “windfall losses” to others. In the case of the Upper Manawatu catchment, a small percentage of landowners would receive windfall gains.
99. A further concern with the grandparenting approach is the messages it sends to landowners outside the target catchments (ie. wealth and future options are captured by the worst polluters). It has the potential to discourage rather than encourage sustainable practices.
100. The major weaknesses of grandparenting, if it becomes the basis for the N limits or allocation of the public utility (N assimilation capacity of surface water body) is it does not consider the future and locks in current land use. It fails to recognise that land is a finite resource and fails to assess land use options in the catchment against the desired water quality outcomes. It also puts the future viability of all farms at risk, by failing to allow growth options and flexibility in land use.

N allocation based on land area

101. The average N leaching loss permissible for each of the 129,638 hectares in the Upper Manawatu Water Management Zone in the Proposed One Plan in Year 1, would be 13.2 kgN/ha below the root zone. If all the land resources in the catchment were the same (ie. they had the same natural capital and were providing the same ecosystems services to the community), all land owners would receive the same N-limit allocation per hectare. This would be a very simple, effective and equitable approach for all landowners in the catchment. It would negate the need to develop policy for each land use and would address the major challenge identified with all the other approaches, ie. setting the initial N-limit allocation.

Table 1. Characteristics of the Upper Manawatu and Mangatainoka catchments

Parameter	Upper Manawatu	Mangatainoka
Size of catchment (ha)	129,638	47,871
Current N loadings (kg N)	745,000	603,000
Proposed One Plan Year 1 N loadings (kg N)	859,000	360,000
N loss limit to achieve the Proposed One Plan loadings, Year 1 (kg/ha) ¹	13.2	15
Long-term water quality standard (kg N)	358,000	248,000
N loss/ha (kg) ²	5.5	10.4
N loadings when all land units are operating at 75% of potential ³	1,004,000	503,000

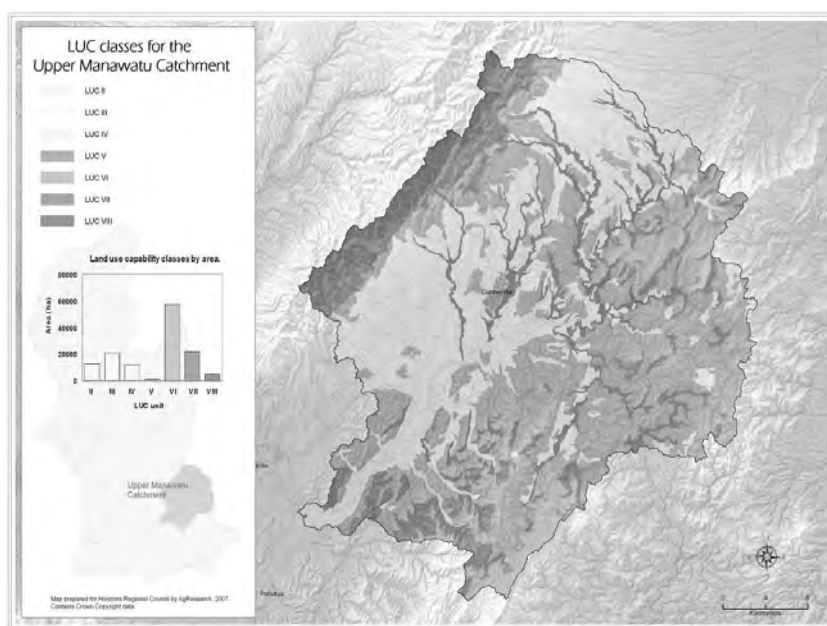
¹ Treating each ha in the catchment the same and assuming the transmission coefficient is 0.5.

² Treating each ha in the catchment the same and assuming the transmission coefficient is 0.5.

³ N loading when all land units in the catchment are operating at 75% of potential production, assuming an attenuation factor of 0.5.

Land is not all the same

102. Landscapes in the Upper Manawatu catchment range from flat to rolling to steep (Figure 3). Treating all land the same fails to recognise these differences. New Zealand enjoys a remarkable diversity of landscapes and soils (Molloy, 1998). The land area of New Zealand covers 26 million hectares, of which half is in pastoral agriculture and forestry. There are 6.5 million ha of flat and rolling land classes in pastoral and forestry. Hill and steep land covers the remaining 6.6 million ha, of which 5.2 million ha is in pastoral agriculture (Mackay, 2008).

**Figure 3.** Land Use Capability (LUC) classes for the Upper Manawatu catchment.

103. Within landscapes (eg. flat, rolling hills) the characteristics of the soils vary greatly in their inherent productive capacity and versatility. They represent a large component of the natural capital on which New Zealand's economy and environment depends. Contrary to popular belief, the area of versatile and elite soils represents less than 5% of New Zealand's soils. More than 65% of the soils have at least one physical limitation to productivity under a pastoral use. For example, approximately 2 million ha of poorly or imperfectly drained soils are farmed in New Zealand. Common features of many of our soils derived from alluvium, loess, volcanic materials, coastal sands or in eroding hill and steep lands are their young age, weakly developed soil structure, poor drainage, limited water-holding capacity and limited nutrient/pollutant absorption capacity. This would suggest that treating all land the same would fail to recognise that some soils are capable of producing more than soils that are less productive and more fragile. Hence, the more capable soils are of greater value to the economy. The market recognises differences in the inherent natural capital of soils, with the more versatile and elite soils commanding a higher price. Land values are a function of current and future potential production levels, which are the sum of the soils' inherent natural capital (eg. texture, organic matter content and soil depth) and added capital. Added capital can be technologies that address nutrient deficiencies (ie. N and P) and low pH and toxicities (liming); through to technologies such as drainage, irrigation and flood control schemes to assist in water regulation; and infrastructure, including buildings, tracks and fences.

Table 2. Potential for leaching losses for soils varying in Profile-Available Water (PAW) and Cation Exchange Capacity (CEC), within the upper 0.6 metres soil depth. The shaded areas correspond to soils with LUC Classes I and II. (Derived from Webb & Wilson, 1994).

PAW (mm)	Cation Exchange Capacity (meq/100g)		
	>12	6-12	<6
>250	minimal	minimal	
150-250	minimal	minimal	moderate
90-150	slight	slight	severe
60-90	moderate	moderate	severe
30-60	severe	severe	v severe
<30		severe	v severe

104. In addition to differences in productive capacity, soils vary in their ability to absorb nutrients, pesticides and wastes. Soils form the critical link between atmosphere, land use and water quality by regulating the time span between rain falling on the land and reaching streams, rivers and aquifers. Not only does the soil store and transmit enormous quantities of water, but it also acts as a renovator and sink for pollutants.

High nutrient absorption capacity and pollutant assimilation are related to the Cation Exchange Capacity (CEC) and organic matter content of a soil, both of which increase the soil's capacity to absorb and assimilate chemical and organic inputs. Soils with high natural capital have high absorption capacity and primary production levels, and minimal adverse environmental impacts. Soils with lower natural capital, such as shallow and stony, or sandy soils have limited ability to store nutrients and water. Shallow or sandy soils require more frequent irrigation and additional nutrients for crop production to compensate for losses and inefficiencies. On these soils there are greater risks that soluble nutrients and pesticides will pass beyond the reach of plant roots and adversely affect water quality (Table 2).

105. An alternative approach to assuming land is the same is to recognise differences between soils and allocate the N-limit based on the soils' natural capital.

B. THE SCIENCE BEHIND THE NATURAL CAPITAL APPROACH

106. This is a new approach, for which direct methods for calculating a soil's natural capital are still in development. Dominati *et al.* (2009) proposed a draft framework for classifying and measuring soil natural capital and ecosystem services, based on current understanding of soil forming processes, soil taxonomy and classification, soil processes, and the links between climate and land use.

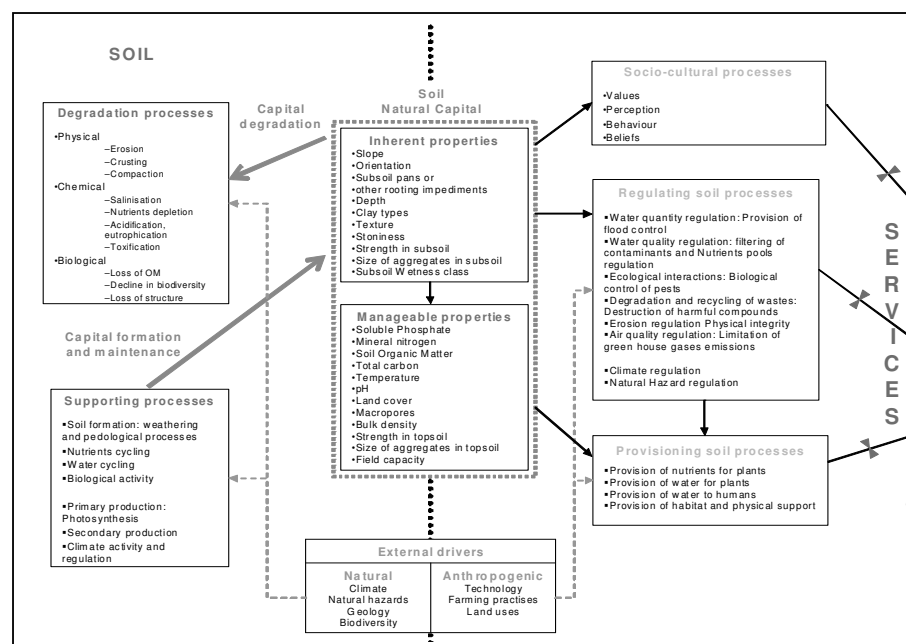


Figure 4. Draft framework for ecosystem services provision from soils' natural capital.

107. The framework shows how the natural capital of soils is embodied by soil properties, how supporting processes ensure the formation and maintenance of that capital, and how degradation processes influence natural capital depletion (Figure 4). A soil provides a range of provisioning services that contribute directly to productivity and economy (eg. nutrient and water supply, growing medium, physical structure for supporting plants and animals). They also provide a range of supporting regulating services (eg. nitrate and greenhouse gas emissions, temperature control, and flood protection). The framework of Dominat *et al.* (2009) also shows that soil services are end roles of ecosystems in the fulfilment of human needs. They are underpinned by provisioning and regulating processes that provide flows of goods or services. Sparling *et al.* (2005) attempted to place a monetary value on soil organic matter and Clothier *et al.* (2008) attempted to calculate the natural capital value of the ecosystem services provided by macro-pores in soils. Physical attributes, along with organic matter, regulate most soil services. Costanza *et al.* (1997) estimated the annual value of 17 terrestrial ecosystem services, all involving the soil-plant-atmosphere system, at US\$5.74 trillion, which is about one third of the annual gross global economic productivity.
108. In the absence of a method for calculating a soil's natural capital, a proxy that serves as a useful alternate is the ability of the soil to sustain a legume-based pasture fixing N biologically under optimum management and before the introduction of additional technologies (eg. N fertilisers, effluent and manures, intensive cropping and irrigation). A legume-based pasture is a self-regulating biological system with an upper limit on the amount of N that can be fixed, retained, cycled and made available for plant growth. The legume pasture dry matter base provides one indicator of the underlying productive capacity of the soil. It includes the influence of new plant germplasm, phosphorus, sulphur and potassium fertilisers, lime inputs, trace elements and technologies to control pests and weeds. The legume pasture dry matter base also reflects the underlying capacity of soil to retain and supply nutrients and water, and the capacity of the soil to provide an environment to sustain legume and grass growth under the pressure of the grazing animal. The introduction of technologies, including irrigation, drainage, N fertiliser, wintering pads, off-farm grazing and imported feeds has the potential to lift pasture and livestock production levels significantly above the inherent productive capacity of a basic legume-based pasture system.
109. Estimates of the potential productive capacity of a legume-based pasture fixing N biologically under a "typical sheep and beef farming system" for each LUC unit in New Zealand are listed in the extended legend of the LUC worksheets under "attainable potential carrying capacity". The definition of the attainable potential carrying capacity is

the number of stock units per hectare capable of being carried on a particular LUC unit, assessed within the limits of the technology of the time (ie. 1980s) and given favourable socio-economic conditions. The definition was designed for typical sheep and beef farming systems (ie. not dairying, cropping or other systems). The technique used for establishing the attainable potential carrying capacity was based on an assessment of representative LUC units by advisory officers of the then Ministry of Agriculture and Fisheries together with NZ Land Resource Inventory specialists from the Land Resources Group (LRG) of the Ministry of Works and Development (LRG, 1981). For national consistency the following criteria were adhered to: 1) the land was assumed to be managed exclusively for livestock grazing; 2) only on-farm feed cropping was considered; 3) it was assumed livestock were carried all year, except for on the high country; and 4) it was assumed that each LUC unit was managed as a discrete entity.

Land Use Capability (LUC)

110. A background to the LUC classification system is provided in the evidence of Grant Douglas. Evidence here covers the use of the information contained within the extended legend of the LUC classification as a basis for quantifying the natural capital of soils. LUC classification is a transparent, robust, science-based approach that has been used to advance sustainable land development and management in New Zealand since 1952. It has national coverage and application. From the LUC survey handbook, LUC classification is defined as “*a systematic arrangement of different land according to those properties that determine its capacity for long-term sustained production*”. Assessment of long-term sustained production using the LUC classification is based on an interpretation of the physical information in a Land Resource Inventory (LRI). This is compiled from a field assessment of rock type, soils, slope, erosion type and severities, and vegetation cover at any one location. The inventory is supplemented with information on climate, flood risk, erosion history and the effects of past practices and productivity indices for livestock and *Pinus radiata*. The five factors (ie. rock type, soils, slope, erosion type and severities, and vegetation cover) mentioned above are mapped simultaneously within the limits of scale. A new map unit is drawn whenever one of the physical factors alters. The ‘art’ of this form of appraisal is judging the degree of variability that is acceptable before creating a new unit.
111. At the broadest grouping, the LUC classification categorises land into eight classes according to long-term capability to sustain one or more productive uses. The general capability for sustained production of the eight LUC classes is summarised in Table 13 (page 77) in the 3rd edition of the LUC Survey Handbook (Lynn *et al.*, 2009). The five

factors collectively provide an insight into the long-term capability to sustain one or more productive uses. For example, assessing the risk of erosion is a product of slope, erosion risk and climate. Any one factor has limited value on its own. Productive capacity is a product of soil texture, drainage, stoniness, depth, climate, and slope. Again, any one factor has limited utility on its own. It is feasible to use the broadest grouping, LUC Class to define the potential for leaching losses and sorption capacity (pollutants, nutrients) of soils, based on information on soil texture, depth, stoniness, drainage, and climate. Webb & Wilson (1994) established that the majority of soils within LUC Classes II and II have high Profile Available Water (PAW) and Cation Exchange Capacity (CEC) (Table 1) and, as a consequence, would have a greater capacity to limit leaching and nutrient losses. Anion Storage Capacity (ASC) would range from low to high. The soils with very low ASC, often referred to as high P loss soils, would fall outside Classes I and II. Lilburne & Webb (2000) ran simulations of crop growth and nitrogen cycling to show that shallow soils (Class III soils) leach 2-3 times more nitrate than deep soils (Classes I and II) under dryland cropping.

112. Each LUC class can be further categorised, using one of four subclasses, based on the dominant limitation (ie. erodibility, wetness, soil, and climate). All four limitations have a major impact on long-term sustained production. For example, the wetness limitation is due to either a high water table, slow internal drainage, and/or frequent flooding. This limits plant growth through a lack of soil aeration. The soil limitation occurs where the major restriction is within the rooting depth, due to a shallow soil profile, stoniness, subsurface pan, poor soil texture and structural conditions, through to low water-holding capacity. The climate limitation can be a short growing season, inadequate or excess rainfall, frost and snow, through to exposure to strong winds. In Horizons' Region, erodibility is the single biggest limitation, followed by soil, wetness and lastly climate. This is shown in Figure 11 (page 82) in the 3rd edition of the LUC Survey Handbook (Lynn *et al.*, 2009).
113. The LUC unit is the most detailed component of the LUC classification. It is the management level in the classification and so the degree of detail depends on the scale of mapping, the intended purpose, etc. Information relevant to each LUC unit is documented in an extended legend. The legend includes a summary of Land Resource Inventory (LRI), climate, land use, factors influencing land use, and productivity indices. It is important to note that classification of land according to its capability for long-term production, based on its physical limitations and site-specific management, provides the most reliable basis on which to advance sustainable land management.

114. The productivity indices (ie. attainable potential carrying capacity) listed in the extended legend of the LUC worksheets, are based on the capability for long-term sheep and beef livestock production. Their use for calculating the natural capital of soils is a new application of the information in the extend legend. It reflects the evolving nature of sustainable land management, with the necessity to set limits on emissions from land to both air and water. In this case it concerns the emissions to water and specifically nitrate leaching losses beyond the root zone. It also demonstrates the potential utility of the information in the extended legend to advance sustainable land management. An attraction of the approach is that it is the basis for land development and evaluation in New Zealand, and the information in the extended legend is available throughout the country.

Calculation of the N loss limit

115. The N leaching loss limit for a given land unit can be calculated using the potential animal stocking rate that can be sustained by a legume-based pasture fixing N biologically, under optimum management and before the introduction of additional technologies. Using the land units listed in the extended legend of the LUC worksheets' "attainable potential livestock carrying capacity" as a proxy for the soil's natural capital, stocking rates were transformed to pasture production and used in the OVERSEER® nutrient budget model to calculate N leaching loss under a pastoral use (Clothier *et al.*, 2007).
116. For example, using the Upper Manawatu Water Management Zone (WMZ) as a case study, the N leaching losses of the soils in the catchment were calculated using the potential stocking rate that could be sustained by a well managed legume-based sward, taken from the extended legend of the LUC worksheets' "attainable potential livestock carrying capacity" for the North Island, as a proxy for natural capital of the soil in each LUC unit.

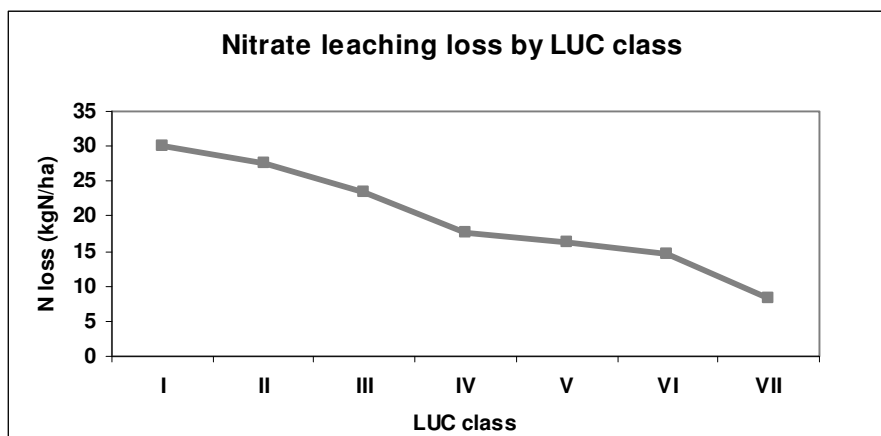


Figure 5. Nitrate leaching loss calculated using OVERSEER (developed dairy operation, annual rainfall 1,200 mm) associated with the potential livestock carrying capacity listed in the extended legend for LUC Classes I-VII in the North Island.

117. The potential livestock carrying capacities for the Upper Manawatu WMZ were transformed to pasture production and used in the OVERSEER nutrient budget model to calculate N leaching losses under a pastoral use. Figure 5 shows the N losses by leaching calculated from the OVERSEER model, summarised for LUC Classes I-VII for the North Island and used in the Upper Manawatu WMZ. As the limitations to use increase (ie. in Classes I to VII) the underlying productive capacity and ability of the soil to sustain a legume-based pasture system declines, as does the potential N leaching loss.
118. For LUC Classes I and II the calculated N leaching loss was 30 kgN/ha and 27.4 kgN/ha, decreasing to 23.5 kgN/ha and 17.5 kgN/ha for soils on Classes III and IV land. Nitrate leaching losses reported from dairy pastoral systems in New Zealand range from 15-115 kg-N/ha¹, with 40 kg-N/ha often used as an average value. (Meneer *et al.*, 2004) and Campbell (2009) from Environment Waikato also reported the value of 40 kgN/ha as the amount of N leached from a typical dairy farm in the Waikato Region. They indicated that in order to achieve the Regional Policy Statement objective of no net decline in water quality, that figure must be reduced to approximately 22-26 kgN/ha/yr. More than 70% of dairy farms in the Waikato Region are on Class I-IV land.
119. The landscape in the Upper Manawatu catchment is dominated by Class VI land, with sheep and beef the dominant land use in the sub-catchments above Weber Road. If all the soils in the Upper Manawatu catchment were farmed at 90% of potential as listed in

the extended legend, and assuming a transmission coefficient of 0.5 for all land classes, the N loading in the river would be 921 tonnes annually. This is higher than its current N loading. The calculation in Table 3 was limited to the use of the potential production for the “average” soil in each LUC class.

120. When potential production is limited to 75% on all LUC classes, the resulting N load in the river is very close to the present loading (Table 3). A significant amount of the most intensively farmed Classes II and III land in the Upper Manawatu catchment would be currently operating above 75% of its potential, while a significant area of the Classes IV and VII land would be operating below 75% of its potential. . The N loss values in Table 3(column 5) provide an N leaching loss limit for each LUC class, above which mitigation would be required to prevent further contamination. If the long-term goal is a reduction on the current N loading in the river, then an adjustment can be made to the percentage of potential production that is permissible before a mitigation strategy must be initiated. The major strength of this approach is that in calculating the N leaching loss limit it considers the whole catchment and is not prescriptive. It is not linked to current land use, but rather linked to the underlying land resources in the catchment.
121. The natural capital based approach does not target a land use, intensity of use, or place a limit on inputs; rather it allocates N leaching loss limits to each landscape unit based on the biophysical potential of natural capital of the soils. It treats farms with the same land resources in the same manner regardless of current use (Figure 1). It disadvantages high input, highly productive farms on soils with little inherent natural capital (eg. sand country, gravels, steepland soil) to limit N leaching even when BMPs have been followed and in this regard could be regarded as inequitable (Anonymous, 2007b).
122. In catchments with no water quality problems at the present time, landowners can be provided with an indication of the level of production and associated N leaching loss that would be permissible before mitigation practices would have to become an integral part of ongoing farming practices.
123. The approach offers the opportunity to engage directly and in a very transparent way with landowners and the wider community in setting the targets. The driver for N leaching loss limits can be changed from resources efficiency to one that recognises the necessity to add greater flexibility to landscapes that have little natural capital and lack versatility in either land use options and/or mitigation strategies. The trade-off between

resource efficiency and retention of land use options is examined further in the last section of this evidence.

Table 3. Area of each LUC Class, calculated N loss associated with the potential productivity of the soils in each LUC class calculated using Overseer, and the contribution of the soils in each LUC class to the N loading in Upper Manawatu River, and average N loss per ha per year if each LUC class is farmed at 90% and 75% of potential.

LUC class	Area (ha)	N Loss based on potential production (kgN/ha/yr)	Fraction of potential	Nitrate loss limit kgN/ha/yr	Transmission coefficient	Total loading N in river (kg N/yr)	Fraction of potential	Nitrate loss limit kgN/ha/yr	Transmission to efficient	Total loading N in river (kg N/yr)
II	12,424	27.4	0.9	24.7	0.5	153,348	0.75	20.6	0.5	127,790
III	20,257	23.5	0.9	21.1	0.5	213,978	0.75	17.6	0.5	178,315
IV	11,508	17.5	0.9	15.8	0.5	90,729	0.75	13.1	0.5	75,608
V	907	16.3	0.9	14.7	0.5	6,666	0.75	12.3	0.5	5,555
VI	57,254	14.5	0.9	13.1	0.5	373,897	0.75	10.9	0.5	311,580
VII	22,108	8.3	0.9	7.5	0.5	82,431	0.75	6.2	0.5	68,693
VIII	5,180	0.0	0.9	0.0	0.5	0	0.75	0.0	0.5	0
Total	129,638					921,049				767,541

C. REFINEMENTS TO THE NATURAL CAPITAL APPROACH

124. The evidence in this section draws heavily on the report prepared by SLURI for Horizons titled Implementation of FARM strategies for contaminant management. Further questions (Mackay *et al.*, 2008). It addresses a series of specific questions on the calculation of the N loss limit and the implications of this for the N loading in the river.

How does the LUC model change if differing levels of detail are used?

125. The net result of utilising more detailed landscape and rainfall data in the calculation of N leaching losses is a more accurate picture of the contribution of each land unit to N leaching. This could be used to provide detail to assist landowners in the calculation of their N-loss limit and for making adjustments to Table 13.2 in the Proposed One Plan to ensure the dual desired outcomes of economic growth and improving water quality are realised.

LUC class, LUC subclass and LUC unit scales

126. Using the Upper Manawatu catchment as an example, the calculated N leaching loss at the LUC class, LUC subclass and LUC unit levels, using the average rainfall value for the catchment, produced the same N loadings in the river when summed for the whole catchment. In the calculation, the potential livestock carrying capacities at the LUC class and LUC subclass level were summed from data held on each LUC unit. There were large differences in calculated N leaching losses at the subclass scale and particularly at the unit scale, compared with the average for the class. This is highlighted in Figure 2 of the report by Mackay *et al.* (2008). The LUC class is the broadest grouping of the capability classification. It includes an assessment of the land's capability for use and takes into account its physical limitations and its versatility for sustained production. The LUC subclass is a subcategory of the class through which the main kind of physical limitation or hazard to use is identified. The unit is the most detailed component of the LUC classification system and groups together areas where similar land inventories have been mapped, which require the same management, are suitable for the same kind of use, and have similar potential yields. As one moves from the LUC class, to subclass and then to unit level, more information is available and used in classification.
127. When additional soil information (eg. drainage class), slope (eg. flat, rolling, hill, and steep) and rainfall beyond the average for the catchment (eg. in 200 mm bands across the catchment) are included in the calculation of the N leaching loss, the contribution

from each LUC unit changes (see Figure 2 of Mackay *et al.*, 2008). The N loading to the river also changes (see Figure 3 of Mackay *et al.*, 2008).

Rainfall

128. Annual rainfall in the Upper Manawatu catchment varies from 1,000 to 3,000 mm and the area weighted average rainfall is 1,357 mm. A closer examination of rainfall in the catchment reveals that the distribution is skewed to the hill and steep land landscape units. Use of an average rainfall value in the calculation of the N leaching loss will tend to overestimate the N leaching loss on the landscapes that receive less than the average rainfall, while underestimating the N leaching losses from the higher rainfall zones at the same level of fertility and stocking rate. Given the influence of rainfall on N leaching and its contribution to the N loading in the river, an average rainfall value for the catchment (1,357 mm) should not be used. Instead, a rainfall database held by the Regional Council should be used (see the evidence of Dr Jon Roygard).

Slope

129. N leaching losses increase with increasing slope. Inclusion of slope in the calculation of the N leaching loss and potential N loadings in the river, like rainfall, also provides more site-specific information on the biophysical factors contributing to N leaching loss.

Flat and rolling landscapes with hill and steep land

130. As a general rule, on flat and rolling landscapes within a catchment that also includes hill and steep land, adding more detailed biophysical information will reduce the calculated N leaching loss and loadings into the river from soils (assuming the same attenuation factor from land to river for all land units). This reduction in N leaching loss and loadings occurs as a consequence of the inclusion of less versatile soils (identified by more detailed mapping), use of actual rainfall (which is often lower than the catchment's average rainfall) and low slope classes. Inclusion of soil drainage class would either increase or reduce the calculated N leaching loss.
131. As a general rule in hill and steep land within a catchment that also includes flat and rolling country, adding more detailed biophysical information, will increase the N leaching loss and loadings into the river from soils (assuming the same attenuation factor from land to river for all land units). This increase in the N leaching loss and loadings occurs as a consequence of the inclusion of more versatile soils (identified by

more detailed mapping), use of actual rainfall (which is often higher than the catchment's average rainfall) and higher slope classes.

132. Inclusion of more detailed soil, landscape and climate information helps provide a more accurate description of the contribution to N leaching losses from landscape units; it is not about defining the N loading in the river, which is achieved by defining the percentage of potential attainable production of the land that can be farmed while still achieving the water quality outcome targets for that water body. On that basis, landowners should have the option of calculating their N leaching loss limit from the NZLRI or from more detailed biophysical resource information (eg. soil type, slope, drainage class, climate data, and production potential) to address spatial inaccuracies in the land resource information and the limitation of using average rainfall information.
133. The findings of the FARM strategy test farm project (Manderson & Mackay, 2008) evaluated the effect of using the NZLRI, which contains land information at a 1:50,000 scale, with that obtained by an on-farm survey, which could be at scales less than 1:5,000. It is worth noting that there is inherently more uncertainty in the available soils information for hill and steep land, suggesting that landowners on these landscapes should consider more detailed mapping before making a decision on the scale at which to calculate their N leaching loss limit.

How do mitigation options change with Land Use Capability class?

134. To address this question it is first necessary to introduce the following concepts with respect to the behaviour of soils within each class, in response to production technologies developed to overcome “limitations to use” on production levels and the environment.

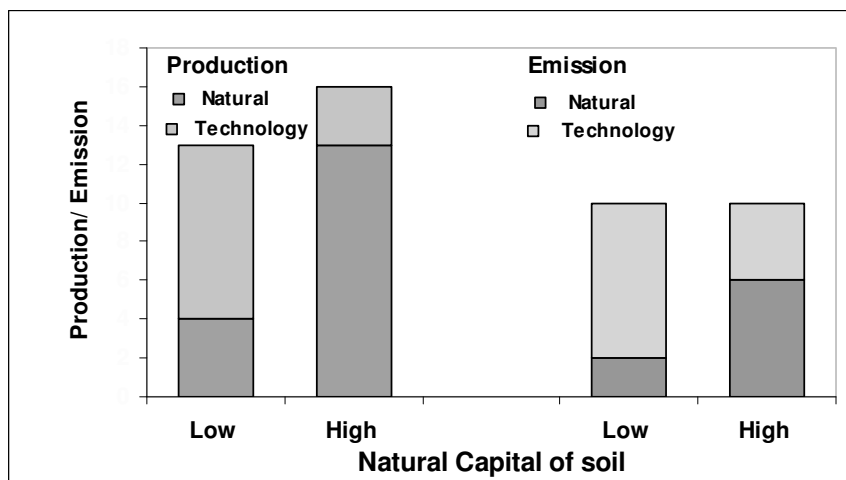


Figure 6. Production and emissions from a well managed legume pasture top dressed with P and sulphur fertiliser, before the introduction of production technologies (eg. irrigation) on soils of low and high natural capital (Ballantine & Mackay, 2008).

The ability to realise and sustain the productive potential of soils

135. Elite and versatile soils (Classes I and II) with high natural capital will produce more and require less input for output at a given level of production. Agricultural production on versatile soils (ie. with high natural capital) requires lower levels of inputs (eg. fossil fuels, fertilisers and irrigation water) per unit of output than soils with lower versatility (ie. with low natural capital). There is abundant evidence for differences in crop yield from different soils with the same inputs. For example, Webb & Purves (1983) demonstrated that there is a close relationship between soil depth and crop yield under dryland conditions. There is good evidence to show that nutrient response is influenced by the natural capital of a soil. Oberle & Keeney (1990) demonstrated that soils not rated as LUC Classes I or II required greater amounts of N fertiliser to obtain equivalent yields to those achieved by the better soils.
136. Soils with high natural capital for pastoral agriculture include those with deep silt loam textured, free-draining top soils (eg. yellow brown loams and brown soils). Soils with limited natural capital for pastoral agriculture include those with poorly developed structures (eg. podzol), shallow soil horizons and shallow plant rooting depth (eg. stony soils), weak cation and anion storage and supply capacities (eg. coastal sands) and low water holding capacity (eg. gravels, pumice). These soils with limited natural capital will require proportionately more inputs in their development and maintenance.

137. Soils with limited natural capital under particular land uses can sometimes attain a level of productivity equal to soil with high natural capital. For example, shallow soils under irrigation can attain pasture production and dairy production equal to production on versatile soils. For the production of a broad range of crops, soil with high natural capital represents land with the greatest soil quality, environmental protection, productive capacity, and highest life-supporting capacity.
138. The use of feed pads and stand-off areas when soils on LUC Classes I and II, and on Classes III and IV, are wet, means their productive capacity is not generally constrained by the physical limitations of the soils. However, this is not the case for soils found on LUC Classes VI and VII, where the physical integrity of the soil will often define the upper limit of production. Once a soil is at its potential, more resource will be required to sustain its physical integrity while maintaining plant numbers and vigour.

The environmental impact of a soil operating at its natural potential

139. Compared with elite soils, emissions (eg. N leaching losses) will be higher on coarse textured, weakly developed, stony soils and soils on slopes (Figure 6). This rule is not universal, because there will be trade-offs. For example, soils with weakly developed structures and poor drainage could potentially lose more N as nitrous oxide than as nitrate.

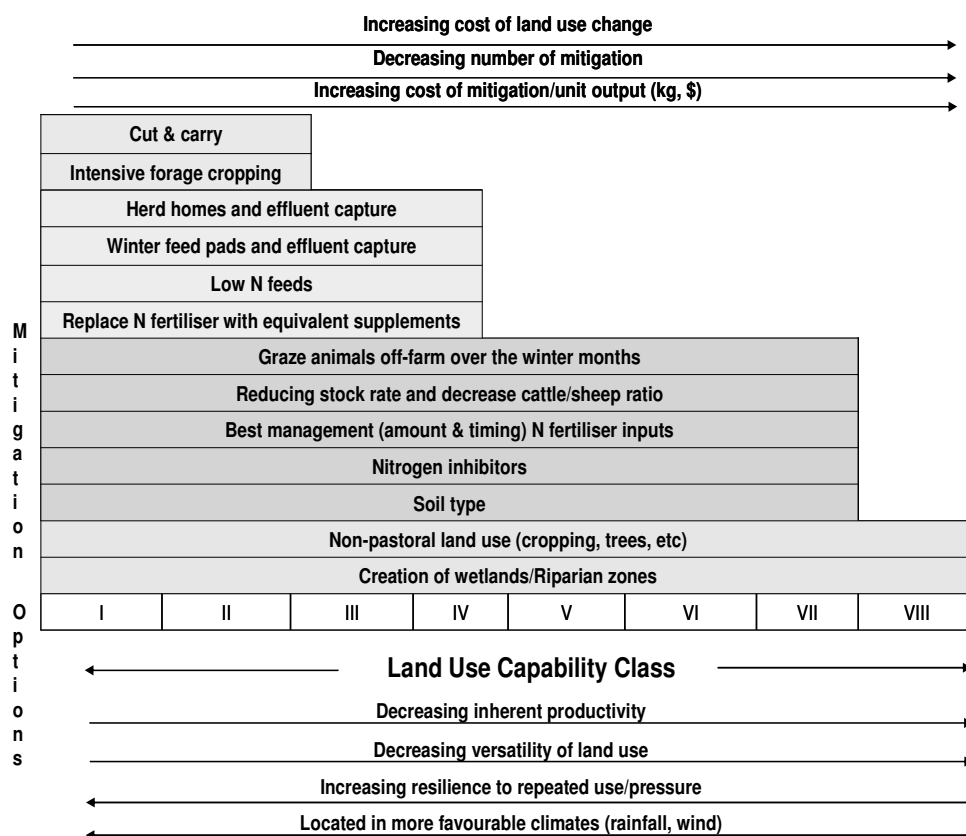


Figure 7. Number and alignment of the mitigation options with the soils in each LUC class

140. As a generalisation, the amount of product per unit of input will be greater, and the emissions resulting from the added production will be less on an elite soil (ie. with high natural capital), when comparing all soils at the same level of potential.

Production beyond the soil's natural capital

141. A number of very effective technologies are available (eg. cultivation, drainage and irrigation) to lift the productive capacity of soils on flat and rolling landscapes beyond their natural capital, compared with soils found in hill country and steep land. There are also more technologies available for sustaining production to compensate for the lack of natural capital of soils on flat and rolling landscapes (eg. feed pads and N fertiliser). The cost of technologies generally increases, as does the production benefit, as the natural capital of a soil declines.

Mitigating nitrogen losses in soils operating beyond their natural productive capacity

142. Technologies (eg. cultivation, drainage and irrigation) used as substitutes for the lack of productive capacity (eg. weakly developed soil structure, limited profile available water) of soils will lead to increased N loss, through a combination of increased production and greater leaching volumes. The number and efficacy of mitigation options for compensating for the limited capacity of soils to retain N in the topsoil horizons declines as the natural capital of soils becomes more limited. Soils on which production technologies have their biggest impact on production levels will also be those landscapes that provide the greatest challenge in mitigating N leaching losses.

Relationship between mitigation options and the natural capital of soils, grouped by LUC class

143. A summary of the mitigation options available and the alignment of the mitigation options with the soils in each of the LUC classes is presented in Figure 7. The number of mitigation options decreases as the producer moves from soils in LUC Classes I and II to those in Classes III and greater. The absolute cost of mitigation (eg. application costs) and/or the cost of mitigation as a function of production, and income from land, increases as the limitations to use increase. The findings from the FARMS test farms project (Manderson & Mackay, 2008) demonstrate that the effectiveness, suitability, cost and acceptability of each mitigation option varies between farms. Evidence will be presented by a number of other experts on mitigation options, their efficiency and cost effectiveness.
144. From a purely biophysical stance, landowners on elite soils have no limitations to use and hence flexibility in their choice of land uses. Landowners on elite soils have available to them the full range of mitigation options. In comparison, on all other soils, the mitigation tool box will be less effective. As the natural capital of the soil declines, the available land use options decline, as does the range and cost competitiveness of the mitigation options.
145. If the question is limited to, "What is the most efficient use of resources with the least environmental impact?" the N leaching loss limit should be weighted towards those soils with the greatest natural capital.

146. If the goal is to sustain rural communities into the future, a case for allocating a higher N loss limit to soils with little natural capital would be required, in order to retain the limited land use options and flexibility available for landowners on these landscapes.

Catchment level outcomes of Table 13.2 of the Proposed One Plan

147. This section explores what the N loss limits would have to be to achieve the absolute standard in this time frame set out in the POP, examines if the absolute water quality standard is achievable by on-farm management utilising available best management practice; examines if it is appropriate to have a single table for nitrogen loss limits for all catchments and if not what are the values in Table 13.2 of the Proposed One Plan appropriate for conversion to intensive land uses as well as in target catchments in reference to test farms.

What would the values have to look like to achieve the absolute standard in this timeframe set out in the POP?

148. Using the Upper Manawatu catchment as an example, the N loss limit permissible to achieve the river's long-term water quality target, as set in the Proposed One Plan, of 358,000 kg N is under 6 kg N/ha if all land is treated the same and assuming an attenuation of 0.5 from land to water. Bringing that analysis back to the initial water quality targets set for Year 1 of the Proposed One Plan for the Upper Manawatu River (859,000 kg N) and again treating all land the same, the N leaching loss limit for each hectare would be 13.2 kg N/ha, again assuming an attenuation of 0.5 from land to water in each catchment. If all the land within the Upper Manawatu catchment was operating at 75% of potential production, and assuming an attenuation factor of 0.5, then the N loading would be 1,004,000 kg N, which is 1.17 times the immediate N loading limit set for the Upper Manawatu Water Management Zone (ie. 859,000 kg N) and 2.8 times the long-term N loading limit set for the UMWMZ (ie. 358,000 kg N) by Horizons in consultation with community.

Is the absolute water quality standard achievable by management on farm using available best management practice?

149. Management on farm using best management practices available would not be able to achieve the long-term water quality target set for Upper Manawatu River in the Proposed One Plan of 358,000 kg N, which is under 6 kg N/ha if all land is treated the

same and assuming an attenuation of 0.5 from land to water. Other evidence covers what reductions are possible and at what cost.

150. Attempting to achieve the absolute water quality standard would cause massive upheaval, because it would require massive changes to current land uses. The only land uses that could continue unchanged would be land under native or exotic forest, scrubland and extensive sheep and beef. For intensive livestock, radical changes would be required. For example, the only mitigation option that would come close to the achieving the required target would be shifting from grazing *in situ* to a 100% cut-and-carry system with animals fed on a pad where all dung and urine was collected.

**Is it appropriate to have a single table for nitrogen loss limits for all catchments?
If not then why not?**

151. The structure of Table 13.2 of the Proposed One Plan would remain the same, as would the process used to populate the table. Adjustments to the table would be in recognition of the changes in the soils and landscape units and rainfall zones as new catchments were brought in and covered by Rule 13-1 of the Proposed One Plan. A comparison of the Upper Manawatu and Mangatainoka Water Management Zones provides an example to reinforce this point. Both the topography (ie. landscape units and slopes) and soil types (ie. drainage classes) in the Upper Manawatu vary significantly from those found in the Mangatainoka catchment. The Upper Manawatu catchment is dominated by Class VI land, whereas the Mangatainoka catchment has significant areas (18,500 ha) of flat and rolling landscape units. Average annual rainfall in the Upper Manawatu is 1,357 mm (range 1,000-3000 mm) compared with 1,789 mm (range 1,000-3,500 mm) for the Mangatainoka. All of these factors affect N leaching losses and N loading. Adjustments would be required in the N loss values in the Table in recognition of the differences in the areal extent of soils and in rainfall between catchments. The structure of Table 13.2 would remain the same, as would the catchment management planning process.

Are the values in Table 13.2 of the Proposed One Plan appropriate for conversion to intensive land uses as well as in target catchments, in reference to FARMS test farms?

152. In the first instance, the N loss limit values in Table 13.2 of the Proposed One Plan for the target catchments would be appropriate for defining thresholds for land being converted to an intensive land use in landscapes outside the target catchments. As the

proportion of land under intensive land use expanded a catchment management plan would need to be developed. The catchment management plan would include the following tasks (see Figure 8):

Task 1: Inventories. The boundaries and area of the Water Management Zone (WMZ), NZLRI database, including the worksheets containing the extended legend, major land uses and areas in non-agricultural use, list of point source discharge points and quantities, and rainfall in 200 mm isohyets for the WMZ.

Task 2: Community of interest. Identify landowners in the WMZ who are interested in acting as test farms to establish the challenges and opportunities; establish a WMZ based community-of-interest group to discuss the proposed targets, timescale and roll-out; engage with key stakeholder (eg. sectors and service providers); review the FARM strategy to ensure all issues are adequately covered and all mitigation options listed are available.

Task 3: Nitrogen loading, targets and farm N losses. Summary of the river's flow rates, lake volumes/levels, inflow rates, resident times, outfall rates and N concentrations in water in each water body; this information is used to calculate the N loadings in the WMZ. (The framework report by Roygard & McArthur (2008) provides a methodology for this task, current nitrogen loading for the WMZ, the standard (nitrogen loading target) and justifications for the standard for the WMZ. Also list the nitrogen leaching loss from each of the major land uses in the WMZ and from point discharges.

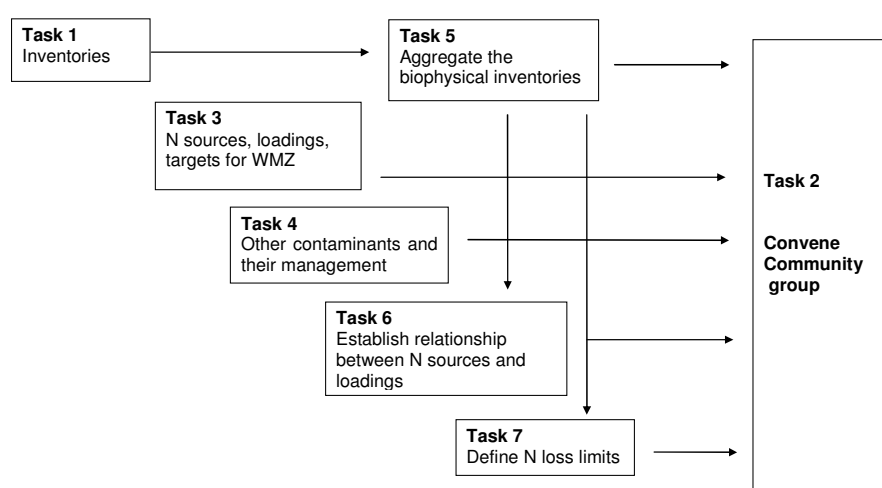


Figure 8. Schematic diagram of the tasks to develop a catchment management plan

Task 4: Other contaminants and their management. List other potential contaminants contributing to poor water quality (eg. sediment, P and faecal matter) in the WMZ, and current levels of contamination; list current and future mitigation options (eg. Clean Streams Accord and Whole farm Plans) for the WMZ.

Task 5: Aggregate the biophysical inventories. List the areas (in hectares) and potential productivity of each LUC class, subclass and unit in the WMZ; list the areas (ha), potential productivity, drainage class and slope of all LUC units in the WMZ catchment; describe rainfall in 200 mm isohyets for the WMZ and develop a set of rules defining the rainfall bands (eg. for the Upper Manawatu WMZ)

Task 6: Calculate N loading in the river from each land use, transmission coefficient and the potential N loss limit for each land unit. In catchments with multiple N water quality sampling sites, calculate the contribution from the major land use to the N loading in the water body. If that is not available, use the N loading values from existing catchments, establish the transmission coefficient by calculating the N loss for each land use using OVERSEER, and expressing it as a percentage of the N loading in the river for each land use. If that is not available, use the transmission coefficient values from existing catchments and calculate the N leaching loss limit for each soil in the catchment, using OVERSEER, by LUC class, subclass and unit, and for each unit, using detailed biophysical and rainfall data.

Task 7: Establish the N loss limit for each land unit. Establish the relationship between the potential N loss limit for each LUC class, subclass and unit, and for each unit, using detailed biophysical and rainfall data and the N loadings in the river, calculate the percentage of potential use of each land unit that is permissible to achieve the current N loading, and the rate of change required in the potential use of each land unit each year to move towards the standard (ie. N loading target for the WMZ) over time. Include data to demonstrate the influence of a differential percentage of potential use for each land unit in achieving the N loading target.

153. Catchment planning would be initiated as the proportion of land under intensive land use expanded to ensure the required water quality outcomes are achievable and at the same time retaining ongoing growth and land use options.

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Appendix 2

Supplementary Evidence to Council-level Hearings Panel hearing submissions on the
Proposed One Plan, March 2010 (Alec Mackay)



Farming, Food and Health. **First**

Te Ahuwhenua, Te Kai me te Whai Ora. Tuatahi

Supplementary Evidence

March 2010



2020
SCIENCE

New Zealand's science. New Zealand's future.



Supplementary Evidence

March 2010

Dr Alec Mackay

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1. Nitrogen loading outcomes under various scenarios for the Upper Manawatu Current situation in the Upper Manawatu

1.1 Introduction

This report compares the in-river nitrogen (N) loading outcomes under various scenarios in the Upper Manawatu to demonstrate potential outcomes under various management scenarios. These scenarios are

- Current situation in the Upper Manawatu
- Proposed One Plan with no change in current land use
- If no action is taken

These scenarios are also compared to the example of growth of dairy in the southland region.

1.2 Current situation in the Upper Manawatu

There are over 400+ sheep and beef producers in the Upper Manawatu¹ farming 77% of the land in the area and contributing to approximately half the N loading (Clothier et al., 2007). Dairy producers contribute to nearly half the N loading from 16% of the catchment (Clothier et al., 2007).

1.3 Proposed One Plan

Under the proposed Rule 13-1 Year 1, 10 and 20 N loadings in the Upper Manawatu with no land use change or intensification are calculated to be 580, 544 and 536 tonnes of N, respectively (Fig.1)

1.4 If no action is taken

As our land based producers have few business options, other than continued growth to remain viable, pressure will continue to mount on surface water quality in catchments dominated by pasture agriculture. The sheep and beef industry has been growing at 1-4% /yr in terms of stock units and production (Neild 2005) and the dairy industry continues to grow at 3% (M. Newman evidence for Fonterra 2010). The combination of difficult climate conditions and poor product returns has seen some retrenchment from that the long-term average growth in the sheep and beef sector in the region in the last 2-3 years.

The combined impact of business as usual for the dairy industry, (scenario S2 for the dairy industry Table 2 M. Newman evidence for Fonterra) and a modest Sheep & Beef growth rate of 1% per year will see the N loading in the Upper Manawatu River to increase to 931 and 1307 tonnes, by 2020 and 2030, respectively (Table 1 and Fig.2). Under this scenario N leaching loss per ha from Dairy land will more than double over

¹Upstream of the Manawatu at Hopelands flow monitoring site.

the next 20 years, there will be a small increase in the land area under Dairy and N leaching losses from sheep and beef will increase one kg of N per ha each decade (Table1).

Scenario		Area	OVERSEER N loss	N loading	Total N loading
		ha	kgN/ha	Tonnes	Tonnes
Current	Dairy	20142	31	312	
	S&B	85677	7.8	334	646
S2 & S&B	Dairy	21172	52	550	
	S&B	84647	9	381	931
2020	Dairy	22225	80	889	
	S&B	83594	10	418	1307

Table 1 Contribution of dairy and sheep and beef to N losses and N loading in the Upper Manawatu under scenario S2 (Table 2 of M. Newman for Fonterra) and Sheep & Beef sector growth of 1%

The difference between the Proposed One Plan and no action, if Year 1 of the proposed Rule 13-1 is aligned with 2010 is a reduction of 387 and 772 tonnes of N in the Upper Manawatu River in 2020 and 2030, respectively.

Under the growth scenario for Dairy in the Tararua District sourced from Neild and Rhodes supplementary evidence (2010) less N is lost by leached as the expected growth of the sector in the District has only been about half that of Region the difference between the Proposed One Plan and no action, again if Year 1 of the proposed Rule 13-1 is aligned with 2010 is a reduction of 175 and 425 tonnes of N in the river in 2020 and 2030, respectively (Fig.1). In this scenario the sheep and beef sector is assumed to grow at 1% per year.

Importantly under the Proposed One Plan with N loss limits in place, Dairy expansion can continue to grow to meet industry goals, without the associated N loadings increasing in the river.

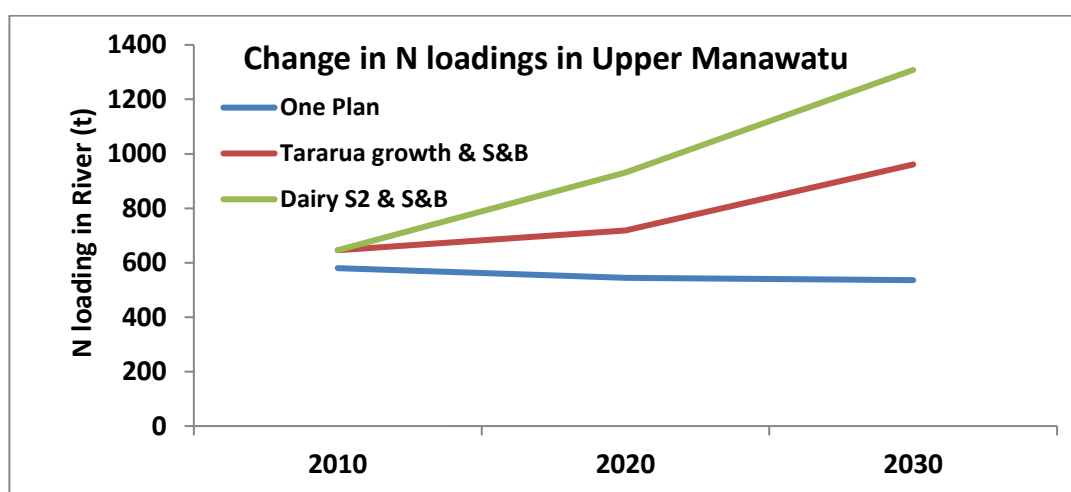


Fig. 1. Changes in the N loading in the Upper Manawatu under the proposed Rule 13-1 with no land use change, under the growth scenario for dairy in the Tararua District sourced from Neild and Rhodes (2010) with sheep and beef sector growth of 1% and

under the growth scenario S2 for dairy in the Horizons Regional sourced from M Newman (Evidence for Fonterra table 2) also with sheep and beef sector growth of 1%

Clothier et al, (2007) provides some example of what happens to N loadings (increase of 132 tonnes) if existing dairy farms increase production from 1000 to 1200 kgMS/ha in the area of the Upper Manawatu between the Weber Road monitoring site and the Hopeland monitoring site. This scenario predicted a 33% increase in the N loadings for that part of the catchment. Clothier et al., (2007) also provides an example of what would happen to N loadings in the Upper Manawatu (tonnes N) if the area in dairy increased from 16% of the catchment to 25% of the catchment at current production levels. This modelling showed a 17.8% increase (132 tonnes) in the current catchment loads. In both cases the sheep and beef industry was assumed to remain at current production levels.

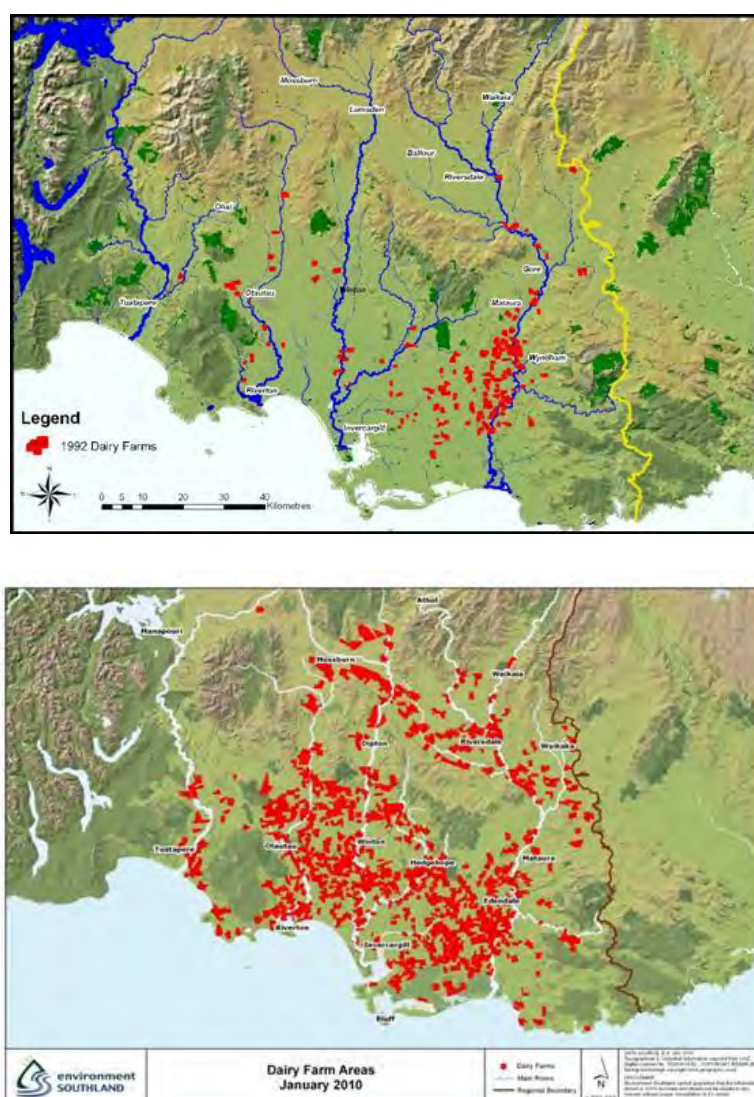


Fig. 2 Dairy operations in Southland in 1992 and 2010

If the growth is greater than the average for the Region over the next 10 years, for example parallels the increases in Southland (Fig.2) which has seen close to a 2.5 fold increase in the area in dairying (from 63,000 ha in 1998/99 to 155,000 ha 2008/09)

and cow numbers (from 170,000 to 418,000) in the last 10 years and in the last 5 years a 40% the increase in the N loading in the river would be much greater. Under scenario 2 the increase in land area under dairying is only 1030 ha by 2020.

In the priority catchments in Horizons (Fig. 2b Mackay) the potential exists to dairy on another 100,000+ ha. Outside the priority catchments a large percentage of the coastal belt, low, down and rolling land (Class 1-3) in the Region could be converted from current land uses into more intensive activities. In the region there is close to 250,000 ha of LUC Class 1 to 3 currently under sheep and beef production. The equivalent values for Southland is over 300,000 ha

It is worth noting that our more versatile land is becoming scarce with the increasing competition between land users. For example the Horticultural industry is looking to double in size in the next 10 years, from a \$5 to 10 billion industry. Currently they occupy 70,000 ha. Twenty thousand plus ha is lost primarily from pasture agriculture each year to urban spread and lifestyle blocks. The land lost to these competing sectors is heavily skewed to the more versatile landscapes.

2. Some answers to the questions on the Natural capital approach using data from the LUC extended legend

2.1 Summary of submitters' questions:

Sean Newland Fonterra

"Fonterra accepts the LUC classes allow for the average natural capital of differing land classes to be assessed" Nonetheless there are several issues (Paragraph 111)

- *Allocation of LUC classes to land*
- *Recognition of existing land use decisions*
- *No trading*
- *N loss limit for LUC Class 2-6 are to low*

Duncan Smeaton for Fonterra

- *"has some merit", but it also has some downside" Lack of skilled operators, slightly different results" "N loss in Table 13.2 for LUC Classes 3-7 should be increased to better reflect the NC approach"*

Nigel Sadlier Ballance Agri-nutrients

"We do not believe LUC classes and associated N leaching/runoff values can be practically applied in a fair and equitable manner"

"Over the long-term values must be adapted to land use and technology changes"

"Capacity for a trading scheme"

Greg Smeath Fert Research

"The allowable N loss limits set for each land class, while scientifically informed, are none-the-less inexact and give rise to somewhat arbitrary N loss targets"

“Use of LUC system, to set single number allowable N loss targets is inappropriate as it is not fit for purpose”

Christopher Hansen Behalf of Ravensdown Fertiliser Co-operative Ltd

“subdivisions and changes in land use and value over recent years means the LUC data may not be accurate” “Current land use are unlikely to reflect the old LUC data” (Paragraph 18)

Antony Roberts Ravensdown Fertiliser Co-operative Ltd.

*“Opposes this as N loss from grazed pasture systems is directly linked to biological productivity which is least often linked to LUC **where productive constraints are overcome by introducing technological advances**” (Paragraph 8)*

*“Approach **does not accurately reflect current agricultural practice**” (Paragraph 9)*

“Not designed for this purpose” (Paragraph 10)

*“Stock carrying capacity is itself a moving target as **technologies, knowledge and experience** allows land managers to improve pasture productivity and hence carrying capacity and” (Paragraph 19).*

*“It unfairly penalises farm businesses who have **introduced technologies and developed skills and abilities to farm productively**, despite the limitations imposed by the physical resources of the land involved” (Paragraph 51 Conclusion)*

The basis of Dr Roberts opposition to the N/C based approach is the potential production of a legume based pasture listed in the extended legend of the LUC worksheets and associated N losses **does not recognise the technological advances that have improved pasture and farm productivity and hence associated N losses are underestimated**. This is captured in his suggestion that “a more equitable system would be to assess each property with WMZ in terms of their current estimated N loss and adopt an individualised staged process of achievable reductions in N loss” (paragraph 23) This also appears to be the approach favoured by Fert. Res.

In this section I address the central issues raised by Dr Roberts “LUC does not recognise the technological advances that have improved pasture and farm productivity and hence associated N losses are underestimated” and Fonterra “N loss limit for LUC Class 2-6 are to low”

I comment on some additional information introduced by Dr Roberts in his supplementary evidence which was not available as part of the caucusing.

The apparent weakness of the LUC for assessing the productive potential of sand country under irrigation and the view that land use and land management practices can accelerate soil development and as a consequence changing the inherent properties of the soils and long- productive potential are also tackled in this section.

A number of submitters point to the difficulty of identifying differences between LUC Classes. I suspect they are talking more about the difficulties in identifying differences between LUC units, not LUC Classes where there is little debate. For more information on LUC Classes, LUC Subclasses and LUC unit see the evidence of Dr Grant Douglas and Roygard.

2.2 Proxy for natural capital

RECAP: The natural capital approach is based on the ability of the soil to sustain a legume-based pasture fixing N biologically under optimum management (i.e. new plant germplasm, use of P, S, K fertilisers, lime, trace elements and technologies to control pests and weeds), **before the introduction of additional technologies (e.g. N fertiliser, supplements)**

A legume based pasture serves as a very useful proxy for a soils natural capital for the following reasons. A legume-based pasture is a self-regulating biological system with an upper limit on the amount of N that can be fixed, retained, cycled, made available for plant growth and lost by leaching. It also reflects the underlying capacity of soil to retain and supply nutrients and water and the capacity of the soil to provide an environment to sustain legume and grass growth under the pressure of grazing animals.

Estimates of the potential productive capacity of a legume-based pasture fixing N biologically under a “typical sheep and beef farming system” for each Land Use Capability (LUC) unit in New Zealand are listed under “attainable potential carrying capacity” in the extended legend of the Land Use Capability worksheets produced 30+ years ago are still a very good measure of the production of a legume based pasture today.

Use of the extended legend of the LUC worksheets for calculating the natural capital of soils is a new application of the information. It reflects the evolving nature of sustainable land management, with the necessity to set limits on emissions from land to both air and water (in this case emissions to water, and specifically nitrate leaching losses beyond the root zone). An attraction of the approach is already established as the basis for land development and evaluation, with the information available throughout New Zealand.

2.3 Improvements in legume based pastures since the 1970's

There is substantial evidence to show there has been virtual no increase in the level of pasture production from our legume based pastures over the last 50 years. Hodgson (1989) found that ceiling pasture yields have not changed in 50 years (Fig. 3a). Hodgson data were updated by Deane (1999) from research stations in the Taranaki and in the Waikato and from top farms in the main North Island dairying areas (Fig. 3b). Little had changed since that time to shift the asymptote.

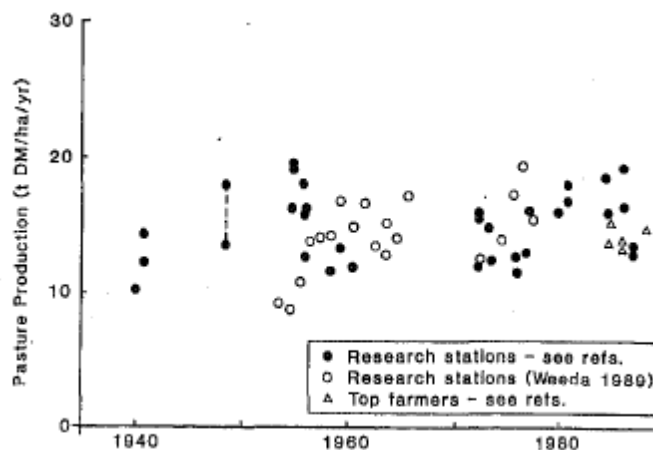


Fig.3a. Annual pasture production on research stations and top farms since 1940 (Hodgson 1989)

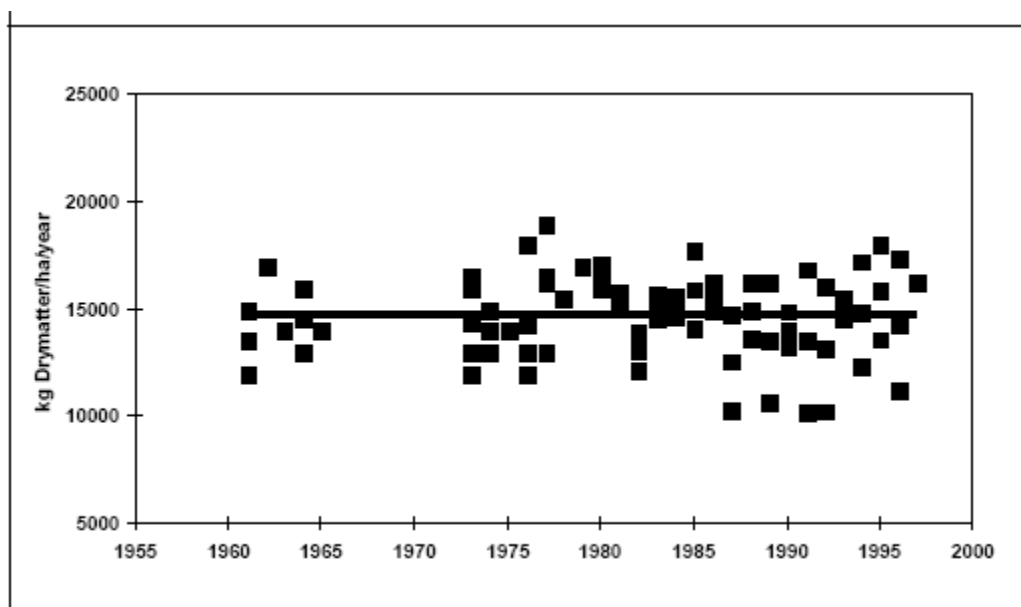


Fig.3b. Annual pasture production on research stations and top farms since 1960 (From Hodgson 1989 and updated by Deane 1999)

The conclusion reached by Hodgson (1989) and Deane (1999) is reinforced by a recently study that completed for the first time a comprehensive evaluation of the merits of different age-classes of perennial ryegrass (bred in the 1980's and 1998) and white clover (bred in the 1960's and 1998) cultivars (Crush et al., 2006). No differences in annual pasture dry matter yield (averaged 17.2 ± 0.9 t DM/ha over years 2-4 of the trial) were found between the different age-classes of perennial ryegrass and white clover pastures. (To compare values with Fig. 3 subtract 1.0-1.5t DM/ha, to compensate for the addition of up to 100kgN/ha) They concluded annual pasture production from a well managed ryegrass-white clover pastures is very close to the practical limit achievable in the Waikato and close to the theoretical Regional upper limit from ryegrass pastures calculated by Mitchell (1963).

On that basis the estimates of the potential productive capacity of a legume-based pasture fixing N biologically under a “typical sheep and beef farming system” for each Land Use Capability (LUC) unit in New Zealand listed under “attainable potential carrying capacity” in the extended legend of the Land Use Capability are still very relevant today. They are not dated as suggested by some.

2.4 Farm productivity improvements

In sharp contrast to the lack of any increase in the production of a legume based pasture, farm productivity has increased every year. Evidence of (M. Newman and Neilds and Rhodes) provides data on the the productivity gains in the dairy sector that have occurred in the region over the last 10 years. On average that has been 3% per year. The sheep and beef sector have shown similar productivity gains (1-4%) per year (Neild 2005).

The increases in farm productivity have come from a wide range of technologies and innovations. For example it includes the increasing use of N fertilisers (Parfitt evidence), irrigation, imported feeds in the dairy industry (Palm kernel, maize), off farm grazing for both replacement heifers and dairy cows, genetics (both animal (i.e. increased fecundity in ewes) and plant (i.e. cool season activity), improved pasture management and utilisation through grazing management, the better matching of feed supply with animal demand through to the use of N inhibitors that reduce N losses that can translate to increases in pasture growth.

The Horizons test farms provide some good examples of the contribution these technologies are now making to dairy farm productivity in the region (Fig.4) . The contribution from the legume pasture based varies from as little as 50% to over 80% of milk solids production.

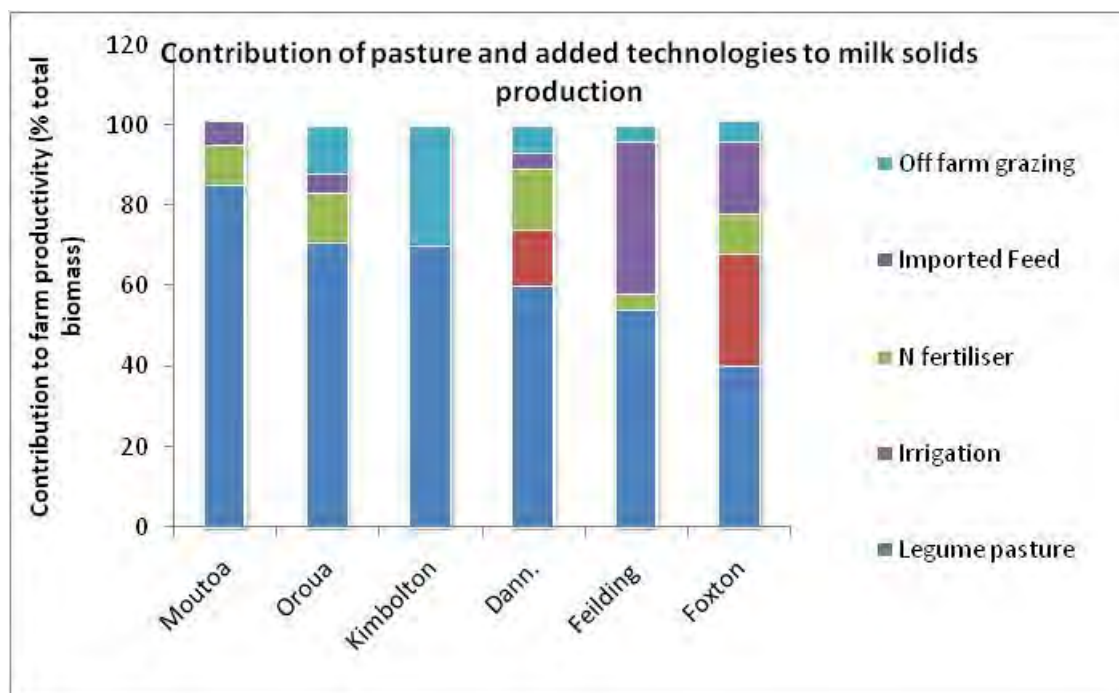


Fig. 4 Breakdown of the contribution (%) of the legume pasture base, Irrigation, N – fertiliser, imported feeds and off-farm grazing (includes the Run-off) to total farm dry matter. *The calculation does not include the feed requirements of replacement heifer. This would increase the contribution from the off farm grazing significantly, reducing further the contribution from the legume pasture base to milk soild production . The data was not always complete so some assumptions have been made.

Nitrogen fertiliser, imported feeds and off-farm grazing, enable productivity gains beyond that possible with a legume based pasture system alone. These technologies contribute significantly to total production and are likely to become an ever increasingly important part of the production system if the current 3% annual growth target is to be sutained. While the legume based pasture system is self regulated with a ceiling yeild and associated N leaching loss that is reflective of the soils underlying natural capital and local climate (Fig. 3), technologies like N fertiliser, imported feeds and off-farm grazing remove that limitation and allow annual productivity gains to continue regardless of the soil underlying productive capacity. There are no limits to the producty increases possible and the environmental impact. Our success in developing technologies to overcome production constraints, has created an environmental problem.

Dr Roberts argues these technologies are part and parcel of an intensive farming operation and as such should be recognised. He argues on that basis “a *more equitable system would be to assess each property with WMZ in terms of their current estimated N loss and adopt an individualised staged process of achievable reductions in N loss*” (Roberts paragraph 23). Evidence has already been presented to show that grand-parenting has a number of serious faults. It fails to recognise that land is a finite resource and fails to assess land use options in the catchment against the desired water quality outcomes. It puts the future viability of all farms at risk, by failing to allow growth options and flexibility in land use. It recognises landowners with the largest N leaching losses disadvantage landowners who had been actively conserving N, for example by using Best Management Practices.

To achieve the necessary reductions under Dr Roberts suggested approach, in addition to managing down N losses from intensive farming practices to some agreed N loss limit, restrictions would have to be placed on the activity of all other land owners with the WMZ. This action would appear to be at odds with the assertion that recognising technologies contributing to production and N losses over and above that of a legume based pasture systems “*is more equitable*”. Equity would only be achieved if all landowner had the same opportunity to intensify to same degree. That creates a host of challenges, not only within, but also across land uses.

2.5 Sustainable legume based pasture production levels

Specific response to Dr Roberts supplementary evidence DSIR trial data

Dr Roberts in his supplementary evidence (Not availablefor discussion at caucusing) introduces data from a DSIR trial on the Judgeford subsoil (B Horizon) to highlight the point that good legume growth can be obtained in soils of poor natural capital because the N status of the soil is low. The definition of natural capital includes not only the

underlying capacity of soil to retain and supply nutrients and water, but also the capacity of the soil to provide an environment to sustain both legume and grass growth under the pressure of grazing animals (Mackay paragraph 31). The Judgeford subsoil (B Horizon) has little physical structure (low natural capital) and would collapse under the pressure of grazing. Inclusion of the physical integrity of the Judgeford subsoil (B Horizon) in the calculation of natural capital identifies as Dr Roberts points out, the Judgeford subsoil as a soil of low natural capital. The Judgeford subsoil (B Horizon) provides an excellent example of the importance of considering both the physical and nutrient status of the soil in assessing a soils natural capital stocks.

2.6 LUC classification of sand country under irrigation

There is a robust and well developed process for examining and making changes in the event a limitation is removed (LUC Survey Handbook pp86-87). In the sand country where permanent irrigation has been installed the classification is made on the basis that the soil moisture limitation has been permanently removed.

In the test farms on the Sand country (Foxton) in addition to irrigation, N fertiliser, imported feed and off farm grazing contribute significantly to farms productivity (Fig.4). From discussions with fertiliser reps. and farm consultants, more N fertiliser is used on the irrigated sand country blocks, than dairy operations on rainfed only landscapes. The point is the “increased pasture production” is from a combination of water and added N fertiliser. There is some question about the economic of irrigation on the sand without N fertiliser. Farm productivity also includes the benefits of imported feeds and and off farm grazing. Lifting the LUC unit one class to reflect the permanent removal of the moisture limitation does reflect that shift in production from water alone, not that of the other technologies, which are not removing a permanent limitation, but simply contributing to production.

2.7 Anthropogenic factors and soil development

It is very difficult to change the inherent properties of the soil, but land use and farm practices have major influences on the manageable attributes. The properties of a soil are listed in figure 5.

In the long-term irrigation trial at Winchmore, established in 1949, the irrigated pastures carry 18 sheep su/ha compared with the dryland pasture which carry only 6 sheep su/ha. Despite the 3-fold difference in primary production and associated litter return to the soil ecosystem over an extended period of time, in a recent study Srinivasan and McDowell (2009) could find no measurable effect of irrigation on the soil moisture holding capacity or the hydraulic conductivity of the soil, indicating little or no “soil development” beyond that required to sustain the higher liveweight loading.

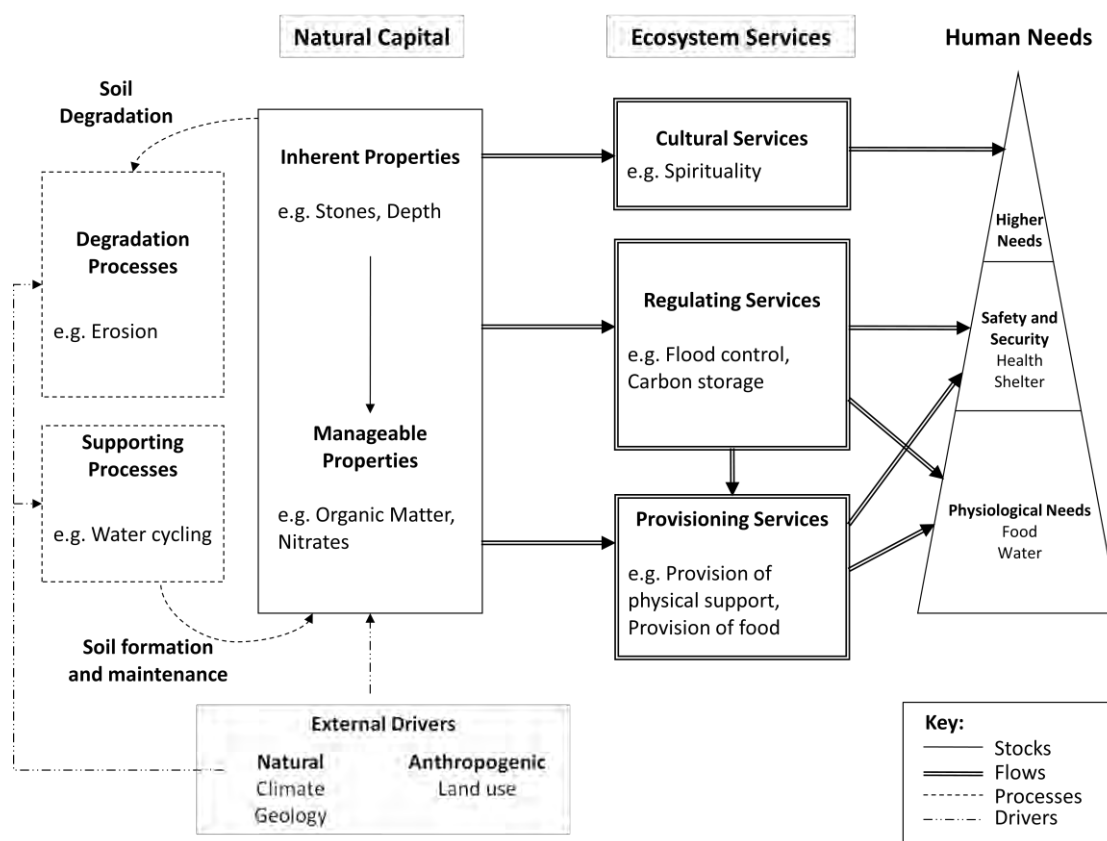


Fig. 4. Relationship between the soils natural capital and ecosystems services

Schon et al., (2010) found to a large extent the soil invertebrate community under irrigation was more characteristic of a dryland soil, and has suggested this is probably to the moisture stress facing the invertebrate community between irrigation events. The exception was earthworm activity which remained active throughout 12 months under the irrigation treatment.

The findings of these two studies highlight that despite 50+ years of irrigation, fertiliser inputs, grazing and nutrient cycling the inherent properties of the soils have not been altered in a measurable way.

In the sand country some increases in soil organic matter might be expected with increased pasture growth, but this is not a given as the losses of C through increased cycling and respiration will also be higher. There will be some colour development in the soil profile associated with for example organic matter. A change in soil organic matter content will not change the water holding capacity of the soil significantly (i.e it will still behave like a sand) or the ability of the soil to filter and prevent the losses of nutrient to ground water. To change these soil attributes the texture of the soil would need to be changed from sand to finer textural classes. Addition of large quantities of organic matter will increase pasture growth by providing nutrients from a fraction that is less vulnerable to leaching. Again this will not change the inherent properties of the soil.

Land development to date has largely been limited to developing technologies for removing limitations to production gains (e.g. Irrigation, drainage). Little thought has

been given to developing technologies that change the inherent properties of a soil and in doing so add to the soils natural capital and ecosystems services. Maybe that is what land development into the future will need to tackle

3. Catchment outcome from wintering dairy cows off the dairy farm as part of the N mitigation strategy within the catchment

A case study was assembled to explore the impact of wintering dairy cows on a sheep and beef unit from a dairy farm within the same catchment

Question

What impact does 400 dairy cows wintered for 6 weeks on a sheep and beef farm have on the N leaching losses?

Characteristics of the sheep and beef operation

- Sheep and beef farm on 500 ha effective
- Carrying 9 su/ha (4500 su) 65:35 sheep cattle ratio (Including cows)
- Docking 135%
- Rolling 30%, hill 40% , steep 30% Sedimentary soils
- Olsen P 12-15. Developing
- 1100 mm rainfall
- N leaching loss of 6kgN/ha

Assessment of feed required for dairy cows

- 400 dairy cow grazers, with a grazing period of 6 weeks
- Daily intake of 10 kgDM/Cow/day (typical dairy farmer demand)
- No forage crops grown for cows

Feed required: 168,000 kgDM

Assuming

- Pre grazing pasture cover of 2500 kgDM/ha and a residual dry matter pasture cover of 1100 kgDM/ha
- An average pasture growth rate of 8 kgDM/ha/d over the grazing period and pasture utilisation of 80%

Using a feed budget the area required by the dairy cows adds up to 197.5 ha. On a “feed in feed out basis”, the number of sheep and beef stock units that would need to be displaced to make room for the dairy cows amounts to approximately 1940 su.

It is important to note that the area to be grazed by dairy cows will need to be “shut up” for a considerable period prior to the cows arriving to ensure sufficient pasture cover accumulates. If pasture growth rates of 30 and 20 kgDM/ha are realised in April and May respectively, they would need to be removed from the sheep and beef system by April 10th. It must be noted that upon removal of the dairy cows the farm may be considered to be significantly under-stocked from mid to late July onwards. Therefore changing the autumn and spring management would be essential to undertake dairy cow grazing in a financially rewarding way. It must be acknowledged that there are many different factors that could be considered when completing this analysis which may drive significantly different results.

The N leaching losses from the sheep and beef operation with a dairy cow grazing operation did not change but remained at 6kgN/ha.

In this case study the comparison was limited to the impact of substituting sheep and beef stock unit with dairy cow grazers. The impact of additional inputs (e.g. N fertiliser, imported feeds) was not explored.

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Appendix 3

Farm Strategies for Contaminant Managements, SLURI for Horizons Regional Council
March 2007



Farming, Food and Health. **First**

Te Ahuwhenua, Te Kai me te Whai Ora. Tuatahi

Farm Strategies for Contaminant Management

A report by SLURI, the Sustainable Land Use Research Initiative, for Horizons Regional Council

March 2007



2020
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Farm Strategies for Contaminant Management

A report by SLURI, the Sustainable Land Use Research Initiative, for Horizons Regional Council

29th March 2007

Brent Clothier, HortResearch
Alec Mackay, AgResearch
Andrew Carran, AgResearch
Ross Gray, AgResearch
Roger Parfitt, Landcare Research
Glyn Francis, Crop & Food Research
Maitland Manning, Crop & Food Research
Markus Duerer, HortResearch
Steve Green, HortResearch

Contact: Alec Mackay – alec.mackay@agresearch.co.nz

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Executive Summary

- At the request of Horizons Regional Council we have developed a framework and produced best management practices for nutrient management on farms in the Manawatu-Wanganui region.
- Horizons Regional Council asked SLURI, New Zealand's multi-CRI Sustainable Land Use Research Initiative 15 questions in order to address farm strategies to limit contaminant management that could be included in the "One Plan". The summary of our responses are:

Summary Responses:

1. Farm Types and the Potential Impact on Water Quality.

Horizons Regional Council have identified the 4 intensive forms of farming as being dairying, irrigated sheep and beef, market gardening and cropping. These we rank for nitrogen (N) and phosphorus (P) as

Ranked Nitrogen Loss		Ranked Phosphorus Loss	
Market Gardening	(100-300 kg-N ha ⁻¹ yr ⁻¹)	Market Gardening	
Cropping	(10-140 kg-N ha ⁻¹ yr ⁻¹)	Cropping	
Dairying	(15-115 kg-N ha ⁻¹ yr ⁻¹)	Dairying	(0.2- 1.0 kg-P ha ⁻¹ yr ⁻¹)
Sheep/beef	(6-60 kg-N ha ⁻¹ yr ⁻¹)	Sheep/beef	(0.1-1.6 kg-P ha ⁻¹ yr ⁻¹)

2. What is the best practice acceptable nutrient loss from a farm that Horizons should endorse?

To establish what the target best management practices (BMP) are for sheep/beef and dairy to ensure that water quality in Horizons Water Management Zones (WMZ) meet their quality criteria, we first needed to link what we consider is happening on the farm, with what is observed in the river.

We used the two sub-catchments of Weber Road and Hopelands in the Upper Manawatu WMZ (UMWMZ) to establish that the transmission factor, $\mathfrak{R}$, for dairying was about 0.5, so that whereas Overseer[®] predicted a farm loss of nitrogen of 31 kg-N ha⁻¹ yr⁻¹, the river only 'saw' it as being 15.4 kg-N ha⁻¹ yr⁻¹. The transmission factor for sheep/beef was also found to be about 0.5. By observing year-to-year variation in the N loadings across 16 years of measurements at Hopelands, we consider that the variability in our derived results, due to changing annual weather patterns, is of the order $\pm 20\%$.

Improvements in dairy-farm operations, through the adoption of best management practices could reduce farm losses by up to a third. If the mitigation options were successful, and if they were capable of application across the whole farm, the loss of N could potentially be reduced to around 21 kg-N ha⁻¹ yr⁻¹. For the sub-catchment of Hopelands, if such a reduction in non-point source pollution could be achieved through the adoption of best management practices, this would translate into a reduction in the N loading on the river of 73,545 kg-N yr⁻¹, an improvement of around 18.3%.

Because dairying and sheep/beef each contributes about one half of the total loading of nitrogen in the river at Hopelands, a one third improvement in either will only translate to an improvement of about half of that improvement in the river. Of course, if both farm types were able successfully to improve practices to reduce losses by one-third, there would be a one-third improvement in the river, according to this linear transfer-function approach. We add that the range of mitigation and optimisation measures available to reduce N loss under sheep/beef grazing is less than that possible in the dairy sector.

We also examined the impact of potential intensification patterns using Overseer® and our linear transfer-function. If dairy farms were to intensify to achieve 1200 kg milk solids (MS) ha⁻¹ the leaching loss of N is predicted to be 49 kg-N ha⁻¹ yr⁻¹, which would result in a 33% increase in N-loading in the river coming from the Hopelands sub-catchment. If sheep/beef farming were to increase the stocking rate through to 12.2 stock units (SU) ha⁻¹, a possible scenario in about a decade's time, the leaching loss of N is predicted to be 9 kg-N ha⁻¹ yr⁻¹, which would lead to about an 8.4% increase in river N-loading coming from the Hopelands sub-catchment.

We also investigated a potential dairy-expansion case. There are 31,580 ha of lands better than Class III in the UMWMZ, and currently dairying only occupies 20,534 ha. If dairying were to expand on all to Class III lands or better, there would then be about a 17.8% increase in N loading at Hopelands emanating from the entire UMWMZ, if current management practices prevailed.

Our transfer-function can also be used 'backwards'. Horizons Regional Council informs us that to meet water quality standards in the river at Hopelands, the N-loading should be 341,000 kg-N yr⁻¹, cf. the current loading of 744,000 kg-N yr⁻¹. Using an inverse approach, going back from the N loading that achieves the water quality standard in the river, and allocating the load back to the farm-type on the basis of the current proportion of the N-loading in the river, would require that dairy farms only leach 15.1 kg-N ha⁻¹ yr⁻¹, and sheep/beef farms 3.8 kg-N ha⁻¹ yr⁻¹. If the allocation back to the farm-type were on the basis of the proportion of the catchment in that farm type, the loadings would be 5.8 kg-N ha⁻¹ yr⁻¹ for both dairying and sheep/beef. These targets would not, in general, seem realistic given current technologies, although the former case represents a halving from current performance, and this is the target in the Dairy Industry's Environmental Strategy. In a subsequent report, we detail how the best management practices required to meet the water quality standard in the river might be split on the basis of the natural capital of the land classes in a WMZ.

3. What are the critical hotspots for nutrient inputs in waterways? Answered as part of responses to questions 2 and 4.

4. Best management practices for effluent application to land if Horizons were to make it a permitted activity. The manual "*Managing farm dairy effluent and Farm Management Issues*" provides a comprehensive list of best practice measures for the application of effluent to land. Horizons should reference the practices listed in Chapter Two 'Land Application' and Chapter Four 'Effluent from Feed Pads, Stand-off Areas and Other Sources, and note the following "... *With the advent of stand-off pad, feed pads and herd homes, the volumes of solid effluent applied to land are likely to increase*

significantly in future years and the council will need to make a decision on the maximum amount of effluent that can be applied based on an N or P loading or on the optimum use of effluent as a nutrient source for plant growth.”

5. What improvements and mitigation measures are likely to be included in Overseer® A new version of Overseer® will be available by December 2007 and include the use and impact of nitrification inhibitors, the role and impact of riparian strips and wetlands, updates of the feed-pad management options, and an update of the greenhouse gas model to meet the new set of IPCC methodologies.

6. What progress has been made in integrating NPlas and Overseer®? Could it be applied to the Manawatu-Wanganui region? Presently, AgResearch has a contract with MAF and Dairy Insight to link their Overseer® model of nutrient management with hydrological and nutrient source models to account for the mitigation impact of riparian strips and wetlands. AgResearch is working with MAF to develop the specifications for this project and will include NIWA. Because the Overseer® model is nationally applicable, so will this riparian strip/wetlands option be nationally available.

7. Best Management Practices to Minimise Faecal Runoff from Farms. Recent reviews have addressed aspects of faecal runoff from rural catchments by examining pathways and models for predicting loads to surface waters. Loadings to waterways are greatest from **surface runoff** and **stock crossings**, but are broadly similar to loadings from drains (notably because of effluent loadings) and dairy shed oxidation ponds with typical effluent strength. Land loadings fall into three broad classes, with the highest loadings occur where stocking rates are highest, viz. wintering pads, block-grazed pasture, and stand-off and feed pads for dairy cattle. The mitigation options, which include the exclusion of animals from waterways, are very closely aligned with those suggested earlier for phosphorus.

8 Should Horizons Regional Council adopt the water-way definition of the Clean Streams Accord to achieve reductions in nutrient and faecal losses? The waterway definition in the Dairying and Clean Streams Accord (Fonterra *et al.* 2003) is: “deeper than a “Red Band” (ankle depth) and “wider than a stride”, and permanently flowing”. The Accord’s target is to have dairy cattle excluded from 50% of streams by 2007, and 90% by 2012. This provides a good starting point for a process that seeks to reduce stock accessing waterways. Compliance is, nonetheless, going to be difficult in many of the region’s hill lands. Farm planning will have more potential for reducing stock in waterway, than further regulation. The Accord’s definition would, it seems, put the waterway somewhere between an order 2, or 3 stream. It would be interesting to know what length of waterways, both ephemeral and permanent, lies outside the Accord’s definition.

9. What are the appropriate upper limits for Table 16-1 in the “One Plan” for N and P? There is no reason at this time we consider to amend the upper limit for reasonable N application ($150 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$) in Table 16-1. Designating a value for P presents more difficulty, because soil chemistry exerts a very large influence on these values. History of P use will also be very important. Decisions about setting a maximum application rate, fits better with the scale of farm plans, rather than with regional scales.

10. Biosolids, Offal Holes & Farm Dumps: Comments on Rules 16-2 & 16-7

We have some comments and suggest some modifications and additions to Rules 16-2 to 16-7 that we consider would achieve best practice. We make comment on 3 of the 5 conditions set out in these two of these Rules, and we add some suggestions taken from the EBoP guidelines.

11. Current Research of Potential Benefit for On-Farm Resource Management.

There are a number of projects currently being undertaken by the SLURI partners that could benefit on-farm management of N, P and microbial contaminants. These are briefly summarised in the report for the pastoral, arable cropping and market gardening and perennial horticulture.

12. Trends within the farming community that may influence the format of individual farm resource management plans/strategies The use of Environmental Management Systems (EMS) and allied approaches to on-farm environmental management is increasing in the primary sector in New Zealand. Most New Zealand primary sector EMS-type arrangements have been developed by individual sectors, and are not ISO 14001 accredited, except in some viticultural cases.

13. What would be the most effective way of measuring the actual N and P loss from farms? Several research tools are available but these are either too expensive for use by farmers, or do not produce paddock- or farm-scale results. One of the objectives of the recently-funded Pasture 21 tender is the development of such a tool for pastoral systems. This may prove to be a long term and difficult task, and the use of farm-scale models (such as Overseer®) may be the best option. One possible monitoring tool is discussed in Appendix 2.

14. Why does Overseer® not consider soil-test results to account for the existing N content of soil? The nutrient budgets calculated in Overseer® are accounts of the inputs and outputs of N across the boundaries of the land units being considered. The processes of N accumulation, and release, are considered to be in balance over decade-timescales. There is an exception when the “Development” options are selected in Overseer®. These assume that more N is being accumulated than released, so total N in the system increases, and the losses are predicted to be lower as a consequence. Defining the conditions where the development options should be invoked is highly subjective, and a test to guide this might be useful. Available soil N is however notoriously difficult to assess in a way that has general application and rapid progress shouldn't be expected.

15. The Waikato Farm Environment Award Trust has produced a guide to preparing a nutrient budget. How useful is this simplified tool? This is a simple and manual nutrient-budget guide, or method, and was of help in situations where land owners had no access to Overseer®. It should not be regarded as a substitute for Overseer®. Since Overseer® is freely available, and accepted by the industry and regulators alike, there seems little reason to adopt anything else. Furthermore, Overseer®'s owners are continually updating the user friendliness and utility of Overseer® through engaging New Zealand's best scientists.

1. Farm Types and the Potential Impact on Water Quality

Horizons Regional Council have identified the 4 intensive forms of farming as being dairying, irrigated sheep and beef, market gardening and cropping.

We agree that these are likely to have the greatest impact on water quality, both from the perspective of nitrogen and phosphorus. It would have been desirable to consider intensive beef cattle operations, but the descriptors in the current database do not allow this group to be identified.

Ranked Nitrogen Loss		Ranked Phosphorus Loss	
Market Gardening	(100-300 kg-N ha ⁻¹ yr ⁻¹)	Market Gardening	
Cropping	(10-140 kg-N ha ⁻¹ yr ⁻¹)	Cropping	
Dairying	(15-115 kg-N ha ⁻¹ yr ⁻¹)	Dairying	(0.2- 1.0 kg-P ha ⁻¹ yr ⁻¹)
Sheep/beef	(6-60 kg-N ha ⁻¹ yr ⁻¹)	Sheep/beef	(0.1-1.6 kg-P ha ⁻¹ yr ⁻¹)

These comments largely relate only to N, as very little research been done on P losses from market gardening and cropping soils in New Zealand.

Market gardening and cropping can all have high potential effects on water quality. The highest risk associated with these land uses occurs when land is cultivated and left fallow over winter before crops are sown. This often occurs as part of a mixed cropping rotation or when land is leased for cropping.

Nitrate leaching losses from these land uses mainly occur over the winter and vary considerably throughout NZ, largely in response to variations in climate. Nitrate leaching losses also vary at the same location from year to year in response to changes in winter rainfall amounts and patterns. In addition, the crops that are grown often vary with time, and their management varies between growers. Moreover, few leaching loss measurements have been made in the Manawatu. Consequently, it is difficult to make predictions for nitrate leaching losses from cropping and market gardening in the Manawatu.

Published results from throughout New Zealand show, in general, that the risk for winter nitrate leaching is greater from market gardening than from arable cropping (Di & Cameron 2002). This is because vegetable crops are inefficient in their uptake of N and high fertiliser rates are often applied when these crops are grown over the winter. Generally, the P losses from these two land uses are likely to be associated with sediment moving in overland flow when land is cultivated or left fallow over winter before crops are sown.

1.1 Market Gardening

Typical leaching losses from intensive market gardening in New Zealand are 100-300 kg N/ha/yr, with the amount leached often increasing with the rate of N fertiliser applied or

with the addition of compost (Spiers *et al.* 1996; Painter *et al.* 1997; Francis *et al.* 2003; Snow *et al.* 2005).

1.2 Cropping

Typical leaching losses from cropping systems in New Zealand are 10-140 kg N/ha/yr (Eco-Link 2000), with the amount leached primarily increasing with the length of the fallow period in the rotation (Francis 1995)

1.3 Dairying

Dairying is, we consider, ranked as the highest risk of the pastoral farming activities. Key factors contributing to this are: there are substantial inputs of N and P in both feed and fertiliser the potential point sources of N and P to develop around animal-movement zones along tracks, across water, and on hard surfaces. There is mobilisation through the soil itself, and nutrient movement to receiving waters. There is leakiness associated with management of effluent and soil management by both irrigation and drainage. The leaching losses reported from dairy pastoral systems in New Zealand range from 15-115 kg-N ha⁻¹ yr⁻¹, with 40 kg-N ha⁻¹ yr⁻¹ often used as an average value. (Meneer *et al.*, 2004) Annual losses of P from dairy pastures subjected to treading damage have been reported at 0.2 -1.0 kg-P ha⁻¹ yr⁻¹ (Meneer *et al.*, 2004).

1.4 Intensive Sheep/Beef

Intensive sheep and beefs farms have lower inputs of N and P in fertiliser than dairying, very limited use of feeds, so they have the least non-point source potential. Sheep and beef farms differ from dairying through having lower stocking rates (see Table1) and lighter seasonal loadings of animals,, and demands for feed. Sediment loss might, nonetheless, be more important than in dairying, because sheep/beef farms tend to be in sloping, and more erosion-prone lands. Typical leaching losses from sheep and beef pastoral systems in New Zealand are as little as 6 kg-N ha⁻¹ yr⁻¹ in the less intensive systems (<10-12 SU ha⁻¹) , up to 60 kg-N ha⁻¹ yr⁻¹ in the more intensive sheep and beef systems, with 10-20 kg-N ha⁻¹ yr⁻¹ often used as a more typical range (Meneer *et al.*, 2004) Annual losses of P from sheep and beef systems have been reported at 0.1-1.6 kg-P ha⁻¹ yr⁻¹, with the losses lower under sheep grazing at 0.1-0.7 kg-P ha⁻¹ yr⁻¹ (Meneer *et al.*, 2004).

2. What is the best practice acceptable nutrient loss from a farm that Horizons should endorse?

We wish to establish what the target best management practices (BMP) are for sheep/beef and dairy to ensure that water quality in Horizons Water Management Zones (WMZ) meet their quality criteria. To do so, we first need to link what we consider is happening on the farm, with what is observed in the river. In so doing, we will address the issue raised by Alexander *et al.* (2002) that "... the description of [nitrogen] sources might be improved by including specific estimates of nutrient inputs from fertilizer and animal wastes"

2.1 Upper Manawatu Water Management Zone – A Case Study

We will first carry out our analysis for the Upper Manawatu Water Management Zone (UMWMZ) to verify the transmission factors we will use for the Manawatu-Wanganui region, and we will compare these with other calculations of transmission from land to water. Next, we will use Overseer[®] calculations to predict the losses from farms. By linking observations of nutrient loadings in the river to Overseer[®] calculations of loss at the farm, we will have a tool to link farm practices to water quality, by which we will be able to suggest BMPs that enable water quality targets to be met

We will use the contrasting patterns of landuse in two monitored sub-catchments of the UMWMZ to explore the farm-to-river transmission link for the key landuses of dairying, and sheep/beef. Above the monitoring station at Weber Road, the catchment is dominated by sheep/beef farms, whereas the area upstream of monitoring at Hopelands has a greater relative proportion of dairy farms. First we present the statistics on which our Overseer[®] calculations will be based. These data were provided by Horizons using their Agribase[™] database. Also, in running Overseer[®] we will take into account the variability of rainfall in the UMWMZ, for as shown in Figure 1, rainfall in the west of the catchment exceeds 1200 mm yr⁻¹, whereas around Dannevirke to the east it is less than 1000 mm yr⁻¹.

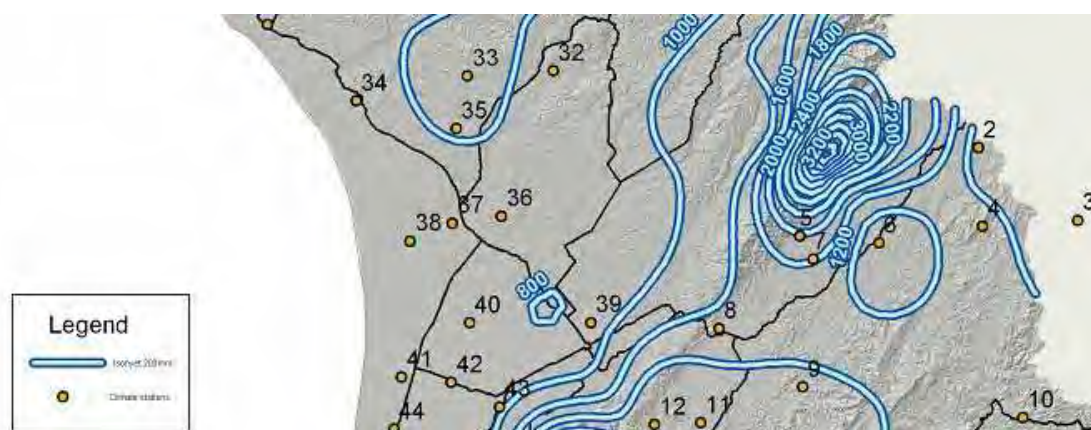


Figure 1. The isohyets of average rainfall across the Manawatu, showing the variation in rainfall in the Upper Manawatu Water Management Zone (UMWMZ) for stations 2 through 8.

2.2 Linking River Observations to Land Practices: A Framework

To establish the link between the land, and receiving waters, we will use a simple transfer-function approach. We will use Overseer® to estimate the loss rate of N from farms in the WMZ. Initially, we will use Overseer® to predict what the loss rates are from current practices:

$$O(L = q_d^*) = f[F, SN, SF, ST, EM, WMP, \dots] \quad [1]$$

$$O(L = q_{sb}^*) = f[F, SN, SF, \dots] \quad [2]$$

where $O(L = q^*)$ is the Overseer® calculation of the N loss, L , being the value of the annual flux of N, q^* ($\text{kg-N ha}^{-1} \text{ yr}^{-1}$), at 600 mm in the soil. The subscript d and sb refer to dairying and sheep and beef. The loss will be, *inter alia*, a function of F , N fertiliser use ($\text{kg-N ha}^{-1} \text{ yr}^{-1}$), SN stock numbers, SF , stock type, ST , supplementary feed, EM effluent management, and the use of winter management practices, WMP .

We adopt an inverse functional notation of O^{-1} for the Overseer® calculation of the N flux q^* as

$$q^* = O^{-1}(L_f) \quad [3]$$

We use this notation to indicate that the flux q^* is estimated from an Overseer® calculation of loss for a specific farm scenario L_f .

This predicted loss q^* will be attenuated in the farm-groundwater-river system, so that from the perspective of the river, a back-calculation based on observations in the river would suggest that actually it only “seems” that farms are losing the flux, q ($\text{kg-N ha}^{-1} \text{ yr}^{-1}$).

Therefore we can estimate transmission factors $\mathfrak{R}$ for both dairy and sheep/beef as:

$$\mathfrak{R}_d = \frac{q_d}{q_d^*} \quad \& \quad \mathfrak{R}_{sb} = \frac{q_{sb}}{q_{sb}^*} \quad [4]$$

Here we have chosen to use a transmission factor, $\mathfrak{R}$, however, we could have alternatively written this as its complement, an attenuation factor, which would be $1 - \mathfrak{R}$.

Using this simple, transfer-function approach, from annual average data we can predict the denominators from Overseer®, and we use the Manawatu River in the Upper Manawatu WMZ (UMWMZ) to assess the numerators.

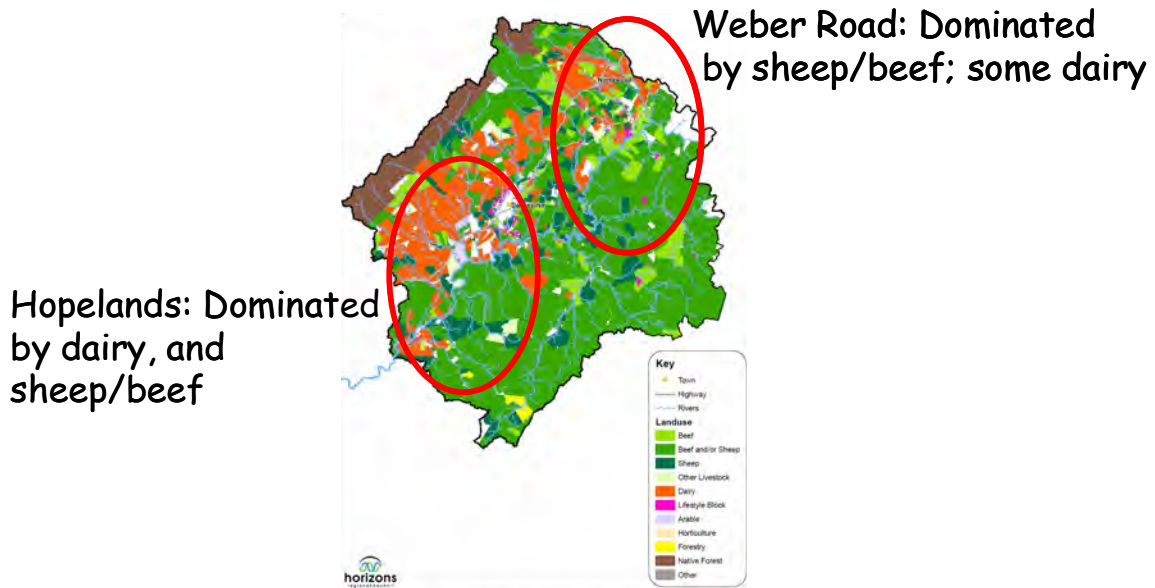


Figure 2: The two sub-catchments of Hopelands and Weber Road in the UMWMZ.

There are two river monitoring stations in the UMWMZ: one at Weber Road, and the other at Hopelands (Figure 2). Because these two catchments, designated W and H , have differing proportions of dairying and sheep/beef farms (Appendix 1), we can set up simultaneous equations to find both $\mathfrak{N}_d$ and $\mathfrak{N}_{sb}$, by first calculating the loss values 'seen' by the river: q_d and q_{sb} . The area of each farm-type in each catchment is A (ha), appropriately subscripted. As well, we need to consider the contribution from the small areas of forest, both native and exotic, and cropping, designated by subscripts f and c . The point-source discharges around Dannevirke, D , (kg-N yr^{-1}) also needs to be accounted for. This D includes point sources discharges at Norsewood, Ormondville, and Oringi, plus Dannevirke itself. Horizons have provided us with the annual river loadings of N at Weber Road and Hopelands: viz Q_W and Q_H ($\text{kg-N ha}^{-1} \text{ yr}^{-1}$). These were calculated by summing the loadings across the percentile classes of flows to arrive at the annual average required by our approach.

2.2.1 Mass Balance Equations

So, on an annual average basis, [5]

$$Q_W = q_d A_d(W) + q_{sb} A_{sb}(W) + q_f A_f(W) + q_c A_c(W)$$

$$Q_H - Q_W = q_d A_d(H - W) + q_{sb} A_{sb}(H - W) + q_f A_f(H - W) + q_c A_c(H - W) + D$$

GIS data from Horizons were used to determine the areas on dairying (A_d), sheep/beef (A_{sb}), cropping (A_c) and forestry (A_f) in the Weber (W) and the Hopelands less Weber ($H - W$) catchments. The town area of Dannevirke area (462 ha) was removed from $H - W$. These are given in Table 1.

Table 1: Areas of land-use types in the two sub-catchments

Land-Use Type	Weber (<i>W</i>) - ha	Hopelands (<i>H-W</i>) - ha
Dairying (A_d)	5,825	14,709
Sheep/beef (A_{sb})	64,101	33,521
Cropping (A_c)	34	459
Forestry (A_f)	1,987	5,685

The contrast in the respective areas, and downstream trends, of dairying and sheep/beef between the two sub-catchments enables us to solve Eq. [5] simultaneously for q_d and q_{sb} , if we assume q values for cropping and forestry. These assumptions will have only a limited effect on our solution for $\mathfrak{R}$: as their respective areas are not great, especially for cropping; or their fluxes q are known not to be large, as for both exotic and native forests. We assume $q_c = 40 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$ from this very small area, and that $q_f = 2 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$ applies for forestry. Next, we need to assume a value for the point-source discharges from around Dannevirke. Horizons have advised us that to consider that D contributes 2% of the N loading ($\text{kg-N ha}^{-1} \text{ yr}^{-1}$) measured at Hopelands. Horizons annual-average river data on N loading (kg-N yr^{-1}) are given in Table 2.

Table 2: Annual average N loadings in the two sub-catchments

	Weber (<i>W</i>)	Hopelands (<i>H-W</i>)
N loading (kg-N yr^{-1})	343,000	401,000

Solving Eq. [5], using these values, enables us to calculate q_d and q_{sb} . We can then compare these with the Overseer[®] calculations of q_d^* and q_{sb}^* , from which we can then estimate the transmissions $\mathfrak{R}_d$ and $\mathfrak{R}_{sb}$. The analysis assumes there is no lag effect, but a direct link between annual N losses at the farm scale with the annual N loadings in the river.

2.2.2 Uncertainties and Variability

There will of course be a certain amount of uncertainty in the derived values from Eq. [5]. In the absence of information, we cannot consider measurement errors in the flow and concentration observations, nor in the error in the loading calculation of summing the percentile classes to arrive at the annual figure. However, we consider that these would be small relative to the variation that results from the inter-annual variability in river flows due to the changing annual patterns of weather. The variation in weather between years will, we consider, be the largest source of variation in the 'leakiness' performance of farming enterprises. Inspection of river loadings at Hopelands over the last 16 years reveals a standard deviation of about 20% of the mean (744 T-N yr^{-1}). This coefficient of variation will transmit directly through our linear analysis, so that we can expect the derived values of q and $\mathfrak{R}$ to exhibit about a 20% variation across the years.

2.2.3 Diagnostics and Results

In Appendix 2 we demonstrate simple diagnostic uses of Eq. [5] for exploring the impact of changes in land-management practices, and for assessing the impact of land-use changes. Using these equations diagnostically, we discuss specific scenarios in Section 2.7.

General results are given in Table 3, for the range of Overseer[®] calculations (Table 7). These will be further in Section 2.5.

Table 3: The river-based farm fluxes q , the median (and range) of Overseer[®] calculations q^* (Table 7), and derived transmission estimates for dairying and sheep/beef

	q (Eq5) kg-N ha ⁻¹ yr ⁻¹	q^* (Eq3) kg-N ha ⁻¹ yr ⁻¹	$\mathfrak{R}$
Dairying	15.4	31 (25-49)	≈ 0.5
Sheep/beef	3.9	7 (6-9)	≈ 0.5

In the absence of data, even as coarse as this for the UMWMZ, we have to estimate $\mathfrak{R}$ for the other two intensive landuses of concern; cropping and market gardening. It would seem reasonable on the basis of farm sizes, plus fertiliser and farm practices, that a transmission factor of 0.5 could also be used, in the first instance, for cropping and market gardening, as indicated in Section 1.

The Overseer[®] calculations of q^* at 600 mm in the soil can, we consider, be corroborated reasonably cheaply through the use of the new research tool of fluxmeters. In Appendix 3 we describe the design and use of fluxmeters. Simple versions of these might only cost around \$500 per unit, but because of the high spatial variability due to urine patches, an as yet unknown and likely large numbers will be required, adding to the overall cost.

2.3 Comparison with Horizons Regional Council (2007)

Horizons Regional Council is presently drafting a report on nutrient load calculation and nutrient source assessment (Horizons Region Council, 2007). We have compared our calculations for the UMWMZ with those in the draft Horizons' report for the same WMZ.

By comparing the farm-loss predictions of Meneer *et al.* (2004) for dairying of q^* 40 kg-N ha⁻¹ yr⁻¹, and of 21 kg-N ha⁻¹ yr⁻¹ for sheep/beef, with the MfE "Lake Managers Handbook" values for specific yield of 20 and 9 respectively, Horizons had fortuitously assumed a transmission, or attenuation, of $\mathfrak{R}=0.5$ for both farm types.

Table 4. A comparison of the river-based losses of N, q , estimated by Horizons (2007), and Eq 5 for the whole UMWMZ above Hopelands

	Specific farm yield of N, q , estimated by Horizons (2007), kg-N ha ⁻¹ yr ⁻¹	River-based loss of N, q , estimated by Eq. [5], kg-N ha ⁻¹ yr ⁻¹
Dairying	20	15.4
Sheep/beef	9	3.9

Our observational methodology, going from what the river 'senses' back to the land, underestimates the yields compared to those of Horizons who have used a presumed leakage from various land practices, and a transmission coefficient, to go from the land to the river. Not surprisingly, there is agreement in the respective assessments of the proportional contributions of the two farming systems to the annual loading on N in the river for the whole UMWMZ at Hopelands (Table 5).

Table 5. The percentage contribution of farm types to the N loading in the Manawatu River at Hopelands

	Percentage estimated by Horizons (2007)	Percentage estimated from Tables 1 & 3.
Dairying	41%	43%
Sheep/beef	57%	51%

2.4 Comparison with Alexander *et al.* (2002)

Here we have been able to link specific farm types, namely dairying and sheep/beef, to nutrient loadings 'seen' in the river. The transmissions we provisionally calculate are similar to those found in other catchment studies which have not attempted, however, to discriminate between the various land-uses in the catchment. Parts of Table 10 from Alexander *et al.* (2002) are presented here in Table 6, and these are used to provide total landscape transmissions for the 4 sub-catchments, and for the total catchment of the Waikato River. The transmission for the whole river system is found to be 0.55, with the lowest value for a sub-catchment, being $\mathfrak{R}=0.25$ for Taupo which reflects the lower level of intensification, with 50% of the catchment area being either the lake, or forestry. Another feature of this catchment contributing to the low transmission factor is the depth to ground water. Alexander *et al.* (2002), in their Table 11, also provide data for total phosphorus, including sediment-bound phosphorus, and these can be used to calculate P transmission factors. These range from 0.45 for the whole catchment, down to 0.15 for the Taupo sub-catchment. It seems from their data that the $\mathfrak{R}$ values for dissolved phosphorus are about 0.1 lower than the equivalent for nitrogen.

Other nitrogen transmission values have been found for dairying catchments, and Ross Monaghan reports (*pers. comm.*) an $\mathfrak{R}$ of 0.5 for a catchment in Taranaki, and 0.75 for another monitored catchment in the Waikato.

Table 6. Transmission coefficients $\mathfrak{R}$ derived from Table 10 in Alexander *et al.* (2002) for the Waikato River system, and its sub-catchments

	Landscape Yield kg-N ha ⁻¹ yr ⁻¹	Watershed Yield kg-N ha ⁻¹ yr ⁻¹	$\mathfrak{R}$
Waikato (Total)	19.2	10.6	0.55
Lower Waikato	28.1	15.6	0.56
Upper Waikato	11.0	6.4	0.58
Taupo*	7.7	1.9	0.25
Waipa	24.0	14.7	0.61

*Long lag

Our framework has been able to establish a link beyond the general landscape to establish leakage losses from different land-use types. The landscape and watershed yields from Alexander *et al.* (2002) (Table 6) are both generally much higher than we find for the UMWMZ, which probably reflects the different levels of farming intensification in the two catchments. We find for the Weber sub-catchment a watershed yield of 4.8 kg-N ha⁻¹ yr⁻¹, and 7.4 kg-N ha⁻¹ yr⁻¹ for the Hopelands sub-catchment. In Table 6, the average for the whole Waikato River systems is 9.8 kg-N ha⁻¹ yr⁻¹. Our runs of Overseer® for landscape yield range from 9 through to 49 kg-N ha⁻¹ yr⁻¹, with an average of 31 for dairying and 7 for sheep/beef. So the area-weighted average for the whole UMWMZ would be (Eq. 5) 10.7 kg-N ha⁻¹ yr⁻¹, compared to the 18 kg-N ha⁻¹ yr⁻¹.

2.5 Overseer® calculations for various scenarios

To assess current average annual nutrient loss, we ran Overseer® for specific scenarios which we considered as the standard practices currently being used. The 24 scenarios are briefly described in Table 5, and the Overseer® Nitrogen Reports for all the scenarios are appended in Appendix 4. For dairying, we analysed 13 scenarios, and for sheep/beef we considered 11 farm set-ups. We obtained stock number information from the Livestock Improvement website, discussions with a local farm consultant, and we used our best knowledge of farm practices. (Appendix 4)

The characteristics of the “average” sheep and beef and dairy farm in the UMWMZ used in the Overseer® nutrient budget to estimate the nitrogen leaching/runoff loss, and the phosphorus run-off risk are described in Table 8, along with the calculated N loss (kg-N ha⁻¹ yr⁻¹) and P run-off risk rating.

The characteristics of the pastoral operations were obtained following discussions with farm consultants operating in the region. Similarly, the description for the cropping operations, as described in Table 8, were obtained from consultants with a long history of working with growers in the region. In addition to obtaining an estimate of the nutrient loss from the cropping operation, the nutrient losses from the pastoral operation on the farm where crops were being grown was also calculated.

The average N leaching/run-off for the average sheep and beef and dairy farm calculated by Overseer® nutrient model was 7 and 31 kg-N/ha, respectively. With both farm types the dissolved P run-off risk were estimated as low, or low-medium.

Additional runs of the Overseer® nutrient budget (Appendix 4) to investigate the influence of rainfall (900-1400 mm), soil type (poorly drained and free draining) and management practices (including changing soil fertility, fertiliser inputs, production levels, stock policy and effluent management) on nutrient losses highlights that there is considerable variation in the N losses from either sheep and beef (6 to 9 kg-N ha⁻¹ yr⁻¹) and dairy (25 to 49 kg-N ha⁻¹ yr⁻¹) operations in the UMWMZ. When the same exercise was conducted for P run-off risk, the risk remained low with the sheep and beef, but increased to include moderate risk under intensive dairying.

An important next step in the development of the water management plan for the upper Manawatu is a more detailed study of the nutrient losses from individual farms in each of

the major sub catchments. Engaging and involving producers and their sector representative and agribusiness as part of that process, is paramount.

Table 7: A brief synopsis of the scenarios used for Overseer® to predict nitrogen leaching from dairy and sheep/beef farms. The Overseer® Nitrogen Reports for all the scenarios are listed in Appendix 4

	N leaching kg-N ha ⁻¹ yr ⁻¹
Dairying	
Typical farm (Fertiliser – 100 kg-N ha ⁻¹ yr ⁻¹)	31
Milk solids down to 800 kg	25
Reduced rainfall at 900 mm	26
Fertiliser at 50 kg-N ha ⁻¹ yr ⁻¹	26
Increase effluent area to 24 ha	30
Increase Olsen P to 50	31
Decrease Olsen P to 20	31
Reduce effluent area to 6 ha	33
Increase rainfall to 1400 mm	34
Poorly drained soil- mole/tile drains	36
Free-draining soil	41
Fertiliser at 200 kg-N ha ⁻¹ yr ⁻¹	44
Milk solids raised to 1200 kg	49
Sheep/Beef	
Typical farm (Fertiliser – 7 kg-N ha ⁻¹ yr ⁻¹)	7
Reduced rainfall to 900 mm	6
Stocking rate at 8 SU ha ⁻¹	6
No N fertiliser	7
P fertiliser at 32 kg SP SU ⁻¹	7
Sheep:beef ratio 90:10	7
Decrease Olsen P to 10	7
Rainfall increase to 1400 mm	8
Sheep:beef ratio 50:50	8
Fertiliser in winter at 50 kg-N ha ⁻¹ yr ⁻¹	9
Stocking rate at 12.2 SU ha ⁻¹	9

Note. For each of the scenarios described above associated management changes were also considered

Table 8: Nitrogen leaching runoff and P runoff risk loss estimates from Overseer® for average sheep & beef & dairy farm in the Upper Manawatu water management zone

	Sheep & Beef	Dairy
Area (ha)	400	110
Production levels		
Stocking rate	10 SU ha-1	2.5 cows ha-1
Sheep to cattle ratio	70:30	
Milk solids		1000 kg ha-1
Wool production	5.5 kg SU-1	
Docking	115%	
Pastures	Developing (Browntop)	Highly developed (Ryegrass, white clover)
Supplements	-	1 tonne DM/ha (70% silage)
Grazing system		Dairy heifers grazed off-farm post- weaning
		Cows wintered off
Soils	Silt loam	Wet/free draining soil types
Soil P fertility	Olsen P 14	Olsen P 30
Exchangeable cations	K = 10; Ca = 12; Mg = 20; Na = 5	K = 8; Ca = 12; Mg = 10; Na = 3
Fertiliser inputs		
Phosphorus	18 kg SSP SU-1	Maintenance P, S & K (DAP15S, Potash super)
Nitrogen	7 kg-N ha-1 (urea)	100 kg-N ha-1 (urea)
Effluent disposal		Spray (4 ha per 100 cows)
Rainfall (mm)	1200	1200
Feed pad	-	-
Overseer ® estimate		
N leaching/runoff	7 (6-9) ¹	31 (25 - 49) ²
P runoff risk	Low (low) ¹	Low (low-medium) ²

¹ The range in N leaching-runoff losses and P runoff risk as a consequence of changing N fertiliser inputs (0-50 kg-N), rainfall (900 – 1400 mm), P fertiliser t (1 to 2xM); Olsen P (10-20 mg ml⁻¹), the sheep cattle ratio (90:10 – 50:50) and stocking rate (8 to 12 SU ha⁻¹) and associated change in maintenance P fertiliser input, with the change in stocking rate.

² The range in N leaching runoff losses and P runoff/risk as a consequence of changing N fertiliser inputs (50 – 200 kg-N ha⁻¹), rainfall (900 – 1400mm), Olsen P (20-50), effluent area (6-24 ha), Soil type (free and poorly drained) and production (800 – 1200 kg MS ha⁻¹), and associated shift in N fertiliser use (50 – 200 kg-N ha⁻¹) and supplements (0 – 2500 kg ha⁻¹) with the change in production.

Table 9: Nitrogen leaching loss estimates from Overseer® and the LUCI Framework Model for potatoes and barley rotations

Event	Potato-pasture rotation Opiki1		Barley-pasture rotation Waitatapia2	
Rainfall (mm) ³	1015		1100	
Soil type	Peat		Sedimentary	
Drainage class	Normal		Poor	
Date pasture ploughed	End Sept		End Oct	
Date main crop sown	Oct		Nov	
Mineral N at sowing main crop (kg N/ha)	100	200	100	200
Fertiliser applied (kg N/ha)	150	150	20	20
Date main crop harvested	Mar		Mar	
Date pasture sown	Mar		Mar	
Min N at sowing pasture (kg N/ha)	OS=not known LFM=estimated by model		OS=not known LFM=estimated by model	
Overseer® estimates				
N leached main crop (kg N/ha)	6	8	5	9
N leached over 12 months (kg N/ha)	9	11	8	12
LUCI framework model estimates (LFM)2				
N leached main crop (kg N/ha)	10	21	9	25
N leached over 12 months (kg N/ha)	10 (15)5	21(15)5	9	25

¹Using Palmerston North rainfall

²Waitatapia weather station used as Ohakea is missing rainfall data 1992-96.

³Average for 1993-2006

⁴LUCI framework model estimates are the average results from simulations run from 1993-2006

⁵**Livestock operation** on 150 of 200 ha includes 1000 ewes and lambs, purchased spring sold summer, finishing lambs autumn through spring and 140 yearlings to 2-yr bulls grazing year round. Wintering 2500 stock units (18 SU/ha) with a sheep to cattle ratio of 68:32. Clip 7000 kg wool mostly dry sheep. **Cropping** on the arable block growing 20 ha potatoes, 20 maize, and 10 milling wheat (which will go into winter green feed after harvesting). **Pasture includes** 20 ha of short term annual forage rye, 110 ha of permanent pasture and 20 of new grass. **Supplements:** 200 bales of baleage (100 sold & 100 fed back). **Fertiliser on permanent pasture:** 30N:12P:0K; 16S kg-1 as SSP and Urea

For cropping scenarios, we used two models: Overseer[®], and the LUCI framework model (Table 9). Nutrient losses calculated by both the Overseer[®] nutrient model for all three rotations, and the LUCI framework model for the potato and barley rotations were in general low (6-25 kg-N ha⁻¹ yr⁻¹) with estimates from Overseer[®] lower (6-12 kg-N ha⁻¹ yr⁻¹) than those calculated by the LUCI framework model (10-25 kg-N ha⁻¹ yr⁻¹). The LUCI framework model is a daily time-step model that was run using 13 years of real weather data (1993-2006) to provide an average value. In contrast, Overseer[®] is an annual time-step model that uses an annual average rainfall value.

We have some concerns about the veracity of predictions here, as these losses are considerably less than much of the published data on N losses from cropping or market gardening in New Zealand. This is because the cropping operations that were simulated in this study (see Table 9) are markedly different from those already reported in publications. In particular, both the barley and potato crops were sown after cultivation in the spring, after most of the winter drainage had occurred. Also, cover crops were sown after harvest early in the autumn and these removed most of the mineral N from the soil before the start of winter drainage. Through an SFF project (Section 11) we are working to improve the predictive capacity of Overseer[®].

Recognising that the cropping operations described in Table 9 are generally limited to only part (10-20%) of the farms total area in anyone year, an estimate of the nutrient loss from the balance of the farm operations was also obtained and then a weighted nutrient loss for the whole farm calculated. The balance of the farm operations in each case was a mix sheep and beef operation (Table 9).

A feature of the analysis of the cropping operations was the lack of data for populating the nutrient models and the lack of field data on the risk cropping operations in the region represent. Developing a research programme to obtain a better understanding of nutrient loss from the major crop types would be prudent. .

There are a range of potential mitigation options for reducing N losses from cropping and market gardening systems.

1. Changing the timing of cultivation from early autumn to late autumn and shortening the length of the fallow period can reduce winter N losses from bare fallow by up to 50% (Francis 1995)
2. When soil has to be cultivated early in the autumn, sowing rapid-growing cover crops early in the autumn can reduce winter N leaching losses compared to bare fallow by up to 50% (Francis 1995)
3. Deducting the amount of soil mineral N content throughout the root zone in N fertiliser recommendations can reduce the amount of unused fertiliser N that remains in the soil at harvest.
4. Splitting fertiliser applications to synchronise N supply to plant demand can result in increased yields with reduced fertiliser application rates while reducing winter losses by up to 50% (Williams *et al.*, 2003). The use of decision support systems are particularly useful for this (Jamieson *et al.* 2006)

5. Using N fertiliser coated with a nitrification inhibitors for winter crops reduced winter leaching by 30% in one study (Martin *et al.*, 2001). However, this resulted in a greater amount of unused fertiliser remaining in the soil at harvest, which increased the leaching risk in the following winter.

Where irrigation is used, its management can be as important as the management of fertiliser in determining N leaching losses (Francis *et al.*, 2007)

In the absence of data mitigation options for reducing P losses from cropping and market gardening systems would concentrate on limiting soil loss when soil are bare, limiting the physical damage to the soil, limiting over land flow and following the fertiliser industry code of practice when using P fertilisers.

2.6 What rates of nutrient loss can be achieved by best practices, and what are these?

It is important when discussing potential mitigation practices, to note that they will vary in both their suitability and effectiveness in reducing nutrient loss from farm to farm, as well they will vary in their cost, in either dollars or time. Implementation will impact on production levels and farm profitability.

Nitrogen In grazing systems loss of N is mainly due to leaching of nitrate down the soil below the roots. This occurs during the period of the year (May to September) when net drainage occurs.

Phosphorus With exception of soils which demonstrate preferential flow, P loss is largely in surface run-off. P is lost in two forms soil bound and dissolved P, with the former the dominant (60-90%). In comparison with N losses, P losses are generally small. Again in comparison to N, a significant proportion of the P loss on an annual basis can occur during single-storm events.

The mitigation options for reducing the losses of P and N from pastoral systems are listed in Tables 10 and 11, respectively. A number of these will be incorporated into Overseer® in the next 12 months including the use and impact of nitrification inhibitors on N, the role and impact of riparian strips and wetlands for both P and N, and an update on feed-pad management options for both N and P. A tool for assessing the mitigation options for reducing soil erosion is an obvious gap.

A number of detailed analysis have been undertaken to assess the potential effectiveness of the mitigation options for reducing the losses of P and N from pastoral systems.

Monaghan (2006) in an examination of the effectiveness of seven “Good environmental practices” found reductions in N losses on a model Waikato dairy farm of 6-44%, with associated cost of -\$22 to \$494 ha⁻¹ yr⁻¹ and impact on the farm EBIT (Earnings Before Interest and Taxes) of -1 to 7%. Restricting autumn-winter grazing, winter pads, riparian/wetland attenuation and nitrification inhibitors were the most effective options for

reducing the farm N losses, with decreases in N losses of 44, 32, 36 and 34%, respectively. A reduction of around one third would seem reasonable.

Re-scheduling late autumn application of fertiliser reduce N losses by 15%. An effective land based disposal system for dairy shed waste led to a 6% decrease in N losses, compared with the pond system.

In sharp comparison P losses could be reduced by 67% by shifting from a pond to land-based effluent disposal, highlighting the importance of ensuring the effluent block is of sufficient size and application rates do not exceed the soils matrix infiltration rate. Monaghan (2006) found the creation of riparian and wetland zones the next most effective attenuation option for reducing the farm P loss. One mitigation option, namely restricted autumn/winter management systems, which reduced N losses by 43%, also had the potential to increase P loss, highlighting the difference in the chemistry and behaviour of these two divalent anions in soils.

In a more recent analysis Monaghan *et al.*, (2007) found reducing maintenance fertiliser inputs and Olsen P values back to the optimum agronomic range offered the greatest saving and a predicted reduction in P losses by 30-37% in two dairy catchments. In situations where soil P levels are close to the agronomic option the opportunity for cost savings and environmental gains are going to be much smaller, highlighting the danger of prioritising or generalising about the suite of mitigations potential available to a producer.

Monaghan *et al.*, (2007) has attempted to go further with the analysis of mitigation options by attempting to assess the cost effectiveness of practices for reducing nutrient losses, by valuing the nutrients saved based on current prices at the local fertiliser works.

In compiling a list of best management practices as part of the one plan there is considerable merit in including an estimate of the cost effectiveness of each option in addition to the amount of nutrient conserved.

Table 10 Mitigation practices for reducing the losses of N from pastoral systems

Mitigation option	Explanation
Land disposal of dairy shed effluent	By treating effluent as a source of nutrients (N, P, K, S, Ca, Mg, etc) rather than waste and applying effluent to ensure that the amount of nutrient applied does not exceed the capacity of the soil to cope (e.g. 150 kg-N ha ⁻¹ yr ⁻¹) will ensure maximum use of the nutrients for pasture growth and limit the impact of land based application of effluent to the wider environment. The Overseer® nutrient budget model can be used to calculate the optimum area for application of dairy shed effluent.
Restricted autumn/winter grazing	Losses of N from urine patches is responsible for most of the N leaching and nitrous oxide emissions occur from grazed pastures. By removing animals from the grazing area during the period of the year when net drainage occurs, the amount of nitrate lost out of the root zone will be reduced. This option would generally be used in conjunction with some type of pad or stand-off area.
Winter feed pads/herd homes	The more time animals spend on a feed pad or Herd Home in the autumn and winter months the greater the reduction in N loss from the root zone. Urine collected while the animal is on a feed pad can be returned at lower rates and more evenly at time of the year when net drainage is unlikely. Management of effluent becomes critical if the benefits of a stand-off pad in reducing losses to the wider environment are to be realised.
Stock expulsion from all streams	Preventing access to perennial streams will reduce direct nutrient contamination from dung and urine and indirectly reduce the amount of vegetation and sediment entering the water ways. Preventing damage to the stream banks will also reduce the amount sediment and P entering the waterway.
Creation of wetland and riparian attenuation zones	Trapping and retaining nutrients and sediment in wetlands and vegetation buffers alongside water courses will reduce direct contamination of waterways. There is a lack of area specific metric data on nutrient N attenuation rates with both these mitigation options.
Fertiliser practices	The fertiliser codes sets out best practices. For example limit the amount of N in each application (30-50 kg-N ha ⁻¹) and the total amount (150kg-N ha ⁻¹ yr ⁻¹ , including Effluent N) and the use of fertiliser N in May-July. These actions will reduce the loss of N directly from N fertiliser. The fertiliser industry Fertiliser code of good practices provides reference to all these options.
Low nitrogen feed supplements	Use of feed supplements such as maize silage as an alternative to using fertiliser N boosted grass lowers the amount of N excreted in urine and can reduce nitrate leaching.
Nitrification inhibitors	Nitrification inhibitors target the animal urine patch limiting the bacterial conversion of urine-N to nitrate, which is the main source of N for leaching and nitrous oxide emission. Losses of N from urine patches is responsible for most of the

	N leaching and nitrous oxide emissions occur from grazed pastures. Current use of nitrification inhibitors on farms is by broadcast application to land (in slurry or granular forms) in order to try to contact urine patches during the high loss winter/early-spring period. An approach that involves using the animal to deliver the nitrification inhibitor in the urine stream, using a slow-release bolus is under development. There is still a considerable amount of uncertainty surrounding the performance of inhibitors. Ongoing field studies indicate that annual pasture responses to inhibitors may vary from 3-15% and leaching reductions from 20-60%.
Whole farm nutrient budgeting	Nutrient budgets are useful tools for assessing N flows within the farm system and identifying opportunities for reducing N losses. The Overseer® nutrient budget provides an estimate of nitrate leaching loss for each part of the farm under different management.

Table 11 Mitigation practices for reducing the losses of P from pastoral systems

Mitigation option	Explanation
Soil erosion	Limiting sediment movement to waterways from erosion during storm events offers the single biggest opportunity for reduce P loss to waterways. Whole farm planning offers a systematic land evaluation and planning approach for tackling this environmental problem. Because this issue is tackled elsewhere in the one plan, no further comment is made here.
Optimum soil phosphorus fertility	The target range should be the agronomic optimum soil Olsen P levels for each of the soil types on the farm. Soil fertility above the agronomic optimum makes little economic sense and increases the P run-off risk on soils with low (<50%) anion storage capacity. The Optimum agronomic soil Olsen P levels for each of the major soils orders are listed in the booklets On fertiliser use published by the fertiliser industry.
Fertiliser practices	The timing of fertiliser application (summer rather than winter), form of application (sparingly water soluble versus water soluble) and avoiding direct contamination of water ways by fertiliser all offers scope for reducing P losses from the farm. The fertiliser industry Fertiliser code of good practices provides reference to all these options.
Land disposal of dairy shed effluent	By treating effluent as a source of nutrients (N, P, K, S, Ca, Mg, etc) rather than waste and applying effluent to ensure that the amount of nutrient applied does not exceed optimum levels (e.g. Olsen P levels <35 ug ml ⁻¹) will ensure maximum use of the nutrients for pasture growth and limit the impact of land based application of effluent to the wider environment. The Overseer® nutrient budget model can be used to calculate the optimum area for application of dairy shed effluent
Deferred and low application effluent irrigation rates	Limiting effluent applications to periods when soils are less than field capacity, limiting the loading on an annual basis and using low application rates all offer options for limiting surface run-off and preferential flow of effluent. Practices which increase the opportunity for effluent to be absorbed into the soil matrix will reduce P losses.
Preventing autumn-winter-spring soil and pasture treading damage	Removing heavy weight animals when soils are wet to free draining soils or a stand-off or feed pad will limit soil and pasture damage. Soils damaged by livestock will have reduced physical function (e.g. infiltration rates). Pastures damaged by livestock will have reduced plant number, which in turn reduces canopy cover exposing the soil surface to rain drop damage. A soil and pasture damaged by treading will contribute more surface run-off and sediment than a well managed soil.
Stand-off/Winter feed pads/herd homes	Management of the P in the effluent is critical if the benefits of a stand-off area in reducing P losses to the wider environment are to be realised.
Stock exclusion from all streams	Preventing access to perennial streams will reduce direct nutrient contamination from dung and urine and indirectly reduce the amount of vegetation and sediment entering the water ways. Preventing damage to the stream banks will

	also reduce the amount sediment and total P entering the waterway.
Creation of wetland and riparian attenuation zones	Trapping and retaining nutrients and sediment in wetlands and in vegetation buffers alongside water courses will reduce direct contamination of waterways. There is a lack of area specific metric data on P attenuation rates with both these mitigation options.
Whole farm nutrient budgeting	Nutrient budgets are useful tools for assessing P flows within the farm system and identifying opportunities for reducing P losses. The Overseer® nutrient budget provides an estimate of P run-off risk for parts of the farm under different management.

2.7 Best management practices and the impact on river-water quality

From the section above, we suggest it could be possible through the adoption of mitigation measures and best management practices to reduce the loss of N from the rootzone, q^* , by up to one third. There would be a commensurate reduction in the amount of N reaching the river, and this could be simply predicted using the linear Eqs [3] and [5]. Indeed, the diagnostic form of these is given in Appendix (2) as Eq. [10]. Here we can predict, using our linear transfer-function model, what the improvement in water quality would be for the Hopelands catchment, for example, if, both for dairy farming and sheep/beef, best practices achieved a 33% reduction in losses.

We explore, using Eq. [10] the impact of this mitigation measure, along with other scenarios.

2.7.1 Impact of Changed Dairying Practices

Adoption of Mitigation Practices: If it were possible through the adoption of mitigation practices to achieve a one-third improvement in dairying practices, then from Table 4 the median loss, q^* , would drop from 31 to just under 21 kg-N ha⁻¹ yr⁻¹, such that given a transmission coefficient of 0.5 across the 14,709 ha of dairying in the Hopelands sub-catchment, there would be a predicted reduction of 73,545 kg-N yr⁻¹ in the river: a diminution of 18.3% from the 401,000 kg-N yr⁻¹ currently observed at Hopelands that comes from the Hopelands sub-catchment. The fact that a one-third improvement in practices does not translate to a 33% improvement in water quality is because the improvement scales with both $\mathfrak{R}_d$ and A_d (Eq. 10), and dairying comprises only 27.1% of the sub-catchment's area.

Intensive Practices: For an intensive practice scenario, we take the case of the greatest leakage for dairying in Table 7, namely q_d^* being 49 kg-N ha⁻¹ yr⁻¹. This is for farms where Overseer[®] simulates leaching when farm practices result in a yield of 1200 kg MS ha⁻¹ and in this example no mitigations practices are employed. If these practices were to expand across all dairy farms in the Hopelands sub-catchment, Eq (10) predicts there would be an additional 132,381 kg-N yr⁻¹ in the river at Hopelands, a 33% increase over the current loading of 401,000 kg-N yr⁻¹.

2.7.2 Impact of Changed Sheep/Beef Practices

Adoption of Mitigation Practices: Likewise, if it were possible through mitigation measures to realise a one-third improvement sheep/beef practices to limit leaching, from Table 4 the median loss, q^* , would drop from 7 to 4.7 kg-N ha⁻¹ yr⁻¹, such that given a transmission coefficient of 0.5 across the 33,521 ha of sheep/beef farms in the Hopelands sub-catchment, there would be a predicted reduction of 39,387 kg-N yr⁻¹ in the river: a diminution of 9.8% from the 401,000 kg-N yr⁻¹ currently observed at Hopelands, and coming from the Hopelands sub-catchment. As seen in Table 5 dairying and sheep/beef each contribute about one half of the total loading of nitrogen in the river at Hopelands, therefore a one third reduction in N loss from either sector will only translate to an improvement of about half of that in the river. We add that the range of mitigation and optimisation measures available to reduce N loss under sheep/beef grazing is less than that possible in the dairy sector.

Intensive Practices: The case of greatest N-leakage for sheep/beef in Table 7 is our prediction of how a sheep/beef farm might perform in 10 years' time with an annual increase of 2% in pasture production and stocking rate. This farm would by then have 12.2 SU ha⁻¹ and the leakage of N from the soil Overseer® predicts to be 9 kg-N ha⁻¹ yr⁻¹. If all sheep/beef farms in the Hopelands sub-catchment were stocked at this rate, there would, according to Eq. [10], be an additional 33,521 kg-N yr⁻¹ in the river at Hopelands, a rise of 8.4%.

2.7.3 Impact of Changed Areas of Farm Types

The other differentiated forms of Eq. [5], namely Eqs [12] and [14] of Appendix 2, can be used to account for an expansion of, say dairying, or conversely sheep/beef, onto larger tracts of land in any WMZ.

We consider, here for the UMWMZ, that if any farm conversions were to be carried out, they would either involve dairy conversion from sheep/beef, or vice versa, namely conversion of sheep/beef from dairying, with all other things held constant. There is, not surprisingly then, given that there are only two complementary farm types, a symmetry between Eqs [12] and [14].

For the UMWMZ, the values of the right-hand sides of Eqs [12] and [14] are given in the left-hand column of Table 3: $\Re_d O^{-1}(L_d) = 15.4 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$, and $\Re_{sb} O^{-1}(L_{sb}) = 3.9 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$. So because of the greater N-leakiness of dairy systems (Table 5), an increase in the area of dairying in the UMWMZ, would degrade river-water quality by 11.5 (i.e. 15.4-3.9) kg-N yr⁻¹ for every hectare converted from sheep/beef. Conversely, because sheep/beef farms have been found to be less leaky, every hectare of dairying converted into sheep/beef in the UMWMZ would improve river-water quality by -11.5 (i.e. 3.9-15.4) kg-N yr⁻¹.

We now carry out a scenario analysis of land-use change by considering that dairying might expand on all lands up to Class III in the UMWMZ. Landcare Research (Robert Gibb *pers. comm.*) determined that some 25% of the entire UMWMZ is in Class III lands or better. So from Table 5, this sums to 31,580 ha. Presently, dairying is carried out on only 20,534 ha (Table 5), so there is potential for dairying to expand over another 11,046 ha.

If current dairy practices were to expand onto these lands, we can find the change in river loading as ΔQ by writing Eq. [12] in finite-difference form as

$$\Delta Q = [\Re_d O^{-1}(L_d) - \Re_{sb} O^{-1}(L_{sb})] \Delta A_d$$

So, with the first bracket on the right-hand side being 11.5 kg-N ha⁻¹ yr⁻¹, and ΔA_d as 11,046 ha, this predicts that if there were such an expansion, there would be another 132,555 kg-N yr⁻¹ in the river at Hopelands, a 17.8% increase on the current loading of 744,000 kg-N yr⁻¹.

2.8 BMPs to meet Water Quality standards

In Eq. [8] (Appendix 2) we have linked the loading in the river, Q , to leakage losses, q^* , from the dominant landuses in a catchment. This equation is presented below for reference

$$Q = \mathfrak{R}_d q_d^* A_d + \mathfrak{R}_{sb} q_{sb}^* A_{sb}$$

We can use this linear transfer-function ‘backwards’ to infer what these leakage losses, q^* , should be in order to meet the value of Q in the river that meets the water quality standard of 0.444 g m^{-3} of soluble inorganic N (SIN). Dr Jon Roygard of Horizons Regional Council informs us that this water quality standard translates into an annualised river loading of $341,000 \text{ kg-N yr}^{-1}$. Using Eq. [8], with one additional rule about how the terms on the right-hand side should be split, we can predict the result from the BMPs for the respective farm types that would meet water quality standards.

2.8.1 Loading-equity split

Table 5 indicates that dairying and sheep/beef both contribute about equally to the loading of N in the river at Hopelands: namely sheep/beef 51% and dairying 43%. Thus one option, amongst others, is to consider that each farm-type contributes savings in proportion to their fractional make-up Q . So to meet the water quality standard, namely 341 T-N yr^{-1} , the split would be $155.5 \text{ T-N yr}^{-1}$ for dairying and $185.5 \text{ T-N yr}^{-1}$ for sheep/beef. Given then the respective areas of farms in the UMWMZ (Table 1), and the same transmission coefficient, $\mathfrak{R}$, of 0.5 for dairying and sheep/beef, the farm losses of N that would meet the water quality standard at Hopelands are for the full UMWMZ, according to Eq.[8]:

- For dairying, $q_d^* = 15.1 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$
- For sheep/beef $q_{sb}^* = 3.8 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$.

In the humid environment of the UMWMZ, it would seem that these would be difficult to achieve given current technologies. This would essentially require a halving of the on-farm losses of N, which fortuitously is the target contained in the Dairy Industry’s Environment Strategy.

2.8.2 Area-equity split

In Table 1, we see that dairying presently occupies 16.3% of the area of the UMWMZ, whereas sheep/beef covers 77.3% of the catchment. If the load of $341,000 \text{ kg-N yr}^{-1}$ which meets water quality standards were equitably split on an areal basis, dairying could only account for 59.3 T-N yr^{-1} . The complement of $281.7 \text{ T-N yr}^{-1}$ would be allocated to sheep/beef. For the UMWMZ, this could, according to Eq. [8] only be achieved if there were the same losses from each sector, namely:

- For dairying, $q_d^* = 5.8 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$
- For sheep/beef $q_{sb}^* = 5.8 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$.

For dairying this would not be feasible with current practices and technologies.

2.8.3 *Natural Capital Split*

In a separate project we have examined an approach to split the load across the catchment according to the natural capital value of the soil as registered by the Land Use Capability class. (Appendix 6)

3. What are the key/critical hotspots of nutrients input into waterways? How should these be managed to reduce their impact on contamination of waterways?

We have elected to answer this query through our responses to questions 2 and 4.

4. Application of effluent to land is currently an activity that requires resource consent. If Horizons were to make it a permitted activity, subject to compliance with best management practices, which best practice measures are recommended?

It is important to remember that for the land owner, the major keys to the successful management of effluent application to land is to have sufficient storage for flexibility, maximise the use of the effluent as a nutrient source for optimum plant growth, and always apply it onto short pasture at the lowest practical application rate with a rest interval between application and grazing.

For Council, success is measured by suitable storage facilities where effluent can be held temporarily if the application system breaks down, or soils are too waterlogged for further liquid application, so the N loading on the land does not effect groundwater, ponding and runoff into surface water is avoided, nuisances from odour or spray drift does not occur and buffer distances between adjoining properties or public roads and the application area are observed.

The manual “*Managing farm dairy effluent and farm management Issues*”, developed by the Dairying and Environment Leadership Group in consultation with Regional Councils, AgResearch, NIWA, Dexcel, Spitfire Irrigators Ltd, Effluent & Irrigation Services, Federated Farmers of New Zealand, Fonterra Co-operative Group Ltd, Westland Milk Products New Zealand and Massey University, and last updated in 2006 in a projected funded by New Zealand dairy farmers through Dairy InSight brings these goals together. The manual is designed to assist dairy farmers and farm management specialists with the practical, effective, safe and legal management of farm dairy effluent. Available to all land owners, the manual provides a comprehensive list of best practice measures for the application of effluent to land

Horizons should reference the practices listed in Chapter Two ‘*Land Application*’ (e.g. rate of application of effluent, timing of application, etc) and Chapter Four ‘*Effluent from Feed Pads, Stand-off Areas and Other Sources*’, which includes effluent from silage pits, races, crossings and underpasses in the One Plan as best practice measures for the application of effluent to land.

Horizons should note the following

1. With the advent of stand-off pad, feed pads and herd homes, the volumes of solid effluent applied to land are likely to increase significantly in future years.

Effluent can be dealt with as liquids, slurry or solids. In general, raw effluent takes the form of slurry. **Liquid** effluent is defined as material containing less than 10% solids. Such material can be conveyed through piping systems by gravity or pumps, and is treated in oxidation ponds or by land application. **Slurry** contains between 10 and 20% total solids and will flow. It is generally spread on land using vehicle spreaders. Effluent exceeding 20% total **solids** is sludge and will not flow. It requires mechanical spreading equipment usually with scrapers, buckets and front-end loaders.

The one plan will need to be able to address all these forms, with the quantities of solid effluent likely to increase in the future.

2. The council will need to make a decision on the maximum amount of effluent that can be applied based on an N or P loading or on the optimum use of effluent as a nutrient source for plant growth.

(a) The N loading (150 or $200 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$). Table 16-1 in the one plan currently suggests the lesser of the two. This assumes application of N up to the maximum allowable loading follows best practices for effluent disposal described in the dairy industry manual.

(b) Optimum use of effluent as a nutrient source for plant growth.

If this approach was adopted the application rate of effluent would be governed by the potassium (K) content of the effluent. In the past, the rule of thumb was 4 ha per 100 cows to achieve an N loading of $150 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$. At this application rate the K input is approximately twice maintenance. This would result in a doubling (8 ha per 100 cows) of the effluent block, if the optimum use of effluent as a nutrient source was used as part of best practice. The Overseer[®] nutrient budget model can calculate the area of the effluent block based on an N loading of $150 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$, $100 \text{ kg-K ha}^{-1} \text{ yr}^{-1}$ or on a maintenance K application. While using K inputs above maintenance does not represent an environmental threat, it does represent poor practice. Obtaining buy in from the industry to include optimum use of nutrients as part of best effluent management practice, would have the bonus of reducing N and P loadings and negate the need for a rule. Excessive K in soils and pasture can result in metabolic problems for lactating animals.

5. What improvements and mitigation measures are likely to be included in Overseer®

Discussions were held with Dr Hilton Furness (Fertiliser Manufacturers' Research Association – a member of the Owners' Committee of Overseer®), and the leader of the Overseer® team within AgResearch, David Wheeler, to find out the future plans for further development of Overseer®.

They noted that it is planned to release a new version of Overseer® by December 2007 and this would include:

- The use and impact of nitrification inhibitors,
- The role and impact of riparian strips and wetlands,
- Updates of the feed-pad management options, and

Priorities for the next update in December 2008 are still being established. Under consideration for further development of the model are:

- Monthly time-steps to take better account of stock movements, and other farm management practices such as multiple calving
- Updating of the market gardening, cropping and horticultural models. This was being assisted through an SFF N management project being carried out for Horticulture NZ by Crop & Food Research, HortResearch, and AgResearch.
- Other considerations, depending on the availability of knowledge and modelling, could include sediment loss and microbes. It is presently unclear as to what modelling strategy might be used for these, given the difficulty in describing the processes. A generalised risk-assessment, and provision of mitigation measures could be an option.
- Other aspects and mitigation measures would be considered by the Owners' Committee on the basis of need, and the provision of appropriate results and robust knowledge.

6. What progress has been made in integrating NPlas and Overseer®? Could it be applied to the Manawatu-Wanganui region?

Presently, AgResearch has a contract with MAF and Dairy Insight to link their Overseer® model of nutrient management with hydrological and nutrient source models to account for the mitigation impact of riparian strips and wetlands. AgResearch is working with MAF to develop the specifications for this project and will include NIWA. The contact for further information is Richard McDowell of AgResearch in Mosgiel.

Because the Overseer® model is nationally applicable, so will this riparian strip/wetlands option be nationally available. The veracity of the predictions will, nonetheless, be dependent on the utility of national calibrations, or the availability of local information.

7. Best Management Practices to Minimise Faecal Runoff from Farms

Recent reviews have addressed aspects of faecal runoff from rural catchments by examining pathways and models for predicting loads to surface waters, namely Collins *et al.* (2005a), and Jamieson *et al.* (2004), as noted by Wilcox (2006).

Loadings to waterways are greatest from **surface runoff** and **stock crossings**, but are broadly similar to loadings from drains (notably because of effluent loadings) and dairy shed oxidation ponds with typical effluent strength. This is because the calculated loads take into account the magnitude of the inputs and the duration of each type of loading.

Land loadings fall into three broad classes.

1. The highest loadings occur where stocking rates are highest, viz. wintering pads, block-grazed pasture, and stand-off and feed pads for dairy cattle.
2. The second group comprises average grazed pasture for dairy and sheep, and land disposal of dairy shed effluent by irrigation. Of note is the high land loading of *E. coli* that can come from intensive sheep farming. Sheep at a stocking rate of 5 sheep ha⁻¹ may deliver up to ten times the loading (*E. coli* ha⁻¹) that is produced by dairy cattle grazing at a rate of 3 cows ha⁻¹.
3. A third, smaller group comprises deer and beef cattle farms, based on what is regarded as 'typical' stocking rates, and runoff from dairy farm laneways.

Other important sources of faecal pollution include direct deposition into stream channels from grazing livestock, and runoff from seeps and wetlands that are accessible by stock.

While it is relatively straightforward to calculate loadings it is much more difficult to estimate *in situ* concentrations, without knowledge of die-off rates and breakdown of faecal matter in conjunction with farm grazing management. (Wilcox, 2006).

"Bridging streams intersected by farm raceways is an appropriate mitigation measure for herd crossings, whilst fencing stream banks, ephemeral streams, wetlands, seeps, and riparian areas prone to saturation to keep livestock out will bring improvements in water quality. "Riparian buffer strips not only prevent cattle access to waterways, they can also entrap microbes (and other pollutants) washed down slope in surface runoff, and, where planted in trees, provide shade and improve aquatic habitat." (Collins *et al.*, 2005b)

"Soil type is a key factor in the transfer of faecal microbes to waterways. The avoidance of, or a reduction in, grazing and irrigation upon poorly drained soils characterised by high bypass flow and the generation of surface runoff, are appropriate management practices, and are likely to lead to improvements in bacterial water quality". (Collins *et al.*, 2005b)

"In addition to the identification of appropriate soil type, timing, volume, location and technique are also key factors in the optimal irrigation of effluent and water. Ideally, dairy

shed wastewater should be irrigated onto land only when the water storage capacity of the soil will not be exceeded. This 'deferred irrigation' can markedly reduce pollutant transfer to waterways, particularly that via subsurface drains and groundwater.. Spray irrigation results in less risk of soil saturation and hence less surface runoff and microbial contamination of groundwater than the border strip technique." (Collins *et al.*, 2005b) Advanced Pond Systems provide excellent effluent quality and have particular application where soil type and/or climate are unfavourable for irrigation. (Collins *et al.*, 2005b)

8. Should Horizons Regional Council adopt the water-way definition of the Clean Streams Accord to achieve reductions in nutrient and faecal losses?

The waterway definition in the Dairying and Clean Streams Accord (Fonterra *et al.* 2003) is:

“... deeper than a “Red Band” (ankle depth) and “wider than a stride”, and permanently flowing”.

The Accord’s target is to have dairy cattle excluded from 50% of streams by 2007, and 90% by 2012.

This provides a good starting point for a process that seeks to reduce stock accessing waterways. Compliance is, nonetheless, going to be difficult in many of the region’s hill lands. Farm planning will have more potential for reducing stock in waterway, than further regulation.

The Accord’s definition would, it seems, put the waterway somewhere between an order 2, or 3 stream. It would be interesting to know what length of waterways, both ephemeral and permanent, lies outside the Accord’s definition. It is considered that there would be a large number of ephemeral waterways, even just temporary surface pondings, that might be accessed by stock and thereby transport nutrients and microbes to receiving waters. This process, even though it would be outside the Accord, would contribute to the leakiness of farms, and would tend to keep the transmission index, $\mathfrak{R}$, higher than expected.

9. What are the appropriate upper limits for Table 16-1 in the “One Plan” for N and P?

As evidenced by the detail of our calculations and analyses here, it is difficult to generalise about nutrients loadings, and so it is hard to prescribe an upper limit. Earlier, we have here tried to prescribe best management practices that will reduce the loss of N and P from farms.

Nitrogen

There are many factors that will influence the upper limit of N which can reasonably be applied with adverse impact. This will, *inter alia*, be influenced by:

- The level of feed intake by the grazing animal. Animal grazing increases the likelihood of N losses through the leaching from urine spots
- The fraction of the N that is applied that might be removed through cut-and-carry during the year.

So at this stage there would seem to be no present reason to amend the upper limit for reasonable N application ($150 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$) in Table 16-1. As Horizons gathers outputs from Overseer® (see Table 7 and the $200 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$ scenario), and other sources, and as other data comes available from areas where N has been used for longer periods of , this value can be reviewed.

Phosphorus

Again, there are many factors that influence P loss. Although P is much less mobile than N, the amount of P that can be applied with adverse effects will be influenced by:

- The grazing animal. Intensive grazing systems would increase the risk of P loss through overland flow, as compared to say, a cut-and-carry operation
- The fraction of P removed by cut-and-carry, relative to that applied will be a lot less in comparison to N. For example, a 10,000 kg-DM pasture, at an N-content of 4% will contain 400 kg-N, but with a P content of 0.4% there will only be 40 kg-P removed.

Designating a value for P presents more difficulty, because soil chemistry exerts a very large influence on these values. History of P use will also be very important. For instance, a capital dressing rate that is appropriate in an undeveloped land setting with soils with high anion storage capacity (ASC), would be excessive in a well developed low ASC soil. Decisions about setting a maximum application rate, fits better with the scale of farm plans, rather than with regional scales. Given the importance of direct contamination of waterways with P, an application rate rule is not a priority at present. The fertiliser industry has developed a comprehensive set of best management practices for P and N use cover such issues as the form and rate of application, timing and method of application. These seek to maximum plant uptake and minimize the impact of fertilisers on the wider environment.

10. Biosolids, Offal Holes & Farm Dumps: Comments on Rules 16-2 & 16-7

We have been asked whether the current conditions on Rules 16-2 to 16-7 are appropriate to achieve best practice.

We have some comments and suggest some modifications and additions to Rules 16-2 to 16-7 that we consider would achieve best practice. We make comment of 3 of the 5 conditions set out in these two of these Rules, and we add some suggestions taken from the EBoP guidelines.

16-4 Biosolids and soil conditioners

Condition (b) There shall be no ponding of material on the soil surface for more than five hours following the application, or any runoff into a surface water body.

Comment: On any site with a slope a ponding that lasts up to five hours will lead to considerable surface runoff and, therefore, pose a risk for surface water contamination (especially with P). We suggest to omit the time limit and to encourage the farmer to take the specific site conditions into consideration. A possible new formulation of Condition (b) could be:

The rate of application shall not exceed the infiltration capacity of the particular soil and topography (citation from 'Dairy Shed Effluent Treatment and Disposal Guidelines', Environment Bay of Plenty Guideline No. 2003/01), and any runoff into a surface water body shall be prevented.

16-5 Offal holes and farm dumps

Condition (d) The lowest point of the offal hole or farm dump shall be at least 1 m above the seasonally highest water table.

Comment: The distance of only 1 m above the seasonally highest water table seems to small. We would suggest to increase it to 2 m (also suggested by the Environment Bay of Plenty Guideline on Offal holes) and encourage the farmer to select a site with a clayey subsoil (suggested by the Guideline for Offal holes of the Gisborne Regional Council). A possible new formulation of Condition (d) could be:

The lowest point of the offal hole or farm dump shall be at least 2 m above the seasonally highest water table and if possible have a clay base.

Additionally, we suggest inclusion of two more conditions. Both conditions are a part of the Environment Bay of Plenty Guideline on Offal holes.

- Leachate is not allowed to pond or flow away from the hole
- The hole must be covered to prevent stormwater entering

16-6 Farm animal effluent including dairy sheds, poultry farms and existing piggeries

Condition (d) There shall be no ponding of effluent on the soil surface for more than five hours following the application, or any runoff into a surface water body.

Comment: On any site with a slope a ponding that lasts up to five hours will lead to considerable surface runoff and, therefore, pose a risk for surface water contamination (especially with P). We suggest to omit the time limit and to encourage the farmer to take the specific site conditions into consideration. A possible new formulation of Condition (b) could be:

The rate of application shall not exceed the infiltration capacity of the particular soil and topography (citation from 'Dairy Shed Effluent Treatment and Disposal Guidelines', Environment Bay of Plenty Guideline No. 2003/01), and any runoff into a surface water body shall be prevented.

In addition we suggest including two more conditions. Both of these conditions are a part of the 'Dairy Shed Effluent Treatment and Disposal Guidelines', Environment Bay of Plenty Guideline No. 2003/01. The recent update of the manual "*Managing farm dairy effluent and farm management issues*" developed by the Dairying and Environment group provides a comprehensive set of best practices for effluent management.

- Any area receiving effluent by irrigation should be rested for a 14-day period between applications to prevent hydraulic inundation of the soil causing a breakdown in the soil treatment process.
- A contingency plan must be available in the event of pump or irrigator failure to prevent overflow to water or land where it may reach water.

11. Current Research of Potential Benefit for On-Farm Resource Management

There are a number of projects currently being undertaken by the SLURI partners that could benefit on-farm management of N, P and microbial contaminants. These are briefly summarised in the tables below (Tables 12, 13 & 14).

Table 12: Pastoral sector

Name	Major Funder(s)	Research provider(s) ¹	Description ²	End date
Soil Services	FRST	LCR	Providing underpinning information on the key services provided by soils that mediate the effects of land use on the transport of nutrients and contaminants to ground waters and sustain the versatility and productivity of our landscapes.	Jun 07
Integrated catchment management (Motueka)	FRST	LCR	Implementing a collaborative learning approach with stakeholders to identify and implement sustainable patterns of land, water and coastal uses, as development pressures increase. Programme goals are: i) the equitable allocation of increasingly scarce natural resources, in a manner acceptable to catchment communities; and ii) the application of tools for managing the cumulative effects of land and water use.	Jun 09
SPINFO	FRST	LCR	The overall outcome will be sound, enduring management decisions about land resources and environments made by central government, local government, consultants, researchers, and land-based industries, supported and informed by rapid access to comprehensive, up-to-date, and accurate databases and associated information	Jun 07

			systems.	
Land to Ocean	FRST	LCR	Effective management of New Zealand's dynamic physical environment is dependent on improved understanding of the processes that transfer sediment, nutrients and carbon from land to ocean. Research will provide new knowledge to strengthen the ability to predict and mitigate the effects of changing climate and land use on those transfers, and to underpin an assessment of terrestrial and marine greenhouse gas emissions.	Jun 07
Enhancing surface water quality in managed landscapes	FRST	AgR	Provide management strategies that minimise leaks and contain potential contaminants within the farm boundary without decreasing farm profitability. Our hypothesis is that considerable reductions in farm contaminant losses to waterways can be realised through the development and adoption of farm management practices, management systems and mitigation technologies that effectively contribute to water quality goals at a catchment scale.	Jun 07
Nitrogen and Lake Taupo	FRST	AgR	Ensure high groundwater and lake water quality while enhancing economic and social well-being of Maori and non-Maori landholders, community and policy bodies. This will be achieved through developing, evaluating and promoting implementation of new technologies, improved land use practices and policy methods using an integrated whole-systems research approach.	Jun 10
Livestock	FRST	AgR	Describe the economic,	Jun

intensification			environmental and social impacts of different pastoral land-use options and define systems where deleterious effects can be balanced against economic gains.	09
Pastoral 21	FRST, DI, FertRes, MAF	AGR, NIWA, CFR, Dexcel, ESR, LCR, Lincoln, Massey, Waikato	Provide farmer-friendly tools and technologies for reducing N, P, sediment and FIO losses to water ways.	Feb 11
SLURI	FRST	CRF, HRT, AGR, LCR	N saturation – Soil Services N mineralization soil quality indicator	Jun 08
Catchment Land Use for Environmental Sustainability (CLUES)	FRST (CDRP). MfE, EW, Horizons	NIWA, AgR, HRT, LCR, Lincoln Ventures, Harris Consulting	Allows a GIS user to model present and future nitrogen and phosphorus loads in streams as land use changes, on national, regional and catchment scales. The system also provides data on socioeconomic implications.	

¹AgR = AgResearch, CFR = Crop & Food Research, HRT = Hort Research, LCR = Landcare Research

²Description of the relevant project component

Table 13: Cropping & market gardening

Name	Major Funder(s)	Research provider(s)¹	Description²	End date
Land Use Change and Intensification (LUCI)	FRST	CFR, AgR	Defining the effects of changes and intensification of land use on nitrate leaching losses to groundwater. This contributes to the Integrated Research for Aquifer Protection (IRAP) programme that is producing tools for use by regional councils to develop their second generation regional plans (for groundwater quality)	Jun 08
Nitrogen Managers for Environmental Accountability	SFF, Hort NZ, FAR, FertRes, RCs	CFR, AgR, HRT	Producing an improved on-farm nutrient budgeting tool for arable, vegetable and horticultural land uses	Jun 09
Improving the nitrogen management of potato crops	SFF, Hort NZ, Horizons, EW, Ballance, HBRC	CFR, HRT	Improving nitrogen use efficiency of potato crops using an on-farm decision support system (the Potato Calculator)	Jun 08
Nitrogen management for sustainable maize production	SFF, FAR, FertRes, EW	CFR	Developing a tool (the AmaizeN calculator) for optimising nitrogen management of maize for economic profitability while minimising environmental impacts	Jun 08

Table 14: Perennial horticulture

Name	Major Funder(s)	Research provider(s)¹	Description²	End date
Regulated Deficit Irrigation in kiwifruit	SFF, ZESPRI	HRT, Fruition Horticulture	Management of irrigation in kiwifruit to improve fruit quality	Jun 09
Nutrient Management in Kiwifruit	SFF, Ballance Agri-nutrients, EBoP, Northland RC	HRT	Managing N in kiwifruit	Jun 07
Summerfruit Nutrition	SFF, Summerfruit NZ	HRT	Developing best practice management for nutrients in summerfruit	Jun 09
Blueberries: Irrigation and nutrient management	SFF, Hauhangaroa Trust	HRT	Developing irrigation and nutrient practices for growing blueberries in the Taupo catchment	Jun 09

12. Are there any trends within the farming community that may influence the format of individual farm resource management plans/strategies (i.e. computer literacy, environmental awareness, market accountability, etc)?

The use of Environmental management systems (EMS) and allied approaches to on-farm environmental management is increasing in the primary sector in New Zealand. An EMS refers to a systematic approach to managing the impacts of a production system on the environment. They have been promoted as a tool for simultaneously meeting market and community demands for environmental assurances in the agricultural, horticultural and forestry sectors. Most New Zealand primary sector EMS-type arrangements have been developed by individual sectors, and are not ISO 14001 accredited. Most are reasonably prescriptive in terms of the environmental issues that should be included, the implementation process and the management options that are acceptable.

Table 15 Summary of the main New Zealand programmes for on-farm environmental management

Programme	Programme Type					
	<i>Integrated EMS/QA</i>	<i>EMS</i>	<i>Quality Assurance</i>	<i>IPM</i>	<i>Standards</i>	<i>Codes of Practice</i>
Horticulture						
Sustainable Winegrowing	X					
The Living Wine Group		X				
Kiwi Green ¹ (kiwifruit)				X		
NZ Fresh Produce Supplier Programme (fruit & vegetables)			X			
Olive Care™			X			
Pipfruit – Integrated Fruit Production				X		
AVO Green				X		
SummerGreen (Stonefruit)				X		
Livestock						
Project Green (Meat)	X					
SmartPlan™ (Dairy)	X					
Market Focused (Dairy)		X				
Merino Benchmarking Group (Wool)		X				
DeerQA			X			
Individual meat company on-farm QA			X			
FarmPride (Landcorp farms)			X			

Cross-sectoral

NOSLaM		X
Greentick	X	
NOSLaM		X
Enviro-Mark™		X

Industry practices

Agrichemical Code of Practice (GROWSAFE)		X
Code of Practice for Fertiliser use		X

In an evaluation of the EMS type arrangements in operation in New Zealand (Table 15), Parminter *et al.*, (2004) found they varied a great deal in their intent, content, credibility and environmental performance. Nonetheless, they have been shown to be effective at delivering desired environmental outcomes. They provide an extra policy instrument for achieving such outcomes along with regulation, encouragement through rewarding achievement, economic incentives or educational approaches.

In viticulture there has, through a consortium of vineyards in Martinborough, been successful accreditation to the ISO 14000 series of EMS accreditation. This could be an increasing trend to environmental accountability to secure market share and premium prices. Furthermore, and also in viticulture, a vineyard in Marlborough (Grovettown), has been accredited with being carbon-neutral.

13. What would be the most effective way of measuring the actual nitrogen and phosphorus loss from farms?

Measuring the actual N and P loss from farms is very challenging as these losses vary greatly both spatially and temporally variable. Currently, there are no cost-effective tools available for use by farmers. Several research tools are available (see Appendix 3), but these can be either too expensive for use by farmers, or do not produce paddock- or farm-scale results.

However, one of the objectives of the recently-funded Pasture-21 tender is the development of such an operational tool for pastoral systems. This work aims to produce this tool by combining the most cost-effective analytical techniques for measuring N and P concentrations (or their surrogates) with an appropriate method for collecting representative, paddock-scale samples (e.g. large lysimeters, ceramic cups).

This may prove to be a long term and difficult task, and the use of farm-scale models (such as Overseer®) may be the only viable option. Options could exist for simple versions of the research tools outlined in Appendix 3 to provide simple month-by-month monitoring, along with these data being able to provide corroboration of Overseer® predictions.

14. Why does Overseer® not consider soil-test results to account for the existing N content of soil?

The nutrient budgets calculated in Overseer® are accounts of the inputs and outputs of nitrogen across the boundaries of the land units being considered. The model does not calculate any change in the stocks of nutrients (e.g. total soil-N) within the boundary, and stocks are treated as a stable property of the system. The processes of N accumulation, and release, are considered to be in near balance over decade-timescales. Indicators like available soil N therefore, do not have any useful role in these calculations.

There is an exception when the “Development” options are selected in Overseer®. These assume that more N is being accumulated than released, so total N in the system increases, and the losses are predicted to be lower as a consequence. Defining the conditions where the development options should be invoked is highly subjective and a test to guide this might be useful. Available soil-N is however notoriously difficult to assess in a way that has general application and rapid progress shouldn’t be expected.

15. The Waikato Farm Environment Award Trust has produced a guide to preparing a nutrient budget. How useful is this simplified tool?

This is a simple and manual nutrient-budget guide, or method, and was of help in situations where land owners had no access to Overseer[®]. It should not be regarded as a substitute for Overseer[®]. Since Overseer[®] is freely available, and accepted by the industry and regulators alike, there seems little reason to adopt anything else. Furthermore, Overseer[®]'s owners are continually updating the user friendliness and utility of Overseer[®] through engaging New Zealand's best scientists.

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Appendix 1: The Upper Manawatu Water Management Zone (UMWMZ)

A.1.1 Above Weber Road

The frequency histogram of dairy farm sizes in this sub-catchment is shown in Figure A1. The median farm size of the 44 farms is 118 ha.

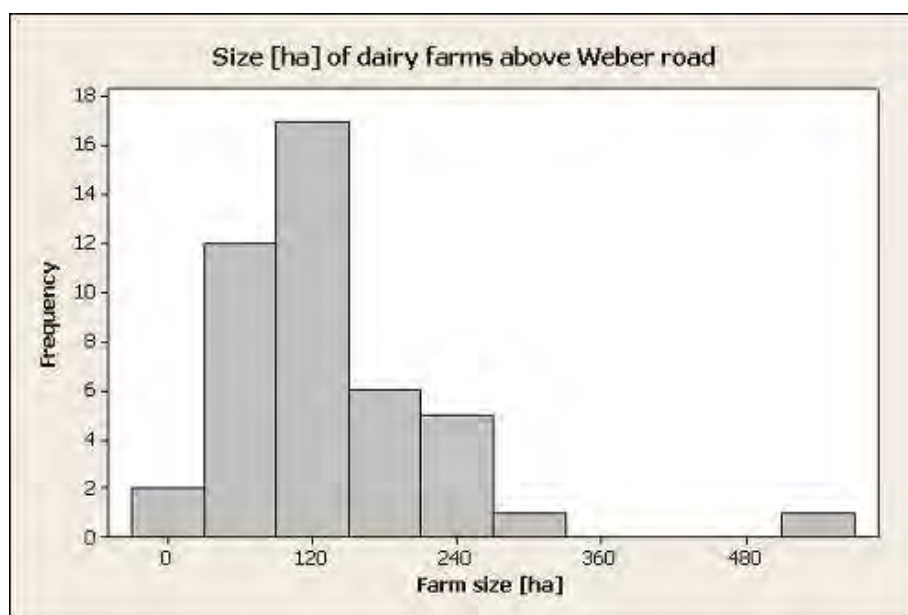


Figure A1. The frequency distribution of dairy farm sizes above Weber Road

The frequency distribution for the number of cows per farm for these 44 farms is shown in Figure A2, from which can be calculated that the median density is 319 cows per farm. We used a non-parametric means to estimate the average stock density on dairy farms above Weber Road to be 16 stock units (SU) per ha (Table A1)

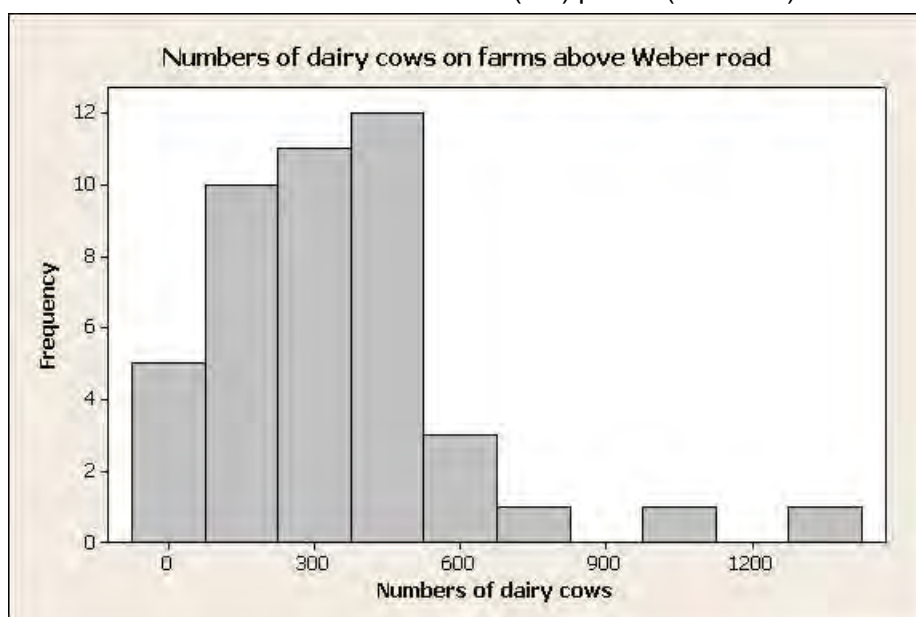


Figure A2. The frequency histogram of dairy cows per farm for the subcatchment above Weber Road

For the 235 sheep/beef farms in the Weber Road sub-catchment of the UMWMZ, the frequency distribution of farm sizes is given in Figure A3. The median farm size is 149.3 ha.

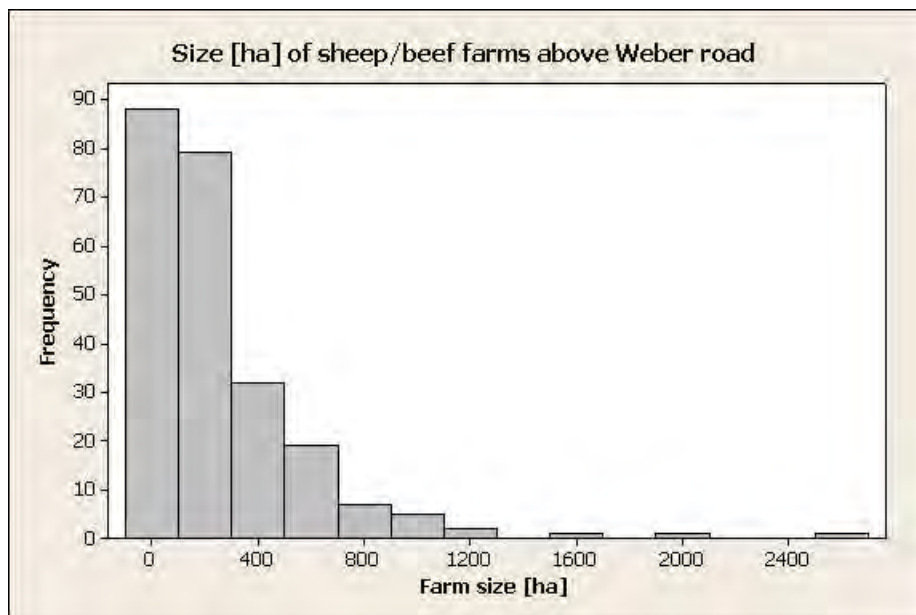


Figure A3. The frequency distribution of farm sizes for sheep/beef units above Weber Road

For these sheep/beef farms, the frequency histogram of animals per farm is given in Figure A4, and we find that the median number of animals per farm is 924. Sheep comprise 91% of the animals in this class. The density of animals on these farms is 9 SU ha⁻¹ (Table A1).

Figure A4. The frequency distribution of the number of animals per farm on sheep/beef units above Weber Road.

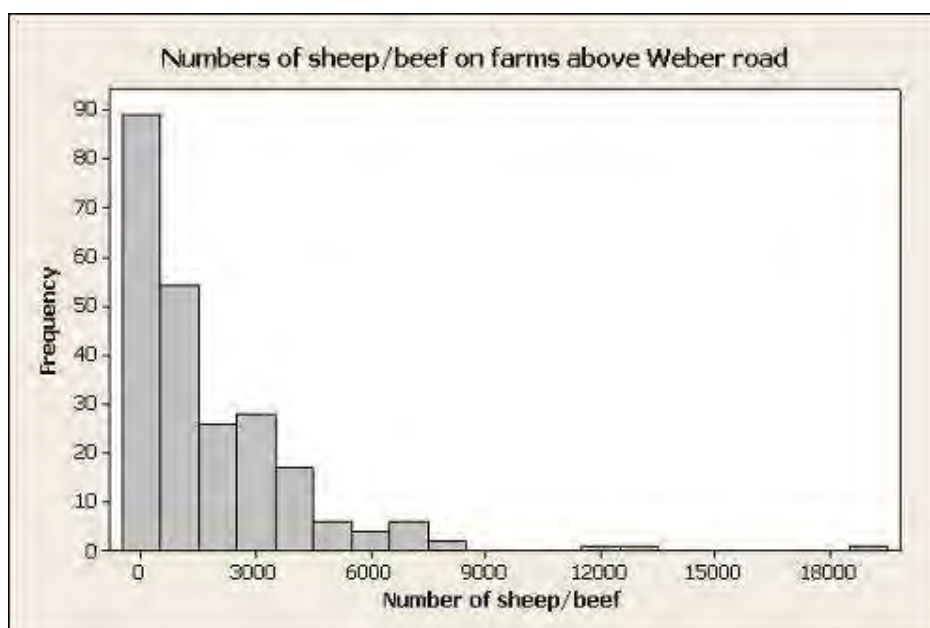


Table A1. Stocking density for dairy and sheep/beef farms above both Weber Road, and Hopelands in stock units (SU) per ha. We used the su-figures of sheep =1.0 SU, beef=4.84 SU, and dairy cows =6.43 SU (updated from MAF (1992) by Harry Clark, AgResearch, *pers. comm.*, and based on an annual dry matter intake of 550 kg SU⁻¹. The principles of this are used in Overseer®). The areas in Table 1 are not the same as those in this Table A1 due to incomplete Agribase™ data.

Area averaged stocking rates [SU/ha]	Above Weber road	Above Hopelands
Sheep/beef	9 (60,891 ha)	10 (28,692 ha)
Dairy	16 (6,020 ha)	16 (16,384 ha)
Both	9.6 (66,911 ha)	12.2 (45,076 ha)

A.1.2 Above Hopelands

We now present similar data for the sub-catchment above Hopelands, where we only consider the area upstream from Hopelands, and not extending past Weber Road.

There are 112 dairy farms in this Hopelands sub-catchment, and their median size is 115 ha (Figure A5). Although the distribution is positively skewed, it did test as being Gaussian. The distribution in the number of cows per farm (Figure A6) reveals that the median density of animals is 317 cows per farm. Both the farm sizes and stocking density are nearly identical to those found above Weber Road.

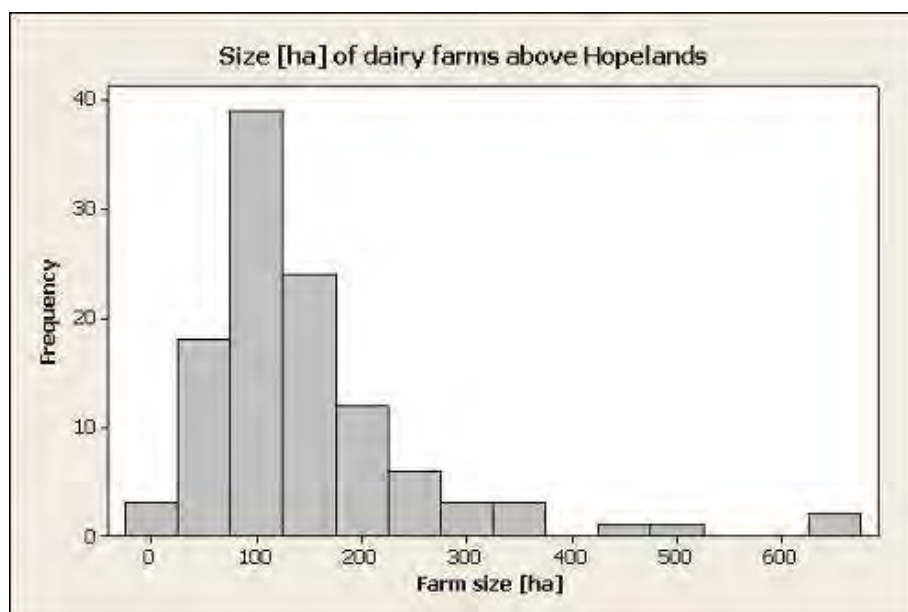


Figure A5. The frequency distribution of dairy farm sizes in the Hopelands sub-catchment.

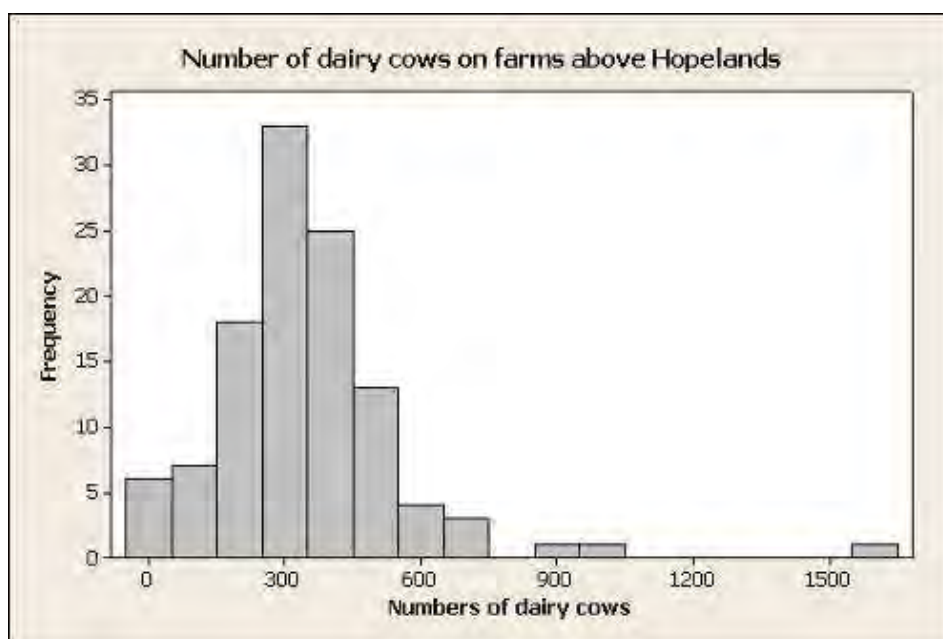


Figure A6. The frequency histogram of cow numbers per dairy farm in the sub-catchment above Hopelands.

Our non-parametric estimate of the average stocking rate of cows on these dairy farms is again 16 SU ha⁻¹ (Table A1). In this Hopelands sub-catchment there are 160 sheep/beef units which have the frequency distribution shown in Figure A7. The median farm size is now just 61 ha, which is less than half that of the Weber Road sub-catchment. The distribution of animals per farm for these sheep/beef units is shown in Figure A8, and the median stocking rate is just 250 animals per farm, well down on the figure of 924 above Weber Road. However, when an estimate is made of the average stocking rate (Table A1), the density is 10 su ha⁻¹.

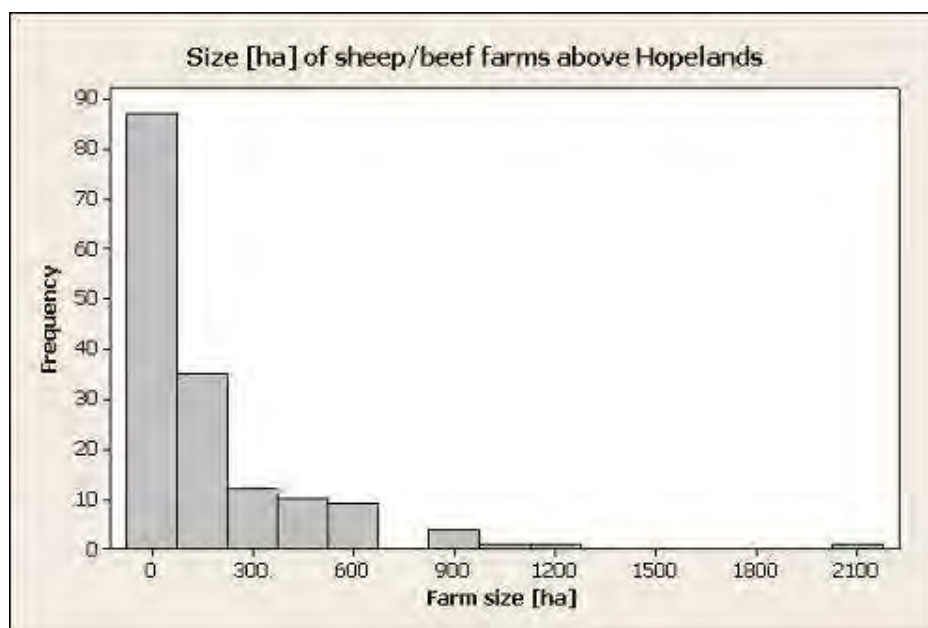


Figure A7. The frequency distribution of farm sizes for sheep/beef units above Hopelands.

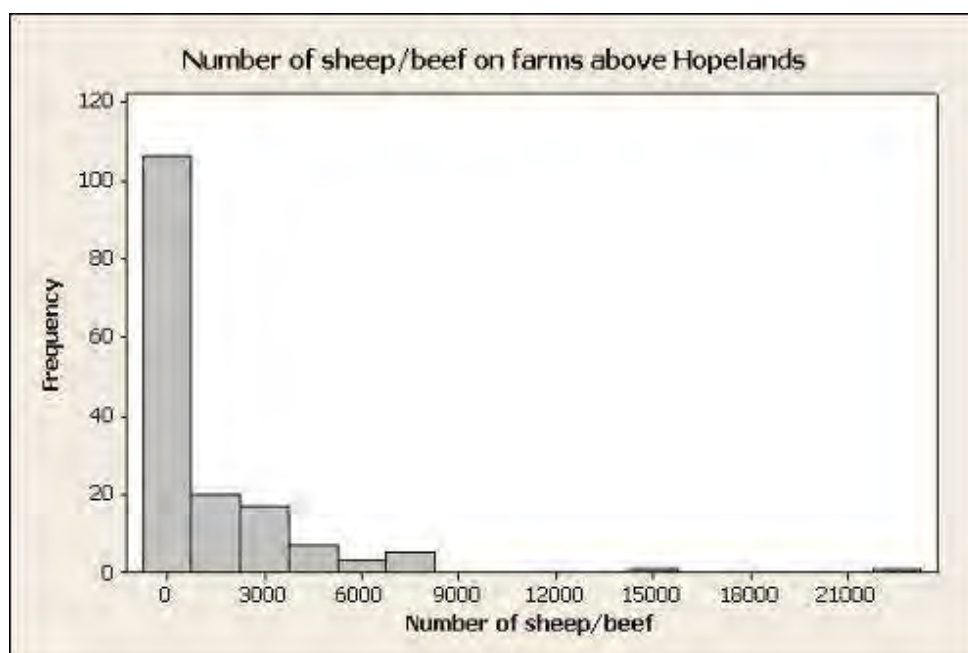


Figure A8. The frequency histogram of the number of animals per sheep/beef farm in the sub-catchment above Hopelands.

Appendix 2: Using Eq [5] Diagnostically and Predictively

An equation of the form of Eq [5] can be used diagnostically to explore the impact, in the river, of changes in landuse practices, and changes to the areas of various landuses.

Consider a hypothetical catchment of area A comprising only the landuses of dairying and sheep/beef:

$$A = A_d + A_{sb} \quad [6]$$

Therefore the annual loading of N in the river, using mass balance will be

$$Q = q_d A_d + q_{sb} A_{sb} \quad [7]$$

or when using transmission factors in a transfer-function scheme

$$Q = \mathfrak{R}_d q^* A_d + \mathfrak{R}_{sb} q^* A_{sb} \quad [8]$$

The fluxes q^* are obtained from Overseer[®] calculations (Eq. 3) so that

$$Q = \mathfrak{R}_d O^{-1}(L_d) A_d + \mathfrak{R}_{sb} O^{-1}(L_{sb}) A_{sb} \quad [9]$$

This equation provides us with a diagnostic means to use Overseer[®] calculations to explore the implications on river water quality, under the assumption that we have faith in our transfer-function approach, and the derived values of the transmission factors $\mathfrak{R}$.

A.2.1 Changing dairy practices

If the only change in a catchment were to on-farm practices in dairying, and that these resulted in changed losses predicted by the Overseer[®] calculations at 60 cm, q^* , then the change in loading in the river, Q , we would expect could be found from interrogation of Overseer[®] by using the partially differentiated form of Eq. [9]:

$$\frac{\partial Q}{\partial q^*} = \mathfrak{R}_d A_d \frac{\partial O^{-1}(L_d)}{\partial q^*} \quad [10]$$

where the term on the right of the right-hand side of Eq [10] could be found from Overseer[®] for the appropriate scenario. This necessarily assumes that the transmission factor, $\mathfrak{R}_d$, is unaffected by the change in farm practice. This highlights a limitation of the transfer-function approach, for it is non-mechanistic. But, with additional data, understanding could be gained as to how changes might affect $\mathfrak{R}_d$, if at all.

Here the differentiation was simply with respect to dairying practices, however, in a general sense it can be carried out in sum for changes in the practices for all the land-use types

A.2.2 Changing the area of either dairying, or sheep/beef in a catchment

A.2.2.1 Changing the area in dairying

In this simple case, we consider that there are only two landuses, dairying and sheep/beef, in this hypothetical catchment. By using Eq. [6], Eq. [9] can be re-written to eliminate explicitly the area in sheep/beef, as

$$Q = [\Re_d O^{-1}(L_d) - \Re_{sb} O^{-1}(L_{sb})] A_d + \Re_{sb} O^{-1}(L_{sb}) A \quad . \quad [11]$$

So, the impact in the river, Q , of a change in the area under dairying, A_d , without any change in farm management, would be obtained by partial differentiation of Eq. [9]:

$$\frac{\partial Q}{\partial A_d} = \Re_d O^{-1}(L_d) - \Re_{sb} O^{-1}(L_{sb}) \quad [12]$$

As with Eq. [10], the right-hand side can here be calculated using Overseer[®], again by assuming that the changed configuration of dairy farms has not altered $\Re_d$.

A.2.2.2 Changing the area in sheep/beef

In this simple case, the complement of the case above, we again consider that there are only two landuses, dairying and sheep/beef, in this hypothetical catchment. By using Eq. [6], Eq. [9] can, this time, be re-written to exclude explicit reference to the area in dairying, as

$$Q = [\Re_{sb} O^{-1}(L_{sb}) - \Re_d O^{-1}(L_d)] A_{sb} + \Re_d O^{-1}(L_d) A \quad . \quad [13]$$

So, the impact in the river, Q , of a change in the area under sheep/beef, A_{sb} , without any change in farm management, would be obtained by partial differentiation of Eq. [9]:

$$\frac{\partial Q}{\partial A_{sb}} = \Re_{sb} O^{-1}(L_{sb}) - \Re_d O^{-1}(L_d) \quad [14]$$

As with Eq. [10], the right-hand side can here be calculated using Overseer[®], again by assuming that the changed configuration of dairy farms has not altered $\Re_{sb}$.

There is, not surprisingly given that there are only two complementary farm types in this hypothetical catchment, a symmetry between Eqs 12] and [14]. For the UMWMZ, the values of the right-hand sides of Eqs [12] and [14] are given in the left-hand column of Table 3: $\Re_d O^{-1}(L_d) = 15.4 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$, and $\Re_{sb} O^{-1}(L_{sb}) = 3.9 \text{ kg-N ha}^{-1} \text{ yr}^{-1}$. So because of the greater N-leakiness of dairy systems (Table 5), an increase in the area of dairying in the UMWMZ, will degrade river-water quality by 11.5 (i.e. $15.4 - 3.9$) kg-N yr^{-1} for every hectare converted from sheep/beef. Conversely, because sheep/beef farms

are found to be less leaky, every hectare of dairying converted into sheep/beef in the UMWMZ will improve river-water quality by -11.5 (*i.e.* 3.9-15.4) kg-N yr⁻¹. We have carried out scenario analyses using this approach this in Section 2.7.3.

As noted in the section above, here the differentiation has been carried out for just dairying and sheep/beef, but it can be done for the mix and mosaic of all landuses.

A.2.3 Conclusions

This transfer-function approach provides:

- Incentive to collect data so that transmission factors can be calculated for various landuse types.
- A means for Overseer[®] calculations of farm losses to be linked to river water quality.
- A diagnostic tool to explore future impacts of changes in land use, and changes in farm management practices.

Appendix 3: Monitoring Devices – An option

We have suggested BMPs that are predicted by Overseer[®] to achieve a level of leachate loading at 600 mm in the soil to meet water quality standards in the river. It would, we consider, be prudent to try to monitor directly the loss of nutrients from the rootzone, even just to corroborate Overseer[®] predictions. New fluxmeters have, as a research tool made this possible. Van der Velde *et al.* (2005) recently described the use of fluxmeters on Tongatapu to monitor the loss of nutrients and pesticides from the soil to the fresh water lens under this raised coral atoll (Figure A9)

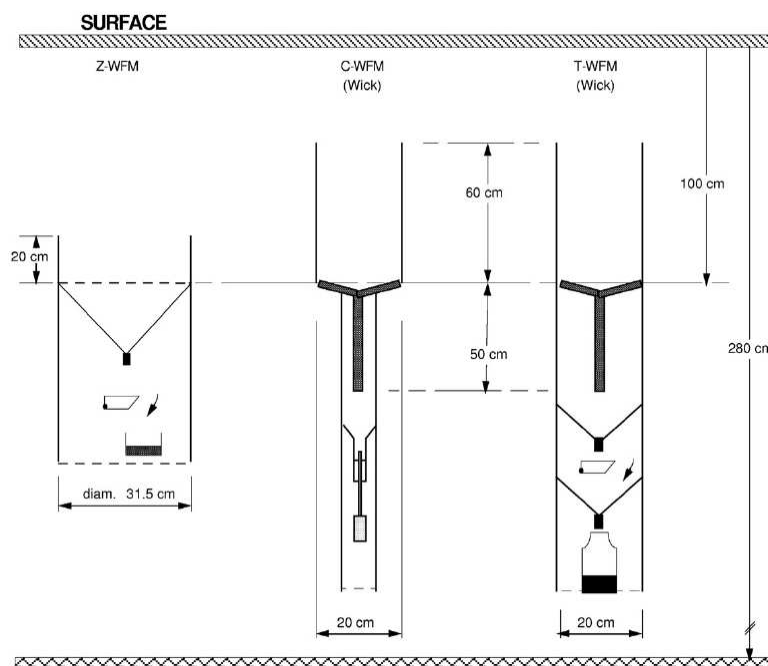


Figure A9. The three types of fluxmeters used by van der Velde *et al.* (2005) on Tongatapu to monitor the losses of nutrients and pesticides to groundwater

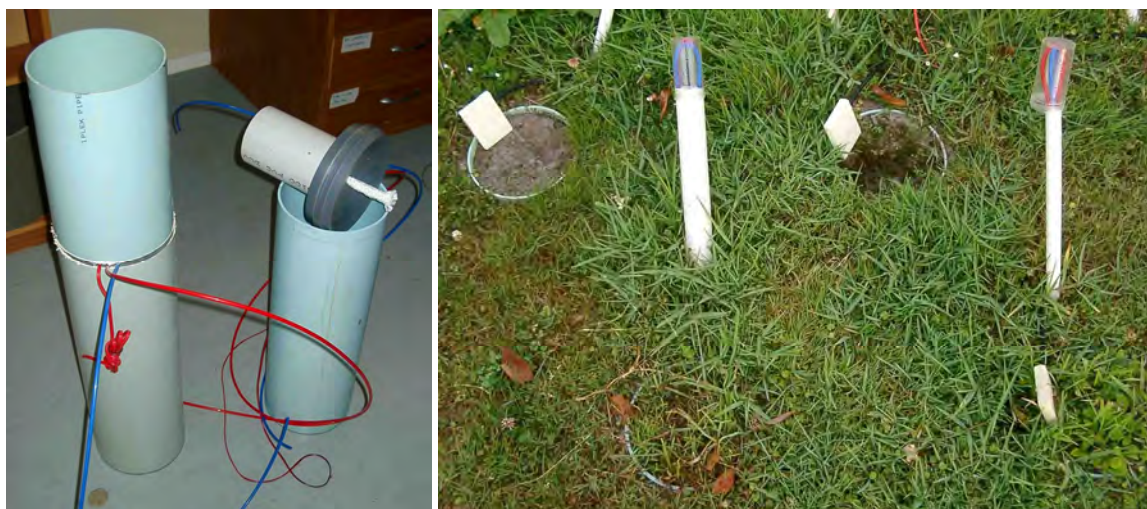


Figure A10. Examples of simple fluxmeters for collecting leachate (left), and their installation in an experiment (right) with soil of the row (upper 2) and inter-row of an orchard (lower 2.

We have also been using simple fluxmeters to monitor the losses of nutrients under a range of crops and pastures in New Zealand. The simple versions, without the tipping bucket to monitor the shape of the drainage 'hydrograph', can be constructed for about \$500 per unit. HortResearch have been carrying out experiments of N leaching under blueberries in the Taupo catchment using these devices. The land-owner is also a dairy farmer, and he has ordered 45 of these instruments so that he can install them himself, and monitor losses from his dairying operation. We understand that a fertiliser company will be used to analyse the leachate concentrations.

The total drainage, and its average solute concentration, can be recorded on, say, a monthly basis. This monitoring would provide a check on the Overseer[®] calculations, and could possibly even be used to refine further, in the field, best management practices, especially at times when leachate loss might be critical. It would be necessary to determine appropriate devices and sample numbers required if this approach was to be used for farm scale monitoring.

Appendix 4: Consultants reports

8 February 2007

AgResearch
C/- Alec MacKay
Private Bag 11008
PALMERSTON NORTH



11 Allardice Street
PO Box 232, Dannevirke, New Zealand
*64 6 374 6199 (tel)
*64 6 374 6189 (fax)
www.sheppardagriculture.co.nz

Dear Alec,

Re: The Average Sheep & Beef Farm

Further to our discussion yesterday I make the following notes:

With respect to the average sheep and beef farm, you are referring to those that feed into the Manawatu river catchment above (North) of the Hopelands bridge.

Generally speaking, this takes in an area bounded by the Waewaepa range in the east, Whetukura (north east), Norsewood to the north and the Ruahine range in the west.

Farm sizes vary considerably in this catchment from small (150-200ha) intensively farmed units to the much more extensive stations (2500-3000ha) in size).

In reviewing our Profit Check database and calling on my experience and clientele as a Farm Management Consultant, I believe the average sheep and beef farm in this region would be something like:

• Total area	425ha	
• Effective area	400ha	
• Carrying capacity	4000su (10su/ha)	
• Sheep:cattle ratio	70:30	
• Lambing percentage	115% MA ewes	
	20% ewe hoggets	
• Lamb weaning weight	27.5kg	
• Average lamb sale weight	31kg (early March)	
• Wool production	5.5kg/ssu	
• Calving percentage	88% MA cows	
	85% R2yr heifers	
• Calf weaning weight	210kg (mid April)	
• Soil fertility	Olsen P	14
	Potassium	8
	Calcium	8-10
	Magnesium	} have not really taken much notice of these
	Sodium	
	pH	5.6

- **Fertiliser use** Predominately superphosphate
180-200kg/ha (16-18kgP/ha)
On average 7kgN/ha.
- **Rainfall** Average 1200ml (range 900ml at
Hopelands to 1800ml; under Ruahine
Range).
- **Soil type** Generally derived from sedimentary parent
material. Soils are stronger/better
structured on Limestone and Greywacke
parent material.
- **Livestock policies** **Sheep:** Romney base breeding and some
lamb finishing.
Cattle: Breeding cows with some steer and
bull beef finishing.
- **Stock reconciliation**

MA Ewes	2250
Ewe Hoggets	660
Rams	30
Sheep Stock Units	2800
MA Cows	100
R2yr Heifers	25
R1yr Heifers	30
R1yr Steers/Bulls	75
Cattle Stock Units	1200
Total Stock Units	4000

I trust this précis of the "average" farm helps. If you require further information please feel free to call me.

Yours sincerely,



Greg Sheppard
Farm Management Consultant



John Simmonds
DairyTeam Consultant
348A Ruahine St
Palmerston North
Ph/fax 06 3533598
Mobile 0274 519 456

28 February 2007

Dr Alec Mackay
AgResearch Grasslands
Private Bag 11008
Palmerston North

DAIRY FARM IN THE UPPER MANAWATU (DANNEVIRKE DISTRICT)

My experience with this district comes from:

1. Working in the district as the Dexcel Consulting Officer from 1997 to 2004, facilitating 3 farmer Discussion Groups that covered approximately 50 dairy farms, and met about 8 times per year. Regular annual analysis of financial and physical data was collected from about 25% of these participants. The 2003/04 data was the last I collected.
2. Working as a private Farm Consultant since Feb 2006 on a monthly individual visit basis. I have 7 clients within the direct catchment's concerned (between Hopelands and Weber Road bridges) and a further 6 clients in the Norsewood and Woodville areas, which are still Manawatu River catchment. I have yet to complete a full dairy season with any of these clients but have some good indications what the statistics will be.

My brief is to describe the average dairy farm in the district, based on the above experience. There is considerable variation between the approx 80 farms so there is some professional guesswork in the following answers.

Farm Size:

About 390 cows milked at peak (Oct/Nov) on 138 hectares (effective in pasture). That is a stocking rate of 2.83 cows/hectare and would require a greater winter/calving number of about 410 cows.

Present Fonterra Fencepost data has 3.06 cows/ha as the stocking rate for district, but that is based on farmers' estimated numbers in winter, prior to calving, which has always overstated cow numbers.

There has been a significant number of split-calving winter milking dairyfarms in the Dannevirke district for about 20 years (more than 15 of the 80 farms in 2004) but most have switched to spring-calving only, seasonal supply as the Fonterra pricing premium is reduced. 1 of my clients still winter milks, and intends to cease within 2 winters.

All but 2 of my present clients have support land (runoffs), which average 40 hectares. About two thirds of these are within the district. This land usually grazes some replacement youngstock and dry cows, as well as providing silage to the milking area.

Milksolids Production:

In recent years these farms are averaging milksolids production (sold to the factory) about 360-370 kg/cow or 1000-1050 kg/hectare.

Imported Feeds:

While the farm systems are primarily pasture grazing, utilizing 11-12 tonne DM/ha/year, other feeds like maize silage, grass silage or concentrates have increased in contribution throughout the last decade. Such imports average about 1200 kgDM/ha annually. Most farms feed these and home made supplements on pasture. One third of my clients do have feedpad facilities, but I think that would be well above the district average.

An additional 1000 kgDM/ha as dry cow grazing is sourced away from the milking platform in winter (June/July). It is unusual to see all dry cows away, with maybe 1 cow/ha remaining grazing pasture at home during the dry period.

Most dairyfarms have no replacement youngstock "at home" after early December, another 2000 kgDM/ha sourced elsewhere.

I have no records how much of these feeds involve their own runoffs, but guess it may be half of it.

Soils & Soil Fertility:

About two thirds of the farms are on primarily free draining, shallow loam type soils over shingle subsoils. The remainder are on heavier soils, primarily the Matamau Silt loams. Soil tests would usually show levels of Olsen P 30, MAF K 6-8, Mg 10, and Ca 12.

Fertiliser inputs:

Annual fertilizer inputs typically would be 35kgP, 40kgK and 45 kgS per hectare per year as one dressing usually in late spring early summer. Fertiliser N has been about 120kg/ha/yr.

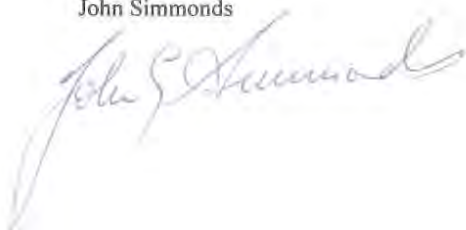
Effluent Disposal:

Most of these farms spray effluent onto pasture daily while milking, with traveling irrigators. The regulation is 4 hectares per 100 cows and I think many would cover a slightly greater number of hectares.

I trust this information is of assistance to you.

Yours Faithfully

John Simmonds



Appendix 5: The Nitrogen Reports from the Overseer[®] for leaching predictions

The information is contained in a separate file called Appendix 5.pdf

Appendix 6: Defining nutrient (nitrogen) loss limits within a water management zone on the basis of the natural capital of soil

The information is contained in a separate file called Appendix 6.pdf

Appendix 6

Defining nutrient (nitrogen) loss limits within a water management zone on the basis of the natural capital of soil

An appendix to the Farm Strategies for Contaminant Management report by SLURI, the Sustainable Land Use Research Initiative for Horizons Regional Council

Project Team

Andrew Carran (AgResearch)
Brent Clothier (HortResearch)
Alec Mackay (AgResearch)
Roger Parfitt (Landcare Research)

Contact: Alec Mackay alec.mackay@agresearch.co.nz

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Executive summary

- Current nitrogen (N) loadings in the Upper Manawatu River and Mangatainoka are more than twice the water quality standard set for each Water Management Zone (WMZ) by Horizons Regional Council in consultation with community.
- Horizons Regional Council have good data sets on the contribution of point-source N loadings to these two rivers and in a recent study “Farm strategies for contaminant mitigation” for Council by SLURI a direct link between land use and management decisions as it influences N losses and loadings in the Upper Manawatu river were established.. That study found significant reduction in the N loading could be achieved by a focus on intensive dairy operations.
- In a debrief with the Council’s Research and Policy Teams on the findings in the draft report the observation was made that limiting policy development to existing intensive land uses, which includes cropping, market gardening, dairy and irrigated intensive sheep and beef, would result in improves to water quality, only if there was no further expansion of intensive land uses in the balance of the catchment. Any policy approach would therefore need to consider all land in the catchment from the outset.
- In this appendix to the “Farm strategies for contaminant mitigation” report, a number of catchment based approaches for achieving the water quality standard are identified and discussed. They included: capping current production systems, placing a limit on nutrient losses from intensive land uses, calculating an average nutrient loss limit for each hectare of land in the catchment, or allocating a nutrient loss limit for each hectare of land based on the biophysical potential of natural capital of the soil.
- Of the approaches listed, **allocating the nutrient loss limit based on the natural capital of the soil in the catchment** offered a basis for developing policy that is linked directly to the underlying natural biophysical resources in the catchment. It is independent of current land use and places no restrictions on future land-use options. It also provides all land users in the catchment with certainty by defining a nutrient loss limit based on the suite of soils they own, beyond this resource consent would be required and that includes a nutrient budget and mitigation strategy.
- The **Nitrogen (N) loss limit** is defined as the amount of N lost by leaching from the soil growing a legume based pasture fixing N biological, under optimum pastoral management (optimum grazing practice, Olsen P in optimum range, etc), before the introduction of additional technologies (N fertilisers, effluent and manures, intensive cropping, irrigation, etc). To calculate the N loss limit for a landscape unit, the values for attainable potential livestock carrying capacity for in a legume based pasture under optimum pastoral management, before the introduction of additional technologies listed in the extended legend of the Land use capability (LUC) worksheets are transformed to pasture production and used in OVERSEER® to calculate N leaching loss under a pastoral use.
- This new and novel natural-capital based approach was tested in two catchments (Upper Manawatu and Mangatainoka) using average data from the extend legend of the North Island LUC worksheets. At the farm scale the N-loss limit could be calculated using the information in the New Zealand Land Resource Inventory (NZLRI), or from information obtained from on-farm mapping. The approach offers the potential to utilise site specific information, including soil type, drainage class, landscape type and geo-spatial position, along with local rainfall to inform the calculations in OVERSEER®.
- To inform future debate and assist in refining current policy using this approach the following issues require further examination including a review of natural resource

based policy initiatives elsewhere in the world, the potential for using the approach as a trading scheme, testing of the approach with landowners in the region operating a range of intensive land uses in catchment with different geophysical configurations, the influence of the resolution of land based information on the calculated values, an examination of the efficiency of resource use when allocating nutrient loss limits based on the soils natural capital and the availability of and effectiveness of mitigation options to land owners farming landscapes with different potentials and limitations to use.

- We consider that this capital based approach to managing nutrient is a new methodology that should be at the forefront of sustainable development. We believe that the resilience of our future land-use production systems will be measured on their sustainable exploitation of natural capital, whilst minimising external cost to the environment. This approach in whatever final form it takes will achieve wins both way: productivity and protection.

1. Background

Current nitrogen (N) loadings in the Upper Manawatu River and Mangatainoka are more than twice (744,000 and 518,000 kgN/yr, respectively) the N limits (341,000 and 238, 000 kgN/yr, respectively) set based on recommended standards for the Notified standards in the One Plan. To be in a position to develop a water management action plan, the point and non-point source N loadings into the river have to be established as the first step in managing down these nutrient loadings.

Horizons Regional Council have good data sets on the contribution of the major point source N loadings to the river and in a recent study conducted by SLURI the contribution of non-point source N loading from dairy and sheep and beef in the Upper Manawatu catchment were established. In that study the N loss in the river from the average dairy farm was found to amount to 15.4 kg/ha/yr. For sheep and beef the N loss was much smaller 3.9 kg/ha/yr. Over 90% of the total N in the river is from these two non-point sources, with dairy contributing about half of the N loading in the river, despite only representing 16% of the land use in the catchment.

The N loss from the average dairy farm calculated using OVERSEER® in the Upper Manawatu catchment was found to be 31 kgN/ha/yr, and for the average sheep and beef farm 7 kgN/ha/yr. By using a nitrogen transmission co-efficient of 0.50 for both dairying and sheep and beef operations, a direct link could be made between land use and management decisions as it influences N losses and loadings in the river.

In the short-term, significant reductions in the N loading in the river could be achieved by a focus on intensive dairy operations, as existing mitigations options offer the potential to reduce N losses by up to a third on the average dairy farm. While this approach offers a short-term policy option for Horizons Regional Council, it is based on the assumption that there will be no further conversion of sheep and beef to more intensive land uses (e.g. cropping, market gardening, dairy) or any further intensification of sheep and beef sector, all of which have the potential to increase the N loading in the river. Any policy approach will therefore need to consider all land owners in the catchment from the outset for a long-term water management action plan to achieve the goals of the community.

2. Options for achieving the water quality standard

There are a number of approaches Horizons Regional Council could use to achieve the water quality standard, including;

1. Capping current production systems and nutrient (e.g. nitrogen) losses.

Manage down regardless of N losses from individual farms, as is the case currently under consideration for the Taupo catchment.

2. Place a limit on the losses of nutrient (e.g. nitrogen) from intensive land uses

Place restrictions of any further intensification, or require mitigation practices as an integral part of any ongoing land development.

3. Calculate a nutrient (e.g. nitrogen) leaching loss limit for each ha.

Using OVERSEER® to achieve the water quality standard and apply equally to each land owner. For the Upper Manawatu WMZ this would be 6.5 kgN/ha (Calculation = 341,000 kgN/yr divided by 130,000 ha Transmission co-efficient = 0.50). At current loading the average loss per ha is 15 kgN/ha.

4. Allocate a nutrient (e.g. nitrogen) loss limit based on the biophysical potential of natural capital of the soils.

Option 1 favours, on one hand, the existing intensive land users and penalises land owners as yet not fully developed. It locks in the current land use pattern, and has the potential to limit future land use change.

Option 2, like 1, has a focus on limiting/controlling N loss by regulating land use. It would require a tight definition of intensification and a detailed description of each land use.

Option 3 fails to recognise that soils differ in their properties. Some soils will have very low N leaching losses because of physical limits to production (e.g. LUC VII).

Option 4 does not target a land use, intensity of use, or place a limit on production. Rather it allocates a nutrient (N) loss limit to each landscape unit based on the biophysical potential of natural capital of the soils.

3. Option 4. Nutrient loss limit based on the natural capital of the soil

Allocating a nutrient loss limit based on the natural capital of the soil in the catchment offered an approach for developing policy that is linked directly to the underlying natural biophysical resources in the catchment. It is independent of current land use and places no restrictions on future land use change or options. It does provide all land uses in the catchment with certainty by defining a nutrient loss limit, beyond which a resource consent would be required, that included a nutrient budget and mitigation strategy. It is not too dissimilar to the concept of a water use take limit.

The nutrient (e.g. nitrogen) loss limit is defined as the amount of N lost by leaching from the soil growing a legume-based pasture fixing N biological, that is under

optimum management (optimum grazing practice, Olsen P in optimum range, etc), before the introduction of additional technologies (N fertilisers, effluent and manures, intensive cropping, irrigation, etc). A legume based pasture system is self-regulating biological process with an upper limit on the amount of N that can be fixed and made available for plant growth and the environment. Potential production therefore reflects the underlying capacity of the soil to produce and cope.

To calculate the N loss limit for a given landscape unit, the potential animal stocking rate that can be sustained by a legume-based pasture fixing N biologically, under optimum management, before the introduction of additional technologies, listed in the extended legend of the LUC worksheets “Attainable potential livestock carrying capacity” are transformed to pasture production and used in OVERSEER® to calculate N leaching loss under a pastoral use.

By linking N loss limits to each landscape unit the difficulties associated with having to define land use (i.e., Option 1 and 2) is avoided. This approach recognises soils differ in their productive capacity. Technologies used to lift production beyond that of a legume based pasture (N fertiliser, Irrigation, Supplement) would require the use of mitigation practices to prevent any further increases in N leaching losses. Option 3 fails to recognise that soils differ in their properties. Some soils will have very low N leaching losses because of physical limits to production (e.g. VIII). Another potential advantage of Option 4 is that in catchments with no water quality problems at the present time, land owners can be provided with an indication of the level of production and associated nutrient losses they can reach, before mitigation practices would become an integral part of ongoing farming practices.

4. Case studies

Option 4 is explored more in two case studies; the Upper Manawatu and Mangatainoka catchments. For this exercise the natural capital of the soils in the catchment, is calculated from the potential stocking rate that could be sustained by a well managed legume based sward, taken from the extended legend of the LUC worksheets “Attainable potential livestock carrying capacity” for the North Island. The potential livestock carrying capacities were transformed to pasture production and used in OVERSEER® to calculate N leaching losses under a pastoral use. The N losses by leaching calculated from OVERSEER® summarised for LUC class I-VII for the North Island and used in the Upper Manawatu and Mangatainoka catchment case studies are presented in Fig. 1. As the limitations to use increase (i.e. Class I to VII) the underlying capacity of soil to sustain a legume based pasture system declines, as does the potential N loss by leaching.

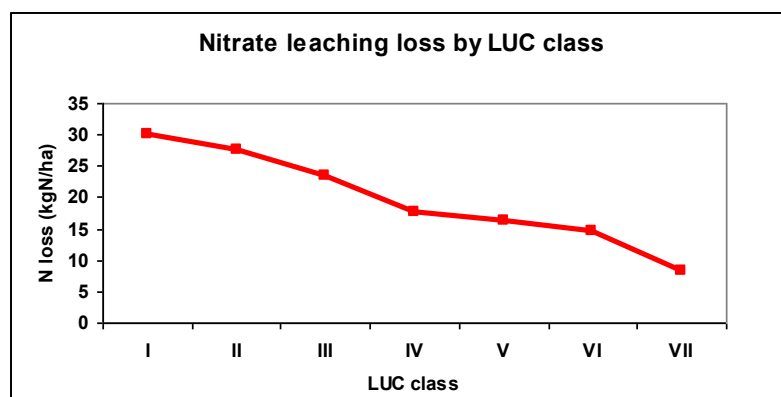


Fig.1 Nitrate leaching loss calculated using OVERSEER (Developed dairy operation, Annual rainfall 1200 mm) associated with the potential livestock carrying capacity of listed in the extended for LUC class I-VII in the North Island.

4.1. Upper Manawatu Catchment

The landscape in the Upper Manawatu catchment is dominated by Class VI, with sheep and beef the dominant land use, in particular in the catchment above Weber Road.

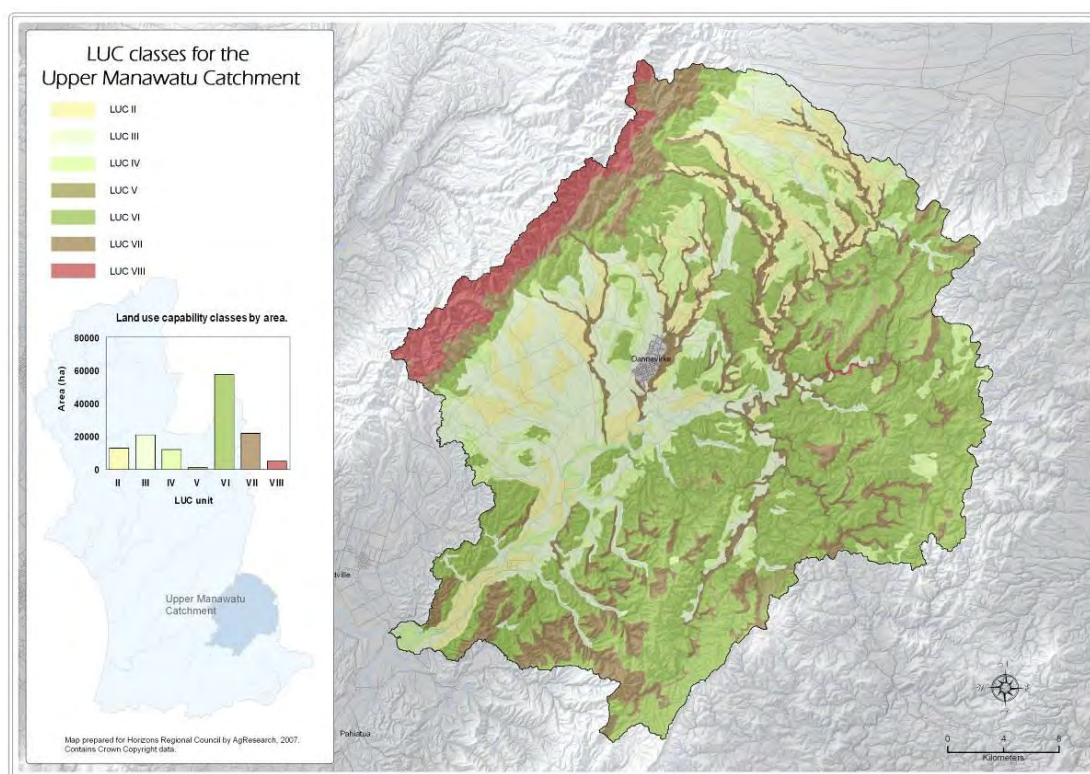


Fig.2 LUC classes for the Upper Manawatu.

If all the soils in the Upper Manawatu catchment were farmed at 90% of potential as listed in the extended legend, and assuming a transmission coefficient of 0.5 for all

land classes, the N loading in the river would be 921 tonnes annually. This is higher than current loadings in the river.

LUC class	Area (ha)	N Loss based on potential production (kgN/ha/yr)	Fraction of potential	Nitrate Loss limit kgN/ha/yr	Transmission Co-efficient	Total N loading in river (kgN/yr)
II	12424	27.4	0.9	24.7	0.5	153348
III	20257	23.5	0.9	21.1	0.5	213978
IV	11508	17.5	0.9	15.8	0.5	90729
V	907	16.3	0.9	14.7	0.5	6666
VI	57254	14.5	0.9	13.1	0.5	373897
VII	22108	8.3	0.9	7.5	0.5	82431
VIII	5180	0.0	0.9	0.0	0.5	0
Total	129638					921049

Table 1 Area of each LUC class, calculated N loss associated with the potential productivity of the soils in each LUC class using Overseer and the contribution of the soils in each LUC to the N loading in Upper Manawatu river and average N loss per ha per yr if each LUC is farmed at 90% of potential.

The calculation in Table 1 was limited to the use of the potential for the “average” soil in each LUC class. The approach offers the potential to utilise site specific information, including soil type, drainage class, landscape type and geo-spatial position within the extended legend, along with rainfall to inform OVERSEER®. This would increase the accuracy of the calculated values.

LUC class	Area (ha)	N Loss based on potential production (kgN/ha/yr)	Fraction of potential	Nitrate loss limit kgN/ha/yr	Transmission Co-efficient	Total N loading in river (kgN/yr)
II	12424	27	0.75	20.6	0.5	127790
III	20257	23	0.75	17.6	0.5	178315
IV	11508	18	0.75	13.1	0.5	75608
V	907	16	0.75	12.3	0.5	5555
VI	57254	15	0.75	10.9	0.5	311580
VII	22108	8	0.75	6.2	0.5	68693
VIII	5180	0	0.75	0.0	0.5	0
Total	129638					767541

Table 2 Area of each LUC class, calculated N loss associated with the potential productivity of the soils in each LUC class using Overseer and the contribution of the soils in each LUC to the N loading in Upper Manawatu river and average N loss per ha per yr if each LUC is farmed at 75% of potential.

When the fraction of potential production is limited to 75% on all LUC classes, the N at the farm scale and the resulting N load in the river are very close to the present loading. If the short-term goal was to prevent any further increase in the N loading in the river the N loss values in column 5 provides an N loss limit, before requiring the introduction of a mitigation practice. If the long-term goal is a reduction on the

current N loading in the river, then an adjustment can be made to the fraction of potential production that is permissible, before a mitigation strategy must be initiated. The major strength of this approach is that in calculating the limit it considers the whole catchment. Further it is not prescriptive, but rather places a limit on the emission, or farm loss, above which a mitigation practice must be employed, rather than an input cap. The approach also offers the opportunity to engage directly and in a very transparent way with land owners and the wider community in setting the targets, without being prescriptive.

4.2. Mangatainoka catchments

The Mangatainoka catchment has 18,500 ha of Class I-IV and the balance is Class VI-VIII. Dairying covers approx. 14,500 ha and sheep and beef approx. 22,823 ha. The average rainfall used in the following calculation was 1600 mm

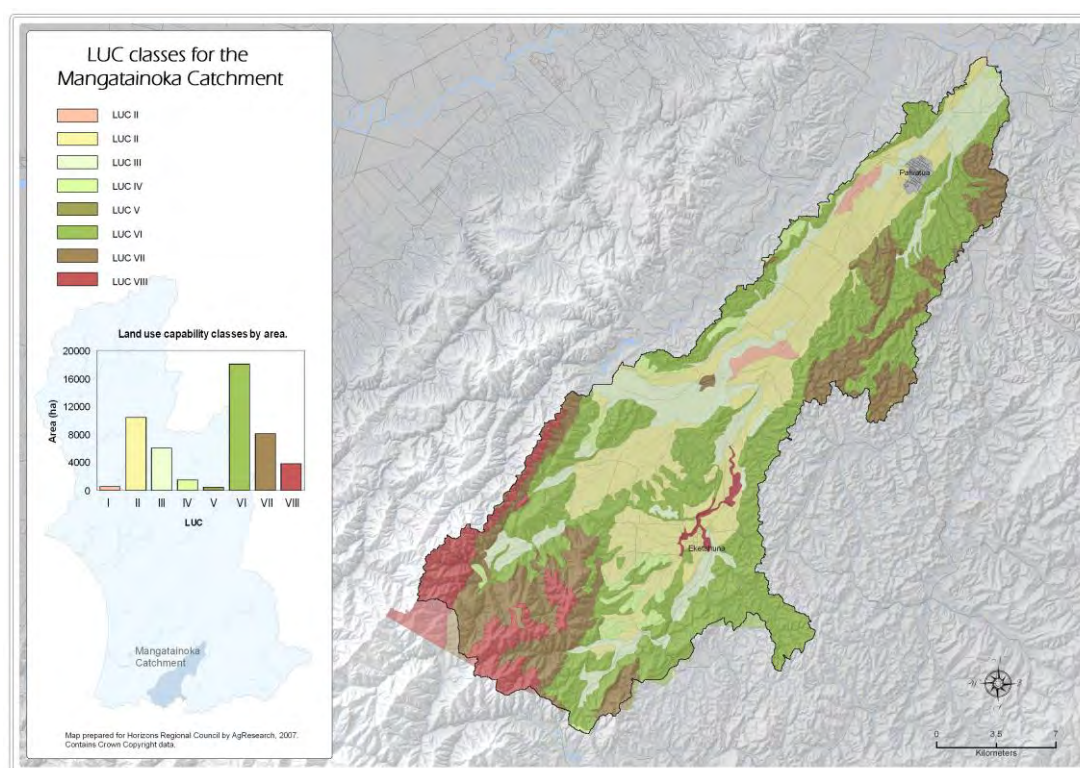


Fig.3 LUC classes for the Mangatainoka.

In the following analysis the calculated N loss for the “average” soil in each LUC class used in the Upper Manawatu analysis was used in the Mangatainoka catchment, despite the average rainfall in the catchment being 250-400 mm higher than in the Upper Manawatu.

LUC class	Area (ha)	N Loss based on potential production (kgN/ha/yr)	Fraction of potential	Nitrate loss limit kgN/ha/yr	Transmission Co-efficient	Total N loading in river (kgN/yr)
I	549	30	0.90	27	0.5	7412
II	10,394	27	0.90	25	0.5	128292
III	6,074	23	0.90	21	0.5	64161
IV	1,498	18	0.90	16	0.5	11810
V	409	16	0.90	15	0.5	3006
VI	18,110	15	0.90	13	0.5	118267
VII	8,057	8	0.90	7	0.5	30041
VIII	3,874	0	0.90	0	0.5	0
Total	48965					362988

Table 3 Area of each LUC class, calculated N loss associated with the potential productivity of the soils in each LUC class using Overseer and the contribution of the soils in each LUC to the N loading in Upper Manawatu river and average N loss per ha per yr if each LUC is farmed at 90% of potential.

Using these values when all the soils in the Mangatainoka are farmed at 90% of potential as listed in the extended legend and assuming a transmission coefficient of 0.5 for all land classes the N loading in the river would be 363 tonnes. This is much lower than the current N loadings in the river, reflecting in part the use of average N loss values in the calculation. These analysis need to be run with N losses calculated for this environment.

LUC class	Area (ha)	Nitrate Loss based on potential production (kgN/ha/yr)	Fraction of potential	Nitrate loss limit kgN/ha/yr	Transmission Co-efficient	Total N loading in river (kgN/yr)
I	549	30.0	0.75	23	0.5	6176
II	10,394	27.4	0.75	21	0.5	106910
III	6,074	23.5	0.75	18	0.5	53467
IV	1,498	17.5	0.75	13	0.5	9842
V	409	16.3	0.75	12	0.5	2505
VI	18,110	14.5	0.75	11	0.5	98556
VII	8,057	8.3	0.75	6	0.5	25034
VIII	3,874	0.0	0.75	0	0.5	0
Total	48965					302490

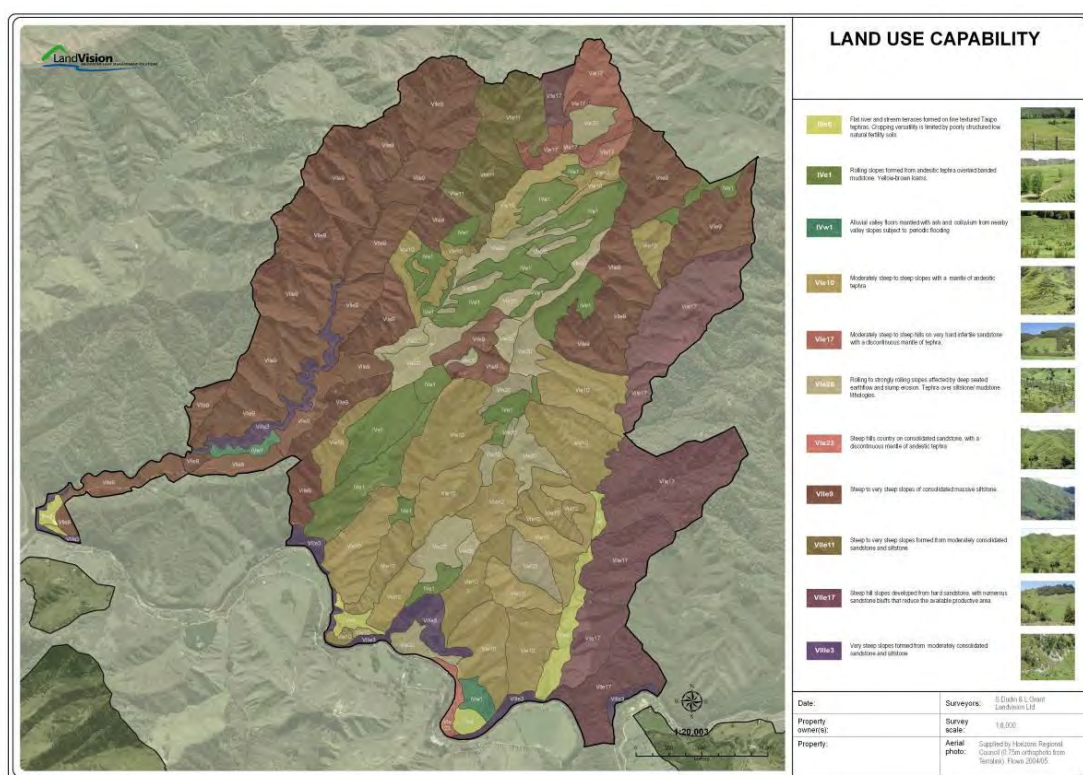
Table 4 Area of each LUC class, calculated N loss associated with the potential productivity of the soils in each LUC class using Overseer and the contribution of the soils in each LUC to the N loading in Upper Manawatu river and average N loss per ha per yr if each LUC is farmed at 75% of potential.

When the fraction of potential is reduced to 75% then the loadings are approaching the long-term N loading for the river.

5. Calculating the N loss limit on-farm

At the farm scale, the N loss limit could be calculated using the information in the NZLRI, or from information obtaining from on-farm mapping (Fig. 4). Horizons Regional Council has a copy of the NZLRI in its data base, so individual landowners could request the required information for their land holdings. This input data is required in OVERSEER to calculate the N loss limit for that land holding.

Recognising the NZLRI was designed to provide an indication of the distribution of soils at the district, rather than the paddock scale, it could be used as a first approximation, with the land owner having the opportunity to obtain a more detailed soil map and calculating N loss limits from the paddock scale information, along with local rainfall data if available.



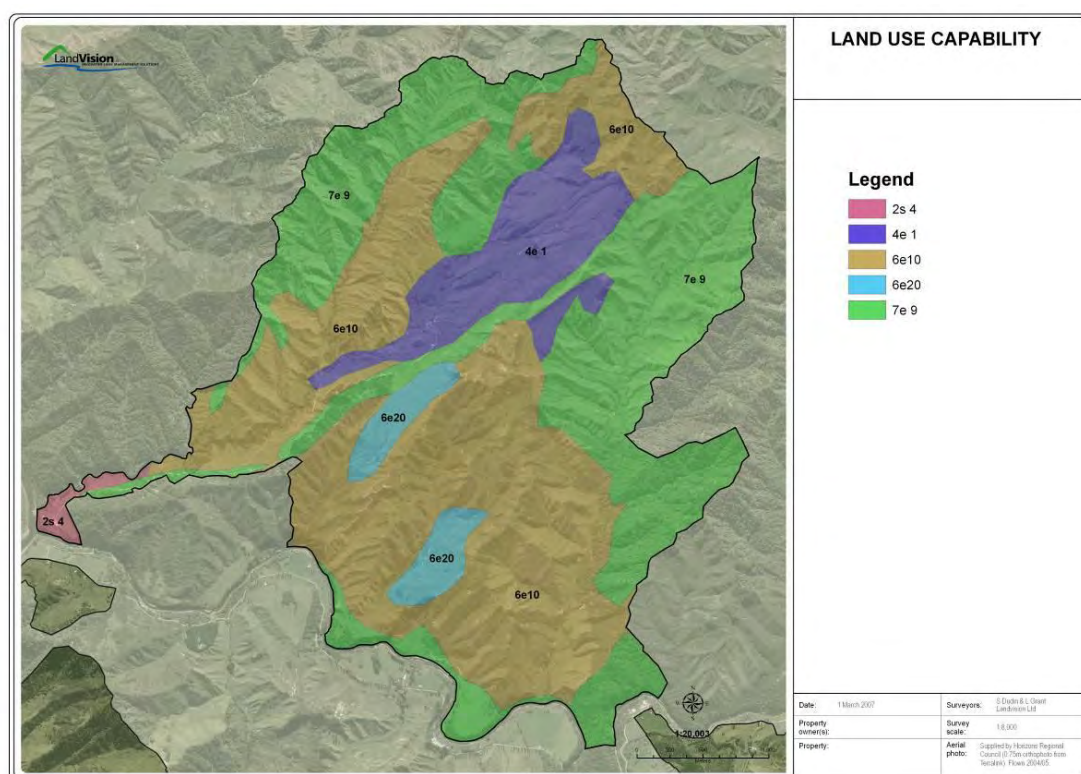


Fig.4 LUC units for a farm mapped at the paddock scale (top) and taken from the NZLRI (bottom).

6. Next step

The approach of allocating **nutrient loss limit based on the natural capital of the soil in the catchment** offers a basis for developing policy that is linked directly to the underlying natural biophysical resources in the catchment, irrespective of current land-use or future options. We stress that this is independent of current land use and places no restrictions on future land use options. It provides all land users in the catchment with certainty by defining a nutrient loss limit based on the suite of soils they own, beyond which resource consent would be required, that included a nutrient budget and mitigation strategy. The approach offers the opportunity for innovation and to engage directly and in a very transparent way with land owners and the wider community in setting the targets

To inform future debate, and assist in refining current policy using this approach, the following issues require further examination including a review of natural-resource based policy initiatives elsewhere in the world. There is the potential for using the approach as a trading scheme, testing of the approach with landowners in the region operating a range of intensive land uses in catchment with different geophysical configurations, assessing the influence of the resolution of land based information on the calculated values, an examination of the efficiency of resource use when allocating nutrient loss limits based on the soils natural capital and the availability of and effectiveness of mitigation options to land owners farming landscapes with different potentials and limitations to use.

He we suggest in more detail what might, in bullet form, be worth assessing

6. 1. Policy development

- Explore the extent to which natural resource based approaches have been used internationally to address nutrient management?
- Examine the literature and review other natural resource based policy approaches for defining N loss limits.
- Include as part of the analysis a comparison of output and input policy based approaches to nutrient management
- Examine the potential for the approach to be used as part of a trading scheme within the water management zone.
- Determine ability to incorporate into the rule more detailed information in the extended legend (e.g. soil type, drainage class, rainfall, distance from water courses, etc).

6. 2. Testing of the approach

- Engage three intensive farming businesses and assess the impact of the approach on the economics of the business. Assess the acceptability to the land owner by building detailed nutrient plans for their farms, from both the NZLRI data base and from farm scale resource mapping
- Test the approach in some other catchments in the region
- Examine the following scaling issues at farm and catchment scale.
 - Average versus site specific data (soils, rainfall, etc)
 - NZ LRI versus paddock mapping (3 case studies Class I-III, II VI and VI-VII)
 - Impact of the LUC handbook update
- Examine the impact of extreme events (Flooding, drought, etc).
- Spatial tools for rainfall, LUC and presentation of OVERSEER® output.

6.3. Allocation of rights

- Explore the efficiency of resource use by soil within each LUC class E.g. Production(kg and \$) per unit N lost
 - Should the loss limit be weighed equally across all soil units to the same degree?
- List the mitigation options (types and cost benefits) available by soil within each LUC class. Land owners on soils in class I have more mitigation options than those of land class with limitations to use, should the weighting on the loss limits reflected the greater flexibility that affords land owners on that land class?

7. Conclusion

We consider that this capital based approach to managing nutrient is a new methodology that should be at the forefront of sustainable development. We believe that the resilience of our future land-use production systems will be measured on their sustainable exploitation of natural capital, whilst minimising external cost to the environment. This approach in whatever final form it takes will achieve wins both way: productivity and protection.

Appendix 4

Implementation of FARM Strategies for Contaminant Management Further
questions, SLURI for Horizons Regional Council July 2008



Farming, Food and Health. **First**

Te Ahuwhenua, Te Kai me te Whai Ora. Tuatahi

Implementation of FARM strategies for contaminant management Further questions

A report by SLURI for Horizons Regional Council

July 2008



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Implementation of FARM strategies for contaminant management

Further questions

A report by SLURI - The Sustainable Land Use Research Initiative for Horizons Regional Council

July 2008

Project team:
Alec Mackay (AgResearch)
Brent Clothier (HortResearch)
Ross Gray (AgResearch)
Steve Green (HortResearch)

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Executive Summary

At the request of Horizons Regional Council, New Zealand's multi-CRI Sustainable Land Use Research Initiative has addressed a number of questions arising from the One Plan proposed approach to *FARM strategies for contaminant management*.

The questions and a summary of our responses are listed below.

1. Determine ability to incorporate into the rule more detailed information in the extended legend (e.g. soil type, drainage class, rainfall, distance from water courses, etc)?

1.1 How does the detailed subclass approach versus the broader scale LUC class approach compare for water quality outcome?

The use of detailed resource information provides more precision in the quantification of the potential N loss limit from each of the landscape units that make up the water management zone.

1. As a general rule on flat and rolling landscapes within a catchment, which also includes hill and steep land, adding more detailed biophysical information, assuming the same attenuation factor from land to river for all land units, will **reduce** the calculated N leaching loss and loadings into the river from soils as a consequence of the

- inclusion of **less** versatile soils identified by more detailed mapping
- use of actual rainfall, which is often **lower**, than the catchments average rainfall
- **low** slope classes

Inclusion of soil drainage class would either increase or reduce the calculated N leaching loss

2. As a general rule in hill and steep land within a catchment which also includes flat and rolling country, adding more detailed biophysical information, assuming the same attenuation factor from land to river for all land units, will **increase** the N leaching loss and loadings into the river from soils as a consequence of the

- inclusion of **more** versatile soils identified by more detailed mapping
- use of actual rainfall, which is often **higher**, than the catchments average rainfall
- **higher** slope classes

Inclusion of soil drainage class would either increase or reduce N leaching loss.

It follows that policy implemented to manage N leaching losses from these landscapes would also be more effective in achieving the goal if aligned with **more detailed** biophysical information.

We recommend that this forms the basis on which policy is based and the basis on which the N leaching loss limits are set for soils in the catchment.

It is important to remember inclusion of more detailed soil, landscape and climate information is about obtaining a more accurate description of the factors contributing to N leaching and loading in the river, and not about defining the N loading in the river. The latter is achieved by defining the fraction of potential attainable production of the land that can be farmed while still achieving the water quality outcome targets for that water body.

We recommend that land owners have the option of calculating their N leaching loss limit from the NZLRI and banded rainfall values for the Upper Manawatu Catchment or from more detailed biophysical resource information (e.g. Soil type, slope, drainage class, climate data, production potential) to address two key issues, spatial inaccuracies in the rainfall database and the uncertainty surrounding the N leaching loss at high rainfall.

Note. We suggest that summary tables containing the averaged N leaching loss limits aggregated for the major soil types grouped into LUC classes are produced for each of the priority catchments. Detailed N leaching loss limits for each polygon within the catchment, would be available within a GIS environment. Further, an independent facility would be available for land owners to calculate their N leaching loss limit using either average or detailed spatial datasets.

1.2 The same numbers across the region are used for LUC class output: Is it necessary to tailor this on a catchment by catchment basis in terms of water quality outcome and farming systems parameters in that catchment (rainfall soils etc). Compare for the Mangatainoka the water quality outcome and the upper Manawatu

We recommend that the N leaching loss limits for the soils are calculated for each water management zone because

1. Current and future water quality targets for each water management zone (catchment) will vary across the region.
2. Each water management zone (catchment) is a unique mix of soils, landscapes and rainfall zones. Not only will the types and total numbers of landscape units differ across the catchment, all of which influences the amount of N leached, but the area distribution of

each land unit and thus contribution to the N loading in the river will also vary between catchments.

Also see response to question 4.

1.3 Impact of the LUC handbook update

The updated LUC handbook, which has support from Regional Councils throughout the country, will have a number of positive impacts including the raising of the profile of the approach for describing and classifying our landscapes, provision of an updated and more user-friendly manual for LUC mapping that also addresses a number of inconsistencies within the current handbook.

The update of the LUC handbook will not change the information contained in the extended legends of the LUC worksheets or its interpretation when calculating the N leaching loss limit from a soil.

The soil data in the extended legend of the LUC worksheets offers a very useful framework for placing the soils of the catchment into groups based on their physical integrity, versatility and productive potential. Looking to the future, evolving the classification of the natural capital of soil beyond LUC groupings, would add clarity to both industry and policy by providing a clear link between the bio-physical and chemical attributes of the soil and production and nutrient and water regulation.

We recommend that additional work is commissioned (Envirolink tools) to explore the options for developing a new approach to describe soil services and to quantify the natural capital value of soils.

2. Explore the efficiency of resource use by soil within each LUC class e.g. Product/ unit N lost.

2.1 Should the loss limit be weighted equally across all soil units to the same degree?

With the question limited to “What is the most efficient use of resources, with the **least environmental impact**” the N leaching loss limit should be weighted towards those soils with the **greatest natural capital**.

2.2 List the mitigation options (types and cost benefits and dollars) available by soil within each LUC class.

Mitigations options for reducing N leaching losses from pastoral soils are listed in the *Farm Strategies for Contaminant Management* report prepared by SLURI for Horizons Regional Council (Clothier et al., 2007) and in a report by AgResearch (Wedderburn, 2008). Both reports contain a commentary on the cost-effectiveness of each mitigation option.

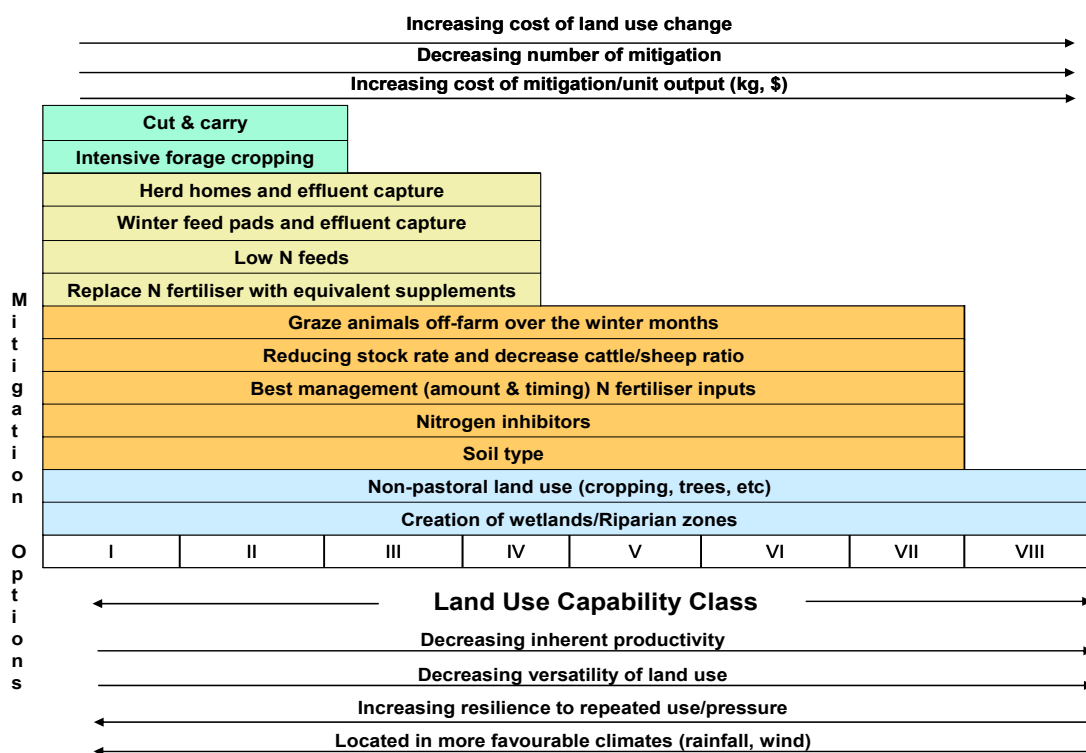


Fig. 8 Number and alignment of the mitigation options with the soils in each of the LUC Classes

As a general rule the number of mitigation options decrease as the producer moves from elite and versatile soils (LUC Classes I and II) to those with limitations to use (Classes III and greater). The absolute cost of mitigation (e.g. application costs) and/or the cost of mitigation as a function of production or income from land increases, as the limitations to use, increase. The findings from the Test farms demonstrate that effectiveness, suitability, cost and acceptability of each mitigation options varies between farms.

2.3 Land owners on soils in class I have more mitigation options than those of Land class with limitations to use, should weighting on the loss limits reflected the greater flexibility that affords land owners on that land class.

Land owners on elite soils have no limitations to use and hence flexibility in their choice of land uses. The mitigation tool box available to land owners on elite soils contains the full range of options. In comparison with all other soils, the tool box has less to offer land managers. As the natural capital of the soil declines, the land use options available decline, as does the range and cost competitiveness of the mitigation options available. Policy

might need to recognise this fact and allocate a higher N leaching loss limit to soils with little natural capital to retain land use options and flexibility for land owners on these landscapes.

2.4 What are the implications of having weighted nutrient loss limits for example on hill country farms?

Hill country includes predominantly Class VI and VII land. To retain the limited land use options available for land owners in hill country again policy might need to recognise this fact and allocate a higher N leaching loss limit to hill soils to retain land use options and flexibility for land owners.

Concluding comment on the weighting of the Nitrogen leaching loss limit

If the goal of policy is to encourage efficient land resource use with the least environmental impact, the N leaching loss limit should be weighted towards those soils with the greatest natural capital. If an imperative of policy is to retain land use options on soils with little natural capital, the weighting of the N leaching loss limit would need to be increased on these soils. These options could be explored in further analysis.

3. What impact does cropping have at a catchment level? Document the current level of knowledge around this type of activity including

3.1 Where does cropping take place?

The priority water management zones in which cropping and commercial vegetable production are found are in and around Levin (Waikawa and Lake Horowhenua) and Ohakune.

3.2 What is the contribution to water quality from cropping?

The N leaching losses in the literature for cropping ranged from 10-140 kg-N ha⁻¹ yr⁻¹ and for commercial vegetables 100-300 kg-N ha⁻¹ yr⁻¹. Using data collected through a MAF_SFF project on crop performance and nitrate leaching under a sequence of 6 vegetable crops and 2 cycles of fallow at a large commercial vegetable enterprise near Levin, SPASMO was used to predict the N leaching load. Over the two-year period of the sequence of 6 crops, the model predicted a total loss of 431 kg NO₃-N ha⁻¹, which is about half of the 1038 kg NO₃-N ha⁻¹ applied.

3.3 What is best practice for cropping in terms of contaminant management?

Using the SPASMO meta-model we explored four management options for reducing N leaching losses to groundwater from commercial vegetable production

1. Application of only half the fertiliser to the second spring onion crop.

The halving of the fertiliser application to the second spring onion crop did not greatly affect the dry matter yield over the 6 crop sequence, in part because this scenario relates only to the last crop in the sequence. The N leaching was reduced by 16%, and the average nitrate-N concentration of the 2-year sequence dropped 13.6%.

2. No application of Living Earth compost at the start of the crop sequence

By not applying the Living Earth compost at the beginning of the cycle, the cumulative N loss was reduced by 30% and the nitrate-N average concentration was reduced 31%. However the N in harvested crop yields was down from 424 to 325 kg N ha⁻¹, indicating a loss of harvested crop of over 20%.

3. Application of only half the compost at the outset, and no application at the planting of the first spring onion crop

If only half the rate of Living Earth compost was applied at the outset, coupled with no application of the 155 kg-N ha⁻¹ at the planting of the second spring onion crop, there would only be a 10% loss in crop yield, and there would be a reduction in cumulative N loss of 25%. The average nitrate concentration would be 50.5 mg NO₃-N L⁻¹, a drop of 27% resulting from the practices over 2001-2003.

4. Over irrigation through the application of water excessively in 75 mm aliquots, cf. 15 mm

To highlight the role that irrigation plays in determining the leachate loading on groundwater, we developed a scenario around excessive irrigation. If irrigation was now applied in 75 mm aliquots, rather than 15 mm, then over the two years, the total amount of water applied by irrigation would rise from 433 mm to 1020 mm. This increase would result in a 13.5% increase in the cumulative loss of nitrate-N, whilst the concentration of nitrate-N in the drainage water would drop by 21%. Thus there is a trade-off in drainage loading and nutrient loading that is dependent on irrigation.

3.4 What needs to be done to advance this approach in relation to cropping?

The SPASMO meta-model approach should now be easily used as a tool to work with individual commercial vegetable growers in conjunction with the Regional Council, to explore options for managing production, and to assess the tradeoffs between fertiliser practices, irrigation schedules, crop yield and nutrient leaching to groundwater. The model

is site specific and uses local weather records. The model has been validated using results obtained over 2001-2003 in an SFF project on a large commercial vegetable operation near Levin.

3.5 *What is the recommended approach to nutrient management plans for cropping*

The focus of the modelling in this report was on commercial vegetable production. It would be a simple matter to translate the model to handle cropping systems. This would allow the prediction of potential N leaching losses and provide the basis for developing nutrient management plans for cropping. Access to this model for this purpose is currently being advanced by building its functionality into OVERSEER® in separate projects (MAF-SFF and Envirolink).

4. **How do the calculations for upper Manawatu in terms of river sensed and OVERSEER® output compare for the Mangatainoka?**

The **topography** (landscape units and slopes) and **soil types** (drainage classes) in the Upper Manawatu vary significantly from those found in the Mangatainoka catchment. The Upper Manawatu catchment is dominated by Class VI land, whereas the Mangatainoka catchment has significant areas (18,500 ha) of flat and rolling landscape units. Rainfall in the Upper Manawatu is 1357 mm (1000 to 3000 mm) compared with 1789 mm (range from 1000 to 3500 mm) for the Mangatainoka and has a significant impact on the calculated N leaching loss. The net effect of differences in the physical and climate characteristics between the two catchments affected N leaching loss and N loading in the river, due to the different contribution of each land class in the two catchments.

5. **What information is required to roll out this approach?**

5.1 *For example for commercial vegetable, lake catchments, water quality information, land use information, flow data etc.*

See answer to the 5.2

5.2 *Consider all catchments where the Rule will apply*

To roll out the approach for any given water management zone the following information is required (Fig. 21).

Task 1 Inventories

- The boundaries and area of the water management zone
- NZLRI database including the worksheets containing the extended legend.

- Major land uses and areas in non-agricultural use
- List of point source discharge points and quantities
- Rainfall in 200 mm Isohyets for the water management zone

Task 2 Community of interest

- Identify land owners in the water management zone interested in acting as test farms to establish the challenges and opportunities
- Establish a water management zone based community-of-interest to discuss the proposed targets, time scale and roll out?
- Engage with key stakeholder (e.g. sectors, service providers, etc)
- Review the FARM strategy to ensure all issues are adequately covered and all mitigation options listed are available.

Task 3 Nitrogen loading, targets and farm N losses

- Summary of the rivers flow rates, lake volumes/levels, inflow rates, resident times, outfall rates and N concentrations in water in each water body, used to calculate the nitrogen loadings in the water management zone. The framework report by Roygard and McArthur (2008) provides a methodology for this task.
- Current nitrogen loading for the water management zone.
- The standard (nitrogen loading target) and justifications for the standard for the water management zone.
- List the nitrogen leaching loss from each of the major land uses in the water management zone and from point discharges.

Task 4 Other contaminants and their management

- List other potential contaminants contributing to poor water quality (e.g. sediment, P, faecal, etc) in the water management zone
- Current levels of contamination
- List current and future mitigation options (e.g. Clean Streams, Whole farm plans, etc) for the water management zone.

Task 5 Aggregate the biophysical inventories

- List the areas (ha) and potential productivity of each LUC Class, Subclass, and Unit in the water management zones (e.g. Appendix 1)
- List the areas (ha), potential productivity, drainage class and slope of all LUC units in the water management zone catchment (e.g. Appendix 2)

- Describe rainfall in 200 mm Isohyets for the water management zone and develop a set of rules defining the rainfall bands (e.g. for the UMWMZ)

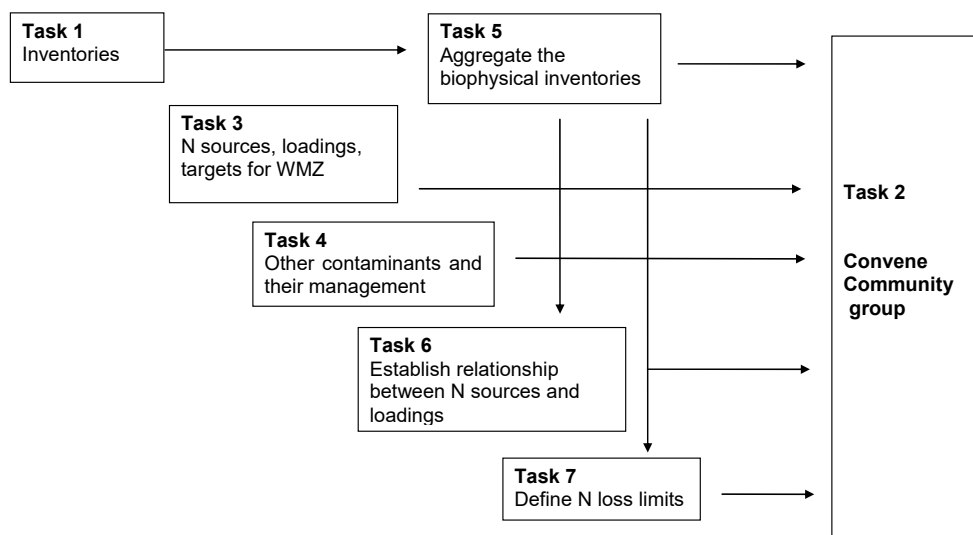


Fig. 21 Schematic diagram of the tasks to develop the catchment management plan

Task 6 Calculate N loading in the river from each land use, transmission co-efficient and the potential N loss limit for each land unit

- In catchments with multiple N water quality sampling sites, calculate the contribution from the major land use to the N loading in the water body. If not available use the N loading values from existing catchments.
- Establish the transmission co-efficient by calculating the N loss for each land use using OVERSEER®, and expressing as a fraction of the N loading in the river for each land use. If not available use the transmission co-efficient values from existing catchments.
- Calculate the N leaching loss limit for each soil in the catchment, using OVERSEER®, by LUC Class, Subclass and Unit and for each unit using detailed bio-physical and rainfall data.

Task 7 Establish the N loss limit for each land unit

- Establish the relationship between the potential N loss limit for each LUC Class, Subclass and Unit and for each unit using detailed bio-physical and rainfall data and the N loadings in the river
- Calculate the percentage of potential use of each land unit that is permissible to achieve the current N loading and the rate of change in the potential use of each land unit each year to move towards the standard (i.e.

N loading target for the water management zone) over time. Include data to demonstrate the influence of a differential percentage of potential use for each land unit in achieving the N loading target.

Notes

1. Tables containing the N loss limits and the relationship between each land unit and the N loading in the river for soil in each LUC Class would be available to the public. More detailed information would be available on request on the contribution of each land use and each LUC land unit on the Regional Council web site.
2. Land owners in the water management zone would be able to access, on request, a confidential report detailing their farm's N loss limit based on the information contained in the NZLRI and Regional rainfall database.

6. How will the FARM strategy approach be linked into the farm practice?

The FARM strategy has the greatest chance of being linked into farm practice and successfully implemented if the experts available within the industry (i.e. Nutrient budgeting and planning, fertiliser advice, farm management and business planning) are primary service providers. This is already partially in place, with a nutrient budget required by all dairy farms since June 2007, as part of the Clean Streams Accord.

Horizons, in partnership with industry, should undertake a stocktake of the capabilities and the capacity in the region to deliver the services that will be required as the priority catchment programme within the 'One Plan' is rolled out, to ensure land owners have access to expertise and a choice of providers. Collating and listing the accredited service providers available to land owners in the region would be a useful resource for all land owners. This could be made available through the Regional Council's website.

This question has also been addressed as part of the FARMS test farms project.

6.1 *Please outline an approach as to how this could be rolled out.*

Roll out. There has already been some discussion on establishing a consortium to provide the expertise necessary to roll out the FARM strategy. This concept should continue to be developed by Horizons in consultation with industry providers. This would maximize the likelihood of the FARM strategy approach being adopted into farm practice and planning cycles by the industry.

An added advantage of Horizons encouraging the development of an industry consortium as the led service provider is the fact the industry already has staff training programmes,

nutrient budgeting and planning protocols and audit processes in place, as part of good practice.

Horizons would have to work through with the consortium an independent audit process to ensure consistency across the providers and adherence to the N loss limits.

Compliance Checking compliance with the consent conditions set out in the FARM strategy should be limited to the factors (e.g. including milk production/ha, cow number/ha, fertiliser inputs (P and N), mm irrigation water/ha, etc) contributing to N leaching loss over which the land owner has control. A table listing the input data (e.g. cow number, milk production, N fertiliser use, etc) to complete the nutrient budget could be populated at the end of the year with actual production data and inputs used on the farm, for submission to Council as part of the annual consent process. An explanation would be required if the N leaching loss limit deviates by more than 5% from the agreed N loss limit. This would also form the basis for the annual audit, required as part of the statutory responsibilities of Council.

6.2 *To what extent do you see need for expertise around fertiliser, farm management, financial management to be involved?*

See FARMS test farms project report for comments on the specific requirements with respect to both nutrient budgeting and planning

6.3 *Consult with industry representatives in answering this question*

The industry was engaged in the FARMS test farms project. We make the suggestion to Council to engage the primary industry (i.e. Fertiliser industry, consultants, etc) in evaluating the findings and recommendations from the Test farm project. It would provide industry with the opportunity to examine the logistics of providing a nutrient budgeting and planning service to their client base as the One Plan is rolled out. Input could be sought from industry on the most appropriate approach for checking on compliance with the consent conditions set out in the FARM strategy.

7. OVERSEER[®], the FARM strategy and the water quality outcomes work on long-term averages.

7.1 *How will the farm strategy work with farm management changes in response to weather e.g. using N to fill a gap in the feed budget*

Our farming systems are designed for the average year. Nutrient budgets and plans are also developed to reflect the conditions that prevail in an average year. Farm system

design includes the capacity to cope with some variation in seasonal and annual rainfall, sunshine hours and temperatures.

Extremes of climate (i.e. prolonged wet or dry conditions) do occur (e.g. 2004 Flood, 2008 drought). These force producers to make wholesale changes to their farm operation and the business plan. Changes to the business plan, in response to an extreme event, will not be made lightly by land owners, as it invariably impacts on production levels, expenditure and income.

An update of the nitrogen budget and plan may be part of the analysis undertaken at the time of the review of the business plan, or it may not be completed, until the farm operation returns to the annual business planning cycle. Once back in the business planning cycle the full implications of the extreme event on the nitrogen budget can be documented and any changes required to the nutrient plan built into next years business plan.

Given extreme events occur infrequently and major change to the business plan are not taken lightly by land owners, and when they are, it is frequently in consultation with their consultant, no change is necessary to the FARM strategy, beyond Horizons requesting the land owners submit an update nutrient budget and plan if the N leaching loss calculated by OVERSEER® is significantly different (>5%) from the nutrient budget submitted as part of the consent process.

We recommend one addition to the FARM strategy to accommodate extreme climatic events. Horizons require intensive land users to submit an update nutrient budget and plan if N leaching losses are higher (>5%) than in the budget submitted as part of the consent process. The plan would include the “how and when” the business would return to the N leaching loss limit for that farm.

7.2 *Examine the impact of extreme events (flooding, drought, etc).*

We see little value in defining what constitutes an extreme event or the actions an intensive land owner should follow, outside of the recommendations we have already made in response to question 7.1. Horizons require intensive land users to submit an update nutrient budget and plan if N leaching losses are higher (>5%) than in the budget submitted as part of the consent process.

Implementation of FARM strategies for contaminant management
Further questions
A report by SLURI - The Sustainable Land Use Research Initiative

1. Determine ability to incorporate into the rule more detailed information in the extended legend (e.g. soil type, drainage class, rainfall, distance from water courses, etc)?

1.1 How does the detailed sub class approach versus the broader scale LUC class approach compare for water quality outcome.

To assess the influence of utilising more detailed soil and landscape information in the extended legend of the worksheets and site specific, rather than average rainfall for the catchment, the influence on N leaching loss calculated from the potential production values for soils aggregated at the LUC Class, LUC Subclass and LUC unit scales and for each polygon in the Upper Manawatu Water Management Zone (UMWMZ) on the N loadings in the river, were compared with the N leaching loss and associated N loadings in the river calculated from soils aggregated at the LUC Class reported in Appendix 6 of the Farm Strategies for Contaminant Management report prepared by SLURI for Horizons Regional Council (Clothier et al., 2007). In the study by Clothier et al., (2007) a direct link between land use and management decisions as it influences N leaching losses and loadings in the UMWMZ was established, allowing investigation of nutrient management policy options that were independent of current land use and linked directly to the land resource.

In the analysis reported in Appendix 6 the natural capital of the soils in the UMWMZ was calculated from the potential stocking rate that could be sustained by a well managed legume based sward, taken from the extended legend of the LUC worksheets “Attainable potential livestock carrying capacity” for the North Island. The potential livestock carrying capacities were transformed to pasture production and used in OVERSEER® to calculate N leaching losses under pastoral (Dairy) use. The N losses by leaching calculated from OVERSEER® summarised for the soils in LUC Classes I-VII for the North Island were used in both of case studies (i.e. Upper Manawatu and Mangatainoka catchments) reported in that study.

In this study the natural capital of the soils in the UMWMZ was calculated from the potential stocking rate that could be sustained by a well managed legume based sward, taken from the extended legend of the LUC worksheets “Attainable potential livestock carrying capacity” for the Upper Manawatu.

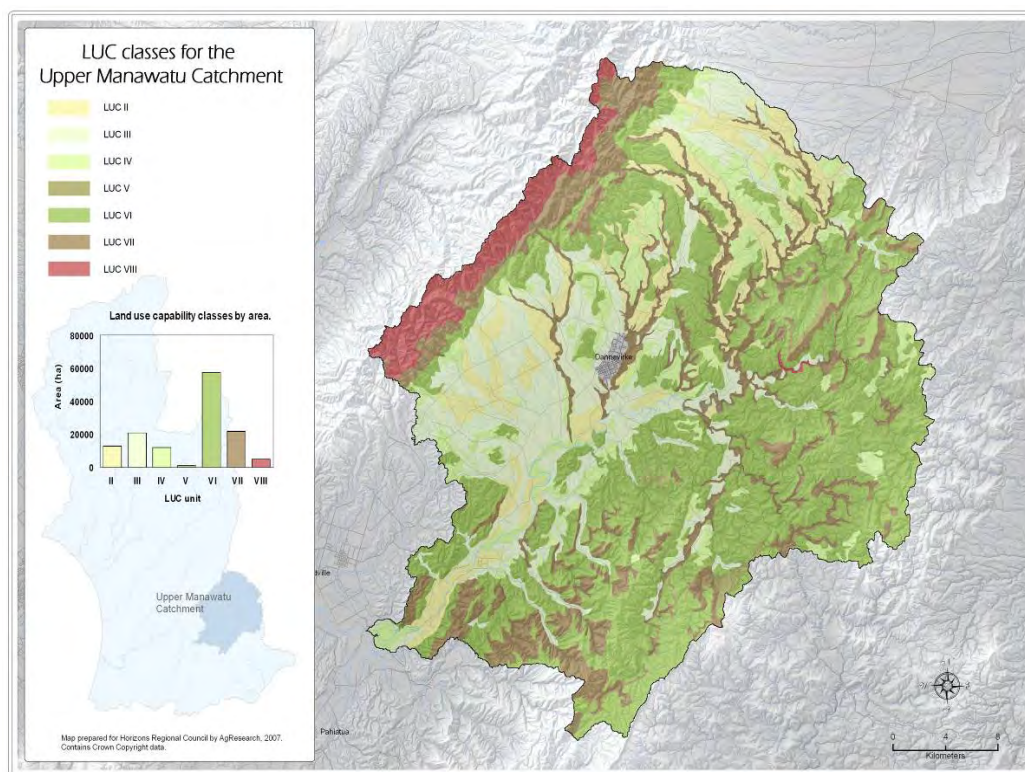


Fig.1 LUC classes for the Upper Manawatu.

Again the potential livestock carrying capacities were transformed to pasture production and used in OVERSEER® to calculate N leaching losses under pastoral (Dairy) use. The calculated N leaching loss associated with the attainable potential production of the soils calculated in OVERSEER® at the LUC Class, LUC Subclass and LUC unit scales using the average rainfall value for the catchment, produced the same N loadings in the river when summed for the whole catchment, assuming an attenuation factor of 0.5 (Table 1), although the contribution from each unit changed (Fig. 2 & 3 and Appendix 1). In the above calculation, the potential livestock carrying capacities at the LUC Class and LUC Subclass were summed from data held on each LUC unit. When soil information (i.e. drainage class), slope (e.g. flat, rolling, hill, steep) and rainfall in 200mm bands was included in the calculation of the N leaching loss, the contribution from each LUC unit changed (Fig. 2 & 3 and Appendix 2), as did the N loading in the river (Table 1).

For comparison the N leaching loss limits for the soils in each LUC class in the One Plan are included in Fig. 2. These were derived from the tables provided in Appendix 6 of the Farm Strategies for Contaminant Management report prepared by SLURI for Horizons Regional Council (Clothier et al., 2007). The 200 mm rainfall bands were calculated from isohyet of average rainfall across the Manawatu provided by Horizons Regions Council (Fig. 4). These were linked to the soil in each land unit using GIS.

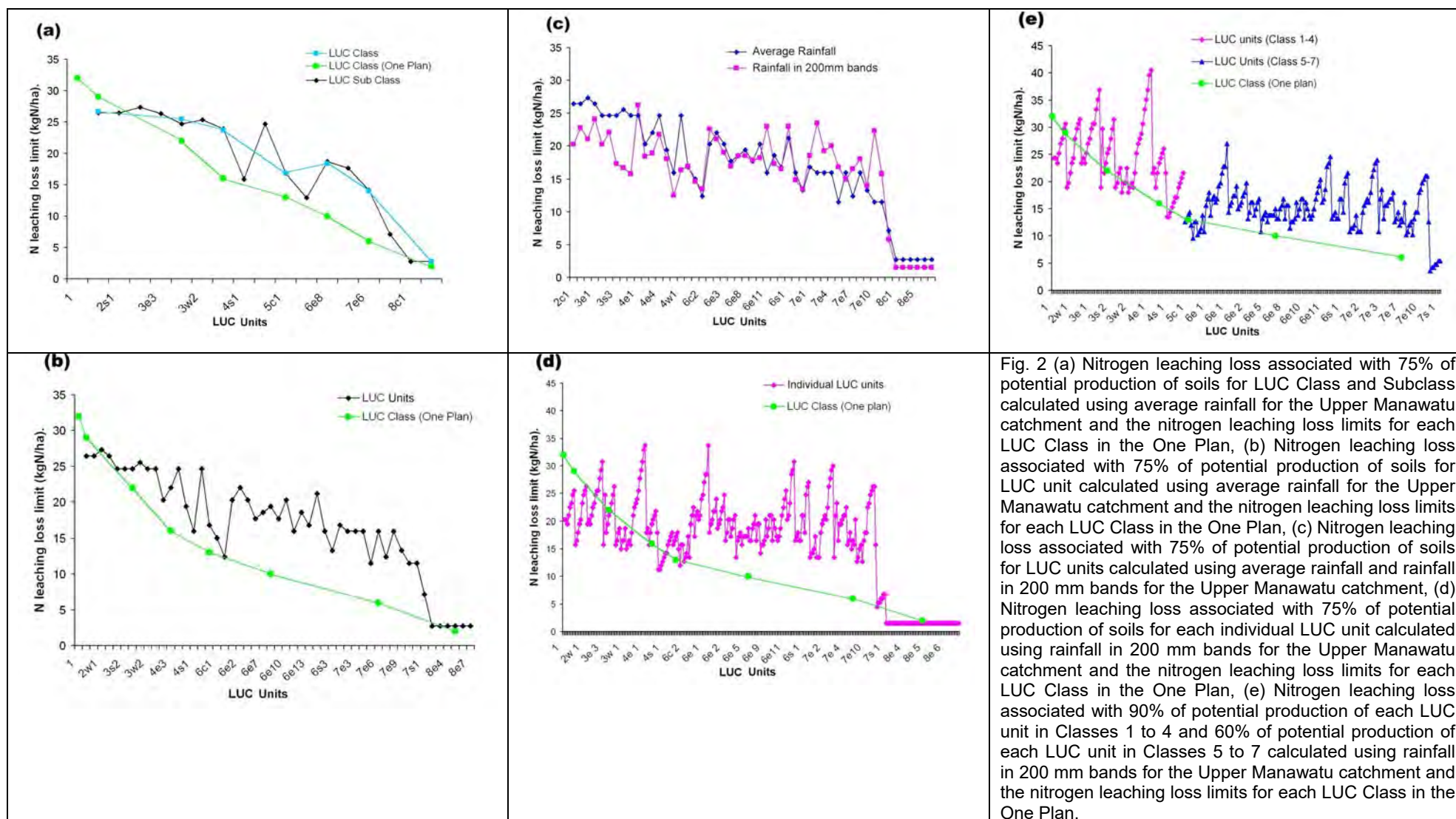


Fig. 2 (a) Nitrogen leaching loss associated with 75% of potential production of soils for LUC Class and Subclass calculated using average rainfall for the Upper Manawatu catchment and the nitrogen leaching loss limits for each LUC Class in the One Plan, (b) Nitrogen leaching loss associated with 75% of potential production of soils for LUC unit calculated using average rainfall for the Upper Manawatu catchment and the nitrogen leaching loss limits for each LUC Class in the One Plan, (c) Nitrogen leaching loss associated with 75% of potential production of soils for LUC units calculated using average rainfall and rainfall in 200 mm bands for the Upper Manawatu catchment, (d) Nitrogen leaching loss associated with 75% of potential production of soils for each individual LUC unit calculated using rainfall in 200 mm bands for the Upper Manawatu catchment and the nitrogen leaching loss limits for each LUC Class in the One Plan, (e) Nitrogen leaching loss associated with 90% of potential production of each LUC unit in Classes 1 to 4 and 60% of potential production of each LUC unit in Classes 5 to 7 calculated using rainfall in 200 mm bands for the Upper Manawatu catchment and the nitrogen leaching loss limits for each LUC Class in the One Plan.

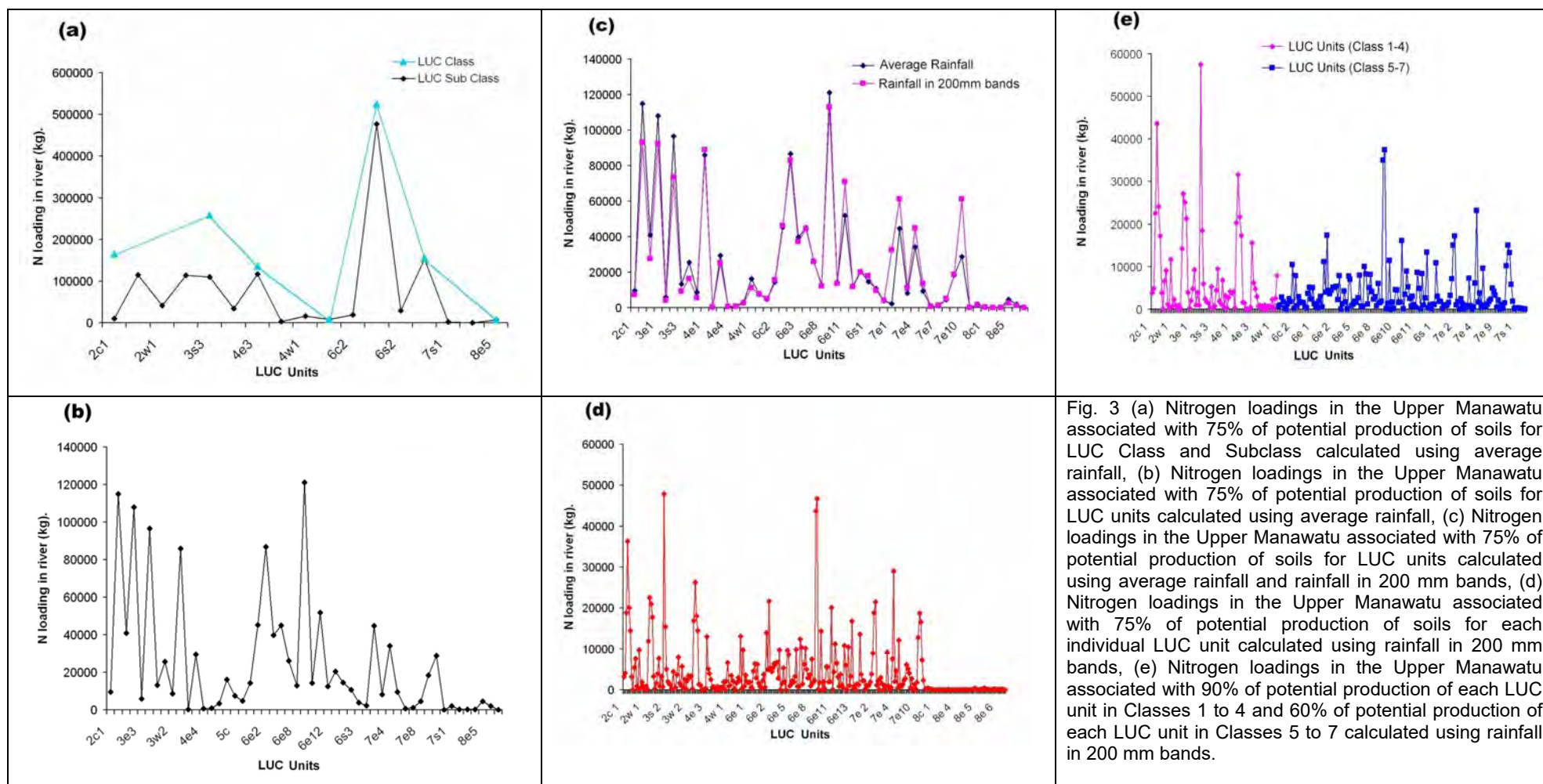


Fig. 3 (a) Nitrogen loadings in the Upper Manawatu associated with 75% of potential production of soils for LUC Class and Subclass calculated using average rainfall, (b) Nitrogen loadings in the Upper Manawatu associated with 75% of potential production of soils for LUC units calculated using average rainfall, (c) Nitrogen loadings in the Upper Manawatu associated with 75% of potential production of soils for LUC units calculated using average rainfall and rainfall in 200 mm bands, (d) Nitrogen loadings in the Upper Manawatu associated with 75% of potential production of soils for each individual LUC unit calculated using rainfall in 200 mm bands, (e) Nitrogen loadings in the Upper Manawatu associated with 90% of potential production of each LUC unit in Classes 1 to 4 and 60% of potential production of each LUC unit in Classes 5 to 7 calculated using rainfall in 200 mm bands.

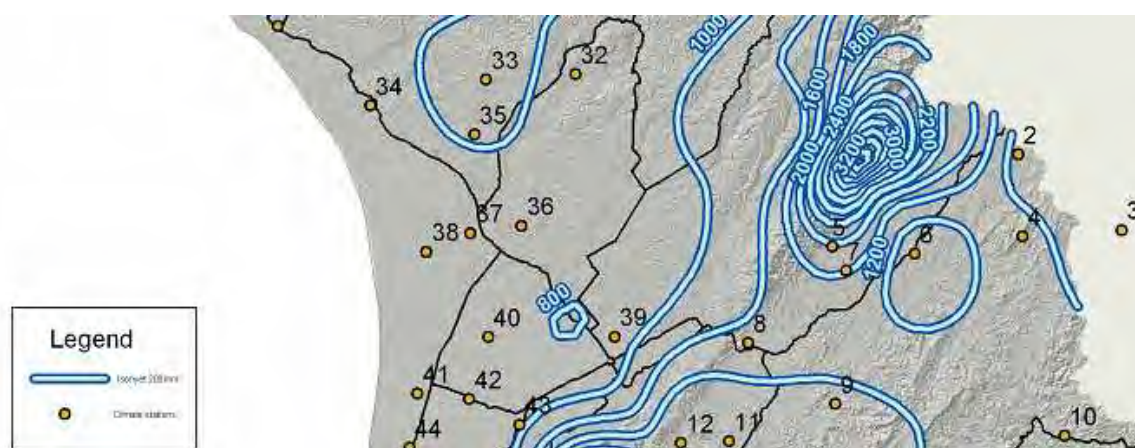


Figure 4 The isohyets of average rainfall across the Manawatu, showing the variation in rainfall in the Upper Manawatu Water Management Zone (UMWMZ) for stations 2 through 8.

For comparison the N loading in the Upper Manawatu summed from the N leaching losses calculated in OVERSEER[®] using 90 and 75% of the average “Attainable potential livestock carrying capacity” for the soils in each LUC Class in the extended legends of the LUC worksheets for the North Island contained in Appendix 6 of the first report are also listed in Table 1. The difference between the data sets reflects differences in the LUC units that make up the worksheets of the two (North Island and Upper Manawatu) legends and the use of land area weighted production data for each LUC Class and Subclass.

Table 1: Effect of scale on the N loadings in Upper Manawatu

Scale	% of potential production	N loading (kg)
LUC Class ¹	75	1,254,843
LUC Subclass ¹	75	1,254,843
LUC unit ¹	75	1,255,464
LUC unit_soil_rainfall_slope ² .	75	1,220,358
LUC Class (Nth Island) ³	90	921,049
LUC Class (Nth Island) ⁴	75	767,541

Note. ¹N loading in the Upper Manawatu summed from the N losses calculated in OVERSEER[®] using 75% of the averaged weighted (by area) “Attainable potential livestock carrying capacity” for the soils in each LUC Class, LUC Subclass and LUC unit with average rainfall (1357 mm) for catchment at all scales.

² N loading in the Upper Manawatu summed from the N losses calculated in OVERSEER® using 75% of the “Attainable potential livestock carrying capacity” for soil in each LUC unit when soil drainage class, slope and actual rainfall for that polygon is included in the calculation.

^{3 & 4} N loading in the Upper Manawatu summed from the N losses calculated in OVERSEER® using 90% and 75%, respectively, of the “Attainable potential livestock carrying capacity” for the soils in each LUC Class in the extended legends of the LUC worksheets for the North Island and contained in the first report. Rainfall for the upper Manawatu was taken as 1200 mm in that analysis.

Including the drainage class of the soil, slope of the landscape unit and the rainfall associated for each polygon in the calculation in OVERSEER®, changed both the total loading and the contribution of each landscape unit to the N loading in the river (Fig. 3).

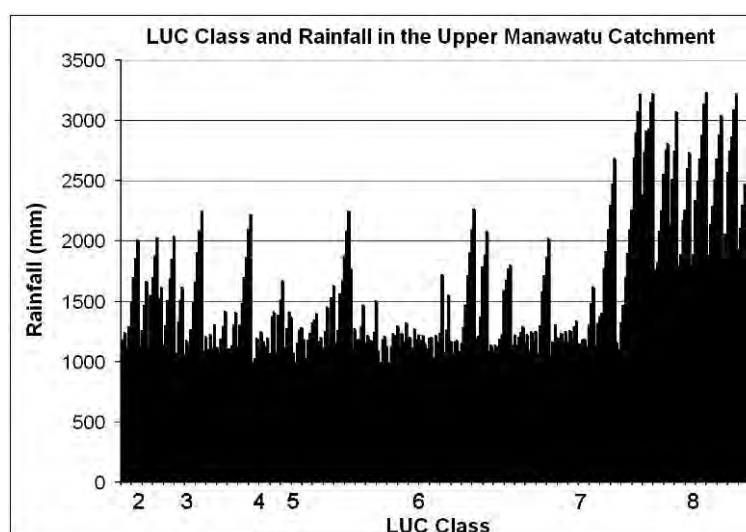


Fig. 5. Rainfall by LUC Class in the Upper Manawatu Catchment (Average rainfall 1357 mm)

Rainfall in the UMWMZ varies from 1000 to 3000 mm pa with the area weighted average rainfall 1357 mm. A closer examination of rainfall in the catchment reveals that the distribution is skewed not unexpectedly to the hill and steepeland in the catchment. In the initial report average rainfall was used in the OVERSEER® calculation to determine the N leaching loss for each land unit. Use of an average rainfall value in the calculation of the N leaching loss will tend to over estimate the N leaching loss on the landscapes receiving less than the average rainfall and under estimates the N leaching losses from the higher rainfall zones in the catchment at the same level of fertility and stocking rate. It is important to recognise at this time, that our data sets on N leaching losses from high rainfall zones above 1600 mm are limited

Given the influence of rainfall on N leaching and contribution to the N loading in the river, we suggest that rather than using an average rainfall value for the catchment (1357 mm) and to address that not all land owners will have access to detailed rainfall records for their farm, the Upper Manawatu Catchment be broken into two rainfall bands.

- If rainfall is < 1357 mm use actual or the Isohyet value
- If rainfall is >1357 mm use actual, the Isohyet value, or a maximum of 1500 mm

These would be default values in the absence of the land owner having good rainfall records for the property. As we suggested earlier with the land information, the land owner would be given the option of utilising the banded rainfall values, Isohyet, or actual rainfall for their farm

This suggestion addresses two key issues, spatial inaccuracies in the rainfall database and the uncertainty surrounding N leaching loss at high rainfall. It also recognises that the area of the catchment under high rainfall is small, as is the number of intensive land uses. In the Upper Manawatu catchment 76% of dairy farms are found in rainfall zones <1500 mm (Houlbrooke 2008).

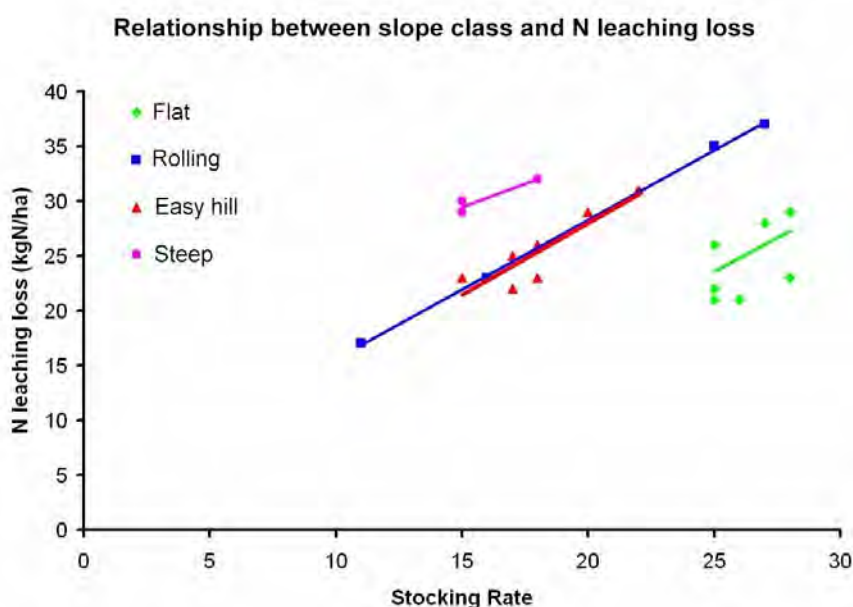


Fig. 6. The relationship between slope class and N leaching

Use of a maximum of 1500 mm of rainfall will result in a reduction in the calculated N leaching loss from those parts of the catchment above 1500 mm. As a consequence the contribution of this part of the landscape to N loading in the river will be under reported.

This needs to be recognised and considered when setting N leaching loss limits. It offers one option for weighting the N leaching loss limit away from the high rainfall zones within the catchment.

At a given level of production calculated N leaching losses increase with increasing slope. Inclusion of slope into the calculation of the N leaching loss and potential N loadings in the river, like rainfall, provide more site specific information on the biophysical factors contributing to N loss.

With the more detailed data there was a trend towards lower N leaching on the soils on flat and rolling country and increased N leaching on hill and steep land (Fig 2) assuming an attenuation factor of 0.5 from all landscape units, due to the higher rainfall (Fig.5) and greater slopes (Fig. 6) in the hill and steep land in the catchment.

The net result of utilising more detailed landscape and rainfall data in the calculation of N leaching losses is a more accurate picture of the contribution of each land unit to N leaching and, as a consequence, provides more confidence in being able to identify the factors influencing N leaching loss and N loadings in the river. In the case of the UMWMZ, the inclusion of more detailed soil, landscape and rainfall information changed the contribution of each of the land unit that makes up the catchment to the N loading in the river (Fig. 3). In general the soils on Classes I and II landscapes contribute less, while the soils in hill and steep land contributed more, when one compares the results from the initial analysis (Fig. 2c).

From the test farms completed to date as part of a separate contract, it is apparent that on lowland there is little increase in the calculated N leaching loss from the use of more detailed soils information. The main reason for this is at the 1:50,000 scale (NZLRI) there are often inclusions of small areas of less versatile soil units within the more productive landscape units. Inclusions of less versatile soils in the analysis lowers the calculated N leaching loss limit, than that predicted from the soils information in the NZLRI. The reverse appears to be the case in hill and steepland where inclusions of soils in Classes IV and VI can be pulled out of Classes VI and VII, respectively, with more detailed soil mapping. Inclusion of the more productive landscape units through soil mapping has the potential to increase the calculated N leaching loss limits for the farm. This is unlikely to be a major issue, because these areas are often small and difficult to manage separately and as a consequence not farmed at potential, limiting their impact on N leaching losses. Further, where more productive areas are developed, pressure is often reduced on the less productive parts of the landscape. It is worth noting that there is inherently more

uncertainty in our soils information in hill and steep land, suggesting that land owners on in these landscapes should consider more detailed mapping before making a decision on the scale at which to calculate their N leaching loss limit.

Summary

The use of detailed resource information provides more precision in the quantification of the potential N loss limit from each of the landscape units that make up the water management zone.

1. As a general rule, on flat and rolling landscapes within a catchment which includes hill and steep land, inclusion of more detailed biophysical information, assuming the same attenuation factor from land to river for all land units, will reduce the calculated N leaching loss and loadings into the river from soils as a consequence of the

- o inclusion of less versatile soils identified by more detailed mapping
- o use of actual rainfall, which is often lower, than the average for the catchment
- o low slope classes

Inclusion of soil drainage class could either increase or reduce the calculated N leaching loss

2. As a general rule, in hill and steep land within a catchment which includes flat and rolling country, inclusion of more detailed biophysical information, assuming the same attenuation factor from land to river for all land units, will increase the N leaching loss limits and loadings into the river from soils as a consequence of the

- o inclusion of more versatile soils identified by more detailed mapping
- o use of actual rainfall, which is often higher, than the average for the catchment
- o higher slope classes

Inclusion of soil drainage class would either increase or reduce N leaching loss

It follows that policy implemented to manage N leaching losses from these landscapes would also be more effective in achieving the goal if aligned with more detailed biophysical information.

We recommend that this forms the basis for the policy and the basis on which the N leaching loss limits are set for soils in the catchment.

It is important to remember inclusion of more detailed soil, landscape and climate information is about obtaining a more accurate description of the factors contributing to N leaching and loading in the river, and not about defining the N loading in the river. The latter is achieved by defining the fraction of potential attainable production that the land can be farmed, while still achieving the water quality outcome target for that water body.

We also recommend that land owners have the option of calculating their N leaching loss limit from the NZLRI and banded rainfall values for the Upper Manawatu Catchment or from more detailed biophysical resource information (e.g. soil type, slope, drainage class, climate data, production potential) to addresses two key issues, spatial inaccuracies in the rainfall data base and the uncertainty surrounding the N leaching loss at high rainfall.

Note. We suggest that summary tables containing the averaged N leaching loss limits aggregated for the major soil types grouped into LUC classes are produced for priority catchments. Detailed N leaching loss limits for each polygon within the catchment, would be available within a GIS environment. Further, an independent facility would be available for land owners to calculate their N leaching loss limit using either average or detailed spatial data sets.

1.2 The same numbers across the region are used for LUC class output is it necessary to tailor this on a catchment by catchment basis in terms of water quality outcome and farming systems parameters in that catchment (rainfall soils etc). Compare for the Mangatainoka the water quality outcome and the upper Manawatu

See response to question 4 “How do the calculations for upper Manawatu in terms of river sensed and OVERSEER[®] output compare for the Mangatainoka? In that section of the report the influence of changing the scale of the soils, landscape and rainfall information used in the calculation of the N leaching loss limit and subsequent contribution to the N loading in the Mangatainoka river is explored in a similar way to that covered in section 1.1 and then the two catchments are compared.

1.2.1 Comparison of N loading in the Upper Manawatu and Mangatainoka Rivers

The N loss limit permissible for the Upper Manawatu to achieve the long-term water quality target in the One Plan of 358,000 kg N is under 6 kg N/ha if all land is treated the same and assuming an attenuation of 0.5 from land to water. For the Mangatainoka to achieve the

water quality target in the One Plan of 238,000 kg N the equivalent value is 10.4 kg N/ha (Table 2), Bringing that analysis back to the initial water quality targets set in the Year 1 of the One Plan for the Upper Manawatu (859, 000 kg N) and Mangatainoka (360,000 kg N) river and again treating all land the same, the N leaching loss limit for each hectare in the Manawatu catchment would be 13.2 kg N/ha and for the Mangatainoka approx 15 kg N/ha, again assuming an attenuation of 0.5 from land to water in each catchment. The N leaching loss limits and N loading in the One Plan for Years 5-20 for the Upper Manawatu and Mangatainoka River are listed in Appendices 6 and 7, respectively.

Table 2 Characteristics of the Upper Manawatu and Mangatainoka catchments

Parameter	Upper Manawatu	Mangatainoka
Size of catchment (ha)	129,638	47,871
Current N loadings (kg N)	745,000	603,000
One Plan Year 1 N loadings (kg N)	859,000	360,000
N loss limit to achieve the One Plan Year 1 (kg/ha) ¹	13.2	15
Long-term water quality standard (kg N)	358,000	248,000
N loss/ha (kg) ²	5.5	10.4
N loadings when all land units operating at 75% of potential ³	1,004,000	503,000

¹Treating each ha in the catchment the same and assuming the transmission co-efficient is 0.5

²Treating each ha in the catchment the same and assuming the transmission co-efficient is 0.5

³N loading when all land units in the catchment are operating at 75% of potential production. Assuming an attenuation factor of 0.5

Further, if all the land within each of the two catchment was operating at 75% of potential production and assuming an attenuation factor of 0.5 then the N loading in the Upper Manawatu and Mangatainoka Rivers would be 1,004,000 and 503,000 kg N, respectively, which is 1.17 and 1.4 times the immediate N loading limit set for the these two water management zones (859,000 and 360,000 kg N, respectively) and 2.8 and 2.0 times the long-term N loading limit set for the these two water management zones (358,000 and 238,000 kg N, respectively) by Horizons Regional Council in consultation with community. This provides an indication of the influence that a single set of limits in policy would have on the water quality outcome in these two catchments.

The net effect of the same N loss limits across the water management zones found in the region rather than a set of tailored values would set for some catchments, unnecessarily low thresholds above which mitigation would be required, and for other catchments set limits that would not achieve the desired water quality outcomes.

In summary we recommend that the N leaching loss limits for the soils in a catchment are calculated for each water management zone because

1. Current and future water quality targets for each water management zone will vary across the region.
2. Each water management zone is a unique mix of soils and landscapes and rainfall zones. Not only will the types and total numbers of landscape units differ across the catchment, all of which influences the amount of N that is leached, but the area distribution of each land unit and thus contribution to N loading in the river will also vary between catchments.

1.3 Impact of the LUC handbook update

The update of the land use capability (LUC) handbook will supersede the previous version which was last printed in 1974 by the Soil Conservation and Rivers Control Council. The LUC classification system has been used in New Zealand for more than 40 years and the entire rural landscape of New Zealand has been classified. The LUC assessment is an integrative assessment of use/risk, based on the sum of scientific and managerial knowledge available at a specific time.

The update of the handbook (Updating the Land Use Capability survey Handbook, Envirolink Tools contract AGRX0604) will include the learning's from science and applied management in the intervening 30 years and will provide the standards for at least the next decade of sustainable land management planning. The application of latest developments in scientific knowledge will be a major advance in its application as currently the emphasis is often on managerial knowledge in the absence of the science.

Horizons Regional Council regards an updated LUC handbook as an important tool to assist with achieving the objectives of the **Sustainable Land Use Initiative (SLUI)**, a regional initiative responding to the devastating February 2004 floods. The update of the LUC handbook which has wide support from Regional Councils throughout the country will have a number of positive impacts including raising the profile of the approach for describing and classifying our landscapes, providing an updated and more user-friendly

manual for LUC mapping through to addressing a number of inconsistencies within the current hand book.

The update of the LUC handbook will not change the information contained in the extended legends of the LUC worksheets or its interpretation when calculating the N loss limit from a soil.

The soil and landscape information in the extended legend of the LUC worksheets offers a very useful framework for placing the soils in the catchment into groups based on their physical nature of the landscape, the physical integrity, versatility and productive potential of each soil. Evolving the basis on which to catalogue the natural capital of the soils to better reflect the services that the soils provide to the land owner and wider community would add clarity to both industry bodies and policy agencies on the links between soil type, soil attributes and processes and the ecosystem services (e.g. productive capacity, nutrient regulation and the water cycle) soils provide. There are currently two SLURI projects investigating approaches for linking soil description to soil attributes and processes through to soil services.

2. Explore the efficiency of resource use by soil within each LUC class e.g. Product/ unit N lost

2.1 *Should the loss limit be weighted equally across all soil units to the same degree?*

There are a number of issues to consider in answering this question

1. **The ability to realise and sustain the soils productive potential**

- Elite and versatile soils, soils with high natural capital, will produce more and require less input/output at a given level of production.
- Compared with an elite soil, soils with less well developed structure, shallow soil horizons and plant rooting depth, weak cation and anion storage and supply capacities, and low water holding capacity, will take longer and require proportionately more inputs in their development.
- The productive capacity of soils on LUC Class I and II, and soils on Class III and IV through the use of feed pads and stand-off areas when soils are wet, are not generally constrained by the physical limitations of the soils, compared with the soils found in Classes VI and VII, where the physical integrity of the soil will often define upper limit of production.
- Once a soil is at potential, more resource will be required to sustain the physical integrity, maintain plant number and vigour, etc on soils with little natural capital.

2. **The environmental impact of a soil operating at its natural potential**

- Compared with elite soils, emissions (e.g. N leaching losses, nitrous oxide) will be higher on coarse textured, weakly developed, stony soils (e.g. 20% increase in N loss from a silt loam to High P loss soil) and soils on slopes (Fig. 6). This rule will not be universal, because there will be trade-off. For example soils with weakly developed structures and poor drainage could potentially lose more N as nitrous oxide than as nitrate.
- Compared with elite soils, sediment and P loss will be higher from soils with poor drainage, exhibiting preferential flow characteristics, low anion storage capacity and with increasing slope

As a generalisation the amount of product per unit input will be greater and the emissions resulting from the added production will be less on an elite soil (i.e. high natural capital), when comparing all soils at the same level of potential.

3. Production beyond the soils natural capital

- There are a number of very effective technologies available (e.g. cultivation, drainage and irrigation) to lift the productive capacity of soils on flat and rolling landscapes beyond their natural capital compared with soils found in hill country and steepland.
- There are also more technologies available for sustaining production to compensate for the lack of natural capital of soils on flat and rolling landscapes (e.g. feed pads, N fertiliser, etc).
- Interestingly, the cost of these technologies generally increase, as does the production benefit, as the natural capital of a soil declines.

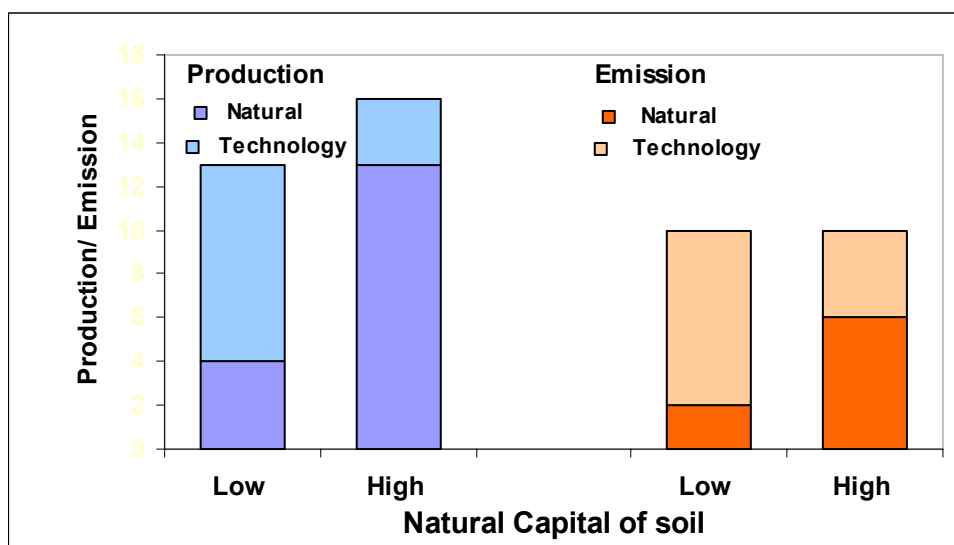


Fig. 7 Production and Emissions from a well managed legume pasture topdressed with P and S fertiliser before the introduction of production technologies (e.g. irrigation, drainage and N fertiliser) on soils of low and high natural capital.

4. Mitigating nitrogen losses in soils operating beyond their natural productive capacity

- Technologies (i.e. cultivation, drainage and irrigation) used as substitutes for the lack of productive capacity (weakly developed soil structure, limited plant available water) of soils will lead to increased N loss, through a combination of increased production and greater leaching volumes.

- The number and efficiency of mitigation options for compensating for the limited capacity of soils to retain N in the topsoil horizons, declines as the natural capital of soils becomes more limited.
- The soils on which the production technologies have their biggest impact on production levels, will be the landscapes that provide the greatest challenge in mitigating N losses.

Summary

The amount of product per unit input will be greater and the emissions resulting from the added production will be less on an elite soil, when comparing all soils at the same level of potential. This comment is supported by the analysis from the test farms, with farms on landscapes with soils with limitations to use, closer to their N loss limit and fewer mitigation options to reduce N losses.

If the question is limited to “What is the most efficient use of resources with the least environmental impact?” the N leaching loss limit should be weighted towards those soils with the greatest natural capital.

2.2 *List the mitigation options (types and cost benefits and dollars) available by soil within each LUC class.*

The mitigations options for reducing N leaching losses from pastoral soils are listed in the Farm Strategies for Contaminant Management report prepared by SLURI for Horizons Regional Council (Clothier et al., 2007) and in the report by AgResearch (Wedderburn, 2008). Both reports contain commentary on the cost-effectiveness of each of the mitigation options.

Relationship between mitigation options and the natural capital of soil grouped by LUC Class

Figure 8 provides a summary of the mitigation options available and the alignment of the mitigation options with the soils in each of the LUC Classes.

Two points are worth noting

- The number of mitigation options decreases as the producer moves from soils in LUC Classes I and II to those in Classes III and greater.

- The absolute cost of mitigation (e.g. application costs) and/or the cost of mitigation as a function of production and income from land increases as the limitations to use increases.

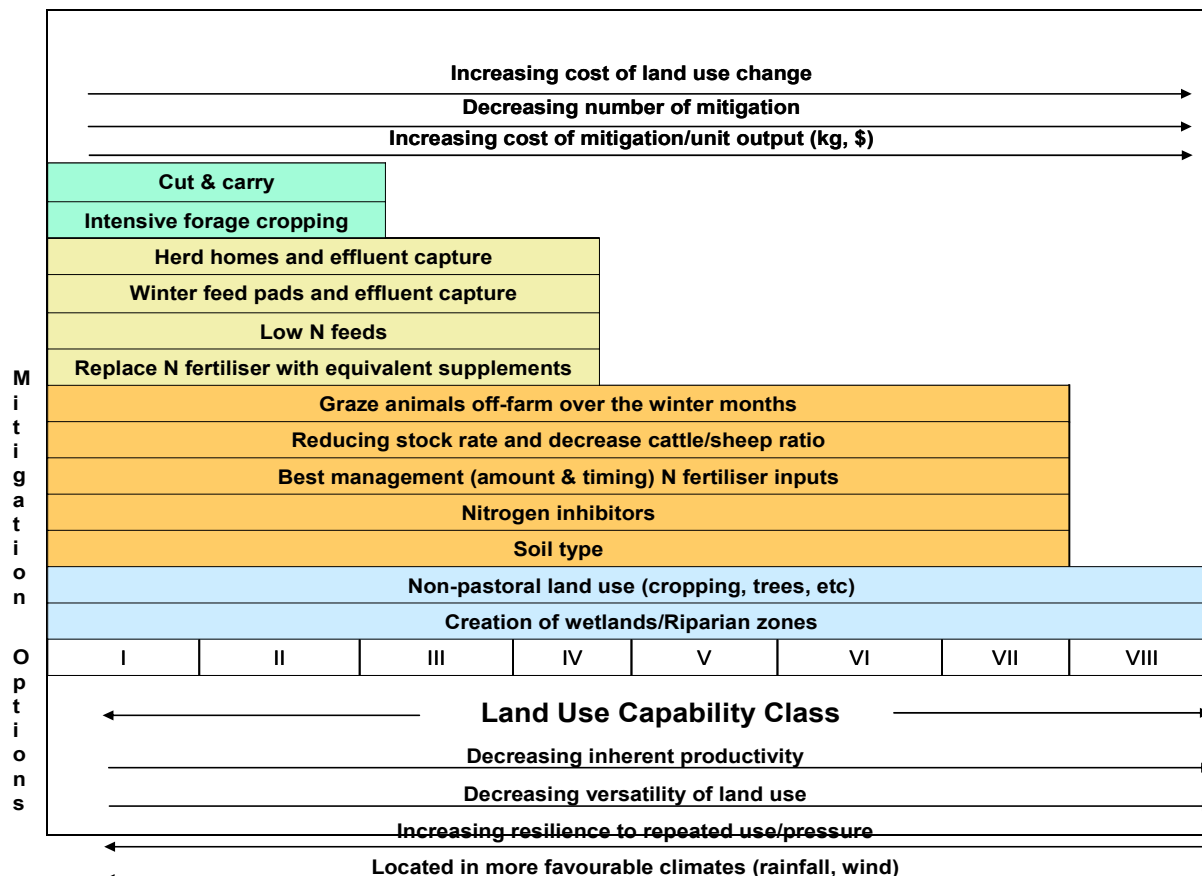


Fig. 8 Number and alignment of the mitigation options with the soils in each of the LUC Classes

The findings from the Test farms demonstrate that the effectiveness, suitability, cost and acceptability of each of the mitigation options varies between farms. The study by Monaghan et al., (2007) summarized in the Farm Strategies for Contaminant Management report prepared by SLURI for Horizons Regional Council (Clothier et al., 2007) provides some indication of the efficacy of each mitigation option and the impact on EBIT. A more recent study in the Rotorua catchment (Smeaton and Ledgard 2008) provides some additional information on the likely reductions in N leaching loss from the range of mitigation option currently available, along with comment on the likely impact of each option on farm economic performance.

2.3 Land owners on soils in class I have more mitigation options than those of Land class with limitations to use, should weighting on the loss limits reflected the greater flexibility that affords land owners on that land class.

From a biophysical stance land owners on elite soils have no limitations to use and hence flexibility in their choice of land uses. The mitigation tool box available to land owners on elite soils contains the full range of options. In comparison, on all other soils, the tool box will be less effective. As the natural capital of the soil declines, the land use options available decline, as does the range and cost competitiveness of the mitigation options. From a policy stance a case could be made for allocating a higher N loss limit to soils with little natural capital, to provide land managers with options and flexibility on what are difficult landscapes.

2.4 What are the implications of having weighted nutrient loss limits for example on hill country farms?

As in 2.3 above, a case could be made for allocating a higher N leaching loss limit to those soils with the least natural capital, to retain the limited land use options available for land owners on these landscapes. Hill country includes primary Classes VI and VII land.

Concluding comment on the weighting of the Nitrogen leaching loss limit

If policy development is limited to encouraging the most efficient use of resources with the least environmental impact, the N leaching loss limit should be weighed towards those soils with the greatest natural capital. If an imperative of policy is to retaining land use options on soils with little natural capital, the weighting of the N leaching loss limit would need to be increased on those soils.

3. What impact does cropping have at a catchment level? Document the current level of knowledge around this type of activity including

3.1 *Where does cropping take place?*

The priority catchments in which cropping and commercial vegetable production are found are in and around Levin (Waikawa and Lake Horowhenua) and Ohakune (Fig 9 and Table 3). In the Upper Manawatu and Mangatainoka catchments cropping is a minor land use activity. The coastal Rangitikei has the largest area of arable cropping 1162 ha, with commercial vegetable production a land use in the Mangawhero/Makotaku catchments (205 ha), Lake Horowhenua catchment (178 ha) and the Northern Manawatu Lake catchment (44 ha).

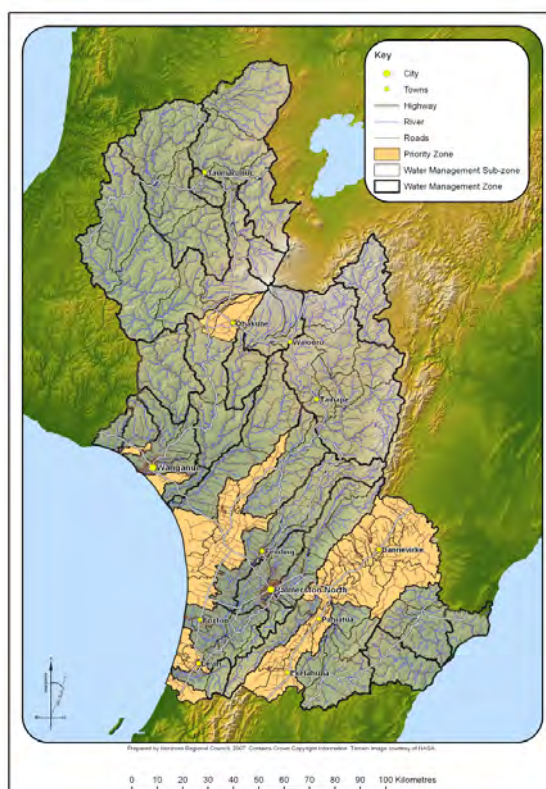


Fig. 9 Priority water management zones

Table 3 Land uses in the priority water management zones

Catchment		Arable	Sheep/Beef	Dairy	Flowers	Fruit	Forestry	Lifestyle	Native	Nursery	Other Livestock	Other	Other planted Types	Vegetable	Total
Mangapapa	No. Farms		22	13				13	2	1		1			53
	Area		1407.02	420.13				41.63	419.67	41.49		26.76	16.73		2373.43
Mowhanau	No. Farms		50	11	1	3		41			5	1		1	113
	Area		1751.33	867.42	3.12	12.51		87.18			7.17	20.82		5.25	2754.79
Mangatainoka	No. Farms	1	175	109	1		2	119	1		20	11			439
	Area	4.56	21564.17	13469.55	0.40		26.91	450.21	5279.82		1049.81	240.29			42085.73
upper Manawatu (Above Hopelands)	No. Farms	3	395	150	1	2	6	247	2		26	13			845
	Area	455.52	81216.08	20430.31	6.29	16.26	553.10	1242.34	4171.44		1241.91	1068.65			110401.91
Lake Horowhenua	No. Farms	2	86	16		9	1	94		1	29	16	1	11	266
	Area	25.25	1776.94	1257.96		39.76	25.53	275.97		8.73	374.38	113.89	17.29	178.27	4093.96
Waikawa	No. Farms		37	14	1	1	6	32	1	2	10	1		6	111
	Area		1243.76	1907.82	2.92	6.25	73.17	86.37	2142.68	10.03	607.42	2.59		94.97	6177.99
Manawatu Above Gorge (mana_6,mana_9a and mana_9c)	No. Farms		99	67			2	48	3	1	4	1			225
	Area		10843.06	6622.36			31.80	184.08	1354.80	10.11	106.31	1.19			19153.71
Waitarere	No. Farms	1	3	8			1	4	1		2				20
	Area	19.39	147.07	1263.78			1289.90	19.67	0.08		236.40				2976.30
Papaitonga	No. Farms	1	20	7			8	21			7	2			66
	Area	6.16	796.38	409.53			197.58	39.80			134.16	2.14			1585.74
Kaitoke Lakes	No. Farms	1	56	4			4	54	1		8				128
	Area	40.16	4045.34	279.88			1343.71	238.11	238.11		294.20				6479.50
Southern Wanganui Lakes	No. Farms	1	58	15			8	13	1		5	4			105
	Area	7.45	10952.95	1836.20			4304.79	73.28	2.42		596.99	111.08			17885.17
Northern Manawatu Lakes	No. Farms		40	52			14	16			14	4		1	141
	Area		2944.04	6858.54			388.81	61.75			201.48	69.22		43.83	10567.67
Coastal Rangiti kei	No. Farms	20	468	109		2	14	200	1	1	52	17			884
	Area	1161.05	36870.40	12495.53		6.00	1287.39	869.12	11.06	0.65	2024.89	320.46			55046.56
Mangawhero/Makotuku	No. Farms		109	4			2	58	4		9	3		5	194
	Area		14703.08	489.02			1.72	234.27	7876.64		1234.18	71.09		205.16	24815.16

3.2 What is the contribution to water quality from cropping?

The N leaching losses reported in the Farm Strategies for Contaminant Management report prepared by SLURI for Horizons Regional Council (Clothier et al., 2007) for cropping range from 10-140 kg-N ha⁻¹ yr⁻¹ and for commercial vegetables 100-300 kg-N ha⁻¹ yr⁻¹.

Data collected through a MAF-SFF project, jointly by HortResearch and Crop & Food Research, and supported by Horizons Regional Council, on crop performance and nitrate leaching under a sequence of six crops and two cycles of fallow on a large commercial vegetable enterprise near Levin (Snow et al., 2004) are used here to validate the SPASMO mete-model for predicting the N leaching load from multiple sequences of crops in commercial vegetable production (Appendix 5). A general description of the SPASMO model and its adaptation to handle multiple and continuous sequences of crops is provided in Appendix 5.

Case study *Nitrate leaching losses under a sequence of 6 crops and 2 cycles of fallow at a large commercial vegetable enterprise*

The sequence of cropping and fallow was 1. Fallow, 2. Silverbeet, 3. Summer lettuce, 4. Spring onion, 5. Summer lettuce, 6. Spring onion, 7. Winter oats and 8. Fallow

Table 4 Model inputs for the soils physical and hydraulic properties.

Soil properties	Variable	Value	Unit
Soil depth	ZR	0.6	m
organic carbon	Soil OC	2.00	%
organic nitrogen	Soil ON	0.29	%
bulk density	rhob	1.08	kg/L
water content - saturated	theta_sat	0.464	L/L
water content - field capacity	theta_FC	0.435	L/L
water content - wilting point	theta_WP	0.233	L/L
depth of water - saturated	WC_sat	278	mm
depth of water - field capacity	WC_FC	261	mm
depth of water - wilting point	WC_WP	140	mm
storage component (above FC)	S_ret	70	mm

The fertiliser calendar is presented in Table 7, and furthermore we have included an application of Living Earth compost near the end of the first fallow period. The soil properties used in the meta-model are given in Table 4, and the initial conditions to begin the simulation of the fallow period on 1st May are given in Table 5. The modelled irrigation regime (Table 6) was used, because it was not possible to obtain a detailed record of the actual irrigation practice.

Table 5 Initial soil water and mineral nitrogen content of the soil.

Initial conditions	Variable	Value	Unit
Soil water content	theta_ini	0.33	L/L
Mineral nitrogen content	NSOIL ini	250	kg/ha

Table 6 Irrigation regime (modelled) at a commercial vegetable enterprise near Levin.

Irrigation parameters	Variable	Value	Unit
Daily irrigation amount	IR_VOL	15	mm
stress fraction below refill	IR_TRIG	0.95	set >1 for every day
irrigation efficiency	IR_EFF	0.85	[%]
Return period	IR_RET	1	d

Table 7 Fertilizer calendar applied to the commercial vegetable enterprise near Levin .

name	Fertilizer date	Product rate [kg/ha]	% N	N applied [kgN/ha]
Compost	26-Sep	25000.0	2.0	500.0
Special	28-Sep	2000.0	5.8	115.0
Nitrophoska Blue	21-Nov	2300.0	12.0	276.0
Nitrophoska Blue	8-Feb	840.0	12.0	100.8
Special	11-Apr	2000.0	5.8	115.0
Nitrophoska Blue	10-Jul	333.0	12.0	40.0
Nitrophoska Blue	6-Nov	840.0	12.0	100.8
CAN	16-Jan	630.0	27.0	170.1
N-phoska Perfekt	15-Feb	570.0	13.8	78.7
Nitrophoska Blue	15-Mar	350.0	12.0	42.0

Table 8 Planting calendar for the commercial vegetable enterprise near Levin.

name	Planting date	Harvest date
fallow	1-May	1-Oct
silverbeet	10-Oct	17-Jan
summer lettuce	2-Feb	4-Apr
spring onion	11-Apr	11-Oct
summer lettuce	6-Nov	8-Jan
spring onion	10-Feb	1-May
winter oats	29-May	15-Nov
fallow	16-Nov	31-Dec

The predicted crop factors of the sequence of 6 crops shown in Figure 10 (lower graph) reflect the modelled growth of the leaf area of the various crops. This crop factor determines the rate of crop water use by the crop sequences. The SPASMO meta-model has been able to simulate successfully the pattern of soil-water content of this two year period of 6 crops and two fallow periods (Figure 10, upper).

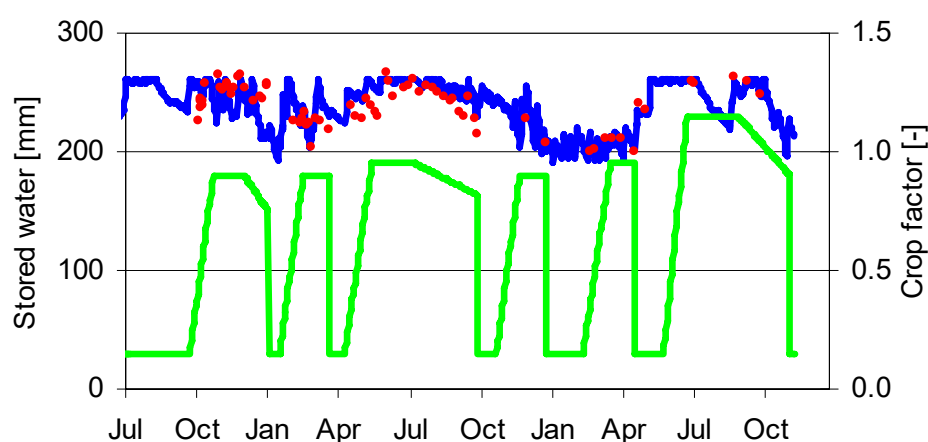


Figure 10. Measurements (red dots) and model output (blue line) of total water content (mm) of the top 0.6 m of the root-zone soil. The sequence of planting (described in Table 5) is expressed by the crop factor curves (green line) that relate actual plant water use to the potential evaporative demand. The meta-model has applied optimum irrigation.

The meta-model then predicts plant dry matter yield based on the pattern of the prevailing weather and the water and nutrient status of the soil, taking into account the fertiliser practices.

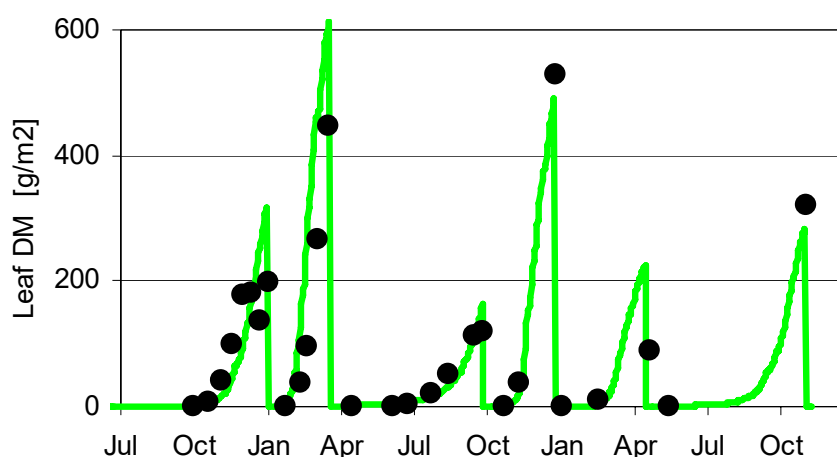


Figure 11. Measurements (dot markers) and model output (green line) for the above-ground dry-matter production at the commercial vegetable enterprise near Levin (Snow *et al.*, 2004).

As can be seen in Figure 11, the meta-model is successful at predicting the dry matter yield of the crops in this sequence of 6 crops. The SPASMO meta-model also predicts the concentration of nitrate in the soil solution below the root zone, being that nitrate destined for groundwater. The comparison of the model predictions with the suction-cup samplings of Snow *et al.* (2004) reveals good correspondence (Figure 12). Also shown in Figure 12 is the cumulative loss of nitrate over the two-year period.

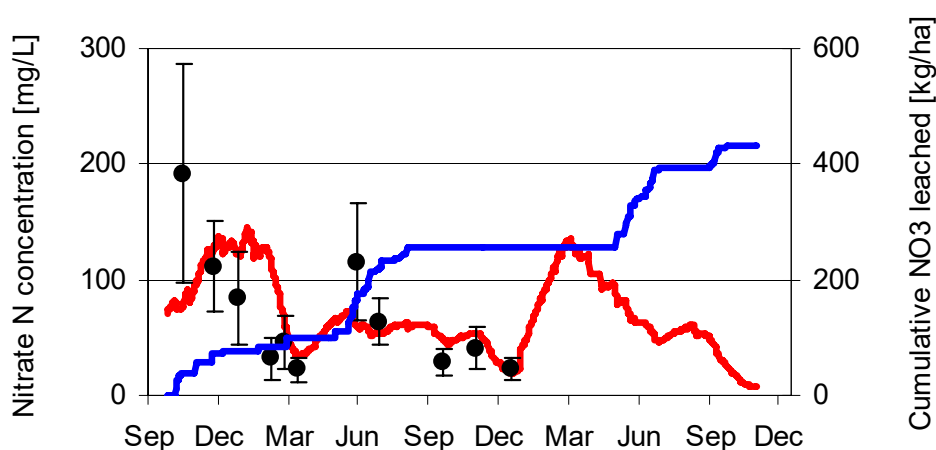


Figure 12. Measurements (markers) and model output (red line) for the nitrate-nitrogen content of drainage water at 60 cm. Open symbols are data from suction cups. Filled symbols are data from soil cores. The blue line represents the model output for the cumulative amount of nitrate leached below the root-zone. Our calculations predict that some 431 kg/ha of nitrate-N was leached during the two year observation period. The average $\text{NO}_3\text{-N}$ concentration was 69 mg/L.

Table 9: Detailed output from the meta-model results shown in Figure 12.

		Nitrogen balance kg/ha	Water Balance [mm/d]			
Inputs	N fert added	1038	RF	2018		
transformations	Tot N uptake	1388	IR	434	mm applied	
	Net N Mineralize	539	ETP	1952		
	crop return					
	N	520	ETA	1215	Esoil	240.9
	Recycle N	72	DR	671		
losses	Volat N	269	RO	70		
	Denit N	145	ETA/ETP	62	[%]	
	Leaching N	431	IRA	510	mm supplied	
	mean NO ₃	69				
Outputs	crop harvest	424				
T FW/ha	FW	50691				

From the outputs of the meta-model, we can construct simple mass balance tables (Table 9) which detail the components of the water and nutrient balances, along with yield details. Thus, over the two-year period of the sequence of 6 crops, the model predicts a total loss of 431 kg NO₃-N ha⁻¹, which on balance is about half of the 1038 kg NO₃-N ha⁻¹ applied. The components of the nitrogen balance reveal that 1388 kg NO₃-N ha⁻¹ was taken by the crops, of which 520 kgN/ha was not harvested and returned to the soil. The soil itself mineralised 539 kg NO₃-N ha⁻¹. Thus nitrate leaching results from the balance between several large components in the paddock's nitrogen cycle.

While the focus of the modelling was on commercial vegetable production, it would be a simple matter to translate the model to handle cropping and to use the same approach to predict potential N leaching losses and as a basis for developing nutrient management plans for cropping and commercial vegetable production farms.

3.3 What is best practice for cropping in terms of contaminant management?

To demonstrate the utility of SPASMO meta-model as a tool to explore options to reduce nutrient loadings on groundwater from commercial vegetable production, we present the

predictions from four scenarios. The format of our results follows that of Figure 12 and Table 9, and we conclude with a summary table (Table 14).

The scenarios are:

1. Application of only half the fertiliser to the second spring onion crop. This is a halving of the last three applications in Table 7
2. No application of Living Earth compost at the start of the crop sequence
3. Application of only half the compost at the outset, and no application on 11 April at the planting of the first spring onion crop
4. Over-irrigation through the application of an excessively in 75 mm aliquots water, *cf.* 15 mm

Scenario 1 (Figure 4 and Table 7) The halving of the fertiliser application to the second spring onion crop did not greatly affect the dry matter yield over the 6 crop sequence (Table 10), in part because this scenario relates only to the last crop in the sequence,. The leachate loading was reduced by 16%, and the average nitrate concentration of the 2-year sequence dropped 13.6% (Table 14)

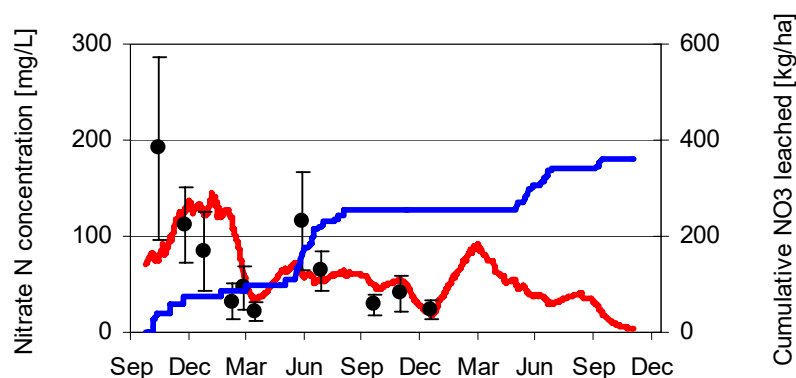


Figure 13. As in Figure 12, but only applying $\frac{1}{2}$ the amount of fertilizer to the second crop of spring onions. This reduced nitrate leaching by about 50 kg/ha *cf* actual practice.

Table 10: Detailed output from the meta-model results shown in Figure 13.

	Nitrogen balance kg/ha		Water Balance [mm/d]			
Inputs	N fert added	914	RF	2018		
transformations	Tot N uptake	1360	IR	434	mm applied	
	Net Mineralize	548	ETP	1952		
	crop return	510	ETA	1215	Esoil	241
	recycle	71	DR	671		
Losses	Volat	252	RO	70		
	Denit	141	ETA/ETP	62	[%]	
	Leaching	362	IRA	510	mm supplied	
	mean NO ₃	60				
Outputs	crop harvest	416				
T FW/ha	Harvest FW	49755				

Scenario 2: By not applying the Living Earth compost at the beginning of the cycle (Figure 14 and Table 11), the cumulative N loss was reduced by 30% and the nitrate-N average concentration was reduced 31%. However the N in harvested crop yields was down from 424 to 325 kg N ha⁻¹, reflecting the loss of harvested crop of over 20% (Table 11).

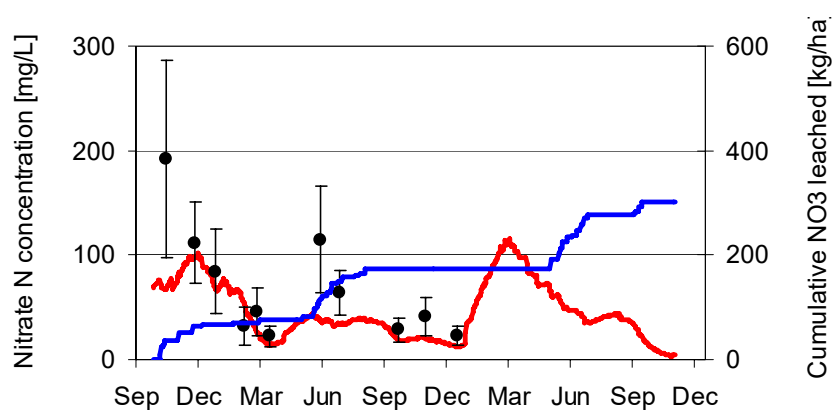


Figure 14. As for Figure 13, but not applying the Living Earth compost at the start. This reduced nitrate leaching by 131 kg/ha *cf* actual practice, but the yields were down by 20%.

Table 11: Detailed output from the meta-model results shown in Figure 14.

	Nitrogen balance	kg/ha	Water Balance [mm/d]			
Inputs	N fert added	1038	RF	2018.4		
transformations	Tot N uptake	1085	IR	433.5	mm applied	
	Net		ETP	1952.3		
	Mineralize	89	ETA	1214.5	Esoil	240.9
	crop return	421	DR	670.9		
losses	recycle	58	RO	70.4		
	Volat	176	ETA/ETP	62	[%]	
	Denit	133	IRA	510.0	mm supplied	
	Leaching	301				
	mean NO ₃	47.3				
Outputs	crop harvest	325				
T FW/ha	Harvest FW	41852.0				

Scenario 3: If only half the rate of Living Earth compost were applied at the outset, coupled with no application of the 155 kg-N ha⁻¹ at the planting of the second spring onion crop, there would only be a 10% loss in crop yield (Table 12), and there would be a reduction in cumulative N loss of 25% (Figure 15, Table 14). The average nitrate-N concentration would be 50.5 mg NO₃ L⁻¹, a drop of 27% resulting from the practices over 2001-2003.

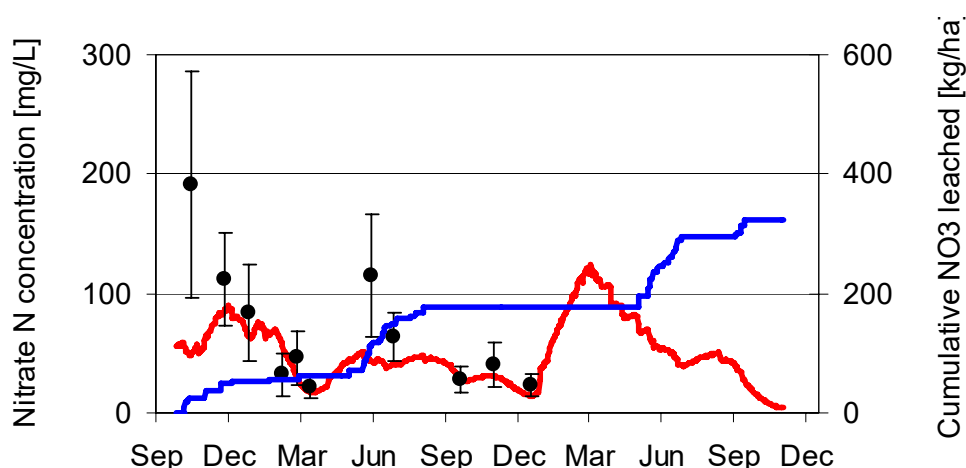


Figure 15. As in Figure 13 but only applying ½ the amount of Living Earth compost at the start and none of the ‘special’ N-fertilizer to the first crop of spring onions. This reduced nitrate-N leaching by 100 kg/ha *cf* actual practice, but crop yields were down by 10%.

Table 12: Detailed output from the meta-model results shown in Figure 15.

		Nitrogen balance kg/ha	Water Balance [mm/d]			
Inputs	N fert added	923	RF	2018		
transformations	Tot N uptake	1169	IR	434	mm applied	
	Net Mineralize	313	ETP	1952		
	crop return	450	ETA	1215	Esoil	240.9
	recycle	62	DR	671		
			RO	70		
losses	Volat	200	ETA/ETP	62	[%]	
	Denit	137	IRA	510	mm supplied	
	Leaching	323				
	mean NO ₃	50				
Outputs	crop harvest	351				
T FW/ha	FW	44779				

Scenario 4: To highlight the role that irrigation plays in determining the leachate loading on groundwater, we developed a scenario around excessive irrigation. If irrigation was now applied in 75 mm aliquots, rather than 15 mm doses, then over the two years, the total amount of water applied by irrigation would rise from 433 mm to 1020 mm (Table 13). This increase would result in a 13.5% increase in the cumulative loss of nitrate-N (Figure 16, Table 13, and Table 11), whilst the concentration of nitrate-N in the drainage water would drop by 21%. Thus there is a trade-off in drainage loading and nutrient loading that is dependent on irrigation.

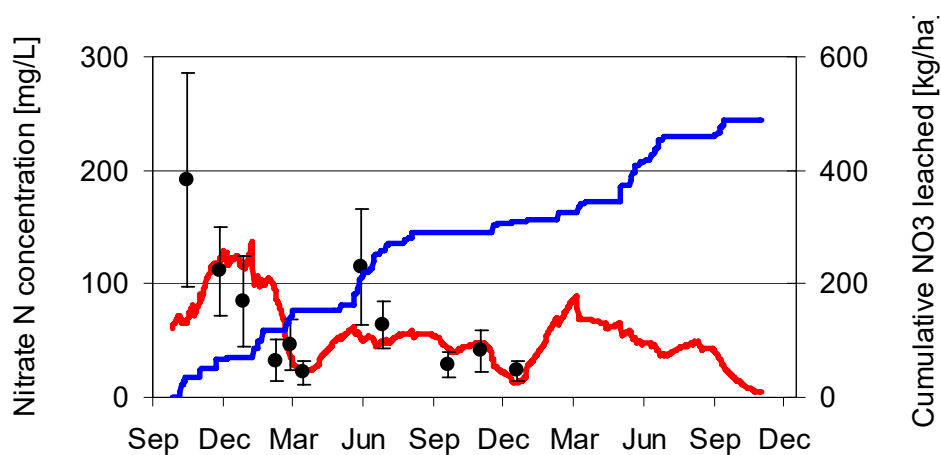


Figure 16. As in Figure 13 but applying excessive amounts of irrigation (in 75 mm aliquots). This increase nitrate leaching by about 60 kg/ha *cf* actual practice

Table 13: Detailed output from the meta-model results shown in Figure 16.

		Nitrogen balance	kg/ha	Water Balance [mm/d]		
Inputs	N fert added		1038	RF	2018	
transformations	Tot N uptake		1302	IR	1020	mm applied
	Net Mineralize		546	ETP	1952	
	crop return		495	ETA	1218	Esoil 223.7
	recycle		69	DR	948	
losses	Volat		254	RO	384	
	Denit		145	ETA/ETP	62	[%]
	Leaching		489	IRA	1200	mm supplied
	mean NO ₃		55			
Outputs	crop harvest		395			
T FW/ha	FW		48899			

A summary of the key results from the use of the SPASMO meta-model is give below in Table 14.

Table 14 Summary of the scenarios

Scenario	Cumulative NO ₃ kg-N ha ⁻¹ Leached over 2 years	Percentage change from control	Average NO ₃ concentration mg-NO ₃ N L ⁻¹	Percentage change from control
Practices over 2001-2003	431	-	69	-
Half fertiliser to 2 nd spring onion crop	362	-16%	59.6	-13.6%
No Living Earth compost at start	301	-30%	47.3	-31.4%
Half does of compost at start, and no application 11-April	323	-25%	50.5	-27%
Excessive irrigation in 75 mm aliquots	489	+13.5%	54.5	-21%

3.4 *What needs to be done to advance this approach in relation to cropping?*

The meta-model of SPASMO developed here to handle multiple sequences of crops runs under Excel, and so results for various scenarios, in the form of Figure 3, Table 6, and Table 11 are an instantaneous output.

Thus the SPASMO meta-model approach can now be easily used as a tool in future within OVERSEER® to work with growers and croppers, in conjunction with the Regional Council, to explore options for managing production, and to assess the trade-offs between fertiliser practices, irrigation schedules, crop yield and nutrient leaching to groundwater. The meta-model is site specific and uses local weather records. We have validated the model using results obtained over 2001-2003 in an MAF_SFF project on a large commercial vegetable operation near Levin.

3.5 *What is the recommended approach to nutrient management plans for cropping*

The focus of the modelling in this report is on commercial vegetable production. It would be a simple matter to translate the model to handle cropping and to use the approach to predict potential N leaching losses and as a basis for developing nutrient management plans for cropping, in addition to commercial vegetable production farms. Access to this model for this purpose is currently being advanced by building its functionality into

OVERSEER[®] in a separate project (MAF_SFF Nitrogen management for environmental accountability). The SPASMO meta-model described here could be used in the interim.

4. How do the calculations for upper Manawatu in terms of river sensed and Overseer output compare for the Mangatainoka?

(a) The exercise conducted in answering question 1.1 is repeated here for the Mangatainoka catchment and then the outputs compared with those from the Upper Manawatu in section 1.2.

In the analysis reported in Appendix 6 the natural capital of the soils in the Mangatainoka was calculated from the potential stocking rate that could be sustained by a well managed legume based sward, taken from the extended legend of the LUC worksheets “Attainable potential livestock carrying capacity” for the North Island. The potential livestock carrying capacities were transformed to pasture production and used in OVERSEER[®] to calculate N leaching losses under a pastoral (Dairy) use. The N losses by leaching calculated from OVERSEER[®] summarised for LUC Classes I-VII for the North Island were used in both the Upper Manawatu and Mangatainoka catchment case studies in that report.

In this study the natural capital of the soils in the Mangatainoka was calculated from the potential stocking rate that could be sustained by a well managed legume based sward, taken from the extended legend of the LUC worksheets “Attainable potential livestock carrying capacity” for the Mangatainoka.

Again the potential livestock carrying capacities were transformed to pasture production and used in OVERSEER[®] to calculate N leaching losses under pastoral (Dairy) use. The calculated N leaching loss associated with the attainable potential production of the soils calculated in OVERSEER[®] at the LUC Class, LUC Subclass and LUC unit scales using the average rainfall value for the catchment, produced the same N loadings in the river when summed for the whole catchment, assuming an attenuation factor of 0.5 (Table 15), although the contribution from each unit changed (Fig. 18 & 19 and Appendix 3). In the above calculation, the potential livestock carrying capacities at the LUC Class and LUC Subclass were summed from data held on each LUC unit. When soil information (i.e. drainage class), slope (e.g. flat, rolling, hill, steep) and rainfall in 200 mm bands was included in the calculation of the N leaching loss for each LUC unit, the contribution from

each unit changed (Fig. 18 & 319 and Appendix 3), as did the N loading in the river (Table 15).

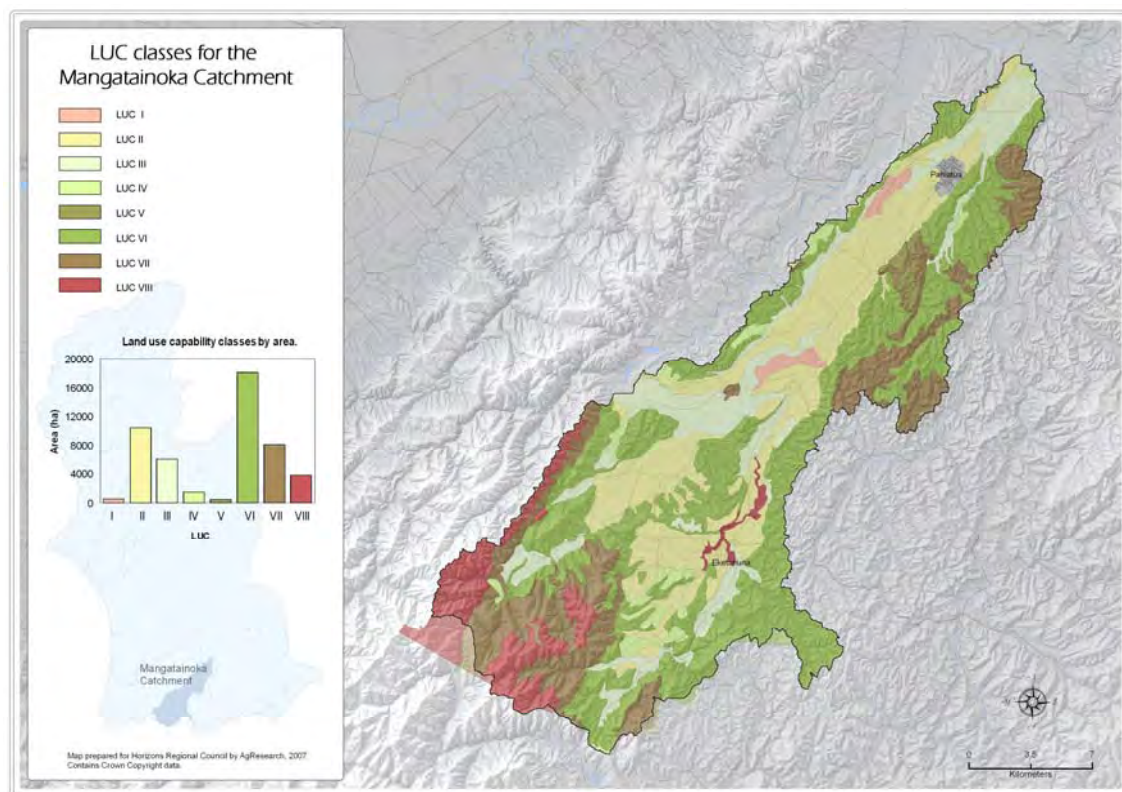


Fig. 17 LUC classes for the Mangatainoka.

For comparison, the N loading in the Mangatainoka summed from the N leaching losses calculated in OVERSEER® using 90 and 75% of the average “Attainable potential livestock carrying capacity” for the soils in each LUC Class in the extended legends of the LUC worksheets for the North Island contained in the first report are also listed in Table 15. The difference between the data sets reflects difference in the LUC units that make up the worksheets of the two (North Island and Upper Manawatu) legends and the use of land area weighted production data for each LUC Class and Subclass.

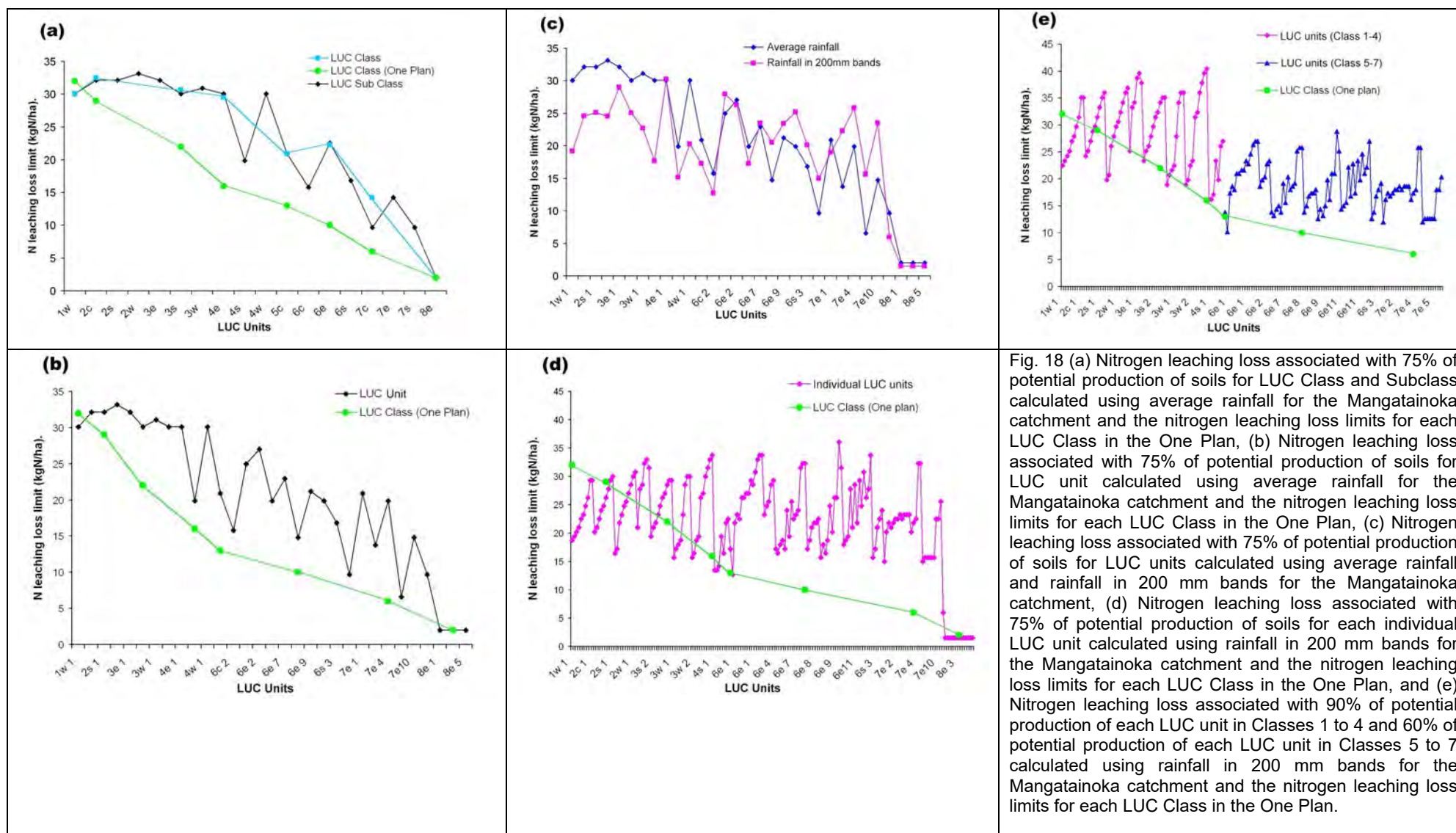


Fig. 18 (a) Nitrogen leaching loss associated with 75% of potential production of soils for LUC Class and Subclass calculated using average rainfall for the Mangatainoka catchment and the nitrogen leaching loss limits for each LUC Class in the One Plan, (b) Nitrogen leaching loss associated with 75% of potential production of soils for LUC unit calculated using average rainfall for the Mangatainoka catchment and the nitrogen leaching loss limits for each LUC Class in the One Plan, (c) Nitrogen leaching loss associated with 75% of potential production of soils for LUC units calculated using average rainfall and rainfall in 200 mm bands for the Mangatainoka catchment, (d) Nitrogen leaching loss associated with 75% of potential production of soils for each individual LUC unit calculated using rainfall in 200 mm bands for the Mangatainoka catchment and the nitrogen leaching loss limits for each LUC Class in the One Plan, and (e) Nitrogen leaching loss associated with 90% of potential production of each LUC unit in Classes 1 to 4 and 60% of potential production of each LUC unit in Classes 5 to 7 calculated using rainfall in 200 mm bands for the Mangatainoka catchment and the nitrogen leaching loss limits for each LUC Class in the One Plan.

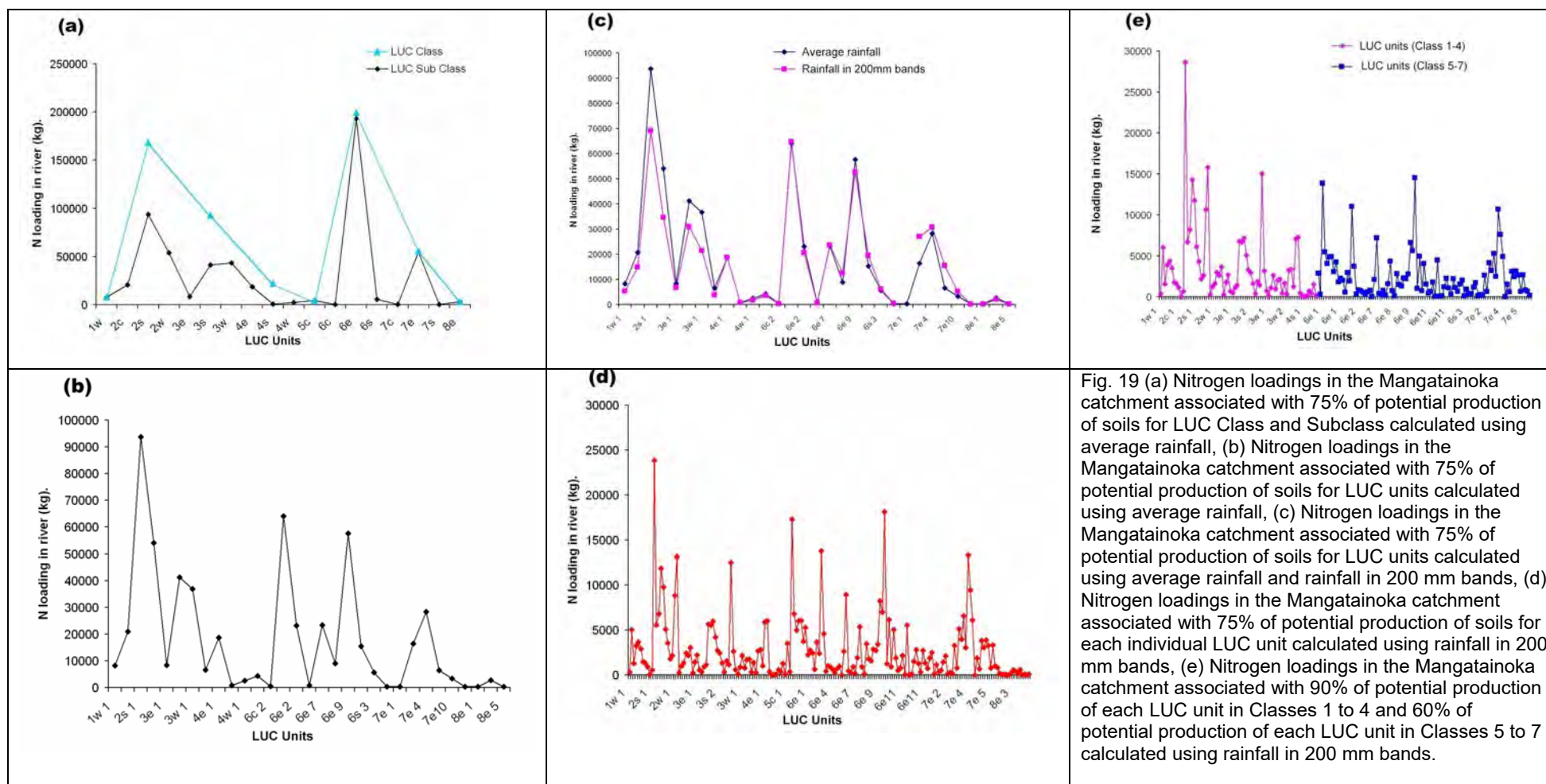


Fig. 19 (a) Nitrogen loadings in the Mangatainoka catchment associated with 75% of potential production of soils for LUC Class and Subclass calculated using average rainfall, (b) Nitrogen loadings in the Mangatainoka catchment associated with 75% of potential production of soils for LUC units calculated using average rainfall, (c) Nitrogen loadings in the Mangatainoka catchment associated with 75% of potential production of soils for LUC units calculated using average rainfall and rainfall in 200 mm bands, (d) Nitrogen loadings in the Mangatainoka catchment associated with 75% of potential production of soils for each individual LUC unit calculated using rainfall in 200 mm bands, (e) Nitrogen loadings in the Mangatainoka catchment associated with 90% of potential production of each LUC unit in Classes 1 to 4 and 60% of potential production of each LUC unit in Classes 5 to 7 calculated using rainfall in 200 mm bands.

Table 15: Effect of scale on the N loadings in the Mangatainoka

Scale	% of potential production	N loading (kg)
LUC Class ¹	75	554,679
LUC Subclass ¹	75	554,679
LUC unit ¹	75	554,679
LUC unit_soil_rainfall_slope ² .	75	494,147
LUC Class (Nth Island) ³	90	362,988
LUC Class (Nth Island) ⁴	75	302,490

Note. ¹N loading in the Mangatainoka catchment summed from the N leaching losses calculated in OVERSEER[®] using 75% of the averaged weighted (by area) “Attainable potential livestock carrying capacity” for the soils in each LUC Class, LUC Subclass and LUC unit, with average rainfall (1789 mm) for the catchment.

² N loading in the Mangatainoka summed from the N leaching losses calculated in OVERSEER[®] using 75% of the “Attainable potential livestock carrying capacity” for soil in each LUC unit when soil drainage class, slope and actual rainfall for each land unit is included in the calculation.

^{3 & 4} N loading in the Mangatainoka summed from the N losses calculated in OVERSEER[®] using 90% and 75%, respectively, of the “Attainable potential livestock carrying capacity” for the soils in each LUC Class in the extended legends of the LUC worksheets for the North Island and rainfall of 1600 mm and contained in the first report.

Including soil type, drainage class, slope and the rainfall associated with the soil in the calculation in OVERSEER[®] and using 75% of the “Attainable potential livestock carrying capacity” for each soil land unit the N loading when summed for each land unit produced a lower N loading in the river (Table 15).

Again with the more detailed data, there was a trend towards lower calculated N leaching losses on the soils on flat and rolling country and increased N leaching losses on hill and steep land due to two factors (Fig 18). Rainfall was higher in the hill and steep land of the catchment and N leaching losses increased with slope in the calculated in OVERSEER[®] (Fig. 21).

In the initial report, average rainfall was used in the OVERSEER[®] calculation to determine the N leaching loss. Rainfall in the Mangatainoka varies from 1000 to 3500 mm pa with the area weighted average rainfall 1789 mm. Use of an average rainfall value in the calculation of the N loss limit overestimates the N leaching loss on the landscapes receiving less than

the average rainfall and underestimates the N leaching losses from the higher rainfall zones in the catchment.

Given the influence of rainfall on N leaching and its contribution to the N loading in the river, we suggest that rather than using an average rainfall value for the catchment (1789 mm), that three rainfall bands are defined.

- If rainfall is < 1789 mm use actual or the isohyet value
- If rainfall is > 1789 - 2200 mm use actual or the isohyet value
- >2200 mm actual, isohyet or a maximum of 2400 mm.

These would be default values in the absence of the land owner having good rainfall records for their property. As we suggested earlier with the land information, the land owner could be given the option of utilising the banded rainfall values or actual rainfall for the farm. This suggestion addresses two key issues, spatial inaccuracies in the rainfall database and the uncertainty surrounding the N leaching loss in high rainfall environments. Placing an upper value of rainfall, recognises that the area of the catchment under high rainfall is found in hill and steep land and the area is often small and generally of low fertility, contributing little to total N losses.

Utilising more detail provides more confidence that the biophysical resources that contribute to N leaching loss are described and included in the analysis. In the case of the Mangatainoka the inclusion of additional information changed the total N loading in the river and the contribution of each land unit to the N loading (Fig.19).

(b) Comparison between the UMWMZ and Mangatainoka

1.2.1 Comparison of soils, landscapes and climate in the two catchments

Table 16 summaries the current state, standard and target N loading in the One Plan for years 1 to 30 for the Mangatainoka and Upper Manawatu.

Table 16: Summary of the current state of the Mangatainoka River based on SH2 Water Quality Data and of the Upper Manawatu based on Hopelands Water Quality Data, standard and target N loadings in the One Plan for the two catchments.

	Mangatainoka	Upper Manawatu
Area (ha)	48965	129638
	River Loading	River Loading
Current State (T)	603	816
Standard (T)	317	458
One Plan Yr 1	360	859
One Plan Yr 5	334	824
One Plan Yr 10	311	773
One Plan Yr 20	301	751
One Plan Yr 30	238	358

The comparisons listed below between the Upper Manawatu and Mangatainoka provides a basis on which to explore the case for adopting a generic or tailored approach to each water management zone.

The **topography** (landscape units and slopes) and **soil types** (drainage classes) in the Upper Manawatu vary significantly from those found in the Mangatainoka catchment. For example the landscape in the Upper Manawatu catchment is dominated by Class VI, whereas the Mangatainoka catchment has significant areas (18,500 ha) of flat and rolling landscape units (Fig 20).

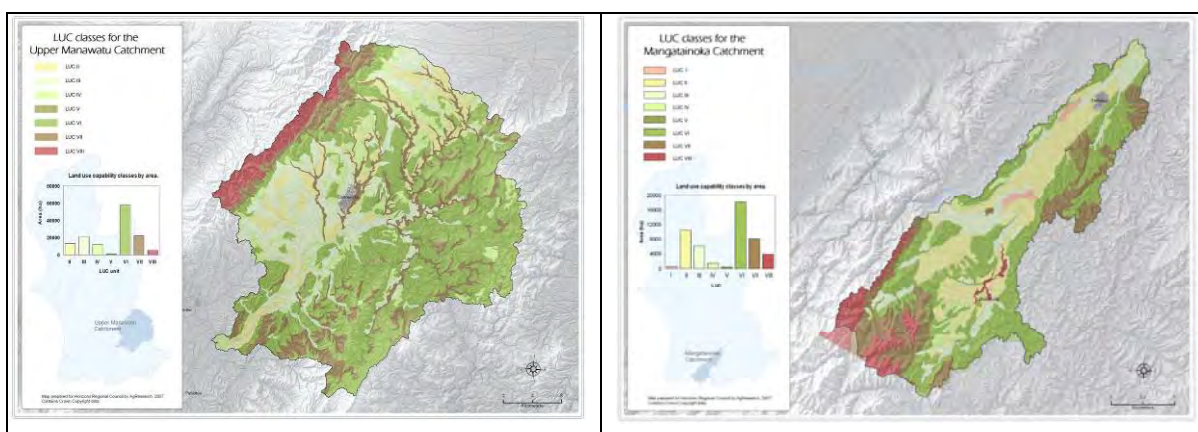


Fig. 20 LUC classes for the Upper Manawatu and Mangatainoka catchments.

Rainfall difference between the Upper Manawatu and Mangatainoka catchments has a significant impact on the calculated N leaching loss (Fig 21). As indicated earlier the rainfall of the Upper Manawatu is 1357 mm (1000-3000 mm) compared with 1789 mm (range from 1000 to 3500 mm) for the Mangatainoka.

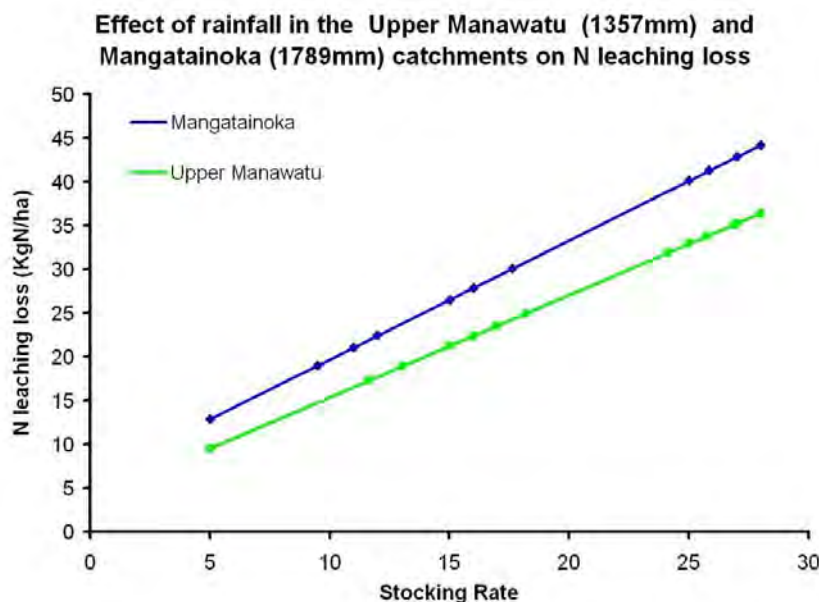


Fig. 21 Effect of rainfall in the Upper Manawatu and Mangatainoka catchments on the calculated N leaching loss

The net effect of differences in rainfall characteristics between the two catchments is reflected in the contribution each landscape unit makes to N leaching losses (Fig 22a & b). The effect of the combined differences of physical and climatic characteristics is reflected in the N loading in the river (Fig. 22c & d).

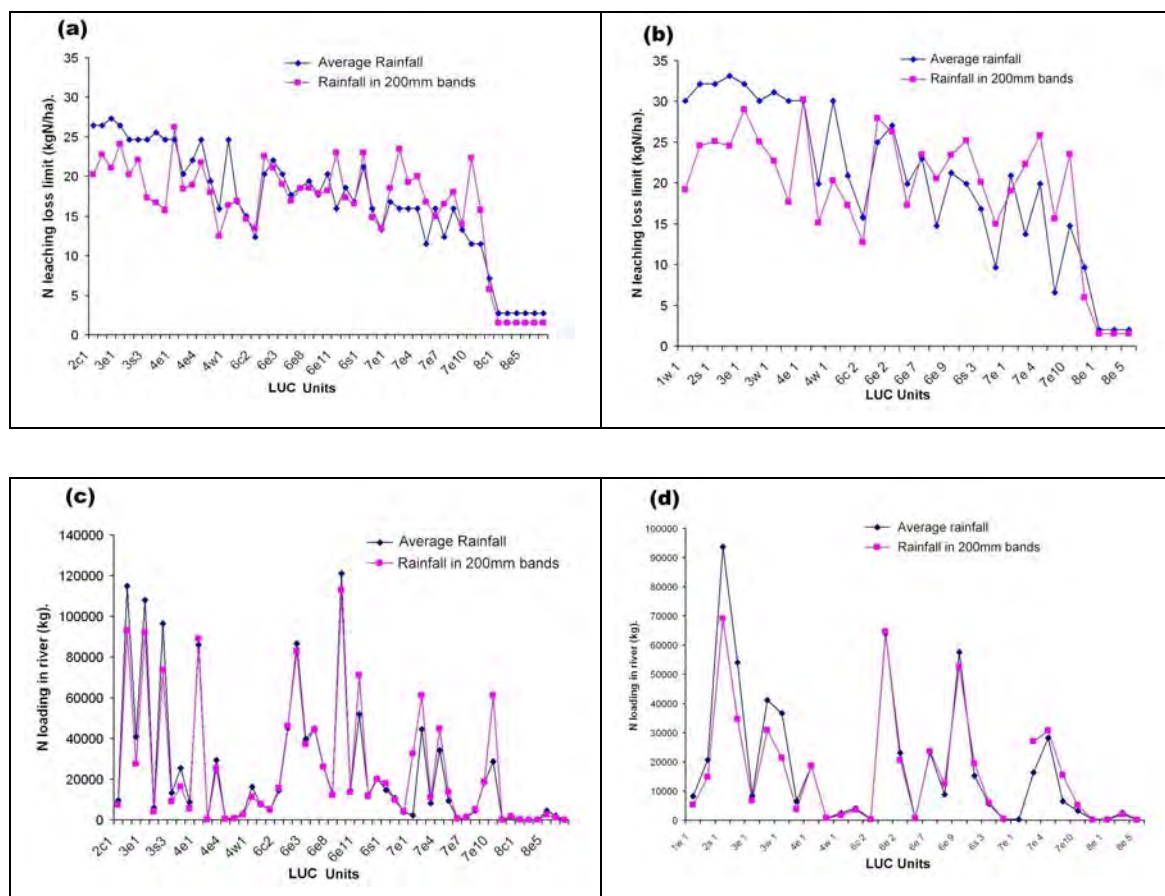


Fig. 22 Nitrogen leaching loss associated with 75% of potential production of soils for each LUC unit calculated using average rainfall and rainfall in 200 mm bands for the (a) Upper Manawatu catchment and (b) Mangatainoka catchment, and (c) the Nitrogen loadings in the Upper Manawatu and (d) the Mangatainoka associated with 75% of potential production of soils for LUC units calculated using average rainfall and rainfall in 200 mm bands.

The pattern of N leaching loss and the potential contribution of landscapes to N loadings are very different between the two catchments, with a greater contribution from the lowland in the Mangatainoka catchment.

Existing and potential future use of the two catchments

Over 60% of the Upper Manawatu is in sheep and beef (Table 17) compared with only 50% in the Mangatainoka River (Table 18). In comparison, more of the Mangatainoka catchment is under an intensive pastoral use, with 28% of the catchment in dairying, compared with 16% of the Upper Manawatu catchment.

While the opportunity exists to potentially double the land in dairy production in the Upper Manawatu, the opportunities in the Mangatainoka catchment is more constrained. Further if dairy production was to expand from 20, 000 to 40,000 ha in the Upper Manawatu (Table 18) by utilising the same land Class mix used by the existing industry and assuming an average farm size of 200 ha, carrying 2.5 cows ha, with each cow producing 340 kg MS per year, 100 new dairy farms could be added to the catchment, with each contributing 170,000 kg MS per year to the regional economy.

Also see section 1.2

Table 17 Land uses by LUC Class for the Upper Manawatu Catchments

Land use	LUC Class								Grand Total
	2	3	4	5	6	7	8	(blank)	
Built-up/Parks/Other	20.4	51.2	18.9		0.2	36.7	0.4	328.8	456.6
Cropping	20.3	413.0	31.7		2.7	11.3			478.9
Dairy	5704.3	7489.6	3207.3	116.8	2409.6	1210.6		0.6	20138.8
Exotic Cover	253.2	532.8	221.0	14.6	1899.9	843.1	27.4		3792.0
Horticulture-Other	7.2	8.5	3.0		2.1			0.2	20.9
Native Cover	233.0	383.9	159.9	1.8	2100.7	4813.0	5064.8		12757.0
Other	85.6	199.9	94.6		478.5	63.3		0.0	921.9
Sheep and/or Beef	5531.3	10888.0	7231.8	663.9	47614.4	13569.7	57.7	120.1	85676.8
Water Body	16.1	26.9	17.7		6.5	22.0	13.3		102.5
Grand Total	11871.2	19993.9	10985.8	797.1	54514.6	20569.5	5163.6	449.7	124345.4

The same exercise could be completed for the Mangatainoka catchment

Table 18 Land uses by LUC Class for the Mangatainoka River

Land use	LUC Class									Grand Total
	1	2	3	4	5	6	7	8	(blank)	
Built up/Parks/Others		56.8	16.6			4.5		2.5	177.2	258
Cropping		3.1	1.5							5
Dairy	407.9	5540.0	2824.9	701.8		4005.9	286.8	81.3		13849
Exotic Cover	0.1	85.6	83.5	11.2	5.8	376.1	330.4	16.5	0.3	909
Horticulture-Other		0.4								0.4
Native Cover		171.1	148.6	52.6	8.5	1192.6	3983.9	3562.2	0.8	9120
Other	6.2	85.1	56.2	0.2		17.4	11.3	0.0		177
Sheep and/or Beef	174.1	4716.1	3044.8	725.1	394.6	12597.6	3399.6	173.9	77.3	25303
Water Body	4.2	61.4	56.4	5.4		1.3	1.1		3.6	133
Grand Total	592.5	10719.8	6232.5	1496.2	408.9	18195.3	8013.1	3836.4	259.1	49754

5. What information is required to roll out this approach?

5.1 *For example for commercial vegetable, lake catchments, water quality information, land use information, flow data etc.*

See answer to the 5.2

5.2 *Consider all catchments where the Rule will apply*

To roll out the approach for any given water management zone the following information is required (Fig. 21).

Task 1 Inventories

- The boundaries and area of the water management zone
- NZLRI data base including the worksheets containing the extended legend
- Major land uses and areas in non-agricultural use
- List of point source discharge points and quantities
- Rainfall in 200 mm Isohyets for the water management zone

Task 2 Community of interest

- Identify land owners in the water management zone interested in acting as test farms to establish the challenges and opportunities.
- Establish a water management zone based community of interest to discuss the proposed targets, time scale and roll out
- Engage with key stakeholder (e.g. sectors, service providers, etc)
- Review the FARM strategy to ensure all the issues are adequately covered and all the mitigation options listed and available.

Task 3 Nitrogen loading and target and farm N losses

- Summary of the rivers flow rates, lake volumes/levels, inflow rates, resident times and out fall rates and N concentrations in water in each of these water bodies, used to calculate the nitrogen loadings in the water management zone. The framework report by Roygard and McArthur (2008) provides a methodology for this task.
- Current nitrogen loading for the water management zone.

- The standard (nitrogen loading target) and justifications for the standard for the water management zone.
- List the nitrogen leaching loss from each of the major land uses in the water management zone and from point discharges.

Task 4 Other contaminants and their management

- List other potential contaminants contributing to poor water quality (e.g. Sediment, P, faecal, etc) in the water management zone
- Current levels of contamination
- List current and future mitigation options (e.g. Clean Streams, Whole farm plans, etc) for the water management zone.

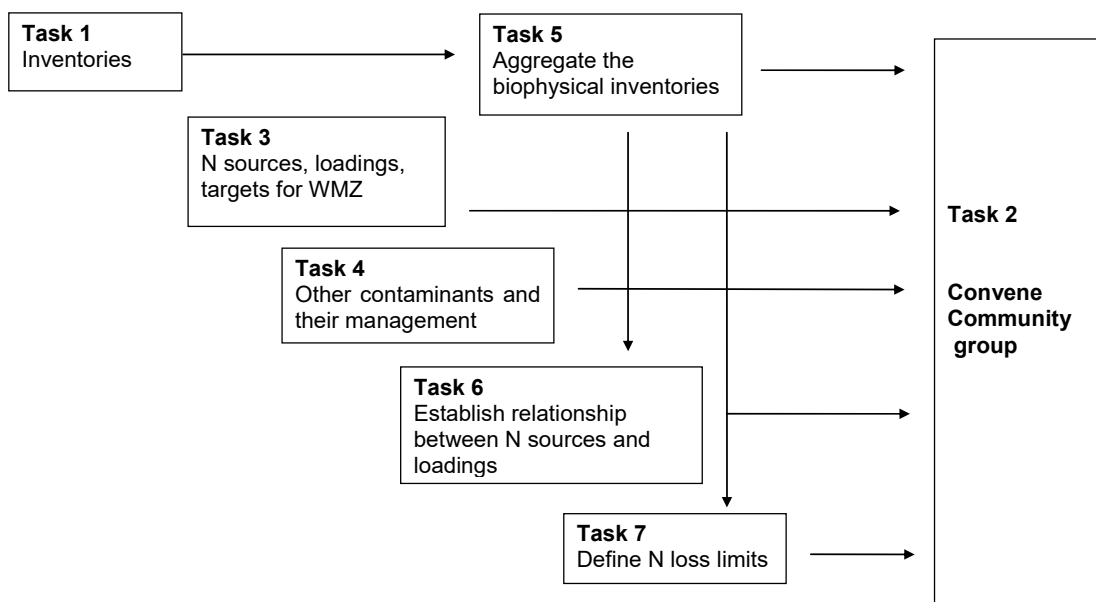


Fig. 21 Schematic diagram of the tasks to develop the catchment management plan

Task 5 Aggregate the biophysical inventories

- List the areas (ha) and potential productivity of each LUC Class, Subclass, and Unit in the water management zones (e.g. Appendix 1)
- List the areas (ha), potential productivity, drainage class, slope of all LUC units in the water management zone catchment (e.g. Appendix 2)
- Describe rainfall in 200 mm Isohyets for the water management zone and develop a set of rules defining the rainfall bands (e.g. for the UMWMZ)

Task 6 Calculate N loading in the river from each land use, transmission co-efficient and the potential N loss limit for each land unit.

- In catchments with multiple N water quality sampling sites, calculate the contribution from the major land use to the N loading in the water body. If not available use the N loading values from existing catchments.
- Establish the transmission co-efficient by calculating the N loss for each land use using Overseer, and expressing as a fraction of the N loading in the river for each land use. If not available use the transmission co-efficient values from existing catchments.
- Calculate the N leaching loss limit for each soil in the catchment, using Overseer, by LUC Class, LUC Subclass and LUC Unit and for each unit using detailed bio-physical and rainfall data.

Task 7 Establish the N loss limit for each land unit

- Establish the relationship between the potential N loss limit for each LUC Class, Subclass and Unit and for each unit using detailed bio-physical and rainfall data and the N loadings in the river.
- Calculate the percentage of potential use of each land unit that is permissible to achieve the current N loading and the rate of change in the potential use of each land unit each year to move towards the standard (i.e. N loading target for the water management zone) over time. Include data to demonstrate the influence of a differential percentage of potential use for each land unit in achieving the N loading target.

Notes

1. Tables containing the N loss limits and the relationship between each land unit and the N loading in the river for soil in each LUC Class would be available to the public. More detailed information would be available on request on the contribution of each land use and each LUC land unit on the Regional Council web site.
2. Land owners in the water management zone would be able to access on request a confidential report detailing their farms N loss limit based on the information contained in the NZLRI and Regional rainfall data base.

6. How will the FARM strategy approach be linked into the farm practice?

The FARM strategy has the greatest chance of being linked into farm practice and successfully implemented if the experts within the industry (i.e. nutrient budgeting and planning, fertiliser advice, farm management and business planning) are the primary service providers. This is already partially in place, with a nutrient budget required by all dairy farms, as part of the Clean Streams Accord since June 2007.

Land owners will require access to a cost-effective and timely nutrient budgeting and planning service. The capacity to update both the nutrient budget and plan on an annual planning cycle, in response to a business opportunity or at short notice following for example an adverse event will need to be developed in the Region.

Horizons in partnership with industry should undertake a stock take of the capabilities and the capacity in the region to deliver the services that will be required as the priority catchment programme within the 'One plan' is rolled out to ensure land owners have access to expertise and a choice of providers. Collating and listing the accredited service providers available to land owners in the Region would be a useful resource for all land owners. This could be made available through the Regional Councils website.

The question has been addressed as part of the FARMS test farms project report (Manderson 2008).

6.1 Please outline an approach as to how this could be rolled out.

Roll out. There has already been some discussion on establishing a consortium to provide the expertise necessary to roll out the FARM strategy. This concept should continue to be developed by Horizons in consultation with the industry providers. This would maximize the likelihood of the FARM strategy approach being adopted into farm practice and planning cycles by the industry. It would also ensure that the FARM strategy document continues to be revised and evolved in response to new knowledge, technologies and practices. There would be merit in examining learning's from Environment Waikato and Taupo including from the farmers, policy and Industry/consultants involved in that process.

An added advantage of Horizons encouraging the development of an industry consortium as the led service provider is the fact the industry already has staff training programmes, nutrient budgeting and planning protocols and audit processes in place, as part of good practice. Horizons does not need to duplicate these systems to ensure service delivery standards are of the highest standard to land owners and land owners have access to the best and most recent advice available on nutrients use and management.

Horizons would have to work through with the consortium an independent audit process to ensure consistency across the providers and adherence to the N loss limits. Would need to consider and built into the audit process to address issues including the version of OVERSEER® to use (e.g. 3.6.2), because the N leaching loss values will inevitably change with a new version release, an agreed procedure for dealing with missing data from farm records, i.e. an agreed list of default values and an agreed system that allows the entire chain from collecting farm records through to producing an N output value to be audited. Again the experiences gain by Environment Waikato, policy, farmers, consultants and the industry with respect to Taupo would be useful

Compliance Checking compliance with the consent conditions set out in the FARM strategy should be limited to the factors (e.g. including milk production/ha, cow number/ha, fertiliser inputs (P and N), mm irrigation water/ha, etc) contributing to N leaching loss the land owner can control. A table listing the input data (e.g. cow numbers, milk production, N fertiliser use, etc) to complete the nutrient budget could be populated at the end of the year with actual production data and inputs used on the farm and submitted to Council each year as part of the consent process. An explanation would be required if the N leaching loss limit deviates by more than 5% from the agreed N loss limit. This would also form the basis for the annual audit, required as part of the statutory responsibilities of Council.

Also see FARMS test farms project report (Manderson 2008) for comments on the specific requirements with respect to both nutrient budgeting and planning

6.2 To what extent do you see need for expertise around fertiliser, farm management, financial management to be involved?

See FARMS test farms project report (Manderson 2008) for comments on the specific requirements with respect to both nutrient budgeting and planning

6.3 *Consult with industry representatives in answering this question*

The industry was engaged in the FARM test farms project. We make the suggestion to Council to engage the primary industry (i.e. Fertiliser industry, consultants, etc) in evaluating the findings and recommendations from the Test farm project. It would provide industry with the opportunity to examine the logistics of providing a nutrient budgeting and planning service to their client base as the One Plan is rolled out. Input could be sought from industry on the most appropriate approach for checking on compliance with the consent conditions set out in the FARM strategy.

7. OVERSEER[®], the FARM strategy and the water quality outcomes work on long-term averages

7.1 *How will the farm strategy work with farm management changes in response to weather e.g. using N to fill a gap in the feed budget*

Our farming systems are designed for the average year. Nutrient budgets and plans are also developed to reflect the conditions that prevail in an average year. Farm system design includes the capacity to cope with some variation in seasonal and annual rainfall, sunshine hours and temperatures. Variable climatic conditions for example, a change in temperature and rainfall in late summer and autumn, might result in some change in the drying-off, harvesting or weaning date. These changes would be seen as minor, not requiring a review of the business plan.

Extremes of climate (i.e. prolonged wet or dry conditions) do occur (e.g. 2004 Flood, 2008 Drought). These force producers to make wholesale changes to their farm operation and the business plan. Changes to the business plan, in response to an extreme event, will not be made lightly by land owners, as it invariably impacts on production levels, expenditure and income. Land owners will often seek additional professional advice during these times to explore options to minimise the short-term impacts, but importantly limit the long-term implications for the production system. An update of the nitrogen budget and plan may be part of the analysis undertaken at the time of the review of the business plan, or it may not be completed, until the farm operation returns to the annual business planning cycle. Once back in the business planning cycle the full implications of the extreme event on the nitrogen budget can be documented and any changes required to the nutrient plan built into next years business plan.

Given extreme events occur infrequently and major change to the business plan are not taken lightly by land owners, and when they are, it is frequently in consultation with their consultant, no change is necessary to the FARM strategy, beyond Horizons requesting the land owners submit an updated nutrient budget and plan if the N leaching loss calculated by OVERSEER® is significantly different (>5%) from the nutrient budget submitted as part of the consent process. Part of that plan would include how and when the business would return to the N leaching loss limit for that farm.

It is important that a distinction is made between the changes to the nutrient budget resulting from a change in the business plan in response to an extreme event, from changes to the business plan driven by market opportunities, a change in the cost structure, purchase of additional land, etc. Business drivers must ensure that any change does not exceed the N leaching loss limit.

We recommend one addition to the farm strategy to accommodate extreme climatic events. Horizons require intensive land users to submit an update nutrient budget and plan if N leaching losses are higher (>5%) than in the budget submitted as part of the consent process. The plan would include the “how and when” the business would return to the N leaching loss limit for that farm.

7.2 *Examine the impact of extreme events (flooding, drought, etc).*

We see little value in defining what constitutes an extreme event or the actions an intensive land owner should follow, outside of the recommendations we have already made in response to question 7.1. Horizons require intensive land users to submit an update nutrient budget and plan if N leaching losses are higher (>5%) than in the budget submitted as part of the consent process.

Extreme climatic events will impact on the N leaching losses to the wider environment. Prolonged wet cold springs could cause an increase in N losses through greater use of N fertiliser and additional leaching events in all intensive land uses. Extended dry periods by reducing pasture growth and production could see the reverse, a significant decrease in N leaching losses to the wider environment. It would be possible to explore the impact of extreme climatic events over the last 10-20 years on N leaching losses to assess if the N leaching loss limits set for an average year, should be adjusted up or down to absorb the additional losses or to release N leaching loss use rights. There would also appear to be a case for examining further the impact of a short-term event on N loadings in the river and

the impact that any sudden change in the N loading might have on the targeted water quality outcomes

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Appendix 1: Nitrogen loading in the Upper Manawatu summed from the N losses calculated in OVERSEER® using 75% of the averaged weighted (by area) “Attainable potential livestock carrying capacity” for the soils in (a) each LUC Class, (b) Subclass and (c) unit and the average rainfall (1357 mm) for the catchment.

(a)

LUC	Area (ha)	Stocking Rate (su/ha)	N-loss Function	Fraction of Potential	N-loss limit	Transmission co-efficient	N loading in river
II	12423.99	27.24	35.532	0.75	26.6	0.5	165544.6
III	20256.66	25.91	33.970	0.75	25.5	0.5	258046.6
IV	11508.03	23.89	31.613	0.75	23.7	0.5	136425.9
V	907.14	16.00	22.391	0.75	16.8	0.5	7616.9
V1	57253.99	17.77	24.458	0.75	18.3	0.5	525122.0
VII	22108.01	12.83	18.687	0.75	14.0	0.5	154925.6
VIII	5180.00	0.00	3.687	0.75	2.8	0.5	7161.6
Total	129638					Total	1254843.1

Foot note Attributes for calculating N leaching losses under a pastoral (Dairy) use, using OVERSEER® Version 5.2.6.0, included Manawatu/Wanganui region, Farm of 112ha, Main Pasture Block of 100ha, Effluent Block of 12ha, relative productivity between blocks, uniform, all cows F x J cross, replacements grazed off farm from weaning, effluent disposed via spray from sump, effluent application rate for effluent block was medium, distance from coast is 70km, temp (12.2 deg-c) and drainage defaults, zero irrigation, ryegrass/ medium white clover, highly Developed Pasture, Soil order was brown, soil texture was silt loam, Olsen P =30, QT K = 8.0, Org S =10, QT Ca = 12, QT Mg = 10, QT Na = 3, fertiliser input 20% potash super @ 864 kg/ha/yr, no supplements removed or added and all other fields either blank or Overseer default.

Variables changed included topography, profile Drainage Class (Advanced field), rainfall, stocking rate and milk solids kg/ha

(b)

LUC	Area (ha)	Stocking Rate (su/ha)	N-loss Function	Fraction of Potential	N-loss limit	Transmission Co-efficient	N load in river
IIc	728	27.00	35.3	0.75	26.4	0.5	9620
IIs	8694	27.00	35.3	0.75	26.4	0.5	114929
IIw	3002	28.00	36.4	0.75	27.3	0.5	40996
IIIe	8648	26.89	35.1	0.75	26.3	0.5	113897
IIIs	8892	25.00	32.9	0.75	24.7	0.5	109745
IIIw	2716	25.74	33.8	0.75	25.3	0.5	34405
IVe	9773	24.12	31.9	0.75	23.9	0.5	116849
IVs	418	15.00	21.2	0.75	15.9	0.5	3332
IVw	1316	25.00	32.9	0.75	24.7	0.5	16245
Vc	907	16.00	22.4	0.75	16.8	0.5	7617
VIc	2962	11.64	17.3	0.75	13.0	0.5	19212
VIe	50956	18.18	24.9	0.75	18.7	0.5	476509
VIIs	3336	16.95	23.5	0.75	17.6	0.5	29401

VIIe	21522	13.04	18.9	0.75	14.2	0.5	152833
VIIIs	586	5.00	9.5	0.75	7.1	0.5	2093
VIIIc	177	0.00	0	0.75	2.8	0.5	245
VIIIe	5003	0.00	0	0.75	2.8	0.5	6917
Total	129638					Total	1254843

(c)

LUC	Area	Stocking	N-loss	Fraction of	N- loss	Transmission	N load
	(ha)	Rate (su/ha)	Function	Potential	limit	Coefficient	in river
IIc1	728	27.00	35.3	0.75	26.4	0.5	9620
IIIs1	8694	27.00	35.3	0.75	26.4	0.5	114929
IIw1	3002	28.00	36.4	0.75	27.3	0.5	40996
IIIe1	8167	27.00	35.3	0.75	26.4	0.5	107961
IIIe3	481	25.00	32.9	0.75	24.7	0.5	5935
IIIs2	7817	25.00	32.9	0.75	24.7	0.5	96472
IIIs3	1075	25.00	32.9	0.75	24.7	0.5	13273
IIIw1	2007	26.00	34.1	0.75	25.6	0.5	25646
IIIw2	710	25.00	32.9	0.75	24.7	0.5	8759
IVe1	6950	25.00	32.9	0.75	24.7	0.5	85775
IVe2	14	20.00	27.1	0.75	20.3	0.5	144
IVe3	2675	22.00	29.4	0.75	22.1	0.5	29500
IVe4	50	25.00	32.9	0.75	24.7	0.5	617
IVe5	84	19.00	25.9	0.75	19.4	0.5	813
IVs	419	15.00	21.2	0.75	15.9	0.5	3332
IVw	1316	25.00	32.9	0.75	24.7	0.5	16245
Vc	907	16.00	22.4	0.75	16.8	0.5	7617
Vlc1	635	14.00	20.1	0.75	15.0	0.5	4770
Vlc2	2328	11.00	16.5	0.75	12.4	0.5	14442
Vle1	4474	20.00	27.1	0.75	20.3	0.5	45414
Vle2	7860	22.00	29.4	0.75	22.1	0.5	86666
Vle3	3916	20.00	27.1	0.75	20.3	0.5	39745
Vle5	5113	17.00	23.6	0.75	17.7	0.5	45170
Vle7	2830	18.00	24.7	0.75	18.5	0.5	26242
Vle8	1325	19.00	25.9	0.75	19.4	0.5	12867
Vle9	13699	17.00	23.6	0.75	17.7	0.5	121028
Vle10	1415	20.00	27.1	0.75	20.3	0.5	14361
Vle11	6535	15.00	21.2	0.75	15.9	0.5	52009
Vle12	1353	18.00	24.7	0.75	18.5	0.5	12549
Vle13	2437	16.00	22.4	0.75	16.8	0.5	20461
Vls1	1382	21.00	28.2	0.75	21.2	0.5	14634
Vls2	1357	15.00	21.2	0.75	15.9	0.5	10800
Vls3	597	12.00	17.7	0.75	13.3	0.5	3967
VIIe1	275	16.00	22.4	0.75	16.8	0.5	2305
VIIe2	5623	15.00	21.2	0.75	15.9	0.5	44749
VIIe3	1029	15.00	21.2	0.75	15.9	0.5	8190
VIIe4	4303	15.00	21.2	0.75	15.9	0.5	34243
VIIe5	1651	10.00	15.4	0.75	11.5	0.5	9521
VIIe6	99	15.00	21.2	0.75	15.9	0.5	784

VIIe7	171	11.00	16.5	0.75	12.4	0.5	1061
VIIe8	575	15.00	21.2	0.75	15.9	0.5	4579
VIIe9	2785	12.00	17.7	0.75	13.3	0.5	18498
VIIe10	5005	10.00	15.4	0.75	11.5	0.5	28858
VIIe11	7.8	10.00	15.4	0.75	11.5	0.5	45
VIIIs1	586	5.00	9.5	0.75	7.1	0.5	2093
VIIIc1	177	0	3.7	0.75	2.8	0.5	245
VIIIe1	94	0	3.7	0.75	2.8	0.5	130
VIIIe4	101	0	3.7	0.75	2.8	0.5	140-
VIIIe5	3259	0	3.7	0.75	2.8	0.5	4506
VIIIe6	1536	0	3.7	0.75	2.8	0.5	2124
VIIIe7	13	0	3.7	0.75	2.8	0.5	18
Total	130087					Total	1255464

Appendix 2: Nitrogen loadings in the Upper Manawatu summed from the N losses calculated in OVERSEER[®] using the 75% of the “Attainable potential livestock carrying capacity” and the soil, landscape and actual rainfall, in 200 mm bands, information for each of the polygon within the catchment.

LUC	Slope	Drainage	Average	Area	N-loss	Fraction of	N-Loss	Trans-mission	N
			Rain (mm)	(ha)	Function	Potential	Limit	Co-efficient	Loading
2c 1	Flat	Well Drained	1184	321	27	0.75	20.3	0.5	3247
2c 1	Flat	Well Drained	1240	407	27	0.75	20.3	0.5	4122
2s 1	Flat	Well Drained	1117	1934	26	0.75	19.5	0.5	18860
2s 1	Flat	Well Drained	1286	3461	28	0.75	21.0	0.5	36341
2s 1	Flat	Well Drained	1492	1793	30	0.75	22.5	0.5	20172
2s 1	Flat	Well Drained	1693	1240	31	0.75	23.3	0.5	14418
2s 1	Flat	Well Drained	1859	259	33	0.75	24.8	0.5	3204
2s 1	Flat	Well Drained	2005	7	34	0.75	25.5	0.5	86
2w 1	Flat	Poor	1129	699	21	0.75	15.8	0.5	5504
2w 1	Flat	Poor	1256	925	22	0.75	16.5	0.5	7629
2w 1	Flat	Poor	1466	106	24	0.75	18.0	0.5	952
2w 1	Flat	Poor	1666	20	26	0.75	19.5	0.5	194
2w 1	Flat	Well Drained	1103	968	27	0.75	20.3	0.5	9802
2w 1	Flat	Well Drained	1548	53	31	0.75	23.3	0.5	619
2w 1	Flat	Well Drained	1700	155	33	0.75	24.8	0.5	1913
2w 1	Flat	Well Drained	1877	66	34	0.75	25.5	0.5	842
2w 1	Flat	Well Drained	2032	11	35	0.75	26.3	0.5	138
3e 1	Flat	Imperfect	1523	86	26	0.75	19.5	0.5	838
3e 1	Flat	Imperfect	1620	16	27	0.75	20.3	0.5	164
3e 1	Flat	Well Drained	1142	1218	26	0.75	19.5	0.5	11875
3e 1	Flat	Well Drained	1303	2152	28	0.75	21.0	0.5	22593
3e 1	Flat	Well Drained	1504	1865	30	0.75	22.5	0.5	20979
3e 1	Flat	Well Drained	1690	1528	31	0.75	23.3	0.5	17764
3e 1	Flat	Well Drained	1852	267	33	0.75	24.8	0.5	3301
3e 1	Flat	Well Drained	2043	21	34	0.75	25.5	0.5	267
3e 1	Rolling	Well Drained	1068	133	34	0.75	25.5	0.5	1702
3e 1	Rolling	Well Drained	1336	292	37	0.75	27.8	0.5	4051
3e 1	Rolling	Well Drained	1510	531	39	0.75	29.3	0.5	7762
3e 1	Rolling	Well Drained	1615	59	41	0.75	30.8	0.5	906
3e 3	Flat	Imperfect	1066	419	21	0.75	15.8	0.5	3298
3e 3	Rolling	Well Drained	1175	62	33	0.75	24.8	0.5	769
3s 2	Flat	Well Drained	1113	5317	24	0.75	18.0	0.5	47857
3s 2	Flat	Well Drained	1263	1581	26	0.75	19.5	0.5	15414

3s 2	Flat	Well Drained	1490	481	28	0.75	21.0	0.5	5051
3s 2	Flat	Well Drained	1659	187	29	0.75	21.8	0.5	2035
3s 2	Flat	Well Drained	1908	127	31	0.75	23.3	0.5	1481
3s 2	Flat	Well Drained	2081	99	33	0.75	24.8	0.5	1230
3s 2	Flat	Well Drained	2253	23	35	0.75	26.3	0.5	305
3s 3	Flat	Imperfect	1087	568	21	0.75	15.8	0.5	4474
3s 3	Flat	Imperfect	1210	43	22	0.75	16.5	0.5	358
3s 3	Flat	Well Drained	1097	68	24	0.75	18.0	0.5	612
3s 3	Flat	Well Drained	1229	396	25	0.75	18.8	0.5	3712
3w 1	Flat	Poor	1109	1063	20	0.75	15.0	0.5	7969
3w 1	Flat	Poor	1311	197	22	0.75	16.5	0.5	1628
3w 1	Flat	Imperfect	1119	132	22	0.75	16.5	0.5	1089
3w 1	Flat	Well Drained	1068	615	25	0.75	18.8	0.5	5764
3w 2	Flat	Poor	1185	53	20	0.75	15.0	0.5	394
3w 2	Flat	Poor	1298	339	21	0.75	15.8	0.5	2667
3w 2	Flat	Poor	1416	32	22	0.75	16.5	0.5	266
3w 2	Flat	Imperfect	1110	286	21	0.75	15.8	0.5	2254
4e 1	Flat	Well Drained	1103	389	24	0.75	18.0	0.5	3497
4e 1	Rolling	Imperfect	1135	298	28	0.75	21.0	0.5	3132
4e 1	Rolling	Imperfect	1301	301	30	0.75	22.5	0.5	3381
4e 1	Rolling	Imperfect	1410	25	31	0.75	23.3	0.5	288
4e 1	Rolling	Well Drained	1123	1413	32	0.75	24.0	0.5	16953
4e 1	Rolling	Well Drained	1300	2063	34	0.75	25.5	0.5	26297
4e 1	Rolling	Well Drained	1488	1305	37	0.75	27.8	0.5	18106
4e 1	Rolling	Well Drained	1693	991	39	0.75	29.3	0.5	14487
4e 1	Rolling	Well Drained	1870	91	41	0.75	30.8	0.5	1404
4e 1	Rolling	Well Drained	2098	72	44	0.75	33.0	0.5	1182
4e 1	Rolling	Well Drained	2222	4	45	0.75	33.8	0.5	66
4e 2	Rolling	Well Drained	982	7	24	0.75	18.0	0.5	65
4e 2	Rolling	Well Drained	1028	7	25	0.75	18.8	0.5	66
4e 3	Flat	Mod Well	1196	56	21	0.75	15.8	0.5	437
4e 3	Rolling	Imperfect	1098	1449	24	0.75	18.0	0.5	13039
4e 3	Rolling	Imperfect	1246	532	26	0.75	19.5	0.5	5189
4e 3	Rolling	Mod Well	1171	399	27	0.75	20.3	0.5	4036
4e 3	Rolling	Well Drained	1125	240	28	0.75	21.0	0.5	2522
4e 4	Rolling	Imperfect	1201	50	29	0.75	21.8	0.5	544
4e 5	Rolling	Well Drained	1066	84	24	0.75	18.0	0.5	753
4s 1	Flat	Imperfect	1376	116	15	0.75	11.3	0.5	654
4s 1	Flat	Imperfect	1414	1	15	0.75	11.3	0.5	4
4s 1	Flat	Well Drained	1081	131	16	0.75	12.0	0.5	784
4s 1	Flat	Well Drained	1379	6	17	0.75	12.8	0.5	40
4s 1	Flat	Well Drained	1513	83	18	0.75	13.5	0.5	557
4s 1	Flat	Well Drained	1670	82	19	0.75	14.3	0.5	586

4w 1	Flat	Poor	1121	76	19	0.75	14.3	0.5	543
4w 1	Flat	Poor	1269	244	21	0.75	15.8	0.5	1921
4w 1	Flat	Poor	1418	9	22	0.75	16.5	0.5	77
4w 1	Flat	Imperfect	1364	251	23	0.75	17.3	0.5	2162
4w 1	Flat	Well Drained	1078	736	24	0.75	18.0	0.5	6624
5c 1	Rolling	Well Drained	992	110	21	0.75	15.8	0.5	867
5c 1	Rolling	Well Drained	1151	146	22	0.75	16.5	0.5	1207
5c 1	Rolling	Well Drained	1264	404	23	0.75	17.3	0.5	3482
5c 1	Easy Hill	Well Drained	1282	247	24	0.75	18.0	0.5	2224
6c 1	Rolling	Well Drained	1189	38	20	0.75	15.0	0.5	282
6c 1	Easy Hill	Poor	1022	4	16	0.75	12.0	0.5	27
6c 1	Easy Hill	Well Drained	1182	206	21	0.75	15.8	0.5	1622
6c 1	Easy Hill	Well Drained	1238	386	21	0.75	15.8	0.5	3043
6c 2	Rolling	Well Drained	1324	349	17	0.75	12.8	0.5	2226
6c 2	Easy Hill	Well Drained	1348	1938	18	0.75	13.5	0.5	13084
6c 2	Easy Hill	Well Drained	1403	40	19	0.75	14.3	0.5	284
6e 1	Rolling	Imperfect	1164	1134	23	0.75	17.3	0.5	9781
6e 1	Flat	Imperfect	1206	148	18	0.75	13.5	0.5	1001
6e 1	Rolling	Well Drained	1107	373	26	0.75	19.5	0.5	3634
6e 1	Rolling	Well Drained	1256	197	28	0.75	21.0	0.5	2068
6e 1	Rolling	Well Drained	1453	160	30	0.75	22.5	0.5	1802
6e 1	Easy Hill	Imperfect	1142	222	23	0.75	17.3	0.5	1914
6e 1	Easy Hill	Imperfect	1529	54	28	0.75	21.0	0.5	565
6e 1	Easy Hill	Imperfect	1632	37	29	0.75	21.8	0.5	406
6e 1	Easy Hill	Well Drained	1151	455	27	0.75	20.3	0.5	4603
6e 1	Easy Hill	Well Drained	1261	618	28	0.75	21.0	0.5	6486
6e 1	Easy Hill	Well Drained	1559	241	32	0.75	24.0	0.5	2889
6e 1	Easy Hill	Well Drained	1676	505	33	0.75	24.8	0.5	6255
6e 1	Easy Hill	Well Drained	1877	120	36	0.75	27.0	0.5	1626

6e 1	Easy Hill	Well Drained	2085	53	38	0.75	28.5	0.5	749
6e 1	Easy Hill	Well Drained	2251	23	38	0.75	28.5	0.5	327
6e 1	Steep	Well Drained	1773	134	45	0.75	33.8	0.5	2268
6e 2	Rolling	Imperfect	1111	421	24	0.75	18.0	0.5	3792
6e 2	Rolling	Imperfect	1273	67	26	0.75	19.5	0.5	652
6e 2	Rolling	Mod Well	1178	1383	27	0.75	20.3	0.5	14003
6e 2	Rolling	Well Drained	1184	456	29	0.75	21.8	0.5	4961
6e 2	Rolling	Well Drained	1298	1998	29	0.75	21.8	0.5	21733
6e 2	Rolling	Well Drained	1466	452	32	0.75	24.0	0.5	5419
6e 2	Easy Hill	Imperfect	1154	479	25	0.75	18.8	0.5	4495
6e 2	Easy Hill	Imperfect	1214	559	26	0.75	19.5	0.5	5448
6e 2	Easy Hill	Mod Well	1185	636	27	0.75	20.3	0.5	6440
6e 2	Easy Hill	Well Drained	1169	584	29	0.75	21.8	0.5	6355
6e 2	Easy Hill	Well Drained	1244	595	30	0.75	22.5	0.5	6696
6e 2	Easy Hill	Well Drained	1502	228	33	0.75	24.8	0.5	2827
6e 3	Rolling	Imperfect	1093	1190	22	0.75	16.5	0.5	9818
6e 3	Rolling	Well Drained	987	6	24	0.75	18.0	0.5	55
6e 3	Rolling	Well Drained	1187	157	27	0.75	20.3	0.5	1587
6e 3	Rolling	Well Drained	1209	526	27	0.75	20.3	0.5	5329
6e 3	Easy Hill	Imperfect	1135	236	23	0.75	17.3	0.5	2036
6e 3	Easy Hill	Well Drained	983	13	25	0.75	18.8	0.5	122
6e 3	Easy Hill	Well Drained	1130	959	27	0.75	20.3	0.5	9710
6e 3	Easy Hill	Well Drained	1228	828	28	0.75	21.0	0.5	8696
6e 5	Flat	Well Drained	1223	144	18	0.75	13.5	0.5	969
6e 5	Rolling	Imperfect	1294	179	22	0.75	16.5	0.5	1474
6e 5	Rolling	Well Drained	1123	263	23	0.75	17.3	0.5	2269
6e 5	Rolling	Well Drained	1234	221	24	0.75	18.0	0.5	1987
6e 5	Easy Hill	Imperfect	1164	419	21	0.75	15.8	0.5	3301
6e 5	Easy Hill	Imperfect	1322	1147	23	0.75	17.3	0.5	9894

6e 5	Easy Hill	Mod Well	1188	103	23	0.75	17.3	0.5	888
6e 5	Easy Hill	Mod Well	1208	91	23	0.75	17.3	0.5	786
6e 5	Easy Hill	Well Drained	1116	1442	23	0.75	17.3	0.5	12440
6e 5	Easy Hill	Well Drained	1278	1104	25	0.75	18.8	0.5	10348
6e 7	Easy Hill	Imperfect	1176	173	22	0.75	16.5	0.5	1431
6e 7	Easy Hill	Imperfect	1224	762	22	0.75	16.5	0.5	6285
6e 7	Easy Hill	Well Drained	1173	1088	25	0.75	18.8	0.5	10196
6e 7	Easy Hill	Well Drained	1220	525	26	0.75	19.5	0.5	5119
6e 7	Steep	Imperfect	1149	282	28	0.75	21.0	0.5	2961
6e 8	Easy Hill	Imperfect	1109	446	22	0.75	16.5	0.5	3677
6e 8	Easy Hill	Well Drained	1194	104	26	0.75	19.5	0.5	1017
6e 8	Easy Hill	Well Drained	1205	775	26	0.75	19.5	0.5	7555
6e 9	Rolling	Imperfect	1029	247	19	0.75	14.3	0.5	1761
6e 9	Rolling	Imperfect	1220	299	21	0.75	15.8	0.5	2356
6e 9	Easy Hill	Imperfect	1159	5541	21	0.75	15.8	0.5	43639
6e 9	Easy Hill	Imperfect	1240	5661	22	0.75	16.5	0.5	46702
6e 9	Easy Hill	Imperfect	1718	16	27	0.75	20.3	0.5	161
6e 9	Easy Hill	Well Drained	1079	203	23	0.75	17.3	0.5	1747
6e 9	Easy Hill	Well Drained	1259	1534	25	0.75	18.8	0.5	14377
6e 9	Easy Hill	Well Drained	1552	4	28	0.75	21.0	0.5	43
6e 9	Steep	Imperfect	1171	194	28	0.75	21.0	0.5	2036
6e10	Rolling	Imperfect	1077	30	22	0.75	16.5	0.5	251
6e10	Rolling	Well Drained	1166	561	27	0.75	20.3	0.5	5684
6e10	Easy Hill	Mod Well	1180	600	25	0.75	18.8	0.5	5626
6e10	Easy	Imperfect	1077	223	23	0.75	17.3	0.5	1924

	Hill								
6e11	Easy Hill	Well Drained	1152	247	22	0.75	16.5	0.5	2036
6e11	Easy Hill	Well Drained	1285	2337	23	0.75	17.3	0.5	20153
6e11	Easy Hill	Well Drained	1467	9	25	0.75	18.8	0.5	88
6e11	Easy Hill	Well Drained	1718	418	28	0.75	21.0	0.5	4391
6e11	Easy Hill	Well Drained	1903	995	30	0.75	22.5	0.5	11198
6e11	Easy Hill	Well Drained	2096	547	32	0.75	24.0	0.5	6566
6e11	Easy Hill	Well Drained	2263	250	34	0.75	25.5	0.5	3191
6e11	Steep	Mod Well	1196	88	27	0.75	20.3	0.5	887
6e11	Steep	Mod Well	1210	360	28	0.75	21.0	0.5	3785
6e11	Steep	Well Drained	1374	105	31	0.75	23.3	0.5	1223
6e11	Steep	Well Drained	1787	44	38	0.75	28.5	0.5	632
6e11	Steep	Well Drained	1884	739	39	0.75	29.3	0.5	10801
6e11	Steep	Well Drained	2079	395	41	0.75	30.8	0.5	6078
6e12	Rolling	Mod Well	1088	18	22	0.75	16.5	0.5	145
6e12	Easy Hill	Mod Well	1137	1214	23	0.75	17.3	0.5	10472
6e12	Easy Hill	Well Drained	1092	122	24	0.75	18.0	0.5	1094
6e13	Rolling	Well Drained	1136	403	22	0.75	16.5	0.5	3321
6e13	Easy Hill	Well Drained	1130	2034	22	0.75	16.5	0.5	16782
6s 1	Rolling	Well Drained	1183	39	28	0.75	21.0	0.5	412
6s 1	Rolling	Well Drained	1226	107	28	0.75	21.0	0.5	1121
6s 1	Flat	Well Drained	1589	9	24	0.75	18.0	0.5	84
6s 1	Rolling	Well Drained	1680	122	33	0.75	24.8	0.5	1509
6s 1	Easy Hill	Well Drained	1770	98	35	0.75	26.3	0.5	1286
6s 1	Easy Hill	Well Drained	1805	1007	36	0.75	27.0	0.5	13592
6s 2	Rolling	Imperfect	1135	562	18	0.75	13.5	0.5	3796
6s 2	Rolling	Imperfect	1226	319	19	0.75	14.3	0.5	2273
6s 2	Easy Hill	Imperfect	1134	315	19	0.75	14.3	0.5	2244
6s 2	Easy Hill	Imperfect	1207	21	20	0.75	15.0	0.5	156

6s 2	Easy Hill	Well Drained	1247	140	23	0.75	17.3	0.5	1207
6s 3	Rolling	Well Drained	1293	147	18	0.75	13.5	0.5	995
6s 3	Easy Hill	Well Drained	1154	154	18	0.75	13.5	0.5	1042
6s 3	Easy Hill	Well Drained	1227	295	18	0.75	13.5	0.5	1994
7e 2	Steep	Imperfect	1091	439	24	0.75	18.0	0.5	3948
7e 2	Steep	Imperfect	1244	919	26	0.75	19.5	0.5	8965
7e 2	Steep	Mod Well	1165	1859	27	0.75	20.3	0.5	18824
7e 2	Steep	Mod Well	1251	2043	28	0.75	21.0	0.5	21453
7e 2	Steep	Well Drained	1071	115	27	0.75	20.3	0.5	1163
7e 2	Steep	Well Drained	1296	196	30	0.75	22.5	0.5	2201
7e 2	Steep	Well Drained	1585	5	35	0.75	26.3	0.5	60
7e 2	Steep	Well Drained	1712	216	37	0.75	27.8	0.5	2997
7e 2	Steep	Well Drained	1873	105	39	0.75	29.3	0.5	1542
7e 2	Steep	Well Drained	2022	1	40	0.75	30.0	0.5	9
7e 3	Easy Hill	Imperfect	1049	164	18	0.75	13.5	0.5	1110
7e 3	Steep	Well Drained	1161	77	28	0.75	21.0	0.5	810
7e 3	Steep	Well Drained	1311	788	31	0.75	23.3	0.5	9156
7e 4	Rolling	Well Drained	1200	116	22	0.75	16.5	0.5	960
7e 4	Steep	Imperfect	1196	2	26	0.75	19.5	0.5	18
7e 4	Steep	Imperfect	1237	65	26	0.75	19.5	0.5	632
7e 4	Steep	Mod Well	1170	751	27	0.75	20.3	0.5	7600
7e 4	Steep	Mod Well	1250	2760	28	0.75	21.0	0.5	28976
7e 4	Steep	Well Drained	1167	193	28	0.75	21.0	0.5	2025
7e 4	Steep	Well Drained	1255	417	30	0.75	22.5	0.5	4688
7e 5	Steep	Mod Well	1189	58	21	0.75	15.8	0.5	454
7e 5	Steep	Mod Well	1288	1463	22	0.75	16.5	0.5	12073
7e 5	Steep	Well Drained	1343	130	24	0.75	18.0	0.5	1170
7e 6	Easy Hill	Mod Well	1154	99	20	0.75	15.0	0.5	739
7e 7	Steep	Well Drained	1144	171	22	0.75	16.5	0.5	1411
7e 8	Easy Hill	Mod Well	1183	292	21	0.75	15.8	0.5	2301
7e 8	Steep	Mod Well	1183	283	27	0.75	20.3	0.5	2867
7e 9	Rolling	Well Drained	1124	972	17	0.75	12.8	0.5	6193
7e 9	Rolling	Well Drained	1300	774	18	0.75	13.5	0.5	5224
7e 9	Rolling	Well Drained	1484	553	20	0.75	15.0	0.5	4150
7e 9	Rolling	Well Drained	1621	62	21	0.75	15.8	0.5	488
7e 9	Easy Hill	Well Drained	1139	424	17	0.75	12.8	0.5	2702

7e10	Steep	Mod Well	1318	4	22	0.75	16.5	0.5	32
7e10	Steep	Well Drained	1376	154	24	0.75	18.0	0.5	1382
7e10	Steep	Well Drained	1400	26	24	0.75	18.0	0.5	236
7e10	Steep	Well Drained	1774	165	30	0.75	22.5	0.5	1851
7e10	Steep	Well Drained	1911	1100	31	0.75	23.3	0.5	12793
7e10	Steep	Well Drained	2098	1518	33	0.75	24.8	0.5	18785
7e10	Steep	Well Drained	2293	1300	34	0.75	25.5	0.5	16581
7e10	Steep	Well Drained	2474	559	35	0.75	26.3	0.5	7338
7e10	Steep	Well Drained	2683	178	35	0.75	26.3	0.5	2341
7e11	Steep	Well Drained	1163	8	21	0.75	15.8	0.5	61
7s 1	Flat	Imperfect	1101	149	6	0.75	4.5	0.5	336
7s 1	Flat	Imperfect	1327	152	7	0.75	5.3	0.5	399
7s 1	Flat	Imperfect	1465	155	7	0.75	5.3	0.5	406
7s 1	Flat	Imperfect	1701	69	8	0.75	6.0	0.5	206
7s 1	Flat	Imperfect	1899	34	8	0.75	6.0	0.5	103
7s 1	Flat	Imperfect	2099	20	9	0.75	6.8	0.5	67
7s 1	Flat	Imperfect	2252	7	9	0.75	6.8	0.5	23
8c 1	Flat	Poor	2694	63	2	0.75	1.5	0.5	47
8c 1	Flat	Poor	2899	41	2	0.75	1.5	0.5	30
8c 1	Flat	Poor	3074	13	2	0.75	1.5	0.5	9
8c 1	Flat	Poor	3224	9	2	0.75	1.5	0.5	7
8c 1	Rolling	Poor	2381	10	2	0.75	1.5	0.5	7
8c 1	Rolling	Poor	2745	27	2	0.75	1.5	0.5	20
8c 1	Rolling	Poor	2909	4	2	0.75	1.5	0.5	3
8c 1	Easy Hill	Poor	2936	1	2	0.75	1.5	0.5	1
8c 1	Easy Hill	Poor	3153	6	2	0.75	1.5	0.5	4
8c 1	Easy Hill	Poor	3228	5	2	0.75	1.5	0.5	4
8e 1	Steep	Mod Well	1265	94	2	0.75	1.5	0.5	71
8e 4	Easy Hill	Poor	1820	16	2	0.75	1.5	0.5	12
8e 4	Easy Hill	Poor	2080	13	2	0.75	1.5	0.5	10
8e 4	Easy Hill	Poor	2252	7	2	0.75	1.5	0.5	5
8e 4	Easy Hill	Poor	2550	3	2	0.75	1.5	0.5	2
8e 4	Easy Hill	Poor	2761	33	2	0.75	1.5	0.5	24
8e 4	Easy Hill	Poor	2810	11	2	0.75	1.5	0.5	8

8e 4	Steep	Well Drained	2140	0	2	0.75	1.5	0.5	0
8e 4	Steep	Mod Well	2510	4	2	0.75	1.5	0.5	3
8e 4	Steep	Mod Well	2750	13	2	0.75	1.5	0.5	10
8e 4	Steep	Well Drained	3073	1	2	0.75	1.5	0.5	1
8e 5	Easy Hill	Poor	1793	10	2	0.75	1.5	0.5	7
8e 5	Easy Hill	Poor	1888	20	2	0.75	1.5	0.5	15
8e 5	Easy Hill	Poor	2175	32	2	0.75	1.5	0.5	24
8e 5	Easy Hill	Poor	2255	36	2	0.75	1.5	0.5	27
8e 5	Easy Hill	Poor	2600	98	2	0.75	1.5	0.5	74
8e 5	Easy Hill	Poor	2732	30	2	0.75	1.5	0.5	23
8e 5	Steep	Mod Well	1794	16	2	0.75	1.5	0.5	12
8e 5	Steep	Mod Well	1889	47	2	0.75	1.5	0.5	35
8e 5	Steep	Mod Well	2333	124	2	0.75	1.5	0.5	93
8e 5	Steep	Mod Well	2500	332	2	0.75	1.5	0.5	249
8e 5	Steep	Mod Well	2678	478	2	0.75	1.5	0.5	359
8e 5	Steep	Mod Well	2878	89	2	0.75	1.5	0.5	67
8e 5	Steep	Mod Well	3130	51	2	0.75	1.5	0.5	38
8e 5	Steep	Mod Well	3240	22	2	0.75	1.5	0.5	16
8e 5	Steep	Well Drained	1883	276	2	0.75	1.5	0.5	207
8e 5	Steep	Well Drained	2136	190	2	0.75	1.5	0.5	142
8e 5	Steep	Well Drained	2291	291	2	0.75	1.5	0.5	218
8e 5	Steep	Well Drained	2509	590	2	0.75	1.5	0.5	443
8e 5	Steep	Well Drained	2677	272	2	0.75	1.5	0.5	204
8e 5	Steep	Well Drained	2884	210	2	0.75	1.5	0.5	157
8e 5	Steep	Well Drained	3041	43	2	0.75	1.5	0.5	33
8e 6	Steep	Mod Well	1884	130	2	0.75	1.5	0.5	97
8e 6	Steep	Mod Well	2057	37	2	0.75	1.5	0.5	28
8e 6	Steep	Mod Well	2572	9	2	0.75	1.5	0.5	7
8e 6	Steep	Mod Well	2742	228	2	0.75	1.5	0.5	171
8e 6	Steep	Mod Well	2869	283	2	0.75	1.5	0.5	212
8e 6	Steep	Mod Well	3086	175	2	0.75	1.5	0.5	131
8e 6	Steep	Mod Well	3225	16	2	0.75	1.5	0.5	12
8e 6	Steep	Well Drained	1928	132	2	0.75	1.5	0.5	99
8e 6	Steep	Well Drained	2110	165	2	0.75	1.5	0.5	124
8e 6	Steep	Well Drained	2293	280	2	0.75	1.5	0.5	210
8e 6	Steep	Well Drained	2479	81	2	0.75	1.5	0.5	61
8e 7	Steep	Well Drained	1773	0	2	0.75	1.5	0.5	0

8e 7	Steep	Well Drained	2299	13	2	0.75	1.5	0.5	10
Total				129638					1220358

Appendix 3: Nitrogen loading in the Mangatainoka summed from the N losses calculated in OVERSEER® using 75% of the averaged weighted (by area) “Attainable potential livestock carrying capacity” for the soils in each (a) LUC Class, (b) Subclass and (c) unit and the average rainfall (1789 mm) for the catchment.

(a)

LUC	Area	Stocking rate	N-loss	Fraction of	N-loss	Transmission	N loading
	(ha)	(su/ha)	Function	Potential	limit	Co-efficient	in river
I	549	25.0	40.1	0.75	30.1	0.5	8256
II	10389	27.3	43.3	0.75	32.5	0.5	168609
III	6074	25.6	40.9	0.75	30.7	0.5	93137
IV	1500	24.4	39.3	0.75	29.5	0.5	22137
V	409	16.0	27.9	0.75	20.9	0.5	4274
VI	17884	17.4	29.7	0.75	22.3	0.5	199501
VII	7820	9.4	18.9	0.75	14.2	0.5	55518
VIII	3246	0.0	0.0	0	2.0	0.5	3246
Total	47871.					Total	554679

(b)

LUC	Area	Stocking rate	N-loss	Fraction of	N-loss	Transmission	N loading
	(ha)	(su/ha)	Function	Potential	limit	Co-efficient	in river
Iw	548.7	25.0	40.127	0.75	30.1	0.5	8256
IIc	1298.8	27.0	42.850	0.75	32.1	0.5	20870
IIIs	5830.6	27.0	42.850	0.75	32.1	0.5	93690
IIw	3260.1	28.0	44.211	0.75	33.2	0.5	54049
IIIe	523.3	27.0	42.850	0.75	32.1	0.5	8409
IIIs	2743.4	25.0	40.127	0.75	30.1	0.5	41282
IIlw	2806.9	25.8	41.276	0.75	31.0	0.5	43446
IVe	1243.7	25.0	40.127	0.75	30.1	0.5	18714
IVs	85.9	15.0	26.514	0.75	19.9	0.5	854
IVw	170.7	25.0	40.127	0.75	30.1	0.5	2569
Vc	408.9	16.0	27.876	0.75	20.9	0.5	4274
Vlc	57.0	11.0	21.069	0.75	15.8	0.5	450
Vle	17149.5	17.6	30.065	0.75	22.5	0.5	193351
VIs	677.7	12.0	22.430	0.75	16.8	0.5	5700
VIIc	65.2	5.0	12.901	0.75	9.7	0.5	316
VIIe	7695.0	9.5	19.030	0.75	14.3	0.5	54912
VIIIs	60.0	5.0	12.901	0.75	9.7	0.5	290
VIIIe	3246.1	0.0	0.000	0.75	2.0	0.5	3246
Total	47871.3				Total		554679

(c)

LUC	Area	Stocking rate	N-loss	Fraction of	N-loss	Transmission	N loading
	(ha)	(su/ha)	Function	Potential	limit	Co-efficient	in river
Iw 1	549	25.0	40.1	0.75	30.1	0.5	8256
Ilc 1	1299	27.0	42.9	0.75	32.1	0.5	20870
Ils 1	5831	27.0	42.9	0.75	32.1	0.5	93690
Ilw 1	3260	28.0	44.2	0.75	33.2	0.5	54049
IIIe 1	523	27.0	42.9	0.75	32.1	0.5	8409
IIIs 2	2743	25.0	40.1	0.75	30.1	0.5	41282
IIIw 1	2369	26.0	41.5	0.75	31.1	0.5	36853
IIIw 2	438	25.0	40.1	0.75	30.1	0.5	6593
IVe 1	1244	25.0	40.1	0.75	30.1	0.5	18714
IVs 1	86	15.0	26.5	0.75	19.9	0.5	854
IVw 1	171	25.0	40.1	0.75	30.1	0.5	2569
Vc 1	409	16.0	27.9	0.75	20.9	0.5	4274
VIc 2	57	11.0	21.1	0.75	15.8	0.5	450
VIe 1	5127	20.0	33.3	0.75	25.0	0.5	64069
VIe 2	1719	22.0	36.0	0.75	27.0	0.5	23229
VIe 4	77	15.0	26.5	0.75	19.9	0.5	767
VIe 7	2030	18.0	30.6	0.75	22.9	0.5	23287
VIe 8	1210	10.0	19.7	0.75	14.8	0.5	8942
VIe 9	5438	16.3	28.3	0.75	21.2	0.5	57653
VIe11	1549	15.0	26.5	0.75	19.9	0.5	15405
VIIs 3	678	12.0	22.4	0.75	16.8	0.5	5700
VIIc 1	65	5.0	12.9	0.75	9.7	0.5	316
VIIe 1	33	16.0	27.9	0.75	20.9	0.5	343
VIIe 2	2384	9.0	18.3	0.75	13.8	0.5	16397
VIIe 4	2848	15.0	26.5	0.75	19.9	0.5	28319
VIIe 5	1979	2.0	8.8	0.75	6.6	0.5	6519
VIIe10	451	10.0	19.7	0.75	14.8	0.5	3334
VIIIs 1	60	5.0	12.9	0.75	9.7	0.5	290
VIIIe 1	277	0.0	6.1	0.75	2.0	0.5	277
VIIIe 3	2698	0.0	6.1	0.75	2.0	0.5	2698
VIIIe 5	271	0.0	6.1	0.75	2.0	0.5	270
Total	47871				Total		554679

Appendix 4: Nitrogen loadings in the Mangatainoka summed from the N losses calculated in OVERSEER[®] using the 75% of the “Attainable potential livestock carrying capacity” and the soil, landscape and actual rainfall, in 200 mm bands, information for each of the polygon within the catchment.

LUC	Slope	Drainage	Average Rain (mm)	Area (ha)	N-loss Function	Fraction of Potential	N-Loss Limit	Transmission Co-efficient	N Loading
1w 1	Flat	Well	1194	32.5	25	0.75	18.75	0.5	305.1
1w 1	Flat	Well	1336	516.1	26	0.75	19.5	0.5	5032.3
2c 1	Flat	Well	1190	127.6	27	0.75	20.25	0.5	1291.6
2c 1	Flat	Well	1292	309.9	28	0.75	21	0.5	3254.0
2c 1	Flat	Well	1479	323.7	30	0.75	22.5	0.5	3641.2
2c 1	Flat	Well	1685	251.6	31	0.75	23.25	0.5	2924.6
2c 1	Flat	Well	1899	119.2	33	0.75	24.75	0.5	1475.7
2c 1	Flat	Well	2076	101.1	35	0.75	26.25	0.5	1326.8
2c 1	Flat	Well	2521	64.0	39	0.75	29.25	0.5	936.1
2c 1	Flat	Well	2615	1.7	39	0.75	29.25	0.5	25.5
2s 1	Flat	Well	1193	55.2	27	0.75	20.25	0.5	558.6
2s 1	Flat	Well	1290	2271.0	28	0.75	21	0.5	23845.5
2s 1	Flat	Well	1488	494.9	30	0.75	22.5	0.5	5568.1
2s 1	Flat	Well	1716	568.3	32	0.75	24	0.5	6819.8
2s 1	Flat	Well	1903	959.9	33	0.75	24.75	0.5	11878.2
2s 1	Flat	Well	2099	745.9	35	0.75	26.25	0.5	9790.2
2s 1	Flat	Well	2268	368.3	37	0.75	27.75	0.5	5110.1
2s 1	Flat	Well	2513	245.5	39	0.75	29.25	0.5	3590.6
2s 1	Flat	Well	2632	121.6	40	0.75	30	0.5	1823.5
2w 1	Flat	Poor	1192	261.9	22	0.75	16.5	0.5	2160.8
2w 1	Flat	Poor	1308	1026.5	23	0.75	17.25	0.5	8853.4
2w 1	Flat	Well	1314	1208.6	29	0.75	21.75	0.5	13143.9
2w 1	Flat	Well	1550	22.0	31	0.75	23.25	0.5	255.9
2w 1	Flat	Well	1714	82.8	33	0.75	24.75	0.5	1024.7
2w 1	Flat	Well	1912	104.4	34	0.75	25.5	0.5	1330.7
2w 1	Flat	Well	2106	183.5	36	0.75	27	0.5	2476.8
2w 1	Flat	Well	2318	152.6	38	0.75	28.5	0.5	2174.9
2w 1	Flat	Well	2486	203.4	40	0.75	30	0.5	3051.0
2w 1	Flat	Well	2618	14.4	41	0.75	30.75	0.5	220.8
3e 1	Flat	Well	1299	138.5	28	0.75	21	0.5	1453.9
3e 1	Rolling	Well	1351	160.6	37	0.75	27.75	0.5	2228.1
3e 1	Rolling	Well	1424	38.8	38	0.75	28.5	0.5	553.4
3e 1	Rolling	Well	1773	24.4	43	0.75	32.25	0.5	392.8
3e 1	Rolling	Well	1875	56.2	44	0.75	33	0.5	926.8
3e 1	Flat	Well	3045	74.8	42	0.75	31.5	0.5	1177.9
3s 2	Flat	Well	1317	580.7	26	0.75	19.5	0.5	5662.0
3s 2	Flat	Well	1527	529.9	28	0.75	21	0.5	5564.0
3s 2	Flat	Well	1688	550.1	29	0.75	21.75	0.5	5982.4
3s 2	Flat	Well	1896	364.5	31	0.75	23.25	0.5	4237.2
3s 2	Flat	Well	2106	222.6	33	0.75	24.75	0.5	2754.9

3s 2	Flat	Well	2303	187.2	35	0.75	26.25	0.5	2457.2
3s 2	Flat	Well	2479	98.7	36	0.75	27	0.5	1331.9
3s 2	Flat	Well	2739	21.3	38	0.75	28.5	0.5	302.9
3s 2	Flat	Well	2926	107.6	39	0.75	29.25	0.5	1574.2
3s 2	Flat	Well	3043	80.8	39	0.75	29.25	0.5	1181.2
3w 1	Flat	Poor	1302	1590.5	21	0.75	15.75	0.5	12525.4
3w 1	Flat	Poor	1462	306.8	23	0.75	17.25	0.5	2646.1
3w 1	Flat	Poor	1685	65.4	24	0.75	18	0.5	588.5
3w 1	Flat	Poor	1839	10.7	25	0.75	18.75	0.5	100.7
3w 1	Flat	Poor	2735	76.9	31	0.75	23.25	0.5	894.1
3w 1	Flat	Well	2660	152.4	38	0.75	28.5	0.5	2172.1
3w 1	Flat	Poor	2846	52.5	40	0.75	30	0.5	786.8
3w 1	Flat	Well	2918	113.5	40	0.75	30	0.5	1701.9
3w 2	Flat	Poor	1325	223.9	21	0.75	15.75	0.5	1762.9
3w 2	Flat	Poor	1426	41.3	22	0.75	16.5	0.5	341.1
3w 2	Flat	Poor	1931	146.4	25	0.75	18.75	0.5	1372.7
3w 2	Flat	Poor	2030	26.5	26	0.75	19.5	0.5	258.8
4e 1	Rolling	Well	1368	203.5	35	0.75	26.25	0.5	2671.5
4e 1	Rolling	Well	1433	209.0	36	0.75	27	0.5	2821.6
4e 1	Rolling	Well	1761	69.3	40	0.75	30	0.5	1038.9
4e 1	Rolling	Well	1905	372.8	42	0.75	31.5	0.5	5871.5
4e 1	Rolling	Well	2078	365.9	44	0.75	33	0.5	6037.4
4e 1	Rolling	Well	2251	23.2	45	0.75	33.75	0.5	390.8
4s 1	Flat	Imperfect	1972	4.6	18	0.75	13.5	0.5	30.9
4s 1	Flat	Imperfect	2047	6.6	18	0.75	13.5	0.5	44.6
4s 1	Flat	Imperfect	2203	14.6	19	0.75	14.25	0.5	104.2
4s 1	Flat	Well	3055	60.1	26	0.75	19.5	0.5	586.1
4w 1	Flat	Imperfect	1242	42.9	22	0.75	16.5	0.5	353.8
4w 1	Flat	Poor	2521	117.8	29	0.75	21.75	0.5	1280.5
4w 1	Flat	Poor	2620	10.1	30	0.75	22.5	0.5	113.5
5c 1	Rolling	Well	1284	408.9	23	0.75	17.25	0.5	3526.6
6c 2	Rolling	Well	1253	57.0	17	0.75	12.75	0.5	363.3
6e 1	Easy Hill	Well	1331	1589.0	29	0.75	21.75	0.5	17280.2
6e 1	Easy Hill	Well	1526	587.4	31	0.75	23.25	0.5	6828.7
6e 1	Rolling	Well	1542	445.4	30	0.75	22.5	0.5	5010.6
6e 1	Easy Hill	Well	1848	458.8	35	0.75	26.25	0.5	6021.5
6e 1	Rolling	Well	1918	464.4	35	0.75	26.25	0.5	6095.4
6e 1	Easy Hill	Well	1891	279.7	36	0.75	27	0.5	3775.6
6e 1	Rolling	Well	2083	392.4	36	0.75	27	0.5	5297.2
6e 1	Easy Hill	Well	2108	155.6	39	0.75	29.25	0.5	2275.1
6e 1	Rolling	Well	2259	194.8	38	0.75	28.5	0.5	2775.3
6e 1	Easy Hill	Well	2292	160.5	41	0.75	30.75	0.5	2468.2
6e 1	Easy Hill	Well	2481	39.5	44	0.75	33	0.5	651.8
6e 1	Easy Hill	Well	2711	218.1	45	0.75	33.75	0.5	3680.9
6e 1	Easy Hill	Well	2868	141.9	45	0.75	33.75	0.5	2395.0
6e 2	Easy Hill	Well	1328	1184.3	31	0.75	23.25	0.5	13766.9
6e 2	Easy Hill	Well	1470	372.5	33	0.75	24.75	0.5	4609.6
6e 2	Rolling	Well	1623	31.3	34	0.75	25.5	0.5	399.0
6e 2	Rolling	Well	1943	70.2	38	0.75	28.5	0.5	1000.1

6e 2	Rolling	Well	2071	60.4	39	0.75	29.25	0.5	882.6
6e 4	Easy Hill	Well	1314	77.1	23	0.75	17.25	0.5	665.3
6e 7	Easy Hill	Imperfect	1184	34.8	22	0.75	16.5	0.5	287.3
6e 7	Easy Hill	Mod Well	1185	81.5	24	0.75	18	0.5	733.2
6e 7	Easy Hill	Well	1168	103.4	25	0.75	18.75	0.5	969.7
6e 7	Easy Hill	Imperfect	1261	0.8	23	0.75	17.25	0.5	6.6
6e 7	Steep Hill	Mod Well	1296	218.8	32	0.75	24	0.5	2625.4
6e 7	Easy Hill	Well	1277	916.9	26	0.75	19.5	0.5	8939.9
6e 7	Steep Hill	Mod Well	1415	36.9	34	0.75	25.5	0.5	470.9
6e 7	Easy Hill	Well	1590	25.8	30	0.75	22.5	0.5	290.1
6e 7	Easy Hill	Well	1675	80.0	31	0.75	23.25	0.5	930.2
6e 7	Easy Hill	Well	1825	16.9	32	0.75	24	0.5	202.3
6e 7	Easy Hill	Well	2734	123.7	42	0.75	31.5	0.5	1949.0
6e 7	Easy Hill	Well	2909	333.5	43	0.75	32.25	0.5	5377.6
6e 7	Easy Hill	Well	3020	56.5	43	0.75	32.25	0.5	910.4
6e 8	Easy Hill	Well	1986	14.4	23	0.75	17.25	0.5	124.5
6e 8	Easy Hill	Well	2103	371.4	25	0.75	18.75	0.5	3481.7
6e 8	Easy Hill	Well	2347	173.8	28	0.75	21	0.5	1825.1
6e 8	Easy Hill	Well	2508	144.7	29	0.75	21.75	0.5	1574.0
6e 8	Easy Hill	Well	2705	263.4	29	0.75	21.75	0.5	2864.2
6e 8	Easy Hill	Well	2887	242.1	30	0.75	22.5	0.5	2724.1
6e 9	Easy Hill	Imperfect	1176	437.0	21	0.75	15.75	0.5	3441.7
6e 9	Easy Hill	Well	1180	915.8	24	0.75	18	0.5	8242.2
6e 9	Easy Hill	Imperfect	1243	849.2	22	0.75	16.5	0.5	7006.1
6e 9	Easy Hill	Well	1291	1933.7	25	0.75	18.75	0.5	18128.4
6e 9	Steep Hill	Mod Well	1440	101.8	33	0.75	24.75	0.5	1260.1
6e 9	Easy Hill	Well	1468	608.8	27	0.75	20.25	0.5	6163.8
6e 9	Steep Hill	Well	2570	69.3	35	0.75	26.25	0.5	909.5
6e 9	Steep Hill	Well	2697	383.3	35	0.75	26.25	0.5	5031.4
6e 9	Steep Hill	Well	2869	105.1	48	0.75	36	0.5	1891.1
6e 9	Easy Hill	Well	3025	33.6	42	0.75	31.5	0.5	529.8
6e11	Easy Hill	Well	1370	85.4	24	0.75	18	0.5	769.0
6e11	Easy Hill	Well	1480	234.0	25	0.75	18.75	0.5	2194.1
6e11	Easy Hill	Mod Well	1714	5.5	26	0.75	19.5	0.5	53.5
6e11	Steep Hill	Well	1712	402.6	37	0.75	27.75	0.5	5586.5
6e11	Easy Hill	Mod Well	1898	5.0	28	0.75	21	0.5	52.6
6e11	Steep Hill	Mod Well	1939	7.5	38	0.75	28.5	0.5	106.7
6e11	Easy Hill	Well	1865	138.8	29	0.75	21.75	0.5	1509.2
6e11	Steep Hill	Well	1845	192.4	39	0.75	29.25	0.5	2813.9
6e11	Easy Hill	Well	2160	105.1	33	0.75	24.75	0.5	1300.7
6e11	Steep Hill	Well	2136	21.9	41	0.75	30.75	0.5	336.3
6e11	Easy Hill	Well	2308	208.6	35	0.75	26.25	0.5	2738.4
6e11	Easy Hill	Well	2445	97.1	37	0.75	27.75	0.5	1346.7
6e11	Steep Hill	Well	2979	45.3	45	0.75	33.75	0.5	764.8
6s 3	Easy Hill	Well	1549	239.2	21	0.75	15.75	0.5	1883.8
6s 3	Easy Hill	Well	1669	290.4	23	0.75	17.25	0.5	2504.5
6s 3	Easy Hill	Well	2183	13.2	28	0.75	21	0.5	138.3
6s 3	Easy Hill	Well	2314	102.4	30	0.75	22.5	0.5	1151.6
6s 3	Easy Hill	Well	2445	32.6	32	0.75	24	0.5	390.7

7c 1	Rolling	Well	2693	65.2	20	0.75	15	0.5	489.1
7e 2	Steep Hill	Mod Well	1168	142.1	27	0.75	20.25	0.5	1438.9
7e 2	Steep Hill	Mod Well	1308	197.0	29	0.75	21.75	0.5	2142.0
7e 2	Steep Hill	Mod Well	1978	12.7	28	0.75	21	0.5	133.1
7e 2	Steep Hill	Mod Well	2046	26.6	29	0.75	21.75	0.5	289.1
7e 2	Steep Hill	Well	2172	16.9	30	0.75	22.5	0.5	189.7
7e 2	Steep Hill	Mod Well	2317	290.8	30	0.75	22.5	0.5	3271.9
7e 2	Steep Hill	Well	2272	66.9	31	0.75	23.25	0.5	778.0
7e 2	Steep Hill	Mod Well	2499	458.2	30	0.75	22.5	0.5	5154.7
7e 2	Steep Hill	Mod Well	2723	342.6	31	0.75	23.25	0.5	3982.7
7e 2	Steep Hill	Mod Well	2882	566.0	31	0.75	23.25	0.5	6579.5
7e 2	Steep Hill	Mod Well	3091	264.3	31	0.75	23.25	0.5	3072.7
7e 4	Steep Hill	Mod Well	1165	1315.9	27	0.75	20.25	0.5	13323.7
7e 4	Steep Hill	Mod Well	1311	869.4	29	0.75	21.75	0.5	9454.9
7e 4	Steep Hill	Well	1269	542.5	30	0.75	22.5	0.5	6102.6
7e 4	Steep Hill	Mod Well	2995	1.4	43	0.75	32.25	0.5	22.4
7e 4	Steep Hill	Mod Well	3052	119.0	43	0.75	32.25	0.5	1919.1
7e 5	Steep Hill	Mod Well	2169	92.7	20	0.75	15	0.5	695.2
7e 5	Steep Hill	Mod Well	2307	489.8	21	0.75	15.75	0.5	3857.3
7e 5	Steep Hill	Mod Well	2495	386.1	21	0.75	15.75	0.5	3040.9
7e 5	Steep Hill	Mod Well	2721	493.5	21	0.75	15.75	0.5	3886.7
7e 5	Steep Hill	Mod Well	2892	415.4	21	0.75	15.75	0.5	3271.5
7e 5	Steep Hill	Mod Well	3038	101.1	21	0.75	15.75	0.5	796.3
7e10	Steep Hill	Well	1764	295.2	30	0.75	22.5	0.5	3321.3
7e10	Steep Hill	Well	1822	91.0	30	0.75	22.5	0.5	1024.0
7e10	Steep Hill	Well	2297	64.9	34	0.75	25.5	0.5	827.2
7s 1	Flat	Well	1488	60.0	8	0.75	6	0.5	179.9
8e 1	Steep Hill	Mod Well	1380	87.5	2	0.75	1.5	0.5	65.7
8e 1	Steep Hill	Mod Well	1516	123.2	2	0.75	1.5	0.5	92.4
8e 1	Steep Hill	Mod Well	1673	66.5	2	0.75	1.5	0.5	49.9
8e 3	Steep Hill	Mod Well	2183	4.8	2	0.75	1.5	0.5	3.6
8e 3	Steep Hill	Mod Well	2320	309.9	2	0.75	1.5	0.5	232.4
8e 3	Steep Hill	Mod Well	2507	722.5	2	0.75	1.5	0.5	541.9
8e 3	Steep Hill	Mod Well	2677	545.1	2	0.75	1.5	0.5	408.8
8e 3	Steep Hill	Mod Well	2896	248.4	2	0.75	1.5	0.5	186.3
8e 3	Steep Hill	Mod Well	3124	776.2	2	0.75	1.5	0.5	582.2
8e 3	Steep Hill	Mod Well	3217	91.5	2	0.75	1.5	0.5	68.6
8e 5	Steep Hill	Mod Well	3142	139.0	2	0.75	1.5	0.5	104.3
8e 5	Steep Hill	Imperfect	3232	27.4	2	0.75	1.5	0.5	20.5
8e 5	Steep Hill	Mod Well	3223	104.1	2	0.75	1.5	0.5	78.0
Total			47808			Total			494147

Appendix 5

Adaptation of SPASMO for multiple crops and creation of a meta-model

We have adapted the full SPASMO model to handle multiple and continuous sequences of crops. This enables us to handle the common practice in commercial vegetable production where more than one crop is grown in a paddock throughout a year. To do this we had to be able to link the final conditions at the end of a crop to enable these to be used as the initial boundary condition for the subsequent crop.

This version of the SPASMO model was set-up as a meta-model so that it could be run under Excel. The meta-model which can now be run interactively in real-time enables modelling to be used to explore the impact of different land-use practices in commercial vegetable production. We present here the use of this meta-model to explore the impact of 4 different scenarios on leachate loadings to groundwater. The model also accounts for the impact of soil nutrient status on crop yield.

Because cropping in general (Question 4) is simply a one-crop sequence, this meta-model could in future be used to provide the same results for crops in the Manawatu.

A.1. A general description of the SPASMO model

The SPASMO computer model considers water, solute (e.g. nitrogen and phosphorus), and microbial (e.g. viruses and bacteria) transport through a 1-dimensional soil profile. The soil water balance is calculated by considering the inputs (rainfall and irrigation) and losses (plant uptake, evaporation, runoff and drainage) of water from the soil profile. The model includes components to predict the carbon, nitrogen and phosphorus budget of the soil. These components allow for a calculation of plant growth and uptake of both N and P, various exchange and transformation processes that occur in the soil and aerial environment, recycling of nutrients and organic material to the soil biomass, and the addition of surface-applied fertilizer and/or effluent to the land. The filtering capacity of the soil with regard to micro-organisms is modelled using an attachment-detachment model with inactivation (i.e. die-off) of microbes.

Model results for the water balance are expressed in terms of mm (= one litre of water per square metre of ground area). The concentration and leaching losses of nutrients are expressed in terms of mg L^{-1} and kg ha^{-1} , respectively. The microbial concentrations and leaching losses are expressed in terms of colony forming units, cfu L^{-1} and cfu m^{-2} ,

respectively. All calculations run on a daily basis and the results are presented at the paddock scale.

A.2. Water and solute flow through the soil

The flow of water through the soil profile is simulated using a capacity model similar to that of Hutson & Wagenet (1993), in which the soil water is divided into mobile and immobile phases. The mobile domain is used to represent the soil's macropores (e.g. old root channels, worm holes and cracks) and the immobile domain represents the soil matrix. The equations describing water and contaminant flow are simple, but lengthy, and so they are not repeated here (see Hutson & Wagenet (1993) for details).

On days when there is rain or irrigation, both applied water and any dissolved solutes are added to the surface layer. The maximum amount of water that can infiltrate the soil is limited by the storage capacity of the profile, and the minimum saturated hydraulic conductivity of the subsoil. The water content of topsoil (0-30 cm) can't exceed saturation, otherwise some runoff is generated. After rainfall or irrigation, water is allowed to percolate through the soil profile, but only when the soil is above field capacity. The infiltrating water first fills up the immobile domain and, once this domain is filled, it then refills the mobile domain as the water travels progressively downward through the soil profile. If the soil is above field capacity, then the infiltrating water and solute resides in the mobile domain where it can percolate rapidly down through the soil profile until it reaches a depth where the water content is no longer above field capacity. This macropore flow is rapid and it does not allow enough time for exchange between the mobile and immobile domains. As a consequence, the two flow domains are temporarily at quite different solution concentrations as water percolates through the soil profile.

Subsequently, on days when there is no significant rainfall, there is a slow approach to equilibrium between the mobile and immobile phases, driven by a difference in water content between the two domains. The rules for the subsequent slow approach to equilibrium between the mobile and immobile phases within a depth, or model segment, are described in their original scientific paper (Hutson & Wagenet 1993).

If a soil layer is below field capacity or if there is no rainfall or irrigation to generate percolation, then each soil segment i is brought towards equilibrium with the segment $i+1$ beneath, starting from the top of the profile. This redistribution of water is achieved by (i)

calculating the amount of water required to move upwards or downwards so that each soil segment reaches an equilibrium water potential with its neighbour, and (ii) allowing only half this water to move, together with its dissolved solute. After all segments have been adjusted, each solute (i.e. ammonium, nitrate, phosphorus and bacteria) is repartitioned between aqueous and solid (sorbed) phases, assuming complete equilibrium between mobile and immobile phases.

The total water content in each soil segment, W_T [mm], is given by the sum of the water contents in the immobile and mobile soil domains

$$W_T = W_I + W_M. \quad [\text{Eq. A1}]$$

and total amount of solute in each soil segment, M_C [mg m⁻²], is calculated as

$$M_C = C_I W_I + C_M W_M + S \rho \Delta z \quad [\text{Eq. A2}]$$

Here, C is the solution concentration [mg L⁻¹], S represents the amount of sorbed solute [mg kg⁻¹], ρ is the bulk density [kg L⁻¹], Δz is the segment thickness [mm], and the subscripts I and M refer to the immobile and mobile domains, respectively. The sorption of ammonium and nitrate is described using a simple linear isotherm of the form

$$S = K_D C \quad [\text{Eq. A3}]$$

where K_D represents the distribution coefficient [L kg⁻¹]. In the case of nitrate, which is considered to be inert, we assume no adsorption and set K_D equal to zero. The equilibrium solution concentration, C , in both mobile and immobile phases of nitrate and ammonium, is then calculated as

$$C = M_C / (\rho S \Delta z + W_T). \quad [\text{Eq. A4}]$$

The sorption of phosphorus is non-linear and is described using a Langmuir isotherm of the form

$$S = \frac{Q b C}{1 + b C} \quad [\text{Eq. A5}]$$

where Q is the maximum total mass of phosphorus at saturation per mass unit of dry soil [$\mu\text{g g}^{-1}$], and b is an empirical constant, with units of inverse of solution concentration [L mg⁻¹]. The b -parameter defines the point where the soil is at half-saturation with respect maximum sorption of P.

Bacterial transport is calculated using the same convection-dispersion type equation as for water and solute transport, with additional terms used to represent the kinetic sorption of bacteria to soil's mineral particles as well as the subsequent detachment and transfer of bacteria between the aqueous and solid phases. The attachment-detachment process is described using first-order rate constants that strongly depend on soil water content (Logan et al. 1995). The rate of change in the solid-phase is modelled as

$$\rho \frac{\partial S}{\partial t} = \theta k_a \psi C - k_d \rho S \quad [\text{Eq. A6}]$$

Here k_a is the first-order deposition (attachment) coefficient [d^{-1}], k_d is the first-order entrainment (detachment) coefficient [d^{-1}], and ψ is a dimensionless colloid retention function [-] that describes blocking of the sorption sites. This ψ -factor is calculated from the size of the sand grains and the relative solid-phase concentration (Johnson & Elimelech 1995). The attachment coefficient is calculated using a quasi-empirical formulation that takes account of the mean grain diameter of the porous media d_c [mm] and the pore-water velocity u [mm d^{-1}], as well as terms to describe the collector efficiency η [-], and the collision (or sticking) efficiency α [-]

$$k_a = \frac{3(1-\theta)}{2d_c} \eta \alpha u \quad [\text{Eq. A7}]$$

The mathematical formulation of these terms, and suggested parameter values are given in Simunek et al. (2005). The collector efficiency accounts for the combined effects of particle size (e.g. bacteria or virus), fluid density and viscosity, pore-water velocity, and the water content and temperature of the soil. Because attachment is (approximately) inversely proportional to the grain size of the soil particles, finer grained soils such as silts and clays tend to be more efficient at trapping bacteria that are transported with the drainage waters. Furthermore, the smaller sized microbes (i.e. virus cf. bacteria) are less likely to be intercepted by the soil particles (i.e. have a smaller collector efficiency), so the relative value of k_a is reduced. For the purpose of modelling, the ratio k_a/k_d has been set to a constant value of 100. Other parameters used in modelling bacterial (i.e. *E. coli*) transport through the soil are discussed in Appendix B.

A.3. Calculation of crop water use

A standard crop-factor approach is used to relate crop water use to the prevailing weather and physiological time of development. The procedure is based on guidelines given by the Food and Agriculture Administration (FAO) of the United Nations (Allen et al. 1998). Daily values of global radiation, air temperature, relative humidity and wind speed are required for the calculation. These have been downloaded from the NIWA database using historical records. The reference evaporation rate, ET_0 [mm d⁻¹], is calculated as

$$\lambda ET_0 = \frac{s(R_N - G_H) + \rho_A c_p (e_s - e_a) / r_A}{s + \gamma(1 + r_s / r_A)} \quad [\text{Eq. A8}]$$

where R_N [MJ m⁻² d⁻¹] is the net radiation, G_H [MJ m⁻² d⁻¹] is the ground heat flux, T [°C] is the mean air temperature, e_s [kPa] is the saturation vapour pressure at the mean air temperature, e_a [kPa] is the mean actual vapour pressure of the air, s [Pa °C⁻¹] is the slope of the saturation vapour-pressure versus temperature curve, γ [66.1 Pa] is the psychometric constant, and λ [2.45 MJ kg⁻¹] is the latent heat of vaporisation for water, and the terms r_s and r_A refer to the (bulk) surface and aerodynamic resistances, respectively. The surface resistance for evaporation from the pasture is set equal to 70 s m⁻¹ (Allen et al. 1998). Similarly, the surface resistance for evaporation from the pond is set equal to zero. The aerodynamic resistance for both the pasture and the pond has been set equal to 208/ U_2 , where U_2 is the median wind speed at a height of 2 m.

ET_0 defines the potential rate of evaporation from an extensive surface of green grass cover, of a short, uniform height, that is actively growing, completely shading the ground, and not short of water or nutrients. The potential water use of the crops is then calculated

$$ET_C = K_C ET_0 \quad [\text{Eq. A9}]$$

using a crop factor K_C derived from the amount of light intercepted by the leaf canopy. Light interception is a function of the leaf-area index, LAI [m² of leaf per m² of ground area] (Green et al. 2003a), and this is re-calculated each day. Coppicing the trees will reduce LAI and this impact on ET_C via a reduction in K_C .

When soil water and nutrients are non-limiting, water is extracted easily by the plant roots and transpiration proceeds at the potential rate ET_C . However, as the soil dries, water becomes more strongly bound by capillary and absorptive forces to the soil matrix. Plant roots then have to work much harder to extract water from 'dry' soil. Plants will tolerate a certain level of water deficit in their root-zone soil, yet they will eventually exhibit symptoms

of water stress (i.e. reduced transpiration and loss of turgor) if the soil water content drops below a certain threshold value.

An empirical adjustment factor K_R [-] is used to represent the plant's tolerance to water stress. The total-available water TAW [mm], as defined by the difference between the water content at field capacity (-10 kPa matric potential) W_{FC} [mm] and wilting point (-1500 kPa matric potential) W_{WP} [mm], is calculated across the depth of the root-zone, z_R [mm]. The plant-available water PAW [mm] is then defined by a fraction p of TAW that a crop can extract from the root-zone without suffering water stress. Values of p are listed in Table 22 of Allen et al. (1998). The pattern of water and nutrient uptake from the root-zone soil is determined from the depth-wise pattern of root development (Green et al. 2002).

A.4. *Modelling surface runoff*

The surface runoff component of SPASMO is based on a daily rainfall total. The calculation uses the Soil Conservation Service (SCS) curve number approach (Williams 1991). The curve number approach was selected here because: (i) it is based on over 30 years of runoff studies on pasture, arable and forest sites in the USA, (ii) it is computationally simple and efficient, (iii) the required inputs are available, (iv) and the calculation relates runoff to soil type, land use and management practice.

Surface runoff is predicted from daily rainfall plus irrigation, using the SCS curve number equation:

$$Q = \frac{(R - 0.2S)^2}{R + 0.8S}, \quad R > 0.2S$$

$$Q = 0, \quad R \leq 0.2S$$
[Eq. A10]

where Q [mm] is the daily runoff, R [mm] is the daily rainfall plus irrigation, and S [mm] is the retention parameter that reflects variations among soils, land use and management. The retention parameter, S , is related to the curve number, CN , using the SCS equation (Soil Conservation Service 1972)

$$S = 254 \left(\frac{100}{CN} - 1 \right) \quad [\text{Eq. A11}]$$

where the constant, 254, gives S in millimetres. Moisture condition 2 (CN_2) or the average curve number, can be obtained easily for any area of land use type from the SCS Hydrology Handbook (Soil Conservation Service 1972). An example of CN numbers is given below for a range of pasture and drainage conditions.

Table A1. SCS curve number for a grazed pasture (Soil Conservation Service 1972).

SCS CN number		Drainage Condition			
		Excessive	Good	Fair	Poor
Pasture Condition	Good	39	61	74	80
	Average	49	69	79	84
	Poor	68	79	86	89

A pasture in good condition that is growing on a free draining soil will have a low CN value (39), while a pasture in poor condition and on a poorly drained soil will have a high CN value (89). A lower CN value implies a bigger retention parameter, S , and so a given soil/pasture combination will yield less runoff for the same daily rainfall total. The SCS runoff calculation also includes an additional adjustment to S , to express the effect of slope and soil water content (Williams 1991). In the calculations presented here, we have assumed the pasture slope is always less than 5% and have used a reference CN value for a pasture sward in average condition. The only other allowance that we have made, with respect to runoff, is to include any changes in S that are due to different soil water contents.

A.5. *Nitrogen balance of the soil*

The nitrogen component of SPASMO is based on a set of balance equations that account for nitrogen uptake by plants, exchange and transformation processes in the soil, losses of gaseous nitrogen to the atmosphere, additions of nitrogen in the effluent or fertilizer, and the leaching of nitrogen below the root zone. SPASMO considers both organic nitrogen (i.e.

in the soil biomass) and the mineral nitrogen (i.e. urea, ammonium and nitrate). Dissolved urea and nitrate are considered to be mobile and to percolate freely through the profile, being carried along with the invading water. The movement of dissolved ammonium is retarded as it binds to the mineral clay particles of the soil. The soil can receive inputs of organic carbon and nitrogen from decaying plant residues, which is added to the litter layer of the topsoil, and inputs of ammonium and nitrate in the effluent applied to the soil surface. Details of the nitrogen component of SPASMO are published in Rosen et al. (2004).

A.6. Crop Growth

The uptake of soil nutrients (i.e. nitrogen and phosphorus) by pasture and trees is determined largely by the growth of the above- and below-ground DM, multiplied by their respective nitrogen concentrations. Daily biomass production is modelled using a potential production rate per unit ground area, G ($\text{kg m}^{-2} \text{d}^{-1}$) that is related, via a conversion efficiency, ε (kg MJ^{-1}), to the amount of solar radiant energy, Φ ($\text{MJ m}^{-2} \text{d}^{-1}$), intercepted by the leaves

$$G = \varepsilon \Phi f_T f_N f_W \quad [\text{Eq. A12}]$$

Here f_T , f_N and f_W are response functions that range between zero and unity depending on temperature, plant nitrogen and soil water status respectively (Eckersten & Jansson 1991). The value of G depends on the daily sunshine and temperature, plus the leaf-area index of the crop, and is moderated by the soil's water and nitrogen status (King 1993; Thornley et al. 1995). Crop growth is maximised only if soil water and soil nutrients are non-limiting.

A simple allometric relationship is used to partition the daily biomass production into the growth of the foliage, stem material and roots. Plant biomass is expressed in terms of the balance between growth and senescence of the plant organs. For each plant organ we write out a simple mass balance equation that considers inputs of DM due to carbon allocation, losses of DM as the plants senescence, and the removal of DM as the plants are harvested. The total mass of foliage, F [kg m^{-2}] is calculated from

$$\frac{dF}{dt} = \alpha_F G - \gamma_F F - H_F \quad [\text{Eq. A13}]$$

the total mass of stem material, S [kg m^{-2}] is calculated from

$$\frac{dS}{dt} = \alpha_S G - \gamma_S F - H_S \quad [\text{Eq. A14}]$$

and the total mass of roots, R [kg m^{-2}], is calculated from

$$\frac{dR}{dt} = \alpha_R G - \gamma_R R \quad [\text{Eq. A15}]$$

Here α_F is the fraction of biomass partitioned to the foliage, α_S is the biomass partitioned to the stem, and $\alpha_R (=1-\alpha_F-\alpha_S)$ is the fraction of biomass allocated to the roots, and γ is the corresponding senescence rate for these plant components. The variable H is used to represent the amount of DM that is removed during harvest. In the case of fruiting crops, additional terms are included in each balance equation to represent an amount of DM transferred to fruit production.

Allocation of DM to the roots depends on the leaf nitrogen content $[N]_F$, having a minimum value $[\alpha_{R0}]$ at a maximum leaf concentration $[N]_{Fx}$, and increasing as N_L decreases (Eckersten & Jansson 1991)

$$\alpha_R = \alpha_{R0} + 1 - \left(1 - \left(\frac{[N]_{Fx} - [N]_F}{[N]_{Fx}}\right)^2\right)^{0.5} \quad [\text{Eq. A16}]$$

This formulation enables SPASMO to accommodate seasonal changes in DM allocation associated with a changing leaf nutrient status. For simplicity, any seasonal changes in senescence rates have been neglected in the model because we are concerned with the long-term consequences of DM allocation.

A.7. Nitrogen and Phosphorus Uptake

The model assumes plant growth will achieve a maximum potential only if water, nitrogen and phosphorus are non-limiting. The nitrogen demand for crop growth is set by the maximum nitrogen content of the root $[N]_{Rx}$, leaf $[N]_{Fx}$ and stem $[N]_{Sx}$ material. During active growth the plant tries to supply new DM material with nitrogen corresponding to these maximum concentrations. The potential uptake of nitrogen, U_N [$\text{kg ha}^{-1} \text{d}^{-1}$], is defined as

$$U_N = (\alpha_F G [N]_{Fx} - \lambda_F \gamma_F F [N]_F) + (\alpha_S G [N]_{Sx} - \lambda_S \gamma_S S [N]_S) + (\alpha_R G [N]_{Rx} - \lambda_R \gamma_R R [N]_R) \quad [\text{Eq. A17}]$$

And this represents the new growth at the maximum N content minus an amount of nitrogen translocated from the senescing plant material. The potential (maximum) nitrogen uptake can only be met if sufficient nitrogen exists in the soil. Otherwise all $[N]$ s will be reduced in low-nitrogen soils, and crop growth will be curtailed. The potential uptake of phosphorus uptake is modelled in the same way based on the maximum P content of the respective plant parts.

Daily uptake of nitrogen is assumed to be proportional to the local distribution of the fine roots, and the total amount of nitrate (NO_3^-) and ammonium (NH_4^+) in each soil layer (Johnsson et al. 1987). The potential uptake of nitrate is calculated as

$$U_{\text{NO}_3^-} = \min \left(\rho_R(z) \frac{\text{NO}_3^-}{\text{NO}_3^- + \text{NH}_4^+} U_N, f_M \text{NO}_3^- \right) \quad [\text{Eq. A18}]$$

based on the relative root fraction in the layer, $\rho_R(z)$, the proportion of total mineral nitrogen as nitrate, and the total growth requirement for nitrogen, U_N . However, the actual uptake of nitrate is limited to a fraction f_M [-] of the total nitrate available in each layer. Ammonium uptake is calculated in a similar way, being proportional to the relative amount of ammonium in solution.

Surface roots are the most active (Clothier & Green 1994) and they preferentially extract soil water and nutrients from the upper soil layers. However, as water and nitrogen stresses develop, the uptake activity typically switches to the deeper roots if more water and nutrients are available there. This feature of root action is modelled in the following way. Whenever the total nitrogen uptake from a given soil layer is less than the potential rate, then the model allows for a compensatory increase in uptake from remaining layers deeper in the root zone (Johnsson et al. 1987). This is achieved by adding a fraction c_{um} [-] of the deficit to the potential uptake from the next soil layer where more mineral nitrogen may be available.

Daily allocation of nitrogen to the new plant material is based on the idea that roots receive nitrogen first, until they reach their maximum concentrations, then nitrogen is allocated to the stem, and finally to the leaves. If soil nitrogen becomes limiting, a reduction factor f_N is used to reduce the total nitrogen uptake. This reduction function also effectively reduces the leaf nitrogen contents and alters the DM allocation pattern (Eckersten & Jansson 1991). A similar scheme is adopted for P uptake and allocation across the new plant material.

Pasture growth parameters in this study have been chosen to generate appropriate levels of DM production i.e. the model simulates between 10-15 Mg DM ha⁻¹ yields from an irrigated pasture, and adds about 1000 kg DM for every 100 kg N ha⁻¹ of nitrogen in the effluent.

A.8. Carbon and Nitrogen dynamics of the soil organic matter

The decomposition of soil biomass adds an amount of mineral nitrogen, in the form of ammonium, to the soil. This transformation process, known as mineralization, is modelled by dividing the soil's total organic matter into three pools – a fast cycling litter pool, an almost stable humus pool, and a manure pool (Johnsson et al. 1987). The relative amount of organic-N in these three pools changes daily to reflect inputs of fresh biomass, and manure, and the losses of soil biomass and plant residue as it decomposes. The nitrogen demand for this internal cycling of the soil's organic carbon and nitrogen is regulated by the C/N ratio of the soil biomass, r_o , which is one of the model inputs.

Decomposition of soil litter carbon (C_L) is modelled as a first-order process and is specified by a rate constant (K_L) that is influenced by temperature and soil moisture. The products of decomposition are CO₂, stabilized organic material (humus) and, conceptually, microbial biomass and metabolites. The relative amount of these products is determined by a synthesis efficiency constant (f_E) and a humification fraction (f_H). The following mass balance equations, which represent the inputs minus the outputs of soil-C and soil-N, are used to model the turnover of carbon and nitrogen in the litter pool

$$\begin{aligned}\frac{\partial C_L}{\partial t} &= [(1 - f_H)f_E - 1] \cdot K_L \cdot C_L + F_{C,L} \\ \frac{\partial N_L}{\partial t} &= \left[(1 - f_H)f_E \frac{1}{r_o} - \frac{N_L}{C_L} \right] \cdot K_L \cdot C_L + F_{N,L}\end{aligned}\quad [\text{Eq. A19}]$$

where F represents the amount of fresh organic matter that is added to the soil biomass. A similar set of equations describes the turnover of carbon and nitrogen in the manure pool (although this pool is not modelled here)

$$\begin{aligned}\frac{\partial C_M}{\partial t} &= [(1 - f_H)f_E - 1] K_M \cdot C_M + F_{C,M} \\ \frac{\partial N_M}{\partial t} &= \left[(1 - f_H)f_E \frac{1}{r_o} - \frac{N_M}{C_M} \right] \cdot K_M \cdot C_M + F_{N,M}\end{aligned}\quad [\text{Eq. A20}]$$

Lastly, the set of mass balance equations describing the turn-over of carbon and nitrogen in the humus pool are given by

$$\begin{aligned}\frac{\partial C_H}{\partial t} &= f_E \cdot f_H \cdot K_L \cdot C_L - K_H \cdot C_H + F_{C,H} \\ \frac{\partial N_H}{\partial t} &= \frac{f_E \cdot f_H}{r_O} K_L \cdot C_L - K_H \cdot N_H + F_{N,H}\end{aligned}\quad [\text{Eq. A21}]$$

Decomposition of soil humus (C_H) follows first-order kinetics with a specific rate constant (K_H) that depends on temperature and soil moisture. The other terms in these mass balance equations have already been described above.

Soil carbon and nitrogen turn-over reactions result either in a net production (mineralization) or a net consumption (immobilization) of ammonium, depending on the C/N ratio of the soil biomass. From a consideration of mass balances, any increase in $\text{NH}_4^+\text{-N}$, due to mineralization, must equal the decrease in organic-N from the three organic matter pools. Thus, the following mass-balance equation is used to predict nitrogen mineralization

$$\frac{\partial \text{NH}_4^+}{\partial t} = \left[\frac{N_L}{C_L} - \frac{f_E}{r_O} \right] K_L \cdot C_L + \left[\frac{N_M}{C_M} - \frac{f_E}{r_O} \right] K_M \cdot C_M + K_H \cdot N_H \quad [\text{Eq. A22}]$$

Net mineralization occurs whenever $\partial \text{NH}_4^+ / \partial t > 0$, otherwise immobilization occurs. The calculations recognise that, if no ammonium is available for immobilization, then nitrate can be used according to the following equation

$$\frac{\partial \text{NO}_3^-}{\partial t} = -\frac{f_E}{r_O} (K_L \cdot C_L + K_M \cdot C_M) \quad [\text{Eq. A23}]$$

During all simulations reported here, literature values were adopted for most of the parameters: the rate constants were set equal to $K_L=0.015 \text{ d}^{-1}$, $K_M = 0.015 \text{ d}^{-1}$ and $K_H=0.00005 \text{ d}^{-1}$; constant values were used for the efficiency of carbon turn-over, $f_E=0.5$, the humification fraction, $f_H=0.2$, and the C/N ratio of the soil biomass, $r_O=10.0$, as suggested by Johnson et al. (1987).

For the purpose of modelling, senescing plant material is added a single pool of organic P in the litter layer. The turnover of this organic phosphorus, to create mineral phosphorus (i.e. dissolved reactive phosphorus) is modelled simply by assuming decomposition is a first-order process specified by the rate constant K_L , and moderated by temperature and soil moisture functions.

A.11. Soil transformation processes for nitrogen

All N-transformation processes in the soil are assumed to be first-order with rate constants that are regulated by both temperature and moisture status of the soil. The effect of soil temperature is expressed using a Q_{10} relationship (Bunnell et al. 1977)

$$f_T(z) = Q_{10}^{\left[\frac{T(z)-T_B}{10}\right]} \quad [\text{Eq. A24}]$$

where $T(z)$ is the soil temperature for the layer, T_B is the base temperature at which f_T equals 1, and Q_{10} is the factor change in rate due to a 10-degree change in temperature. The soil moisture factor decreases, on either side of an optimum level, in drier soil or in excessively wet soil (Johnnson et al. 1987), i.e.

$$\begin{aligned} f_w(z) &= f_s + (1 - f_s) \left[\frac{\theta_s(z) - \theta(z)}{\theta_s(z) - \theta_H(z)} \right]^M & \theta_H(z) < \theta(z) < \theta_s(z), \\ f_w(z) &= 1 & \theta_L(z) < \theta(z) < \theta_H(z), \\ f_w(z) &= \left[\frac{\theta(z) - \theta_w(z)}{\theta_L(z) - \theta_w(z)} \right]^M & \theta_w(z) < \theta(z) < \theta_L(z), \end{aligned} \quad [\text{Eq. A25}]$$

where θ_s is the saturated water content, θ_H and θ_L are the high and low water contents, respectively, for which the soil moisture factor is optimal, and θ_w is the minimum water content for process activity. The factor f_s defines the relative effect of moisture when the soil is completely saturated, and M is an empirical constant.

The nitrogen model accounts for the internal cycling and transformation of three forms of mineral nitrogen (i.e. urea, ammonium and nitrate). The hydrolysis of urea (U , mg L^{-1}) to ammonium (NH_4^+ , mg L^{-1}), is modelled as

$$\left. \frac{dU}{dt} \right|_{U \rightarrow \text{NH}_4^+} = -k_1 f_T(z) f_M(z) \text{NH}_4^+ \quad [\text{Eq. A26}]$$

and this process is defined by a first-order rate constant (k_1). The transfer of ammonium to nitrate, (NO_3^- , mg L^{-1}), is modelled as

$$\left. \frac{d\text{NH}_4^+}{dt} \right|_{\text{NH}_4^+ \rightarrow \text{NO}_3^-} = -k_2 f_T(z) f_M(z) \left[\text{NH}_4^+ - \frac{\text{NO}_3^-}{n_q} \right] \quad [\text{Eq. A27}]$$

and depends on the potential rate constant (k_2) which is reduced as the nitrate-ammonium ratio (n_q) of the soil is approached. If $\text{NH}_4^+ < \text{NO}_3^- / n_q$ then no transfer of ammonium to nitrate takes place.

Denitrification is the transfer of nitrate to gaseous nitrogen (N_2 and N_2O) products. This is an anaerobic process and consequently is highly dependent on soil aeration. Soil water content is used as an indirect expression of the oxygen status of the soil. The influence on the denitrification rate is expressed as a power function

$$f_D(z) = \left[\frac{\theta(z) - \theta_D(z)}{\theta_S(z) - \theta_D(z)} \right]^d \quad [\text{Eq. A28}]$$

that increases from a threshold point (θ_D), is maximum at saturation (θ_S), and d is an empirical constant. No denitrification occurs below the threshold point. The denitrification rate for each layer is modelled as

$$\left. \frac{d\text{NO}_3^-}{dt} \right|_{\text{NO}_3^- \rightarrow \text{gas}} = -k_3(z) f_T(z) f_D(z) \left[\frac{\text{NO}_3^-}{\text{NO}_3^- + c_S} \right] \quad [\text{Eq. A29}]$$

and depends on a potential denitrification rate (k_3), the soil aeration status (f_D), and the same temperature factor (f_T) used for the other biologically-controlled processes. The rate constant k_3 is assumed to be a linear function of soil organic-carbon (Smith & Arah 1990). The factor c_S is the nitrate concentration where the denitrification rate is 50% of the maximum, all other factors are optimum.

The ammonia volatilization model incorporates the effect of soil and effluent pH, soil and air temperature, wind speed, and soil water content (Smith et al 1996). The following mechanistic equation of Wu et al. (2003) is used to prescribe the soil-surface volatilization rate, J_V [$\text{kg m}^{-2} \text{s}^{-1}$], as

$$J_V = \left(\frac{\theta_0}{\theta_s} \right) h_M \left(\frac{K_A K_H}{10^{-pH}} NH_4^+ \right) \Big|_{z=0} \quad [\text{Eq. A30}]$$

where h_M is the average mass transfer coefficient, K_A is the equilibrium constant relating the concentrations of ammonium ion and dissolved ammonia in soil solution, K_H is Henry's constant for the dissolution of gas-phase and liquid-phase ammonia in soil solution. The formulation for these three factors is presented in Wu et al. (2003).

A.12. Mass-balance equations for mineral nitrogen and phosphorus and microbes

The nitrogen transport model allows for an input of mineral nitrogen in the form of urea, ammonium or nitrate. The fate of surface-applied urea is determined by two competing processes:

- Losses due to hydrolysis of urea to ammonia
- Losses due to the drainage of urea through the soil profile.

We have assumed that all the urea enters the soil, and that any surface runoff of urea is negligible. The total mass of urea M_U [mg m⁻²], in each soil slab of thickness z_R [mm] is found by solving the following mass balance equation

$$\frac{dM_U}{dt} = z_R \frac{d\theta R_U U}{dt} = X_{U,i} - (k_1 z_R \theta U + J_w U) \quad [\text{Eq. A31}]$$

where U [mg L⁻¹] is the concentration of urea in soil solution, θ [m³ m⁻³] is the soil's volumetric water content, $X_{U,i}$ [mg m⁻²] is the mass of urea added to the i -th segment (=0 if $i > 1$), k_1 [d⁻¹] is the rate-constant describing the hydrolysis of urea to ammonium, $J_w U$ [mm d⁻¹] represents the percolation of dissolved urea through the soil. Urea is rapidly hydrolysed to ammonium, in a matter of a few days. The fate of ammonium-nitrogen is determined by six competing processes:

- Inputs from the mineralization of the soil biomass
- Retardation due to the adsorption of ammonium to the soil particles
- Losses due to the nitrification of ammonium into nitrate
- Losses due to the volatilization of ammonia gas
- Losses due to the drainage of ammonium through the soil slab
- Losses due to plant uptake.

The total mass of ammonium, M_A [mg m⁻²], in each soil slab is found by solving the following mass balance equation:

$$\frac{dM_A}{dt} = z_R \frac{d\theta R_A A}{dt} = (X_{A,i} + S_M + k_1 z_R \theta U) - (k_2 z_R \theta (A - N / n_q) + J_V + P_A + J_W A) \quad [\text{Eq. A32}]$$

where A [mg L⁻¹] is the concentration of ammonium in soil solution, $X_{A,i}$ [mg m⁻²] is the total mass of ammonium added to the i -th layer ($=0$ if $i > 1$), S_M [mg m⁻²] is rate of mineralization, P_A [mg m⁻² d⁻¹] is the rate of plant uptake, k_2 [d⁻¹] is a rate constant to describe the nitrification of ammonium to nitrate, and $J_W A$ [mg m⁻² d⁻¹] represents the percolation of dissolved ammonium through the soil slab. Here J_V represents the volatilisation of ammonia to the atmosphere. For simplicity, we have calculated J_V only for the top 10 cm of soil and set it equal to zero elsewhere. $R_A = (1 + \rho K_D / \theta)$ is the retardation factor for ammonium, ρ [kg L⁻¹ soil] is the soil's dry bulk density, and K_D [L kg⁻¹] is the distribution coefficient that determines how much ammonium gets adsorbed to the cation-exchange sites of the soil.

The fate of any nitrate in the soil water is determined by the following six processes:

- Inputs of nitrate from fertilizer application
- Inputs from the nitrification of ammonium
- Retardation due to the adsorption of nitrate ($= 0$ in most mineral soils)
- Losses from denitrification
- Losses due to plant uptake
- Losses due to the drainage of nitrogen beyond the root zone.

The total mass of nitrate-nitrogen, M_N [mg m⁻²], in each soil slab is found by solving the following mass balance equation

$$\frac{dM_N}{dt} = z_R \frac{d\theta R_N N}{dt} = (X_{N,i} + k_2 z_R \theta A) - \left(k_3 z_R \theta \left[\frac{N}{N + c_S} \right] + P_N + J_W N \right) \quad [\text{Eq. A33}]$$

where N [mg L⁻¹] is the concentration of nitrate in soil solution, $X_{N,i}$ [mg m⁻²] is the total mass of nitrate-nitrogen added to the i -th layer ($=0$ if $i > 1$), k_3 [d⁻¹] is a rate constant to describe denitrification losses, P_N [mg m⁻² d⁻¹] is the rate of plant uptake, and $J_W N$ [mg m⁻² d⁻¹] represents the drainage of nitrate through the soil slab. We consider denitrification to be

a microbial process that is rate-limited by the amount of soil organic carbon (the energy source) and mineral nitrogen (the nutrient source).

The total mass of mineral phosphorus, M_P [mg m⁻²], in each soil slab is found by solving the following mass balance equation

$$\frac{dM_P}{dt} = z_R \frac{d\theta R_P P}{dt} = (X_{P,i} + S_P - P_P + J_W P) \quad [\text{Eq. A34}]$$

where P [mg L⁻¹] is the concentration of dissolved reactive phosphorus in soil solution, $X_{P,i}$ [mg m⁻² d⁻¹] is the total mass of phosphorus added to the i -th layer ($=0$ if $i > 1$), S_P [mg m⁻² d⁻¹] is the rate of mineralization of organic phosphorus, P_P [mg m⁻² d⁻¹] is the rate of plant uptake, and $J_W P$ [mg m⁻² d⁻¹] represents the drainage of dissolved phosphorus through the soil slab. The adsorption of phosphorus is modelled using a Langmuir isotherm (Eq. A5), and so the retardation for phosphorus, R_P , is calculated as

$$R_P = \left[1 + \left(\frac{\rho}{\theta} \right) \left(\frac{Qb}{1 + bP} \right) \right] \quad [\text{Eq. A35}]$$

where Q is the maximum total mass of phosphorus at saturation per unit mass of dry soil [$\mu\text{g g}^{-1}$], and b is an empirical constant, with units of inverse of solution concentration [L mg^{-1}].

Bacterial transport is calculated using the same convection-dispersion type equation for water and solute transport, with additional terms used to represent the kinetic sorption of bacteria to the soil's mineral particles as well as the subsequent detachment and transfer of bacteria between the aqueous and solid phases (Schijven and Hassanizadeh 2000). The mass balance equation for water-borne bacteria (considering only those bacteria applied in the effluent) is given by the following equation

$$\frac{d\theta B}{dt} = (X_{B,i} - k_a \theta \psi B + k_d \rho S - \mu_w \theta B - \mu_s \rho S - J_W B) \quad [\text{Eq. A36}]$$

where B represents the bacteria concentration in the liquid phase [cfu L⁻¹], S_B represents the bacteria concentration in the solid (sorbed) phase [cfu g⁻¹], $X_{B,i}$ is the total mass of bacteria added to the i -th layer ($=0$ if $i > 1$) [cfu m⁻² d⁻¹], the k_a term represents attachment of bacteria to the soil particles, and the k_d term represents detachment of bacteria from the

soil particles and $J_w B$ [$\text{mg m}^{-2} \text{d}^{-1}$] represents the drainage of bacteria through the soil slab. The inactivation (die-off) of bacteria is described using a simple first-order decay model, where μ is the mortality rate [d^{-1}] and the subscripts 'w' and 's' refer to the liquid and solid phases, respectively. The overall mortality rate for *E. coli* bacteria in soil has been reported to be between 0.09 and 0.17 d^{-1} in two contrasting silt loams (Mubiru et al. 2000). Sukias & Nguyen (2003) report the rate constant for bacterial die-off in a Te Kowai silt loam, Hamilton, is about 0.056 d^{-1} . This represents a 'half life' of between about 1.8 and 3.3 days.

Calculation procedure

The model is run using a daily time step, to track the fate of nutrients and contaminants in effluent-applied land. The model considers the 11 irrigation areas separately, adding different amount of effluent to each site depending on pond disposal requirements and set irrigation rules. The calculations are made in the following sequence:

- Subtract evaporation, transpiration and plant uptake of nutrients from each soil segment
- Add and subtract the nitrogen, phosphorus and bacteria involved in the various transformation processes
- Partition each contaminant between solution and sorbed fractions, assuming complete equilibrium between the mobile and immobile phases
- If there is rain or irrigation, then perform the leaching process
- Redistribute water and contaminants vertically, according to water potential and solution concentration
- Repeat the contaminant partitioning.

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Appendix 5 Nitrogen leaching loss limits and nitrogen loading in the One Plan for Years 1-20 for the Upper Manawatu Water Management Zone.

Table 1: **Summary Table Upper Manawatu**

upper Manawatu	LUC I	LUC II	LUC III	LUC IV	LUC V	LUC VI	LUC VII	LUC VIII	Total
Year 1 (when rule comes into force) (kg of N/ ha/year)	32	29	22	16	13	10	6	2	
Year 5 (kg N/ha/year)	27	25	21	16	13	10	6	2	
Year 10 (kg N/ha/year)	26	22	19	14	13	10	6	2	
Year 20 (kg N/ha/year)	25	21	18	13	12	10	6	2	
Area of LUC in upper Manawatu (ha)	0	12424	20257	11508	907	57254	22108	5180	129638
Year 1 (Tonnes/year)	0	180	223	92	6	286	66	5	859
Year 5 (Tonnes/year)	0	155	213	92	6	286	66	5	824
Year 10 (Tonnes/year)	0	137	192	81	6	286	66	5	773
Year 20 (Tonnes/year)	0	130	182	75	5	286	66	5	751
Target (Tonnes/year)									358
current state (Point source + Non Point source) (Tonnes/year)									745.1
current state (PS) (Tonnes/year)									21.0
current state (NPS) (Tonnes/year)									724.1

Appendix 6 Nitrogen leaching loss limits and nitrogen loading in the One Plan for Years 1-20 for the Mangatainoka River.

Table 2: **Summary Table Mangatainoka**

Mangatainoka	LUC I	LUC II	LUC III	LUC IV	LUC V	LUC VI	LUC VII	LUC VIII	Total
Year 1 (when rule comes into force) (kg of N/ ha/year)	32	29	22	16	13	10	6	2	
Year 5 (kg N/ha/year)	27	25	21	16	13	10	6	2	
Year 10 (kg N/ha/year)	26	22	19	14	13	10	6	2	
Year 20 (kg N/ha/year)	25	21	18	13	12	10	6	2	
Area of LUC in the Mangatainoka catchment (ha)	549	10394	6074	1498	409	18110	8057	3874	48965
Mangatainoka (ha)	549	10394	6074	1498	409	18110	8057	3874	
Tonnes/year	8.8	150.7	66.8	12.0	2.7	90.6	24.2	3.9	360
Tonnes/year	7.4	129.9	63.8	12.0	2.7	90.6	24.2	3.9	334
Tonnes/year	7.1	114.3	57.7	10.5	2.7	90.6	24.2	3.9	311
Tonnes/year	6.9	109.1	54.7	9.7	2.5	90.6	24.2	3.9	301
Target (Tonnes/year)									248
current state (Point source + Non Point source) (Tonnes/year)									603
current state (NPS) (Tonnes/year)									?

Appendix 5

"Notes on the derivation of One Plan Table 14.2" prepared by Barry Gilliland,
Senior Policy Analyst, Horizons Regional Council 1 November 2017

Notes on the derivation of One Plan Table 14.2

PURPOSE

1. This is a short paper to examine how the values for the cumulative nitrogen leaching maximums in Table 14.2 of the One Plan were developed and whether there is any benefit in recalibrating Table 14.2 after changes in Overseer versions.

SCOPE

2. These notes focus on how the values in Table 14.2 were derived. The advantages and disadvantages of using the natural capital approach for nitrogen allocation, or consideration of alternatives to allocation by natural capital are not within scope.

DEFINITIONS

3. Measured SIN annual load - the quantity of SIN passing a point on the river, in kg/year or tonnes/year, calculated from a river flow statistic and water quality data collected at that location.
4. Target SIN annual load - the quantity of SIN passing a point on the river, in kg/year or tonnes/year, calculated from a river flow statistic and One Plan Schedule E water quality target for that location.

5. QUICK CONCLUSIONS

6. The year 1 cumulative nitrogen leaching maximums in Table 14.2 appear to be directly linked to OVERSEER outputs and would change according to OVERSEER version.
7. The year 20 cumulative nitrogen leaching maximums in Table 14.2 were set at a level to manage nitrogen leaching in over-allocated catchments after weighing up the environmental, economic and social consequences of doing so. They are therefore policy decisions related to, but not determined by the OVERSEER outputs.
8. The year 5 and 10 targets appear to be stepdown modifications of the year 1 nitrogen leaching maximums and could change should the year 1 cumulative nitrogen leaching maximums change.

BACKGROUND

9. During development of the One Plan, Horizons identified that the measured annual loads of **soluble inorganic nitrogen (SIN)** in some **Water Management Sub-zones (WMSZs)** exceed the target SIN annual loads derived to safeguard the life supporting capacity of waterways and provide for the surface water management values identified for those WMSZs (Table 1).
10. Resource accounting showed that over 90% of SIN was derived from non-point source run-off. The non-point source contributions were estimated as 50% from sheep and beef (which makes up 84% of the land use) and 50% from dairy (which makes up 16% of the land use).
11. It was decided that the most effective approach was to manage N from intensive farming land uses because this would be the most cost effective option and there were more mitigations available for this class of land use, e.g., dairy farming.
12. One Plan Table 14.2 specifies cumulative nitrogen leaching maximums according to **Land Use Capability (LUC)**. It is used in the One Plan as a tool to allocate nitrogen leaching loads amongst intensive farming land users.
13. OVERSEER was used during development of the cumulative nitrogen leaching maximums in Table 14.2 and this has led to the perception that the N leaching numbers in the table are affected by version changes. It is argued that the calculations should be re-run and Table 14.2 recalibrated to take account of OVERSEER version changes.

DISCUSSION

14. The Manawatū River at Hopelands and Mangatainoka River at S.H. 1 were used as case studies in development of the cumulative nitrogen leaching maximums in Table 14.2. The case study information is repeated below to help demonstrate how the values in Table 14.2 were derived.

Over-allocation and target SIN annual loads in the rivers

15. The measured and target SIN annual loads for the case study catchments are presented in Table 1.

Table 1: Target and measured SIN annual loads in case study rivers

	Manawatū River at Hopelands	Mangatainoka River at S.H. 1
One Plan Schedule E target for SIN (g/m ³)	0.444	0.444
Target SIN annual load (calculated from river flow statistic and Schedule E target (kg/year))	364,000	264,000
Measured SIN annual load as at 2012 (kg/year)	762,000	542,000
Identified over-allocation of SIN in catchment (kg/year)	398,000 (209%)	278,000 (205%)

16. The comparison of measured and target SIN annual loads identifies over-allocation in both catchments and supports the case for managing nitrogen discharges, including non-point discharges to these rivers.
17. The annual target SIN annual loads are reference points toward which efforts, including allocation of nitrogen leached from intensive farming activities, are directed.

Allocation using the natural capital approach

18. There are a number of methods available for allocation of nitrogen. It was decided that the natural capital approach developed by a project team contributing to the Sustainable Land Use Research Initiative for Horizons Regional Council would be the most appropriate allocation method (Curran et al, 2007).
19. The approach derives N leaching limits using LUC as a proxy for the natural capital of soils. The process can be summarized as follows:
- Estimate the potential productive capacity of a legume-based pasture fixing nitrogen biologically under a typical sheep and beef system for each LUC unit from the extended legends of LUC worksheets;
 - Transform the average attainable potential livestock carrying capacity into pasture production.
 - Use pasture production values in OVERSEER to calculate nitrogen leaching losses from a legume based pasture under optimum management of a dairy farm for each LUC Class.
20. The calculated nitrogen losses rank soils on the basis of their natural capital stocks or productive capacity for legume-based pasture. There are some challenges in doing this modelling.
21. Modelling nitrogen leaching in OVERSEER for each LUC Class involves choosing a set of characteristics to represent the sub-classes of the LUC Class, e.g., a representative livestock

carrying capacity. This is challenging because there is a considerable range within a LUC Class, reflecting the different soil versatilities, variability associated with the LUC Subclass limitations, and the variations in landform and slopes, soil parent materials, degree of soil development, soil depth, stoniness, drainage, texture, and climate.

22. Another underlying assumption is that higher (lower number) LUC Class soils can achieve higher production with lower inputs and have less potential for nitrogen leaching than poorer (higher number) LUC Class soils. However, like the considerable variation in the livestock carrying capacities within an LUC Class, there is also considerable variability in the tendency of soils to leach within each LUC Class.
23. The calculated nitrogen losses and the cumulative nitrogen leaching maximums are compared in Table 2. The nitrogen leaching values calculated using OVERSEER appears to form the basis for the year 1 leaching maximums in Table 14.2. Since these are based on OVERSEER outputs, it follows that these values would change according to the OVERSEER version used.

Table 2: OVERSEER derived nitrogen leaching based *attainable potential livestock carrying capacity* as a proxy for natural capital and year 1 values in Table 14.2

	LUC Class							
	I	II	III	IV	V	VI	VII	VIII
N leaching based on <i>attainable potential livestock carrying capacity</i> (kg/ha/year)	30	27.4	23.5	17.5	16.3	14.5	8.3	0
Table 14.2 <u>Year 1</u> cumulative nitrogen leaching maximum for comparison (kg/ha/year)	30	27	24	18	16	15	8	2

Derivation of year 5, 10 and 20 cumulative nitrogen leaching maximums

24. The Manawatū River at Hopelands and Mangatainoka River at S.H. 2 were used as case study catchments in Curran et al (2007). Two scenarios were modelled in which 90% and 75% of the nitrogen leaching based on the *attainable potential livestock carrying capacity* were used to estimate the total nitrogen loadings in the case study WMSZs. The scenarios were based on:
 - a. The estimated area for each LUC class in the catchment; and
 - b. An average land to water transmissivity of 0.5.
25. The scenario results were then compared against the measured (as at 2012) and target SIN annual loads in the case study (Table 3).

Table 3: Nitrogen leaching based on 90% and 75% of nitrogen leaching based on *attainable potential livestock carrying capacity* and year 5 and 20 values in Table 14.2

	LUC Class							
	I	II	III	IV	V	VI	VII	VIII
N leaching based on 90% of <i>attainable potential livestock carrying capacity</i> (kg/ha/year)	27	25	21	16	15	13	7	0
Table 14.2 <u>Year 5</u> nitrogen leaching maximum for comparison (kg/ha/year)	27	25	21	16	13	10	6	2
N leaching based on 75% of <i>attainable potential livestock carrying capacity</i> (kg/ha/year)	23	21	18	13	12	11	6	0
Table 14.2 <u>Year 20</u> nitrogen leaching maximum for comparison (kg/ha/year)	25	21	18	13	12	10	6	2

26. The scenario modelling carried out by Curran et al (2007) can be repeated for the Table 14.2 nitrogen leaching maximums in Table 14.2 (See Table 3) to check how the modelled annual nitrogen loads relate to the measured and target annual loads in the case study rivers. The modelling for the Manawatū River at Hopelands shows that application of the year 20 cumulative nitrogen leaching maximums in Table 14.2 would hold SIN annual loads in the catchment at the 2012 measured levels, but would make very little progress toward the target SIN annual loads needed to address over-allocation.
27. The modelling for the Mangatainoka River at S.H.2 shows that application of the year 20 cumulative nitrogen leaching maximums in Table 14.2 would make substantial progress in reducing SIN annual loads in the river toward the target SIN annual load needed to address over-allocation.
28. The case study differences show how the variability of soils, landscape units and rainfall affect the OVERSEER outputs. The topography, soil types and average annual rainfall in the Upper Manawatu vary significantly from those in the Mangatainoka catchment and these differences affect nitrogen leaching loss and nitrogen loading.

Table 3: Modelled annual nitrogen loads in two case study catchments using Table 14.2 nitrogen leaching maximums

Modelled total annual nitrogen loading in river (kg/year)	Manawatū River at Hopelands	Mangatainoka River at S.H. 1
Year 1 cumulative nitrogen leaching maximums (consistent with the OVERSEER derived nitrogen leaching calculated for <i>attainable potential livestock carrying capacity</i>)	1044653	410123
Year 5 cumulative nitrogen leaching maximums (consistent with 90% of the OVERSEER derived nitrogen leaching calculated for <i>attainable potential livestock carrying capacity</i>)	823732	334351
Year 10 cumulative nitrogen leaching maximums	773331	310914
Year 20 cumulative nitrogen leaching maximums (consistent with 75% of the OVERSEER derived nitrogen leaching calculated for <i>attainable potential livestock carrying capacity</i>)	750783	301452
Measured SIN annual load as at 2012	762,000	542,000
Target SIN annual load to address over-allocation	364,000	264,000

CONCLUSIONS

29. The year 1 cumulative nitrogen leaching maximums in Table 14.2 appear to be based on the unmodified OVERSEER derived nitrogen leaching rates presented in Curran et al (2007). The values for these cumulative nitrogen leaching maximums are likely to change according to OVERSEER version.
30. The year 20 cumulative nitrogen leaching maximums are consistent with 75% of the year 1 cumulative nitrogen leaching maximums. It is clear from the case study modelling that these values would not achieve the target SIN annual loads. The year 20 cumulative nitrogen leaching maximums in Table 14.2 were set at a level to manage nitrogen leaching in over-allocated catchments after weighing up the environmental, economic and social consequences of doing so. They are policy decisions related to, but not determined by the OVERSEER outputs. They are, therefore, unlikely to change according to OVERSEER version.

31. The year 5 and 10 targets appear to be step-down modifications of the year 1 nitrogen leaching maximums. They are linked to both the year 1 and year 20 values. In general, the year 5 nitrogen leaching maximums appear to be about 90% of the year 1 values and the year 10 values appear to be about 80% of the year 1 values.

Barry Gilliland

SENIOR POLICY ANALYST

1 November 2017

REFERENCES

1. A Curran, B Clothier, A MacKay and Parfitt, R, 2007: Appendix 6: *Defining nutrient (nitrogen) loss limits within a water management zone on the basis of the natural capital of soil in Farm Strategies for Contaminant Management report by SLURI, the Sustainable Land Use Research Initiative for Horizons Regional Council.*
2. Environment Court Decision, 2012: *Manawatū-Whanganui Regional Council Proposed One Plan Appeals, Part 5 - Surface Water Quality – Non-point Source Discharges.*
3. LR Lilburn, IH Lynn and TH Webb, 2016: *Issues in Using Land Use Capability class to set nitrogen leaching limits in moisture deficient areas – a South Island case study, New Zealand, Journal of Agriculture Research*, 59:1, 1-17.
4. Manawatū-Whanganui Regional Council, 2014: *One Plan – The Consolidated Regional Policy Statement, Regional Plan and Regional Coastal Plan for the Manawatu-Wanganui Region.*
5. Manawatū-Whanganui Regional Council, 2010: *Decisions on Submissions to the Proposed One Plan, Volume 1 – Reasons for the Decisions*, section 8.6.9.4.

Appendix 6

Rebuttal Evidence of Peter Harold Taylor, 20 January 2017

**BEFORE THE ENVIRONMENT COURT
AT WELLINGTON**

ENV-2016-WLG-000038

IN THE MATTER of the Resource Management Act 1991

AND

IN THE MATTER of an application for declarations under sections 310
and 311 of the Act

BETWEEN

WELLINGTON FISH AND GAME COUNCIL

AND

ENVIRONMENTAL DEFENCE SOCIETY INC

Applicants

AND

MANAWATU-WANGANUI REGIONAL COUNCIL

Respondent

REBUTTAL EVIDENCE OF PETER HAROLD TAYLOR

20 January 2017

Counsel instructed

For Wellington Fish and Game Council:
Sarah Ongley
Barrister
PO Box 8213
New Plymouth
Telephone: 06 769 9400
Email: sarah@ongley.co.nz

For Environmental Defence Society Inc:
John Burns / Madeleine Wright
c/- Kirkland Morrison O'Callahan
PO Box 2137
Auckland
Telephone: 09 366 1366
Email: johnb@kmolegal.co.nz

1. My name is **PETER HAROLD TAYLOR**.
2. I am a Practice Leader at The Catalyst Group, a consultancy based in Palmerston North. My experience and qualifications are set out in my affidavit evidence dated 15 September 2016 (paragraphs 4 to 6). I am qualified as an Overseer Nutrient Budget Operator. I gained the Intermediate Sustainable Nutrient Management Certificate from Massey University in 2012 and the Advanced Sustainable Nutrient Management Certificate from Massey University in 2013.
3. This further statement of evidence is filed in support of the application by the Wellington Region Fish and Game Council (**Fish and Game**) and Environmental Defence Society (**EDS**) for declarations filed with the Environment Court on 16 September 2016.
4. This evidence responds to the evidence of:
 - a. Mr Greg Bevin, Regulatory Manager, Manawatu-Wanganui Regional Council (**Horizons**); and
 - b. Mr Geoffrey Taylor, Programme Facilitator at Dairy NZ.

Mr Greg Bevin

5. Paragraphs 62 to 63 of Mr Bevin's affidavit, in reference to Dr Peet's affidavit, state that "...*there is real doubt as to whether appropriate maximum leaching values can feasibly be set for individual farms, and whether they could be enforced in practice*". Dr Peet does not appear to cover the enforcement aspect. Mr Bevin further states:

"I consider great care should be taken when imposing conditions to ensure that they can be complied with. Non-compliance with conditions is considered a serious matter..."

6. At paragraph 64 Mr Bevin notes that nitrogen leaching values are set via conditions that require the consent holder to undertake the activity in accordance with a Sustainable Management Plan (**SMP**). These documents contain a planned nitrogen trajectory.¹

¹ As explained in my original affidavit the One Plan uses the terminology "Nutrient Management Plan" or NMP whereas Horizons has adopted the terminology "Sustainable Management Plan" or SMP for this.

7. Whether nitrogen leaching maximums are set as a condition of consent, or through reference to another document such as an SMP, I consider that such maximum values are capable of being set. They are also capable of being enforced. In relation to setting, OVERSEER® is a reasonable tool for deriving the number, provided the model's assumptions and limitations are taken into account.

8. I agree OVERSEER® is a model subject to uncertainty as described by Freeman *et al* in the document *Using OVERSEER in Regulation. Technical Resources and Guidance for the appropriate and consistent use of OVERSEER® by Regional Councils, August 2016 (Overseer Technical Guidance Report)*. These authors say²:

“Uncertainty is not a reason to take no action. Rather, the higher the uncertainty, the greater the need for robust monitoring and review processes for plan provisions and resource consents.”

9. The Overseer Technical Guidance Report explores the issue of uncertainty in OVERSEER® nutrient loss estimates in some detail and makes recommendations as to how regional authorities should manage uncertainty. Many of the issues raised in that Report I encountered during my time at the Horizons, and particularly when I shared direct responsibility for the implementation of Rules 14.1 to 14.4. I assisted the then Compliance Manager to draft a monitoring and enforcement policy that accounted for uncertainties in OVERSEER®'s output estimates and that adopted the relevant approaches recommended by Freeman *et al*.

10. Specifically, these solutions included:
 - a. Using qualified and experienced OVERSEER® model operators.

 - b. Ensuring consistency and verification of input data. This resulted in the Rural Advice Team contributing to the development of the OVERSEER® Best Practice Data Input Standards (**BPDIS**).

 - c. Initiating discussions with Fonterra, DairyNZ, and fertiliser companies for the purposes of agreeing to a 'one farm one nutrient budget' approach to avoid farmer confusion.

² At page 55.

- d. Contracting AgResearch to produce two OVERSEER® sensitivity analysis reports. The project recognised that, with respect to an individual farm, OVERSEER® retains consistency over time in respect of climate and soils (the two primary drivers of N leaching). Because OVERSEER® is a long-term averaging model, and because these two inputs should remain unchanged once a farm's nutrient budget is completed, it can generally be expected that annual changes in outputs are the result of annual changes to farm management inputs and the sensitivity analysis was sought to quantify that.
 - e. Initiating a three-year N leached averaging consent condition.³
 - f. A draft monitoring and enforcement policy that proposed certain N leached thresholds (percentages from nitrogen leaching values in consents) that would be deemed acceptable and beyond which discussions would be held between the consent holder and the Rural Advice Team and then, should persistent exceedances occur, enforcement would be undertaken.
11. I also developed a Draft Implementation Practice Note as referred to in paragraph 16 of my affidavit of 15 September 2016. Most of these initiatives ceased following changes to senior management that occurred within Horizons, as referred to in paragraph 27 of my affidavit of 15 September 2016.⁴
12. Appended and marked "A" is Part 4 of the Overseer Technical Guidance Report, relating to Resource consent conditions.

³ This can be seen for example in 2014 consents (Annexure C to Ms Marr's affidavit) e.g. Doug and Areta Hutching Page 5 of the Consent Decision *"The farm targeted reductions have been set as the maximum to be leached over the term of this consent. This number is a rolling average over a three year period to allow for seasonal variations. Should any management practises change on farm that will affect the farm targeted reductions on the property and are of a permanent nature rather than a one off seasonal change, then a new NMP will need to be provided."* This addressed the consideration on Page 23 of the Overseer Technical Report that states *"When rules are set that rely on OVERSEER estimates to determine compliance, an averaging technique e.g., defining a typical farm system, averaging inputs or calculating a rolling average of outputs, can be used to manage some of the uncertainty due to climatic variability (see Section 8). Generally, a minimum of a rolling average of three to five years is considered adequate."*

⁴ Dr Peet became the Group Manager – Strategy & Regulation and Mr Munneke (not providing evidence in these proceedings) became Regulatory Manager..

Mr Geoffrey Taylor

13. Mr Geoffrey Taylor refers (paragraph 18) to the Regional Council Agenda Report 15-214 “*One Plan Nutrient Management Provisions*”.⁵ Part 9.3 of that report is headed “*The Change to Overseer modelled estimates of N-Leaching*”. Figure 1 highlights the shift in modelled N leaching rates for farms in the Mangatainoka Catchment between Environment Court evidence (modelled using OVERSEER®5) and estimates for farms modelled using OVERSEER®6 as part of the consenting process for farms in that catchment. Mr Taylor references this Report and states:

“...Version 6 increased the estimates of N loss, compared to the same farming activity modelled in an earlier version. To put this in perspective, initial modelling in the Mangatainoka catchment carried out in 2008 during the early formulation of the One Plan estimated average nitrogen loss to be 24.7kg N/ha/yr based on nutrient budgets provided by approximately one third of the farmers in the catchment. By comparison, using version 6, the Environmental Farm Plan project found an average loss rate of 39.5kg N/ha/yr during 2013/14”.

14. I have the following comments to make about the comparison contained in Report 15-124 and Mr Taylor’s use of this information.
15. It is correct that, for the One Plan Environment Court hearings, Horizons used nutrient budget data from the Mangatainoka catchment dairy farms to show N leaching averaged 24.7kg N/ha/yr. This estimate of average leaching was the best evidence that was available to Horizons in the absence of information being made available by the pastoral farming industry (in particular Fonterra), that was not at that time forthcoming. This information was used for the purpose of modeling the effects of different scenarios or nutrient management regimes on water quality by Dr Roygard, Science Manager, Horizons. The scenarios that were modeled are set out in the Annexure A to Ms Marr’s rebuttal evidence.
16. The 2008 nutrient budgets were completed by fertiliser company field staff for fertiliser recommendations and supplied by farmers to the Horizons Compliance Manager as a requirement of consents held. As

⁵ Attached as Annexure F to my original affidavit.

stated, they represented the best information available to Horizons at the time. It is erroneous to compare nutrients budgets prepared in 2008 with those prepared in 2012/13 and claim the differences are solely a result of the change in using OVERSEER®5 to OVERSEER®6, because there are significant differences in how the two datasets were generated.

17. In 2008, the nutrient budgets contained very few nutrient management blocks (usually two), used generalised large scale soil information, used peak cow numbers rather than monthly cow numbers, rarely included fodder crops, and did not include run-off blocks. Using peak cow numbers was a simple way of entering cow numbers into OVERSEER®. When OVERSEER® enabled monthly inputs of cow numbers, the Rural Advice Team observed a difference between the two methods where significantly less leaching was estimated when using peak cow numbers. Fodder crops, and particularly those grazed in winter, leach high per hectare rates of N. Therefore, where a nutrient budget has used peak cow numbers and/or omitted fodder cropping, and these inputs are later corrected, irrespective of an OVERSEER® version change, a higher N leaching estimate can be expected. The Environmental Farm Plan Mangatainoka Catchment Project (**EFP project**) used small scale (about 1:7,000) soil mapping and refined capabilities within OVERSEER® for inputting these data. These factors will have caused unknown shifts in N leaching compared to the 2008 budgets. Dairy milking platforms invariably leach more per hectare than run-off blocks. Omitting run-off blocks from a nutrient budget would likely show a higher N leaching for the farm and conversely, including them will likely show a decrease in N leaching.
18. There have been significant improvements in the quality of nutrient budget preparation between 2008 and 2012/13 when the EFP Project using OVERSEER®6 budgets were prepared for a different purpose. Also, the EFP Project recorded average N leaching of 34kg N/ha/yr (*Project Report, Environmental Farm Plan Project, Manawatu Freshwater Clean-Up Fund Project, December 2014*) and not 39.5kg N/ha/yr as claimed. Further, dairy production had intensified in the Tararua region during this time, of which the Mangatainoka catchment is part. Total cow numbers had increased from 95,348 to 101,324 and total effective hectares used for dairy production increased from 35,336ha to 37,321ha (*New Zealand Dairy Statistics 2007/08 and 2013/14, LIC and DairyNZ*,

2008 and 2014). This represents a 6.3% and 5.6% increase respectively which is likely to have contributed to an increase in N leaching and it is reasonable to assume these percentages reflect similar increases in the Mangatainoka catchment.

19. The conclusions in Mr Geoffrey Taylor's evidence at paragraph 23 that *"following the Mangatainoka Catchment example, instead of the average farm having to reduce end loss from 24.7 kg N/ha/year to 17.3 kg N/ha/year (7.4 kg N), the change in Overseer meant that the average farm had to achieve a reduction of 22.2 kg N/ha/year to meet the CLM in Table 14.2, three times as much"* therefore relies on an invalid comparison and incomplete information.
20. For the purposes of assessing the potential social and economic impacts of the cumulative nitrogen leaching maximums (**CNLM**) in Table 14-2 on farms, I presented evidence in the Environment Court⁶ that calculated limits and reductions required for 18 dairy farms in the Mangatainoka catchment. The evidence that I presented to the Environment Court that assessed the ability of dairy farms to comply with Table 14-2 CNLM's was based on the *"FARM Strategy Test Farms"*.⁷ Of these 18 farms, it was estimated that 28% were able to meet Table 14-2 Year 1 CNLMs without applying additional N loss mitigation practices (i.e. more mitigation than practiced at the time of assessment) and 22% of these farms would be able to meet the Year 20 CNLMs. It was estimated that if high to medium cost effective N loss mitigation practices were applied 78% of the 18 farms could meet the Year 1 CNLMs and 61% could achieve the Year 20 CNLMs.
21. Specifically my evidence to the Environment Court was:⁸

"Using 18 dairy farms described ... I calculate the limits and reductions required for these farms should this Rule apply to them.

Ten of these farms would need to reduce N leaching. Three of these farms would achieve this by the end of year one, two by the end of year two, leaving five to be compliant by the end of the third year.

⁶ Statement of Technical Evidence by Peter Taylor on the Topic of Surface Water Quality – Non-Point Source Discharges dated 2 February 2012 and referring to Technical Evidence Bundle Volume 4 pages 1757 – 1824 Taylor, Section 42A Report, 2009.

⁷ As referred to in paragraph 7 of my affidavit.

⁸ Paragraphs 10 – 12 and referred to at paragraph 5-170 of the Environment Court's decision.

For the majority of these farms achieving these reductions would be relatively easy. For two farms it would be possible but with some difficulty and for three farms very difficult.”

22. I note that the 18 Farm Strategy Test Farms were not randomly selected to represent ‘average regional dairy farms’. Instead, intensive dairy farms and those with higher rainfall and a higher proportion of high land use classes were targeted. The effect of this showed a higher proportion of dairy farms in priority catchments unable to meet Table 14-2 than I would have expected had the Farm Strategy Test Farms been randomly selected.
23. Mr Geoffrey Taylor states that *“it was generally accepted that under the original conditions (Overseer 5.4 and DCD available) approximately 80 percent of existing farms would be able to comply with Table 14.2 to meet controlled activity (CA) status ...”*⁹ This statement refers, I assume, to my Environment Court evidence. Mr Taylor goes on to claim the combination of OVERSEER® and the unavailability of Dicyandiamide (DCD) meant 80% of all farms would now have *“significant difficulty”* achieving Table 14-2 Year 1 CNLMs and implies that Years 5, 10, and 20 would be beyond their reach.
24. I agree in part with respect to the unavailability of DCD removing a potential N loss mitigation tool. However how useful this mitigation would have been was and is unknown. The effectiveness of DCD is untested in warmer and wetter climates such as those encountered in the Manawatu-Wanganui Region
25. As I stated in paragraph 23 of my affidavit of 15 September 2016, I also agree that the application of OVERSEER® would have caused increased leaching numbers from farms with freer draining soils in higher rainfall areas, in the Tararua Region in particular. However I disagree that this can be claimed for all dairy farms everywhere in the Manawatu-Wanganui Region.
26. The Council Report 15–124 also appears to assume that the OVERSEER® N leaching data gained in the Mangatainoka catchment would apply to the whole Region. To my knowledge, there has been no quantified or robust analysis undertaken as to the extent of the impact of

⁹ Paragraph 22.

OVERSEER®6 in generating an increased output as compared with OVERSEER®5, and so influencing the number of farms that could comply with the numbers in Table 14-2 as compared to evidence I presented to the Environment Court. The Council Report does contain reference to some further modelling work carried out¹⁰ but upon requesting this re-modelling work, Fish and Game have been informed that it is no longer available.

27. During my time at Horizons I was involved in preliminary discussions with Dr Mackay of AgResearch regarding the ability of existing intensive land uses in priority catchments to meet Table 14-2 given the change to OVERSEER®6. Mr Munneke, the then Regulatory Manager, who was given the responsibility to pursue this investigation did not do so for reasons unknown to me. This would have enabled an objective assessment quantifying the effect of OVERSEER®6 on the ability of farms in all targeted catchments to achieve the CNLM in Table 14-2.
28. It is stated in OVERSEER® Technical Note No.5 (*August 2012*)¹¹ that N leaching between versions 5.4 and 6 increased under some situations but that overall there was “*no consistent bias*” and that “*the shift will vary depending on a whole range of factors*”. It is stated that the analysis shows most change will be observed in high rainfall areas, shallow soils, and where there is surplus irrigation.
29. Whenever an OVERSEER® version upgrade occurs now, the OVERSEER® website explains the changes made and compares the N leaching estimates between versions. They invariably show that N leaching will increase for some farms and decrease for others. They repeatedly point out the extent of change will depend on the changes made to the model, the type of farm being modelled, and its location with respect to soils and climate. Indeed, the impact of OVERSEER®6 (and OVERSEER®6 versions) may, for some catchments, have *increased* the number of farms that could achieve Year 1 and Year 20 CNLM in Table 14-2 without applying additional N reducing mitigation practices.

¹⁰ “Ongoing changes to versions of the Overseer model also present significant challenges in identifying the degree of reduction made when farmers employ mitigations. For example, in analysing 15 farms consented under Overseer version 6.1.2 they achieved an average reduction of 4.8 kg N/ha or equivalent to an average 12% reduction across those farms. With the release of Overseer 6.1.3, a few months later, the reduction was re modelled at an average 2.5 kg N/ha or an average 7% reduction”.

¹¹ Page 17.