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Implementation of FARM strategies for contaminant management Further questions

A report by SLURI for Horizons Regional Council

May 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

May 2008

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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 physicals 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.

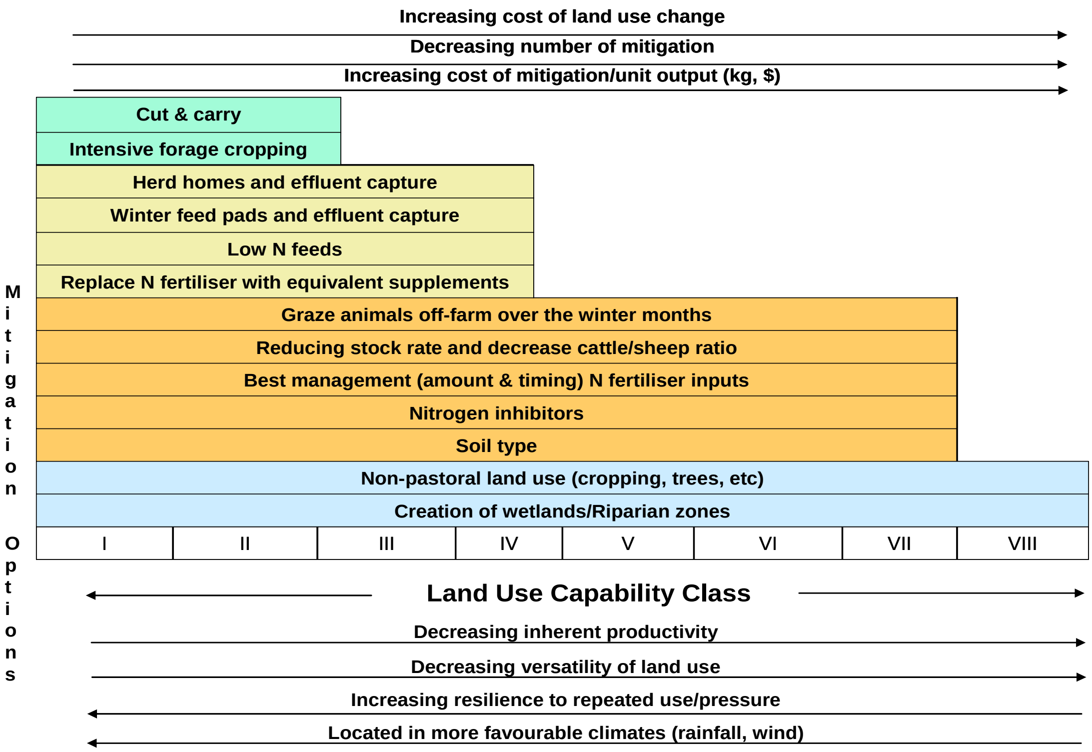

Fig. 8 Number and alignment of the mitigation options with the soils in each of the LUC Classes

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 NO_3-N ha^{-1}, which is about half of the 1038 kg NO_3-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 NO_3-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 a13.5% 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)

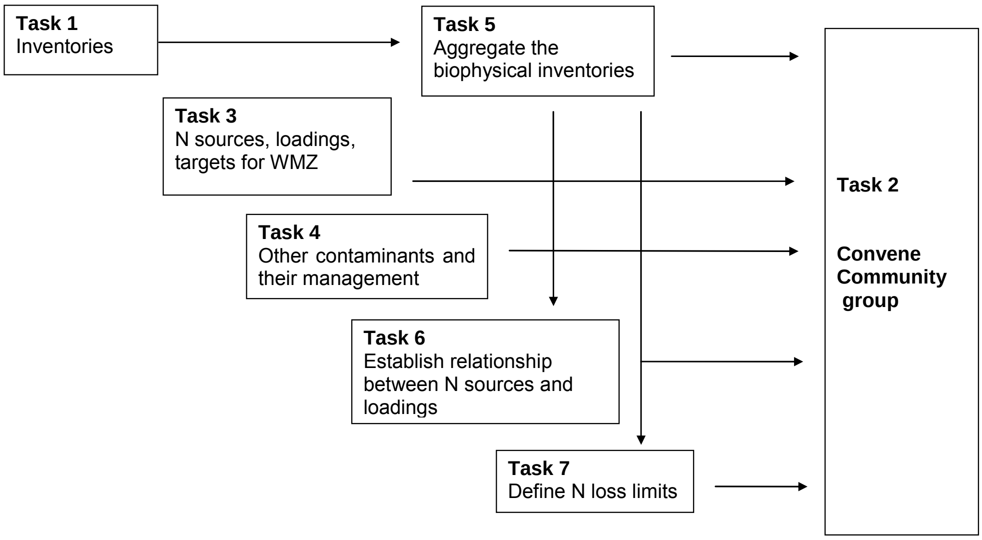

Fig. 21 Schematic diagram of the tasks to develop the catchment management plan

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 constituents 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
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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.

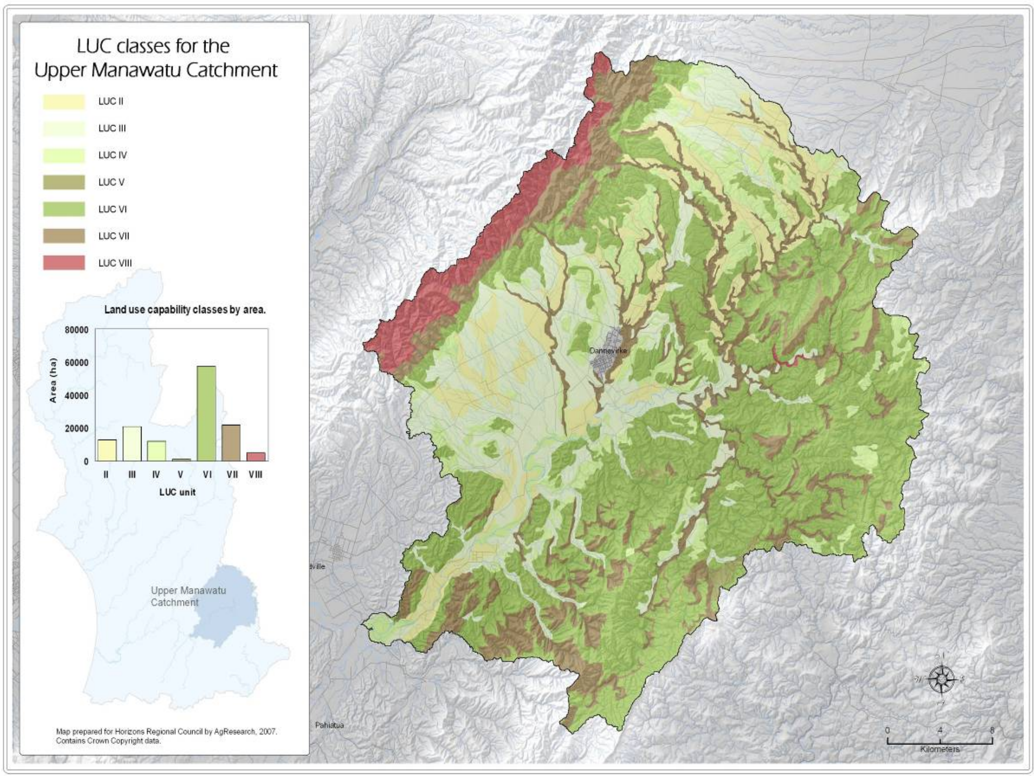
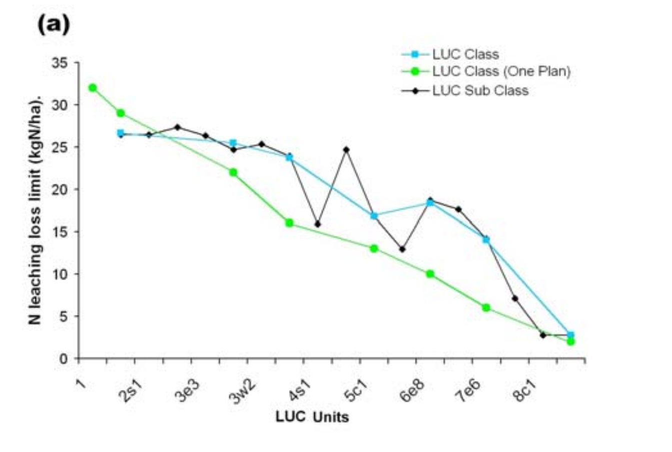
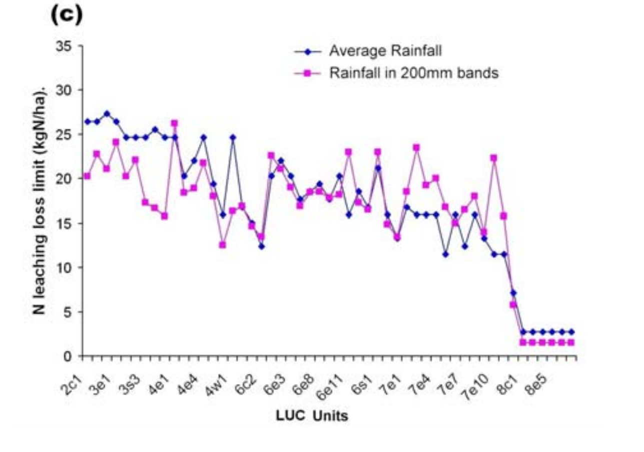


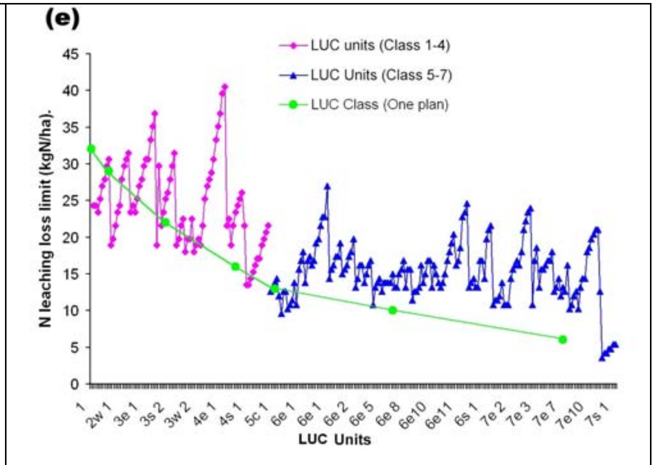
Fig.1 LUC classes for the Upper Manawatu.

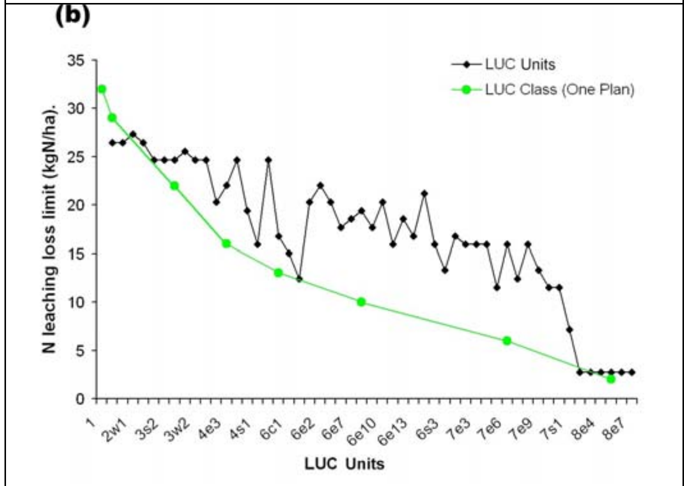
Again the potential livestock carrying capacities were transformed to pasture production and used in OVERSEER® to calculate N leaching losses under pastoral (Dairy) use. The calculated N leaching loss associated with the attainable potential production of the soils calculated in OVERSEER® at the LUC 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.









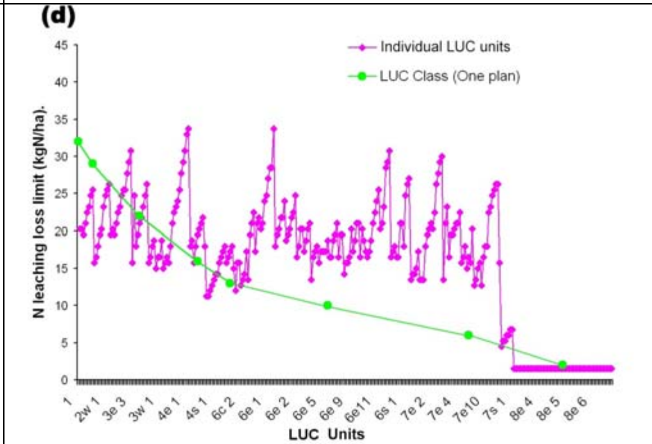
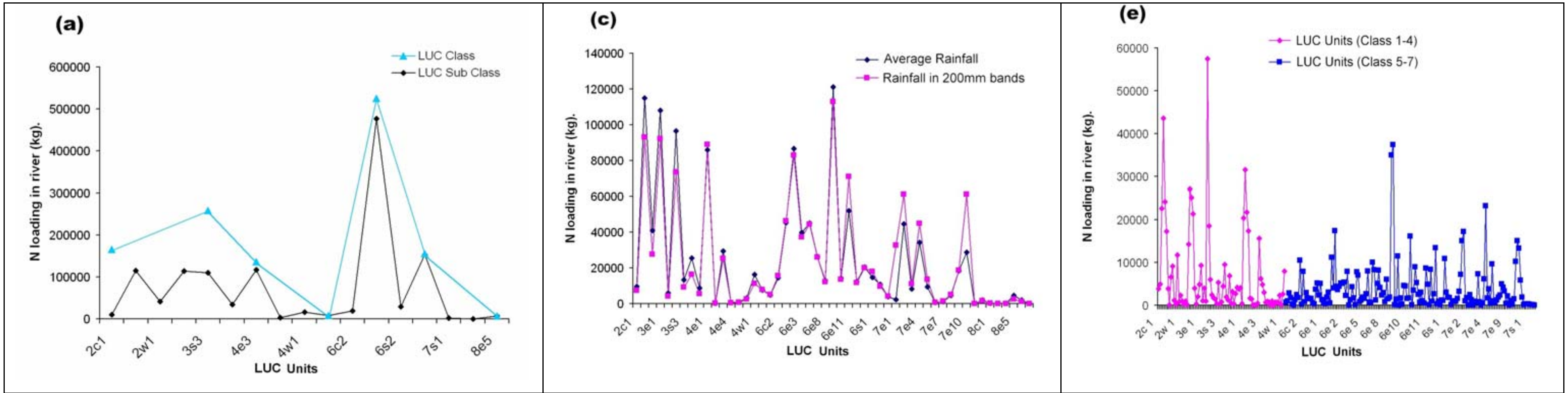


Fig. 2 (a) Nitrogen leaching loss associated with 75% of potential production of soils for LUC Class and Subclass calculated using average rainfall for the Upper Manawatu catchment and the nitrogen leaching loss limits for each LUC Class in the One Plan, (b) Nitrogen leaching loss associated with 75% 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.



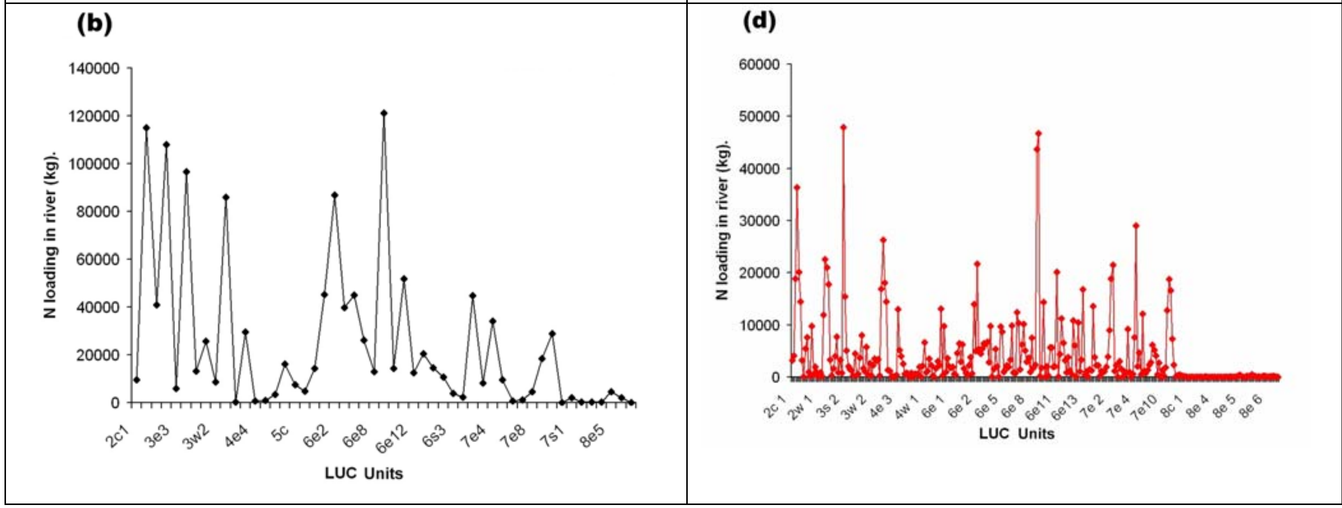


Fig. 3 (a) Nitrogen loadings in the Upper Manawatu associated with 75% of potential production of soils for LUC Class and Subclass calculated using average rainfall, (b) Nitrogen loadings in the Upper Manawatu associated with 75% of potential production of soils for LUC units calculated using average 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.

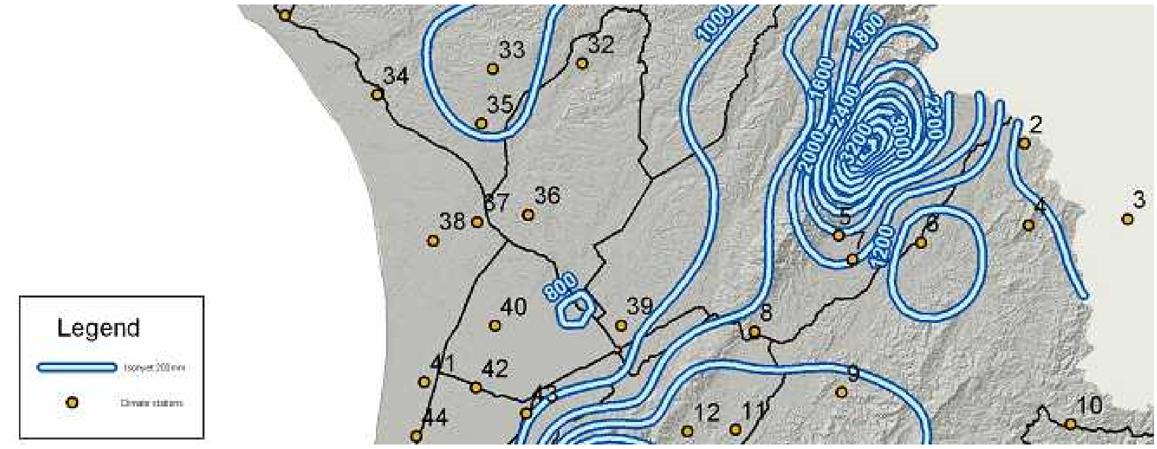


Figure 4 The isohyets of average rainfall across the Manawatu, showing the variation in rainfall in the Upper Manawatu Water Management Zone (UMWMZ) for stations 2 through 8.

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. [1]N 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).

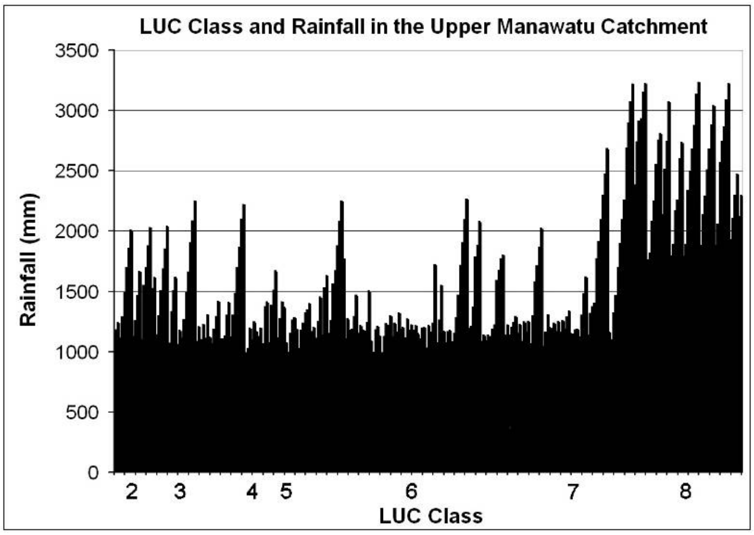


Fig. 5. Rainfall by LUC Class in the Upper Manawatu Catchment (Average rainfall 1357 mm)

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 steepland 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).

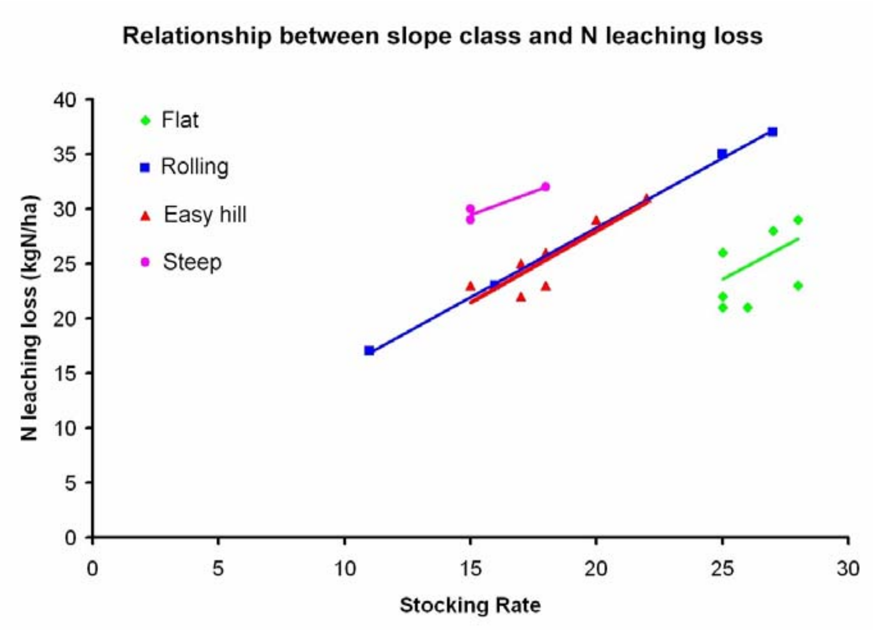


Fig. 6. The relationship between slope class and N leaching

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 steepland, 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

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

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

[1]Treating each ha in the catchment the same and assuming the transmission co-efficient is 0.5
[2]Treating each ha in the catchment the same and assuming the transmission co-efficient 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

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 course 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.

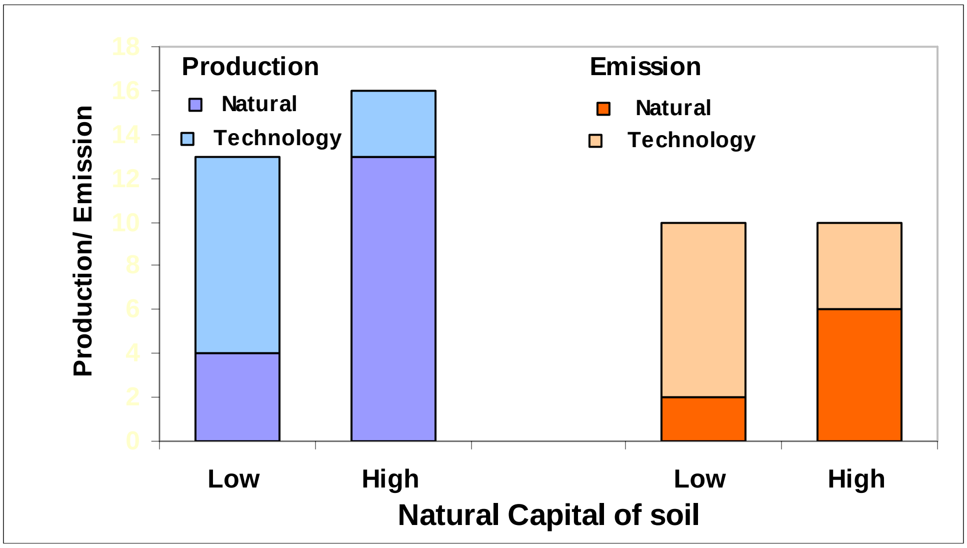


Fig. 7 Production and Emissions from a well managed legume pasture topdressed with P and S fertiliser before the introduction of production technologies (e.g. irrigation, drainage and N fertiliser) on soils of low and high natural capital.

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.

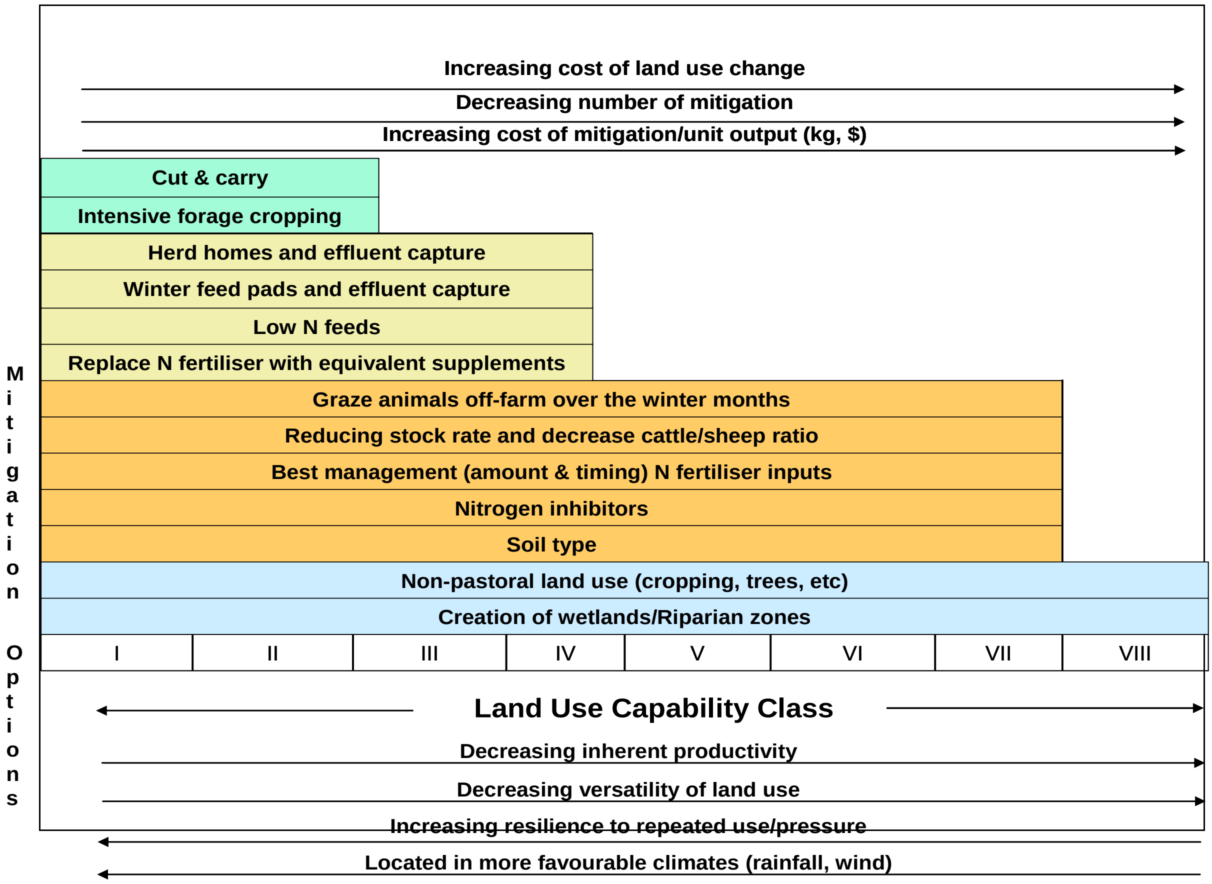


Fig. 8 Number and alignment of the mitigation options with the soils in each of the LUC Classes

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).

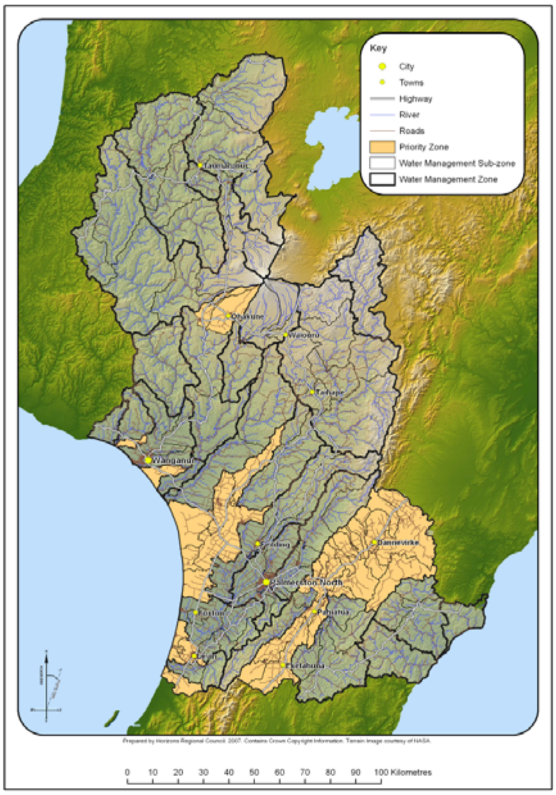


Fig. 9 Priority water management zones

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
	No. Farms		22	13				13	2	1		1	1		53
Mangapapa	Area		1407.02	420.13				41.63	419.67	41.49		26.76	16.73		2373.43
	No. Farms		50	11	1	3		41			5	1		1	113
Mowhanau	Area		1751.33	867.42	3.12	12.51		87.18			7.17	20.82		5.25	2754.79
	No. Farms	1	175	109	1		2	119	1		20	11			439
Mangatainoka	Area	4.56	21564.17	13469.55	0.40		26.91	450.21	5279.82		1049.81	240.29			42085.73
	No. Farms	3	395	150	1	2	6	247	2		26	13			845
upper Manawatu (Above Hopelands)	Area	455.52	81216.08	20430.31	6.29	16.26	553.10	1242.34	4171.44		1241.91	1068.65			110401.91
	No. Farms	2	86	16		9	1	94		1	29	16	1	11	266
Lake Horowhenua	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
	No. Farms		37	14	1	1	6	32	1	2	10	1		6	111
Waikawa	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	No. Farms		99	67			2	48	3	1	4	1			225
and mana_9c)	Area		10843.06	6622.36			31.80	184.08	1354.80	10.11	106.31	1.19			19153.71
	No. Farms	1	3	8			1	4	1		2				20
Waitarere	Area	19.39	147.07	1263.78			1289.90	19.67	0.08		236.40				2976.30
	No. Farms	1	20	7			8	21			7	2			66
Papaitonga	Area	6.16	796.38	409.53			197.58	39.80			134.16	2.14			1585.74
	No. Farms	1	56	4			4	54	1		8				128
Kaitoke Lakes	Area	40.16	4045.34	279.88			1343.71	238.11	238.11		294.20				6479.50
	No. Farms	1	58	15			8	13	1		5	4			105
Southern Wanganui Lakes	Area	7.45	10952.95	1836.20			4304.79	73.28	2.42		596.99	111.08			17885.17
	No. Farms		40	52			14	16			14	4		1	141
Northern Manawatu Lakes	Area		2944.04	6858.54			388.81	61.75			201.48	69.22		43.83	10567.67
	No. Farms	20	468	109		2	14	200	1	1	52	17			884
Coastal Rangitikei	Area	1161.05	36870.40	12495.53		6.00	1287.39	869.12	11.06	0.65	2024.89	320.46			55046.56
	No. Farms		109	4			2	58	4		9	3		5	194
Mangawhero/Makotuku	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).

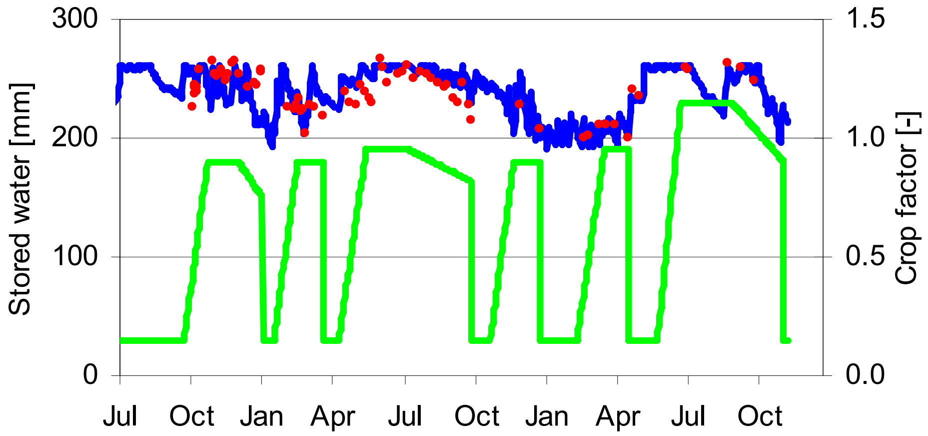


Figure 10. Measurements (red dots) and model output (blue line) of total water content (mm) of the top 0.6 m of the root-zone soil. The sequence of planting (described in Table 5) is expressed by the crop factor curves (green line) that relate actual plant water use to the potential evaporative demand. 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.

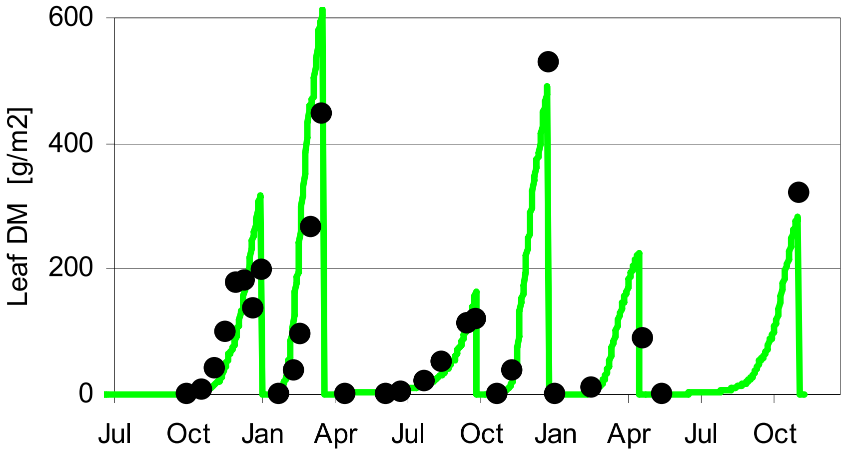


Figure 11. Measurements (dot markers) and model output (green line) for the above-ground dry-matter production at the commercial vegetable enterprise near Levin (Snow et al., 2004).

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.

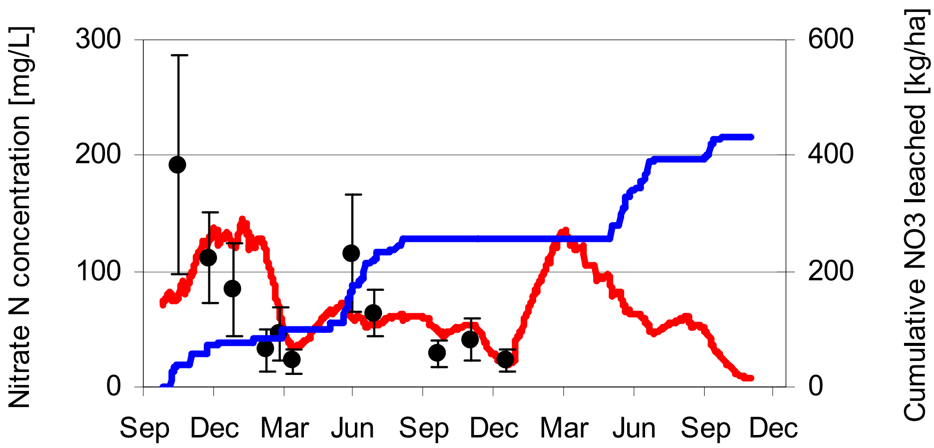


Figure 12. Measurements (markers) and model output (red line) for the nitrate-nitrogen content of drainage water at 60 cm. Open symbols are data from suction cups. Filled symbols are data from soil cores. The blue line represents the model output for the cumulative amount of nitrate leached below the root-zone. Our calculations predict that some 431 kg/ha of nitrate-N was leached during the two year observation period. The average NO_3-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	Harvest 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 NO_3-N ha^{-1}, which on balance is about half of the 1038 kg NO_3-N ha^{-1} applied. The components of the nitrogen balance reveal that 1388 kg NO_3-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 NO_3-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)

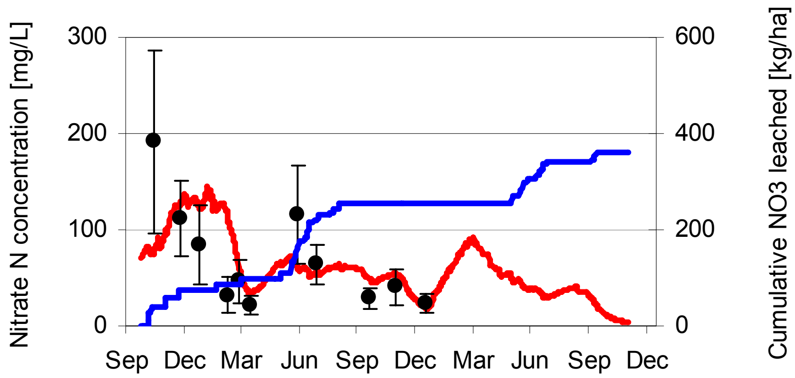


Figure 13. As in Figure 12, but only applying ½ the amount of fertilizer to the second crop of spring onions. This reduced nitrate leaching by about 50 kg/ha *cf* actual practice.

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).

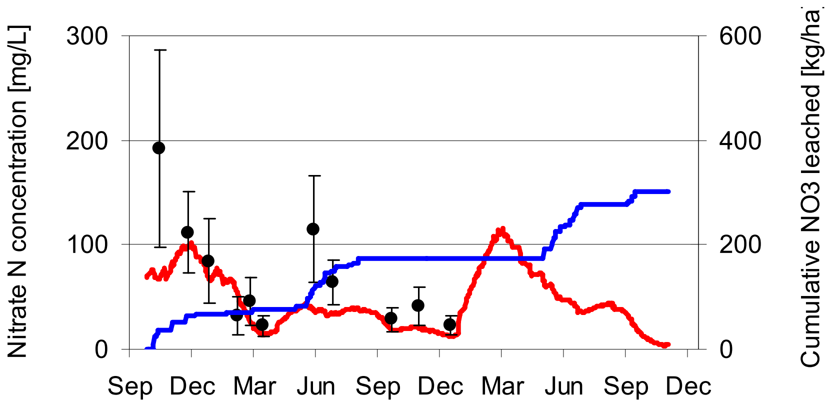


Figure 14. As for Figure13, but not applying the Living Earth compost at the start. This reduced nitrate leaching by 131 kg/ha *cf* actual practice, but the yields were down by 20%.

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 Mineralize	89	ETP	1952.3		
	crop return	421	ETA	1214.5	Esoil	240.9
	recycle	58	DR	670.9		
losses	Volat	176	RO	70.4		
	Denit	133	ETA/ETP	62	[%]	
	Leaching	301	IRA	510.0	mm supplied	
	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 NO_3 L^{-1}, a drop of 27% resulting from the practices over 2001-2003.

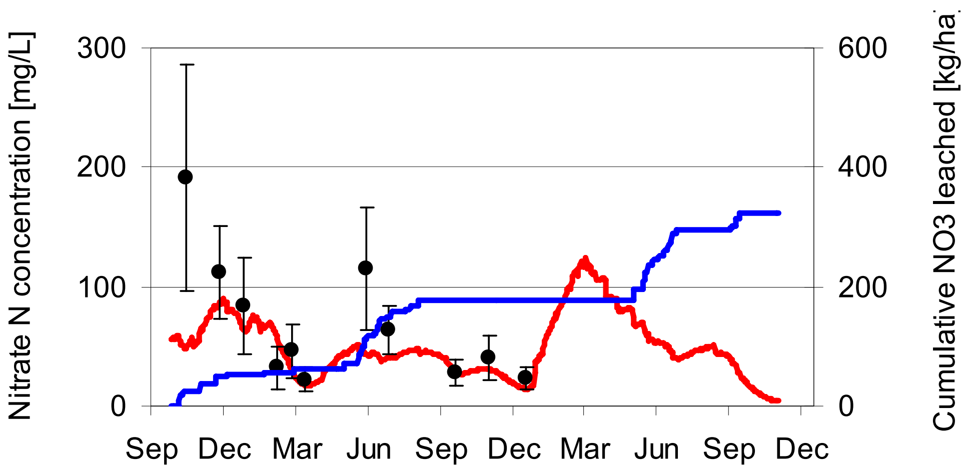


Figure 15. As in Figure 13 but only applying ½ the amount of Living Earth compost at the start and none of the 'special' N-fertilizer to the first crop of spring onions. This reduced nitrate-N leaching by 100 kg/ha *cf* actual practice, but crop yields were down by 10%.

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		
losses	Volat	200	RO	70		
	Denit	137	ETA/ETP	62	[%]	
	Leaching	323	IRA	510	mm supplied	
	mean NO_3	50				
Outputs	crop harvest	351				
T FW/ha	Harvest 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.

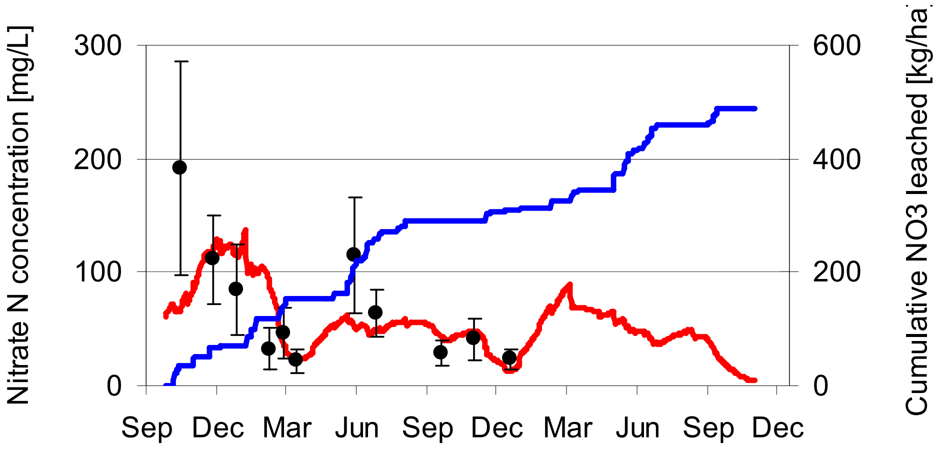


Figure 16. As in Figure 13 but applying excessive amounts of irrigation (in 75 mm aliquots). This increase nitrate leaching by about 60 kg/ha *cf* actual practice

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	Harvest 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 2nd 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 & 319and Appendix 3), as did the N loading in the river (Table 15).

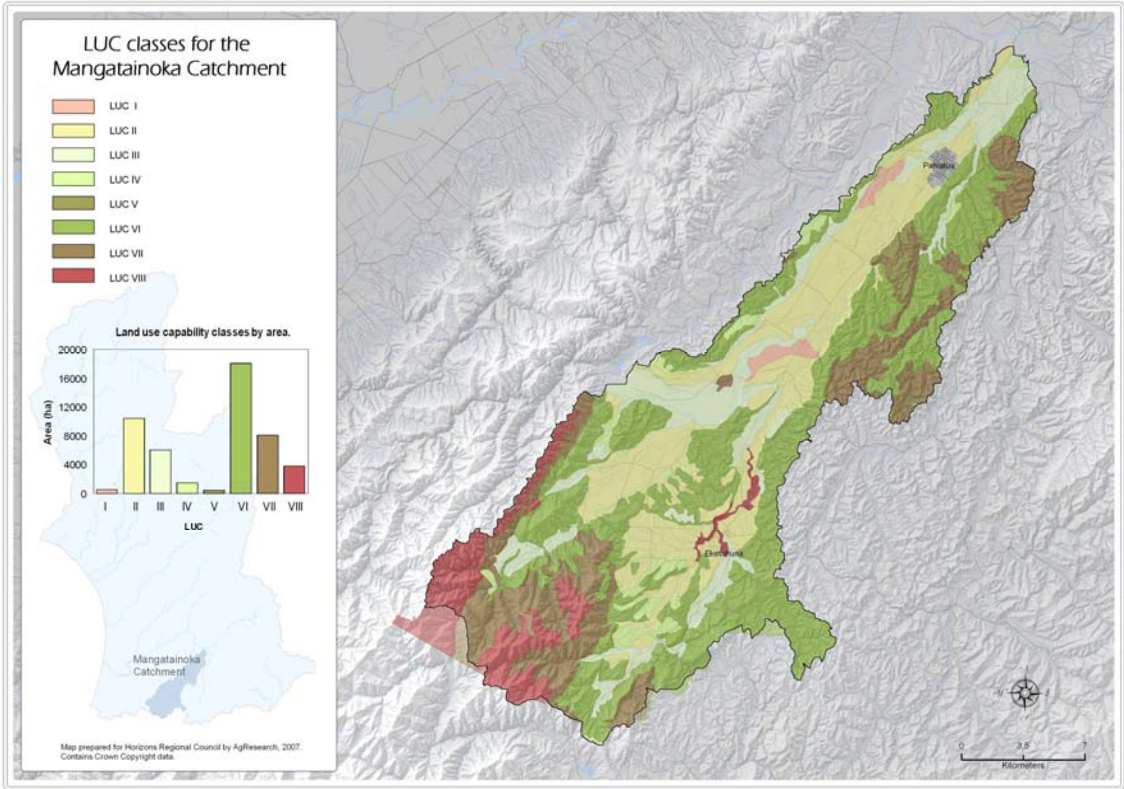
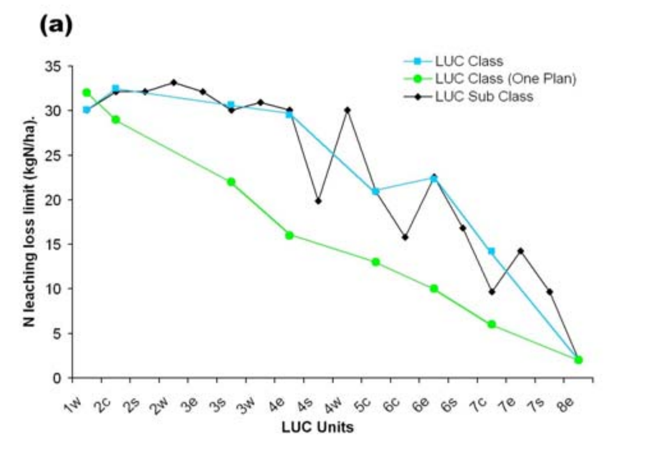
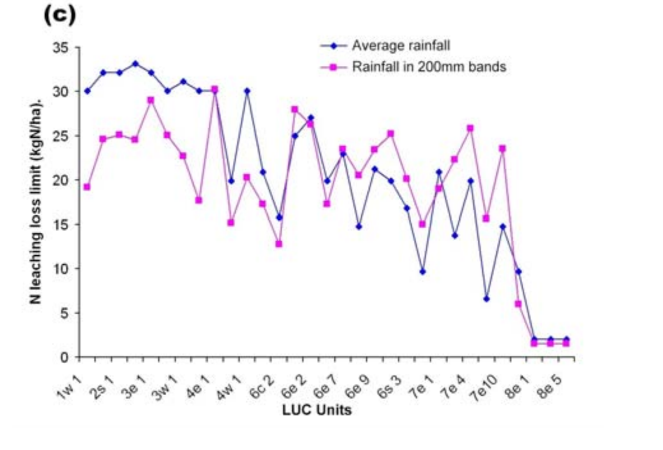
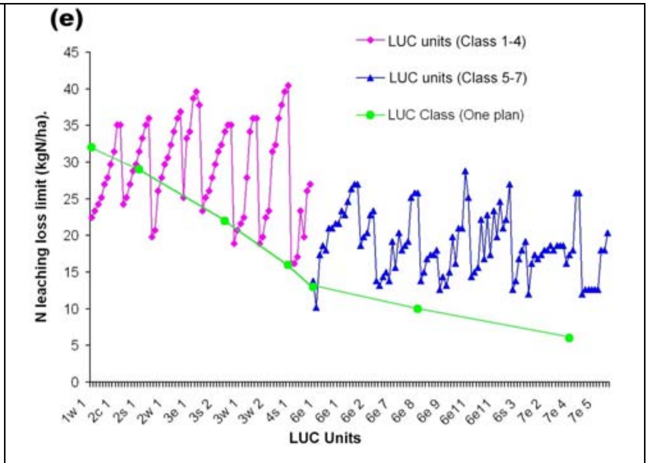


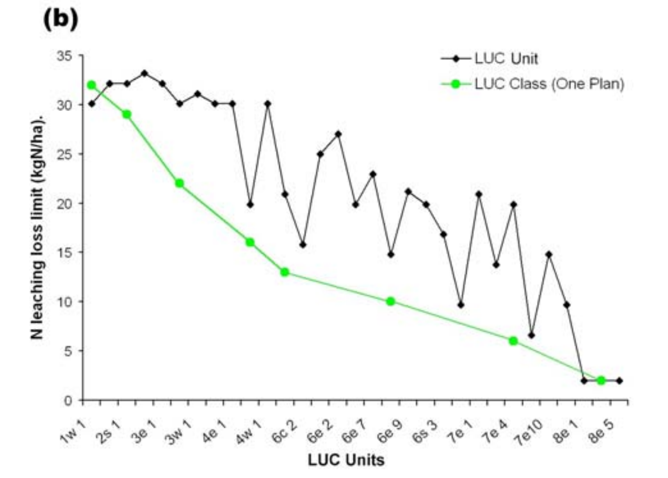
Fig. 17 LUC classes for the Mangatainoka.

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.









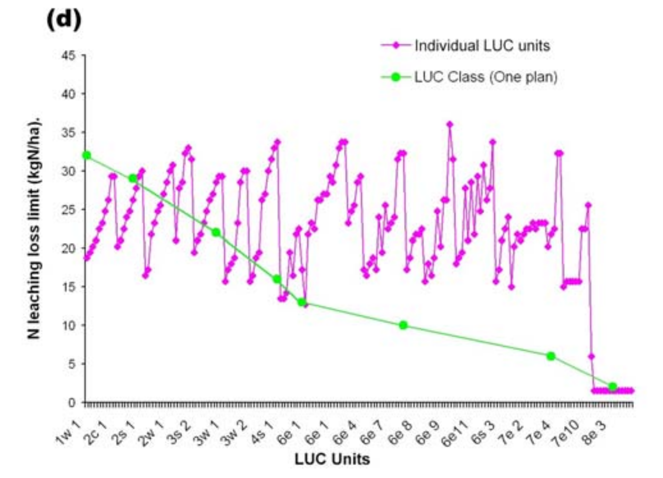
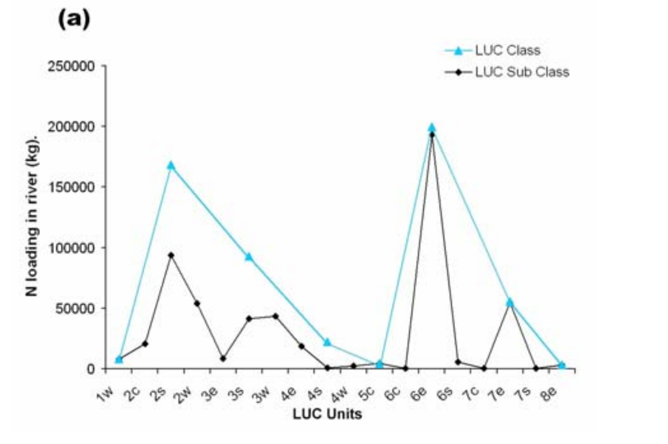
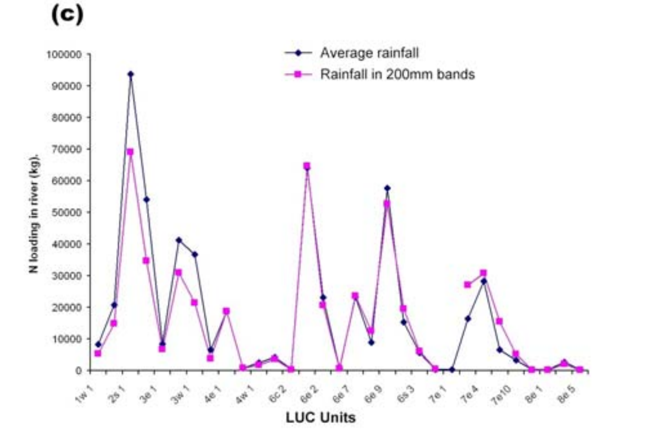
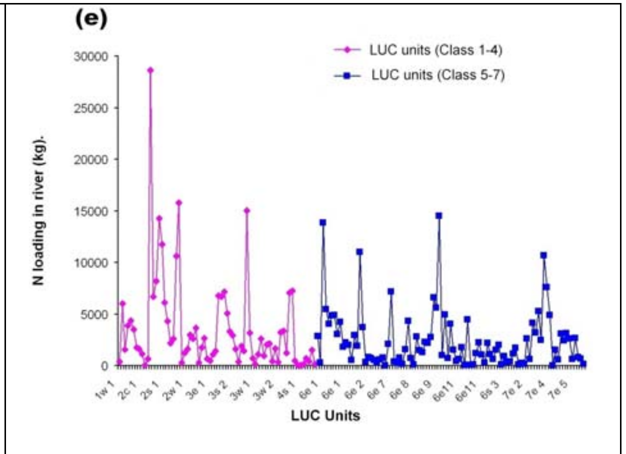
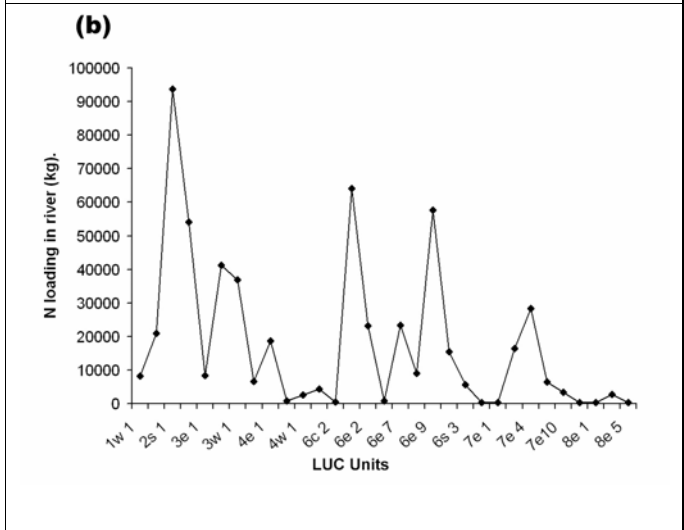


Fig. 18 (a) Nitrogen leaching loss associated with 75% of potential production of soils for LUC Class and Subclass calculated using average rainfall for the Mangatainoka catchment and the nitrogen leaching loss limits for each LUC Class in the One Plan, (b) Nitrogen leaching loss associated with 75% 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.









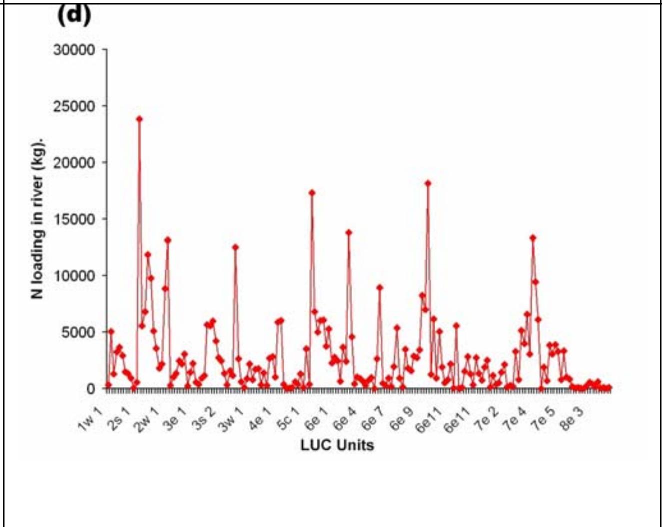


Fig. 19 (a) Nitrogen loadings in the Mangatainoka catchment associated with 75% of potential production of soils for LUC Class and Subclass calculated using average rainfall, (b) Nitrogen loadings in the Mangatainoka catchment associated with 75% of potential production of soils for LUC units calculated 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. [1]N 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).

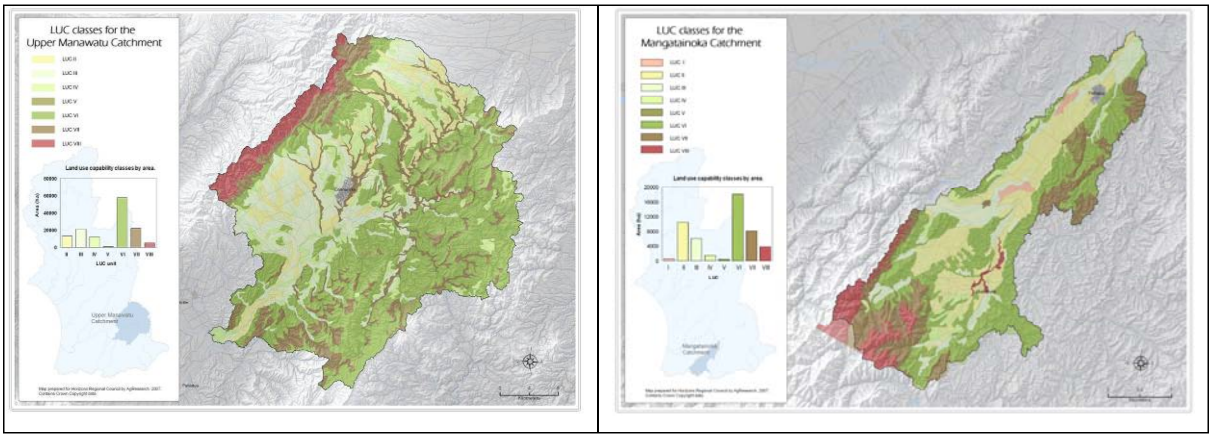


Fig. 20 LUC classes for the Upper Manawatu and Mangatainoka catchments.

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.

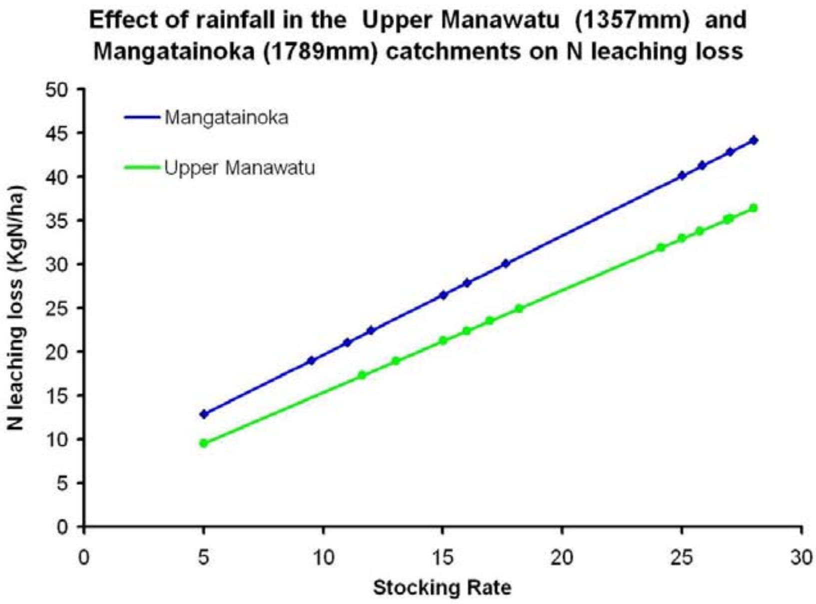


Fig. 21 Effect of rainfall in the Upper Manawatu and Mangatainoka catchments on the calculated N leaching loss

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).

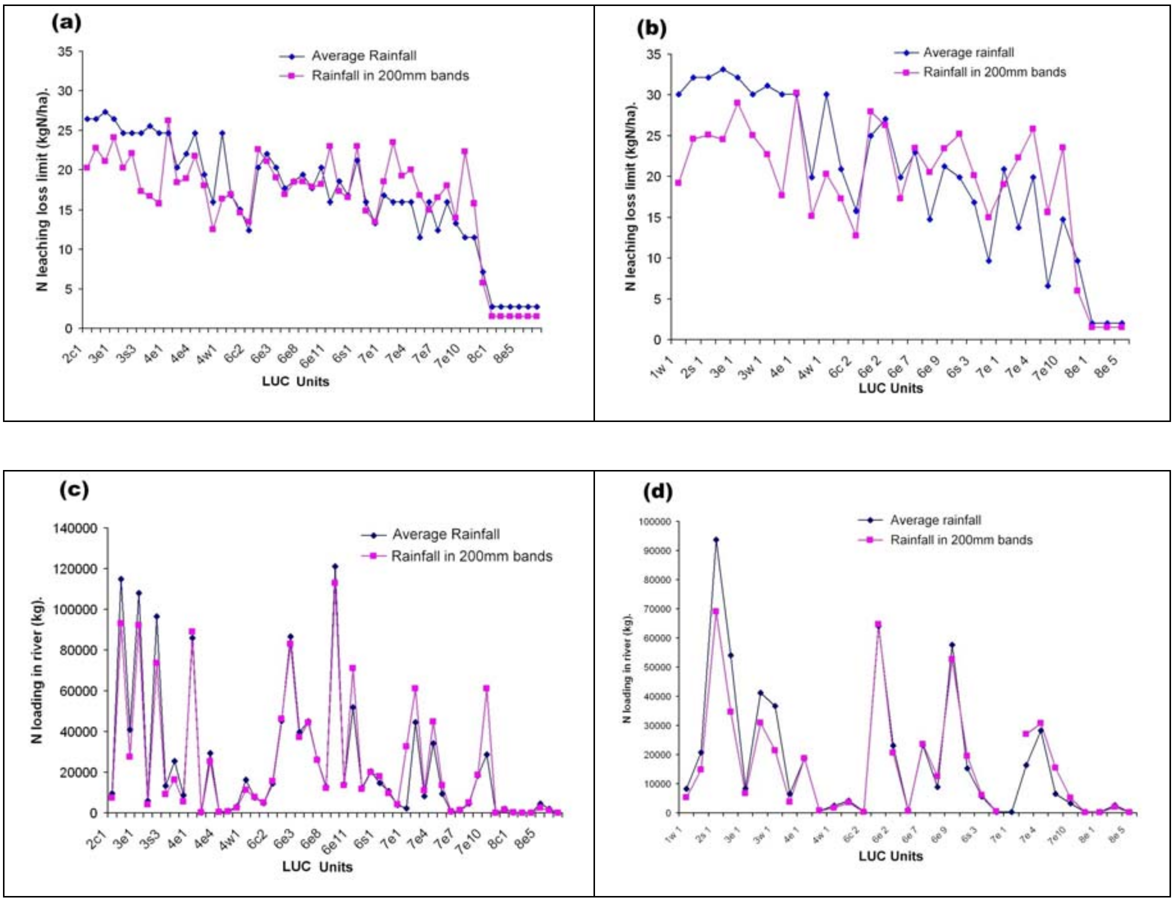


Fig. 22 Nitrogen leaching loss associated with 75% of potential production of soils for each LUC unit calculated using average rainfall and rainfall in 200 mm bands for the (a) Upper Manawatu catchment and (b) Mangatainoka catchment, and (c) the Nitrogen loadings in the Upper Manawatu and (d) the Mangatainoka 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.

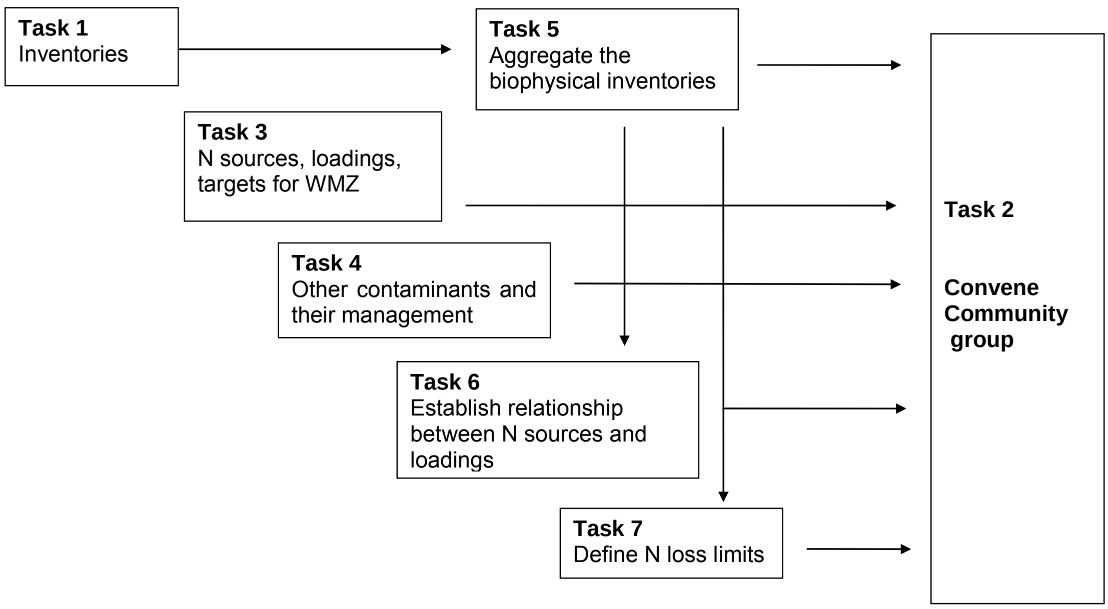


Fig. 21 Schematic diagram of the tasks to develop the catchment management plan

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 constituents 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
VIs	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
VIIs	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 (ha)	Stocking Rate (su/ha)	N-loss Function	Fraction of Potential	N-loss limit	Transmission Coefficient	N load in river
IIc1	728	27.00	35.3	0.75	26.4	0.5	9620
IIs1	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
VIc1	635	14.00	20.1	0.75	15.0	0.5	4770
VIc2	2328	11.00	16.5	0.75	12.4	0.5	14442
VIe1	4474	20.00	27.1	0.75	20.3	0.5	45414
VIe2	7860	22.00	29.4	0.75	22.1	0.5	86666
VIe3	3916	20.00	27.1	0.75	20.3	0.5	39745
VIe5	5113	17.00	23.6	0.75	17.7	0.5	45170
VIe7	2830	18.00	24.7	0.75	18.5	0.5	26242
VIe8	1325	19.00	25.9	0.75	19.4	0.5	12867
VIe9	13699	17.00	23.6	0.75	17.7	0.5	121028
VIe10	1415	20.00	27.1	0.75	20.3	0.5	14361
VIe11	6535	15.00	21.2	0.75	15.9	0.5	52009
VIe12	1353	18.00	24.7	0.75	18.5	0.5	12549
VIe13	2437	16.00	22.4	0.75	16.8	0.5	20461
VIs1	1382	21.00	28.2	0.75	21.2	0.5	14634
VIs2	1357	15.00	21.2	0.75	15.9	0.5	10800
VIs3	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
VIIs1	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 Rain (mm)	Area (ha)	N-loss Function	Fraction of Potential	N-Loss Limit	Trans-mission Co-efficient	N 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 (ha)	Stocking rate (su/ha)	N-loss Function	Fraction of Potential	N-loss limit	Transmission Co-efficient	N loading 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 (ha)	Stocking rate (su/ha)	N-loss Function	Fraction of Potential	N-loss limit	Transmission Co-efficient	N loading 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
IIs	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
IIIw	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
VIc	57.0	11.0	21.069	0.75	15.8	0.5	450
VIe	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
VIIs	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 (ha)	Stocking rate (su/ha)	N-loss Function	Fraction of Potential	N-loss limit	Transmission Co-efficient	N loading in river
Iw 1	549	25.0	40.1	0.75	30.1	0.5	8256
IIc 1	1299	27.0	42.9	0.75	32.1	0.5	20870
IIs 1	5831	27.0	42.9	0.75	32.1	0.5	93690
IIw 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
VIs 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
VIIs 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

$$W_T = W_I + W_M \, . \qquad \text{[Eq. A1]}$$

and total amount of solute in each soil segment, M_C [mg m^{-2}], is calculated as

$$M_C = C_I \, W_I + C_M \, W_M + S \, \rho \, \Delta z \qquad \text{[Eq. A2]}$$

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

$$S = K_D C \qquad \text{[Eq. A3]}$$

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

$$C = M_C / \left(\rho \, S \, \Delta z + W_T \right). \qquad \text{[Eq. A4]}$$

The sorption of phosphorus is non-linear and is described using a Langmuir isotherm of the form

$$S = \frac{Q \, bC}{1 + bC} \qquad \text{[Eq. A5]}$$

where Q is the maximum total mass of phosphorus at saturation per mass unit of dry soil [µg 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

$$\rho \frac{\partial S}{\partial t} = \theta k_a \psi C - k_d \rho S \qquad \text{[Eq. A6]}$$

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 & Elimelich 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 υ [mm d^{-1}], as well as terms to describe the collector efficiency η [-], and the collision (or sticking) efficiency α [-]

$$k_a = \frac{3(1-\theta)}{2 d_c} \eta \alpha \upsilon \qquad \text{[Eq. A7]}$$

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

$$\lambda ET_0 = \frac{s(R_N - G_H) + \rho_A c_P (e_s - e_a)/r_A}{s + \gamma(1 + r_S / r_A)} \qquad \text{[Eq. A8]}$$

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 [^{o}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 ^{o}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

$$ET_C = K_C \, ET_0 \qquad \text{[Eq. A9]}$$

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 [m^2 of leaf per m^2 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:

$$Q = \frac{(R - 0.2S)^2}{R + 0.8S}, \qquad R > 0.2S$$
$$Q = 0, \qquad R \le 0.2S \qquad \text{[Eq. A10]}$$

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)

$$S = 254\left(\frac{100}{CN} - 1\right)$$ [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 (kg m^{-2} d^{-1}) that is related, via a conversion efficiency, ε (kg MJ^{-1}), to the amount of solar radiant energy, Φ (MJ m^{-2} d^{-1}), intercepted by the leaves

$$G = \varepsilon \Phi \ f_T \ f_N \ f_W \qquad \text{[Eq. A12]}$$

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

$$\frac{dF}{dt} = \alpha_F G - \gamma_F F - H_F \qquad \text{[Eq. A13]}$$

the total mass of stem material, S [kg m^{-2}] is calculated from

$$\frac{dS}{dt} = \alpha_S G - \gamma_S F - H_S \qquad \text{[Eq. A14]}$$

and the total mass of roots, R [kg m^{-2}], is calculated from

$$\frac{dR}{dt} = \alpha_R G - \gamma_R R \qquad \text{[Eq. A15]}$$

Here α_F is the fraction of biomass partitioned to the foliage, α_S is the biomass partitioned to the stem, and α_R (=1-α_F-α_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 [α_{R0}] at a maximum leaf concentration $[N]_{Fx}$, and increasing as N_L decreases (Eckersten & Jansson 1991)

$$\alpha_R = \alpha_{R0} + 1 - \left(1 - \left(\left([N]_{Fx} - [N]_F\right)/[N]_{Fx}\right)^2\right)^{0.5} \qquad \text{[Eq. A16]}$$

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 [kg ha^{-1} d^{-1}], is defined as

$$\begin{aligned} U_N = \; & \left(\alpha_F G[N]_{Fx} - \lambda_F \gamma_F F[N]_F\right) \\ & + \left(\alpha_S G[N]_{Sx} - \lambda_S \gamma_S S[N]_S\right) + \left(\alpha_R G[N]_{Rx} - \lambda_R \gamma_R R[N]_R\right) \end{aligned} \qquad \text{[Eq. A17]}$$

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

$$U_{NO3-} = \min\left(\rho_R(z)\, \frac{NO_3^{\ -}}{NO_{3-} + NH_4^{\ +}}\, U_N\, ,\, f_M\, NO_3^{\ -} \right) \qquad \text{[Eq. A18]}$$

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 (Johnnson 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 CO_2, 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

$$\frac{\partial C_L}{\partial t} = \left[(1 - f_H) f_E - 1\right].K_L.C_L + F_{C,L}$$

$$\frac{\partial N_L}{\partial t} = \left[(1 - f_H) f_E \frac{1}{r_O} - \frac{N_L}{C_L}\right].K_L.C_L + F_{N,L} \qquad \text{[Eq. A19]}$$

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)

$$\frac{\partial C_M}{\partial t} = \left[(1 - f_H) f_E - 1\right].K_M.C_M + F_{C,M}$$

$$\frac{\partial N_M}{\partial t} = \left[(1 - f_H) f_E \frac{1}{r_O} - \frac{N_M}{C_M}\right].K_M.C_M + F_{N,M} \qquad \text{[Eq. A20]}$$

Lastly, the set of mass balance equations describing the turn-over of carbon and nitrogen in the humus pool are given by

$$\frac{\partial C_H}{\partial t} = f_E \cdot f_H . K_L . C_L - K_H . C_H + F_{C,H}$$

$$\frac{\partial N_H}{\partial t} = \frac{f_E \cdot f_H}{r_O} K_L . C_L - K_H . N_H + F_{N,H} \qquad \text{[Eq. A21]}$$

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 NH_4^+-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

$$\frac{\partial NH_4^+}{\partial t} = \left[\frac{N_L}{C_L} - \frac{f_E}{r_O}\right] K_L . C_L + \left[\frac{N_M}{C_M} - \frac{f_E}{r_O}\right] K_M . C_M + K_H . N_H \qquad \text{[Eq. A22]}$$

Net mineralization occurs whenever $\partial NH_4^+/\partial t > 0$, otherwise immobilization occurs. The calculations recognise that, if no ammonium is available for immobilization, then nitrate can be used according to the following equation

$$\frac{\partial NO_3^-}{\partial t} = -\frac{f_E}{r_O}\left(K_L . C_L + K_M . C_M\right) \qquad \text{[Eq. A23]}$$

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 d^{-1}, K_M = 0.015 d^{-1} and K_H=0.00005 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 Johnnson 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)

$$f_T(z) = Q_{10}^{\left[\frac{T(z)-T_B}{10}\right]} \qquad \text{[Eq. A24]}$$

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.

$$f_W(z) = f_S + (1 - f_S)\left[\frac{\theta_S(z) - \theta(z)}{\theta_S(z) - \theta_H(z)}\right]^M \qquad \theta_H(z) < \theta(z) < \theta_S(z),$$

$$f_W(z) = 1 \qquad \theta_L(z) < \theta(z) < \theta_H(z),$$

$$f_W(z) = \left[\frac{\theta\ (z) - \theta_W(z)}{\theta_L(z) - \theta_W(z)}\right]^M \qquad \theta_W(z) < \theta(z) < \theta_L(z), \qquad \text{[Eq. A25]}$$

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

$$\left.\frac{dU}{dt}\right|_{U \to NH4+} = -k_1\ f_T(z)\ f_M(z)\ NH_4^{\ +} \qquad \text{[Eq. A26]}$$

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

$$\left.\frac{dNH_4^+}{dt}\right|_{NH4+\rightarrow N03-} = -k_2\ f_T(z)\ f_M(z)\left[NH_4^+ - \frac{NO_3-}{n_q}\right] \qquad \text{[Eq. A27]}$$

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 $NH_4^+ < NO_3^- / n_q$ 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

$$f_D(z) = \left[\frac{\theta(z) - \theta_D(z)}{\theta_S(z) - \theta_D(z)}\right]^d \qquad \text{[Eq. A28]}$$

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

$$\left.\frac{dNO_3^-}{dt}\right|_{NO3-\rightarrow gas} = -k_3(z)\ f_T(z)\ f_D(z)\left[\frac{NO_3^-}{NO_3^- + c_S}\right] \qquad \text{[Eq. A29]}$$

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 [kg m^{-2} s^{-1}], as

$$J_V = \left(\frac{\theta_0}{\theta_S}\right) h_M \left(\frac{K_A K_H}{10^{-pH}} NH_4^{\ +}\right)\Bigg|_{z=0} \quad \text{[Eq. A30]}$$

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

$$\frac{dM_U}{dt} = z_R \frac{d\theta R_U U}{dt} = X_{U,i} - \left(k_1 z_R \theta U + J_W U\right) \quad \text{[Eq. A31]}$$

where U [mg L^{-1}] is the concentration of urea in soil solution, θ [m^3 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:

$$\frac{dM_A}{dt} = z_R \frac{d\theta R_A A}{dt} = \left(X_{A,i} + S_M + k_1 z_R \theta\, U\right) - \left(k_2 z_R \theta \left(A - N / n_q\right) + J_V + P_A + J_W A\right) \qquad \text{[Eq. A32]}$$

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

$$\frac{dM_N}{dt} = z_R \frac{d\theta R_N N}{dt} = \left(X_{N,i} + k_2 z_R \theta\, A\right) - \left(k_3 z_R \theta \left[\frac{N}{N + c_S}\right] + P_N + J_W N\right) \qquad \text{[Eq. A33]}$$

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

$$\frac{dM_P}{dt} = z_R \frac{d\theta R_P P}{dt} = \left(X_{P,i} + S_P - P_P + J_W P \right) \qquad \text{[Eq. A34]}$$

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

$$R_P = \left[1 + \left(\frac{\rho}{\theta} \right) \left(\frac{Qb}{1 + bP} \right) \right] \qquad \text{[Eq. A35]}$$

where *Q* is the maximum total mass of phosphorus at saturation per unit mass of dry soil [μg 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

$$\frac{d\theta B}{dt} = \left(X_{B,i} - k_a \theta \psi B + k_d \rho S - \mu_W \theta B - \mu_S \rho S - J_W B \right) \qquad \text{[Eq. A36]}$$

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 $J_W B$ [mg m^{-2} 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)									?