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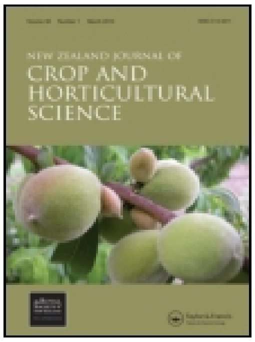

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# Fruit mineral removal rates from New Zealand apple (*Malus domestica*) orchards in the Nelson region

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**Abstract** Total picked yields and whole fruit mineral analyses just before harvest were recorded from seven apple (*Malus domestica*) orchards over the Nelson region of New Zealand over 2–3 years from mature trees of 'Braeburn', 'Cox', 'Fuji', and 'Royal Gala' as part of the Nelson Focus Orchard Project. Estimated mean fruit nutrient removal rates for a 70 t ha$^{-1}$ picked yield of apples were 82 kg ha$^{-1}$ potassium, 31 kg ha$^{-1}$ nitrogen, 7 kg ha$^{-1}$ phosphorus, and both calcium and magnesium at c. 4 kg ha$^{-1}$ per year. These results are discussed in relation to fertiliser inputs and previous reports of nutrient removal for other cultivars and locations, both in New Zealand and overseas.

**Keywords** fruit mineral content; nitrogen; potassium; phosphorus

## INTRODUCTION

Sustainable pipfruit orchard production requires the application of nutrients according to tree needs and soil availability to ensure economic growth and cropping with minimum loss of nutrients to the wider environment. Although it is possible to recycle nutrients taken up in leaves and the woody tissue, fruit removal from the orchard remains an unavoidable loss of nutrients. As New Zealand's pipfruit industry is primarily an export driven one, nutrients inevitably leave the country for the international markets of the world. In turn, New Zealand imports all its inorganic fertiliser requirements, apart from some local manufacture of urea. New Zealand also has some of the highest pipfruit yields in the world (Palmer et al. 2002), so the magnitude of this nutrient loss from the orchard in the fruit is also likely to be very high. Accurate data on the rates of fruit mineral removal for apple (*Malus domestica* Borkh.) in New Zealand are few, apart from the widely quoted work of Haynes & Goh (Haynes & Goh 1980a; Goh & Haynes 1983), with 'Golden Delicious', which is no longer an important New Zealand cultivar.

The Nelson Focus Orchard Project was set up in 1998 to investigate measures to increase the profitability and environmental sustainability for pipfruit growers in the Nelson growing region. It was essentially a grower-run project with three areas of interest—productivity, nutrition, and water—with a number of orchards in the Nelson region contributing samples and data to the project. The opportunity was taken to use yields and fruit mineral analyses to assess fruit mineral removal rates from these orchards, which covers several years, cultivars, and sites within the region.

## MATERIALS AND METHODS

Although the Nelson Focus Orchard Project included 10 orchards across the Nelson region, the data set has been limited to seven orchards, as 2 or 3 years (1999–2001) of records of yields and fruit mineral

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concentrations were available from individual blocks from within these particular orchards. All blocks were mature, with planting dates from 1981 to 1993, and typically on MM.106 or M.793 rootstock planted at 5 × 3m (666 trees/ha). The orchards were representative of the Nelson pipfruit growing region covering the Waimea Plain in the east to Riwaka in the west. The soil types varied from deep clay to silt loams. As many of the soils are alluvial, some contain a high proportion of stones or gravels. Natural fertility ranges from high to very low, with the majority in the medium to low category (Chittenden et al. 1966). All orchards were grown under herbicide strip management with mixed grass alleyways. The data set covered four major New Zealand commercial cultivars—'Braeburn', 'Cox's Orange Pippin' (hereafter referred to as 'Cox'), 'Fuji', and 'Royal Gala'.

Each year, a 30-fruit sample (1 fruit/tree from 30 trees) was taken from each orchard block 7–10 days before the start of picking. Fruit selected were at about shoulder height (1.5m), of export quality, and from all sides of the trees. To reduce sampling errors, sampling was done from the same trees each year and the same person collected all the samples from all orchards. Fruit mineral analysis was done on whole fruit, excluding stalks, but including seeds, by Hill Laboratories, Hamilton, New Zealand. Each 30-fruit sample was subsampled by halving down the axis of the core of each fruit and taking a quarter wedge from one of the halves. The wedges were pulped to give a thick suspension of homogenised tissue. Nitrogen (N) was determined with a VarioMax CN Combustion (Elementar Analysensysteme GmbH, Hanau, Germany) and phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), copper (Cu), and boron (B) determined by ICP-OES (Inductively Coupled Plasma-Optical Emission Spectroscopy, GBC Scientific, Melbourne, Australia and Thermo Jarrell Ash Corp., Franklin, MA, United States) after nitric/perchloric acid digestion.

Yield of picked fruit from each orchard block was taken from the packhouse records of total weight of fruit in each pick. Fruit removal rates were then calculated from the product of the total picked yield of fruit per orchard block and the fruit mineral analysis for that block.

## RESULTS AND DISCUSSION

Fruit mineral concentrations (Table 1) were very comparable with published data (Perring 1964, 1982; Perring & Sharples 1975; Wolk et al. 1998; Johnson 2000), where whole fruit minus seeds and stalks were used in the analyses. In New Zealand, fruit minerals are frequently analysed from tissue sampled in cortical plugs, particularly for prediction of Ca-related disorders such as bitter pit. Such analyses give lower mineral concentrations than those from whole fruit samples (Turner et al. 1977) and are therefore unsuitable for the estimation of fruit nutrient removal rates. Although stalks were not included in the mineral analyses in this current work, the data of Wilkinson & Perring (1968) suggests omitting the stalks might cause a 7% underestimation of Ca concentration but less than 0.5% underestimation of K, N, Mg, and P. Even omitting the seeds, as is often done in whole fruit analysis, would lead to an underestimation of Ca, Mg, and N concentrations by 17%, 12%, and 11% respectively in 'Cox' fruit of 100g, according to the data of Wilkinson & Perring. The magnitude of error would obviously depend on fruit size and number of seeds. Similarly, data tabulated by Batjer et al. (1952) for 'Delicious' results in an underestimation of Ca, Mg, and N concentrations by 8%, 8%, and 16% respectively where seeds are removed.

The fruit mineral removal rates calculated from the data in Table 1 may be subject to systematic overestimation if the fruit mineral concentration at time of sampling is higher than at the time of picking,

**Table 1** Fruit nutrient concentrations of four apple (*Malus domestica*) cultivars just before harvest (whole fruit samples). Data averaged over all orchards and years, with associated standard deviations.

| | mg 100 g$^{-1}$ fresh weight | | | | | μg 100 g$^{-1}$ fresh weight | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar | N | P | K | Ca | Mg | Fe | Mn | Zn | Cu | B |
| Braeburn | 40.3±5.3 | 9.2±1.9 | 103±23 | 5.3±1.0 | 4.8±0.8 | 104±44 | 27±7 | 41±27 | 60±41 | 192±56 |
| Cox | 63.2±12.3 | 12.6±2.3 | 142±21 | 6.5±1.7 | 6.3±1.2 | 162±47 | 45±14 | 54±36 | 216±255 | 326±106 |
| Fuji | 39.0±7.9 | 9.7±2.4 | 113±27 | 5.4±1.7 | 4.9±1.0 | 119±41 | 38±16 | 46±19 | 82±96 | 217±91 |
| Royal Gala | 40.2±8.0 | 9.8±1.4 | 123±18 | 6.3±1.6 | 5.6±0.9 | 141±44 | 43±16 | 49±24 | 128±130 | 257±63 |
| Mean | 44.8±12.7 | 10.2±2.3 | 119±26 | 5.9±1.6 | 5.4±1.1 | 130±48 | 38±15 | 47±27 | 117±153 | 244±92 |

as the fruit continue to grow over the intervening time. Although fruit samples were taken 7–10 days before the start of picking, fruit of any one cultivar are normally picked in New Zealand over a 3-week period to ensure a more even maturity profile in the fruit. Consequently there may be a difference of 7–30 days between sampling and time of picking, although the method of sampling would tend to favour fruit that were picked earlier rather than later and also the last pick is unlikely to be more than 20% of the total crop. This error would be unlikely to be large for K and P as the concentrations of these two elements change slowly near picking time (Wilkinson & Perring 1964; Wolk et al. 1998). However, fitting exponential declines to the preharvest concentrations of N and Ca tabulated by Wolk et al. (1998) suggest that, from 10 days before harvest to 10 days after a strip harvest (by extrapolation), concentrations of both elements could decrease by 15%. In the current work, omitting the stalks in the fruit analyses would tend to halve this error for Ca.

Averaging across all cultivars and years, the major nutrient removals of a 70 t ha$^{-1}$ picked yield of apples (Table 2) were K at 83 kg ha$^{-1}$ and N at 31 kg ha$^{-1}$, with smaller amounts of P (7 kg ha$^{-1}$) and both Ca and Mg at c. 4 kg ha$^{-1}$.

Fruit mineral concentrations were poorly correlated with yield; consequently nutrient removals per ha were a linear function of yield (Fig. 1–3). The N fruit removal data set (Fig. 1) does however, show a significant effect of one cultivar, 'Cox', compared with the other three cultivars. This effect of cultivar was not related to a differential rate of fertiliser application, e.g., mean N application at 84 kg ha$^{-1}$ was highest on 'Royal Gala' and lowest on 'Cox' at 56 kg ha$^{-1}$.

Some of the variation evident in Fig. 1–3 may be associated with the sampling size, crop load, soil type, fertiliser applications, and seasonal variation. Year-to-year variation in fruit mineral concentration in the same orchard can be higher than 20% for N (Perring 1984). Samples of 'Elstar' fruit from 67 Dutch commercial orchards in 1994 and 71 orchards in 1995 revealed an overall range of ×3.5, ×1.8, and ×2.0 in the fruit mineral concentrations of N, P, and K respectively (Jager & Putter 1999), somewhat similar to the range shown in Fig. 1–3. These authors also stated that similar ranges in mineral concentrations were observed in fruit of 'Cox', 'Boskoop', and 'Jonagold'. Despite these large differences in fruit mineral concentrations of 'Elstar', Jager & Putter (1999) did not find high correlations between fruit mineral content and fruit quality at harvest and after storage, although firmness at harvest was negatively correlated with N content and positively correlated with P content and Mg content. Generally, however, apple fruit quality is reduced by high N, low Ca, high K, high Mg, and low P concentrations in fruit tissue (Bramlage 1993).

Comparison of fruit removal rates are obviously confounded by yield. To make comparisons between published data easier, Table 3 gives a summary of both current and published data. Mean fruit mineral removal rates in the current work (Table 2) are very comparable with those quoted by Drahorad (1999) for the South Tyrol, Batjer et al. (1952) in the United States, and Greenham (1980) in the United Kingdom. Removal rates of N with 'Cox' are consistently higher than the other cultivars, irrespective of location. In New Zealand, the results of Goh & Haynes (1983), with 'Golden Delicious' on 'Northern Spy' rootstock, were tabulated in units of dry matter (DM) rather than of fresh weight. If a fruit DM of 11% is assumed (the value observed by Haynes & Goh (1980b) for 'Golden Delicious' in work over the same seasons at a nearby orchard in Canterbury), this would convert their 5.95 t ha$^{-1}$ fruit DM yield to 54 t ha$^{-1}$ fresh weight. K removals by 'Golden Delicious' in New Zealand (Haynes & Goh 1980b; Goh & Haynes 1983) would seem to be particularly high. Published

**Table 2** Mean annual yield and annual fruit nutrient removal in picked fruit of four apple (*Malus domestica*) cultivars. Data averaged over all orchards and years, with associated standard deviations.

|  | Yield | kg ha$^{-1}$ |  |  |  |  | g ha$^{-1}$ |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cultivar | t ha$^{-1}$ | N | P | K | Ca | Mg | Fe | Mn | Zn | Cu | B |
| Braeburn | 88±17 | 35.4±7.2 | 8.1±2.1 | 91±24 | 4.7±1.3 | 4.2±0.9 | 94±51 | 23±6 | 36±27 | 55±44 | 171±62 |
| Cox | 57±17 | 36.2±11.8 | 7.1±2.0 | 80±24 | 3.7±1.4 | 3.6±1.1 | 92±36 | 25±9 | 32±23 | 120±149 | 178±50 |
| Fuji | 62±17 | 23.9±6.9 | 5.9±1.7 | 69±19 | 3.4±1.4 | 3.0±0.8 | 71±27 | 24±12 | 28±13 | 45±46 | 126±43 |
| Royal Gala | 72±15 | 28.8±8.6 | 7.1±2.1 | 89±25 | 4.6±1.8 | 4.1±1.2 | 105±48 | 31±14 | 35±20 | 104±120 | 185±67 |
| Mean | 70±20 | 31.1±9.8 | 7.1±2.1 | 83±24 | 4.2±1.6 | 3.7±1.1 | 92±44 | 26±11 | 33±21 | 80±101 | 166±60 |

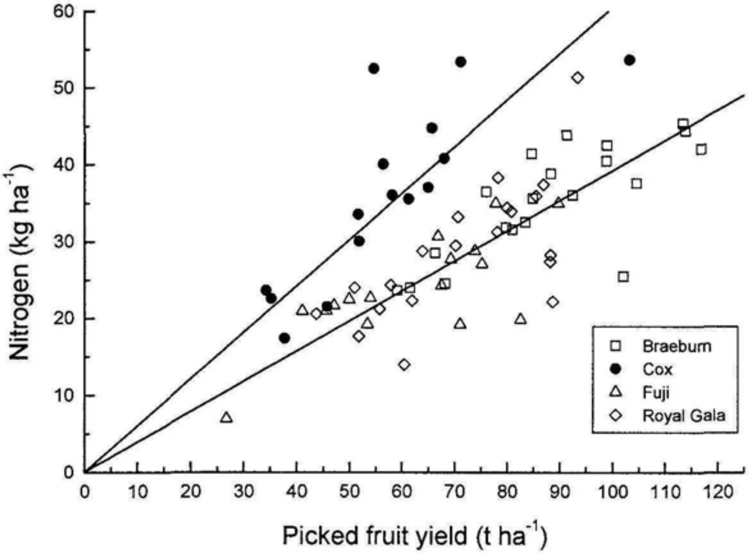

**Fig. 1** Relationship between picked apple (*Malus domestica*) yield and nitrogen removal from Nelson, New Zealand orchards (1999–2001). Equation of line for 'Cox' ($y = 0.60x$, variance accounted for = 80%) significantly different ($P < 0.05$) from 'Braeburn', 'Fuji' and 'Royal Gala' ($y = 0.39x$, variance accounted for = 64%).

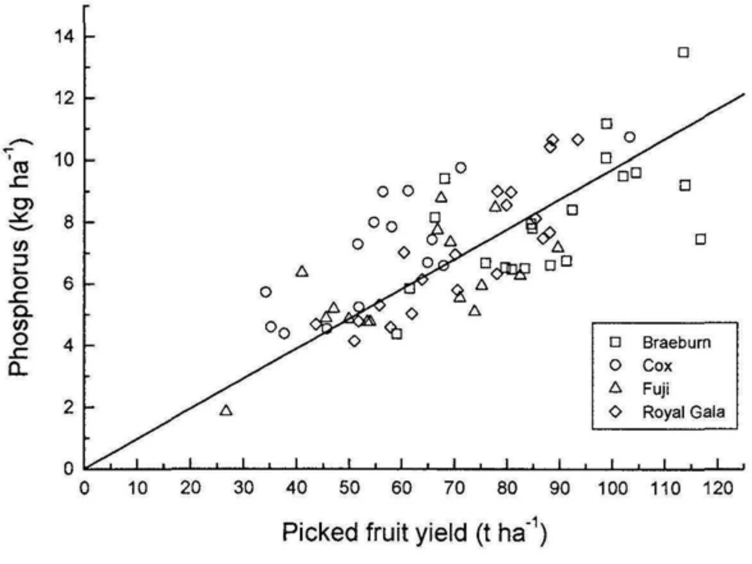

**Fig. 2** Relationship between picked apple (*Malus domestica*) yield and phosphorus removal from Nelson, New Zealand orchards (1999–2001). Equation of line $y = 0.097x$, variance accounted for = 50%.

data sets of K concentration of 'Golden Delicious', e.g., Perring (1982) or Wolk et al. (1998) do not show unusually high K concentration in fruit of 'Golden Delicious' compared with other cultivars. The orchards in question were not receiving high rates of K fertiliser (46–57 kg $ha^{-1}$ per year) but were completely grassed down under the trees which would tend to result in high K supply from the cut grass. Luxury consumption of K can occur with apple (Delver 1980) but on the other hand leaf K concentrations of 1.2% dry weight at the end of the season (Goh & Haynes 1983) would not indicate luxury consumption. Nevertheless, the variation evident between orchards in Fig. 1–3 and that quoted by Jager & Putter (1999), emphasises the importance of growers obtaining fruit mineral concentrations from their own orchards for accurate calculation of fruit mineral removal rates.

Mean fertiliser application rates were 69 kg $ha^{-1}$ N, 13 kg $ha^{-1}$ P, and 91 kg $ha^{-1}$ K across the whole data set. Considering the minerals removed in the fruit, these rates of application would appear to be

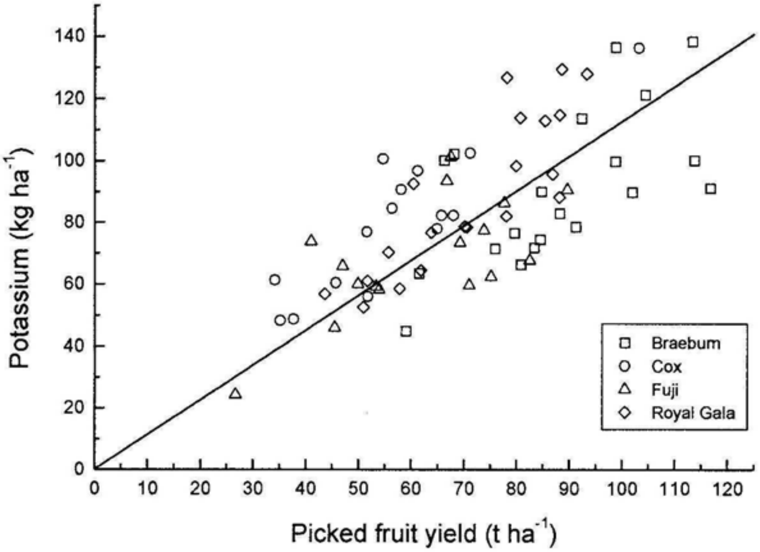

**Fig. 3** Relationship between picked apple (*Malus domestica*) yield and potassium removal from Nelson, New Zealand orchards (1999–2001). Equation of line y = 1.13x, variance accounted for = 57%.

**Table 3** Estimated apple (*Malus domestica*) fruit removal rates (kg ha$^{-1}$) of minerals from published and current data, all normalised to 70 t ha$^{-1}$ fresh weight yield.

| Reference | Cultivar | N | P | K | Ca | Mg |
|---|---|---|---|---|---|---|
| Batjer et al. (1952) | Delicious | 32 | 10 | 88 | 7 | 3 |
| Greenham (1980) | Cox | 50 | 10 | 101 | 4 | 4 |
| Greenham (1980) | Cox | 44 | 5 | 97 | 5 | 5 |
| Haynes & Goh (1980b) | Golden Delicious | 29 | 5 | 154 | 6 | 6 |
| Haynes & Goh (1980b) | Granny Smith | 20 | 4 | 90 | 4 | 4 |
| Drahorad (1999) | various | 24–35 | 7 | 70–93 | 4 | 3 |
| Goh & Haynes (1983)* | Golden Delicious | 28 | 5 | 158 | 6 | 5 |
| Current | Braeburn | 28 | 6 | 72 | 4 | 3 |
| Current | Cox | 45 | 9 | 99 | 5 | 4 |
| Current | Fuji | 27 | 7 | 78 | 4 | 3 |
| Current | Royal Gala | 28 | 7 | 87 | 5 | 4 |

*Yield given in dry weight, 11% dry matter assumed, based on their previous data.

reasonable, assuming that nutrients in the leaves and prunings are recycled *in situ* and allowing for additional lock up of nutrients in the woody tissue of the trees. According to Haynes & Goh (1980a), working on mature trees of 'Golden Delicious' on 'Northern Spy' rootstock, this tie up in woody tissue could amount to 4 kg ha$^{-1}$ N, 0.5 kg ha$^{-1}$ P, and 2.3 kg ha$^{-1}$ K per year. Unfortunately this current study did not include assessments of nutrient leaching or tree growth to enable us to construct a complete nutrient budget.

The high mineral removal rates in harvested fruit in New Zealand does provide a particular challenge to organic growers to supply sufficient nutrients on a long-term basis to replace those in the harvested fruit, especially in soils of low nutrient status and considering their limited fertiliser options. Even in organic orchards, high yields are essential to maintain economic viability.

## ACKNOWLEDGMENTS

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## REFERENCES

Batjer LP, Rogers BL, Thompson, AH 1952. Fertilizer application as related to nitrogen, phosphorus, potassium, calcium and magnesium utilization by apple trees. Proceedings of the American Society for Horticultural Science 60: 1–6.

Bramlage WJ 1993. Interactions of orchard factors and mineral nutrition on quality of pome fruit. Acta Horticulturae 326: 15–28.

Chittenden ET, Hodgson L, Dodson KJ 1966. Soils and agriculture of Waimea County, New Zealand. DSIR Soil Bureau Bulletin 30.

Delver P 1980. Uptake of nutrients by trees grown in herbicide strips. Acta Horticulturae 92: 229–240.

Drahorad W 1999. Modern guidelines on fruit tree nutrition. Compact Fruit Tree 32: 66–72.

Goh KM, Haynes RJ 1983. Nutrient inputs and outputs in a commercial orchard and their practical implications. New Zealand Journal of Experimental Agriculture 11: 59–62.

Greenham DWP 1980. Nutrient cycling: the estimation of orchard nutrient uptake. Acta Horticulturae 92: 345–352.

Haynes RJ, Goh KM 1980a. Distribution and budget of nutrients in a commercial apple orchard. Plant and Soil 56: 445–457.

Haynes RJ, Goh KM 1980b. Variation in the nutrient content of leaves and fruit with season and crown position for two apple varieties. Australian Journal of Agricultural Research 31: 739–748.

Jager A de, Putter H de 1999. Preharvest factors and postharvest quality decline of apples. Acta Horticulturae 120: 103–110.

Johnson DS 2000. Mineral composition, harvest maturity and storage quality of 'Red Pippin', Gala' and 'Jonagold' apples. Journal of Horticultural Science and Biotechnology 75: 697–704.

Palmer JW, Wünsche JN, Meland M, Hann A 2002. Annual dry matter production by three apple cultivars at four within-row spacings in New Zealand. Journal of Horticultural Science and Biotechnology 77: 712–717.

Perring MA 1964. The mineral composition of apples. 1. Introduction, sampling methods and ashing techniques. Journal of the Science of Food and Agriculture 15: 739–752.

Perring MA 1982. Mineral concentrations in the fruit of varieties other than Cox's Orange Pippin and Bramley's Seedling. Annual Report of East Malling Research Station for 1981. Pp. 193–195.

Perring MA 1984. Indirect influences on apple fruit mineral composition and storage quality. Proceedings of the 6th International Colloquium for the Optimisation of Plant Nutrition 4: 1199–1206, AIONP/GERDAT, Montpellier, France.

Perring MA, Sharples RO 1975. The mineral composition of apples. Composition in relation to disorders of fruit imported from the Southern Hemisphere. Journal of the Science of Food and Agriculture 26: 681–689.

Turner NA, Ferguson IB, Sharples RO 1977. Sampling and analysis for determining relationship of calcium concentration to bitter pit in apple fruit. New Zealand Journal of Agricultural Research 20: 525–532.

Wilkinson BG, Perring MA 1964. Changes in the chemical composition of apples during development, and near picking time. Journal of the Science of Food and Agriculture 15: 146–152.

Wolk WD, Lau OL, Neilsen GH, Drought BG 1998. Factors and time of sample collection for correlating storage potential of 'McIntosh', 'Spartan' and 'Golden Delicious' apples. Journal of the American Society for Horticultural Science 123: 104–109.

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# Modelling the Source and Fate of Nitrate-Nitrogen Losses from Waimea Plains Land Uses

## Envirolink Advice Grant:
## 1592-TSDC116

# Modelling the Source and Fate of Nitrate-Nitrogen Losses from Waimea Plains Land Uses

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# Contents

## Summary

This modelling project has assessed nitrate-nitrogen losses to groundwater and downstream waters generated by current land uses and projected future land use scenarios.

Results are being used by the Waimea Freshwater and Land Advisory Group (FLAG) to inform their recommendations to Tasman District Council on management of water quality in the Waimea catchment. Nitrogen is the focus as nitrate concentrations may exceed aquatic toxicity and/or periphyton limits for spring-fed streams and drinking water standards in some aquifers.

Modelling of nitrate–nitrogen leaching losses was carried out using the SPASMO model for 40 years to 2013 for apples, grapes, outdoor vegetables, and dairy land uses on the four major soil series of the Waimea Plains. Averaged nitrate losses were:

| | Dairy | Apples | Grapes | Outdoor vegetables | Other pasture* | Forest & scrub[†] |
|---|---|---|---|---|---|---|
| N-$NO_3$ loss kgN/ha/yr | 24–69 | 3–18 | 4–18 | 16–51 | 10.7 | 2.5 |

* represents SPASMO modelled losses for extensive sheep and beef farming

[†] an adopted average value from literature

Modelling shows there is little difference between nitrate losses for the same land use with or without irrigation; however, irrigation allows more intensive land use, which does produce higher nutrient losses.

Soil water-holding capacity is a much greater determinant of nitrogen losses than irrigation. Plains soils generating highest nitrate leaching rates are Ranzau, then Waimea and Wakatu soils.

Total modelled nitrate loss from the 40600 ha of the lowland Waimea catchments is 287 tonnes per year.

Groundwater flow tube analysis for various scenarios of converting pasture to outdoor vegetable production (market gardening) predicted that nitrate concentrations in the spring-fed Pearl Creek could increase by 0.44 to 0.48 g/m$^3$ for 200–562 hectares converted. For the spring-fed Neimann Creek, equivalent increases in nitrate concentration would be 0.54 to 1.06 g/m$^3$, slightly increasing the risk of exceeding acceptable aquatic ecosystem limits, depending on what values those limits are ultimately based.

# 1 Purpose

The Waimea Freshwater and Land Advisory Group (FLAG) is charged with recommending policy and rules relating to water quality management in the Waimea catchment. Previous monitoring and research indicates that the leaching of nitrate-nitrogen (‘nitrate’) from intensive land uses across the Waimea Plains will require specific attention, because nitrate concentrations and/or loads in some receiving waters either currently or in future may exceed guideline limits.

Tasman District Council has commissioned this modelling work to help FLAG members evaluate nitrate losses from various land uses, understand the flow paths and any attenuation of leached nitrate, and assess projected concentrations in both aquifers and downstream surface waters under current and potential future land use patterns.

This work builds on current knowledge of the hydrology of the Waimea Plains, and a recent scoping study for the Waimea Water Augmentation Committee on water quality risks and responses with increased irrigation (Fenemor et al. 2013). Primarily it draws on hydrological and land use modelling work completed for MPI that examined crop production, profit, and nutrient losses in relation to irrigation water allocation and reliability (Fenemor et al. 2015). This project was funded under Envirolink grants TSDC112 and TSDC116 (http://www.envirolink.govt.nz/).

A draft of this summary report was presented to and discussed with the Waimea FLAG members at their meeting of 19 August 2015.

# 2 Approach Taken

Nitrate leaching losses through the soil profile were modelled for selected Waimea Plains farm-soil combinations and a 40-year time series of climate in two previous studies using the Plant & Food Research SPASMO model (Green et al. 2012). Modelled results have been applied in this project to create catchment maps of nitrate losses to groundwater for current land use and projected future land use scenarios.

Steady-state maps of groundwater flow direction (‘flow nets’) have been superimposed to calculate aggregated nitrate losses into receiving waters which comprise the three aquifers, the Waimea River, spring-fed streams, and the Waimea Inlet.

Aggregated losses for current land use have been compared with measured nitrate concentrations in receiving waters to check how realistic this modelling approach is, and what reliance might be placed on projected concentrations for assumed future land uses.

Initial results of the nitrate loss modelling were presented in a discussion document by Andrew Fenemor and a presentation on SPASMO by Steve Green at the Waimea FLAG meeting of 18 June 2015. FLAG members requested more analysis of the impacts of land uses along groundwater flow paths draining towards receiving waters, which is the basis for the flow net analysis presented below, and was discussed at their meeting of 19 August 2015.

# 3 Representative Farm Systems selected for modelling

Rather than selecting a particular land use at paddock scale, the modelling of production, irrigation water use, and nutrient leaching need to take account of the variability of operations at the whole farm scale. This is because of changes in crop mixes over time, movement of animals to and from a property, and allowance for areas of a property used for support rather than production activities.

Based on the criteria of predominance of land use by area, commercial scale farming types, and likely relative responses to irrigation water availability and nutrient leaching, we have selected the following farm systems:

- Pipfruit – a typical apple orchard
- Dairy – a typical dairy farm
- Grapes – a typical vineyard
- Outdoor vegetable production – a typical large-scale market gardening operation, excluding glasshouse production

Characteristics of each of these farm systems are summarised below. For the remainder of the catchment, a nitrogen loss rate from literature figures has been adopted for forest and scrub, and a proxy land use of unirrigated extensive sheep and beef has been adopted for modelling losses from the predominantly pasture land use.

## 3.1 Pipfruit

This is an intensive 40-ha apple orchard planted at 3.4 × 1.2 m spacing, corresponding to the MPI model orchard. The variety mix is 20% Royal Gala, 20% Braeburn, 20% Jazz, 20% Pink Lady, and 20% other premium varieties.

Due to a greater volume of intensive orchards and higher level of management on the Waimea Plains, average yield is 67.9 T/ha, which is slightly higher than the 58 T/ha from the 2013 MPI model orchard. Packout is set at 78% (cf. 75% from MPI model) and average fruit size at 106 (170 g). Unharvested fruit are assumed at 10% and apple dry matter content as 0.16.

Market returns for apples are averaged from the past 5 years as this includes good years and poor, which should reflect future volatility. Average price was $23.93 per carton based on 2010–12 data from Pipfruit NZ and 2013–14 data from ENZA. Modelled returns are adjusted from these actual averages based on modelled fruit size and weight.

The fertilizer regime is assumed to involve application of 40 kg N per year, applied as 20 kg/ha post-harvest foliar spray and 20 kg/ha solid fertilizer applied in spring. Approximately 10% of the planted area is non-producing at any time.

### 3.2 Dairy

There are approximately 1000 dairy cows farmed in the central Waimea Plains on five farms. The dairy farm system has been based on data from Dairy NZ (2012) and information kindly provided by Murray King of Kingsway Farms, Appleby.

The model farm is 80 ha with 3.4 cows/ha and a herd of 272 cows, with a targeted annual milk solids production of 1500 kgMS/ha/yr[1] and average annual dry matter production of 16 000 kgDM/ha/yr. Market returns for dairy are averaged from the past 5 years at $6.00/kgMS, but obviously higher than current (2014) returns.

When drought occurs, the farm first uses its own supplements, none of which are assumed to have been sold off the property. Bought-in dry matter (DM) supplements are modelled as costing $0.25/kg. If own supplements are insufficient, off-farm supplements are purchased up to $0.38/kgDM up to a maximum of 750 kgDM/ha. If feed reserves are low, poorer performing cows would start being dried off after Christmas. In the modelling this is assumed to happen in blocks of 20% of the stock.

The modelled farm assumes 25% of paddocks are excluded from grazing between October and December for silage or hay production, unless there is inadequate DM for the herd. Wintering on averages 1 cow/ha, with the remainder wintered outside the plains. Younger stock are preferentially wintered off. There is no longer any winter milking on the Waimea Plains.

The fertilizer regime assumes 180 kgN/ha applied as six 30-kg/ha applications.

### 3.3 Grapes

The design vineyard is 9 ha, corresponding to the average size among Nelson winegrowers. It is an owner-operated, self-contained, contract-supply vineyard, and is machine harvested. Grapes are planted at a spacing of 2.4 × 1.8 m.

Following analysis of New Zealand Winegrowers statistics and discussion with Phillip Woollaston of Woollaston Estates, the assumed varietal mix for the Waimea Plains is 55% Sauvignon Blanc, 15% Pinot Noir, 15% Pinot Gris, 5% Chardonnay, and 10% other varieties.

Average yield is 9.0 T/ha, comprising 11 T/ha for Sauvignon Blanc, 6 T/ha for Pinot Noir, 9 T/ha for Pinot Gris, and 8 T/ha for Chardonnay and other varieties. Modelled returns are calculated from weighted returns for each variety and average $1360/tonne.

The fertilizer regime applies an average of 5kg N per year, although in some vineyards this is applied as an ‘organic’ form and would range from 0 to 20 kgN/ha/yr.

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[1] Mirka Langford (Fonterra and Waimea FLAG member) advised after presentation of this report at the Waimea FLAG meeting on 19 August 2015 that the average milk solids production from Waimea dairy farms is slightly lower, i.e. less intensive, than assumed in this analysis: <u>1383 instead of 1500 kgMS/ha/yr</u>. This would have the effect of marginally reducing the modelled nitrogen losses reported from dairy land uses later in this report. Average modelled milk production is in the 1450–1460 kgMS/ha/yr range.

## 3.4 Outdoor vegetables

The wide range of vegetable crops and rotations used on the Waimea Plains has made it difficult to devise a representative outdoor market gardening operation able to be modelled in SPASMO.

There are three large grower operations each with some 200 ha cropped, plus smaller operators. The use of leased land is common. Growers express a preference for market gardening on a band of land extending from Wairoa Gorge across towards Rabbit Island (Fig. 1) because of the breeze, lower risk of frosts, and more suitable soils (Pierre Gargiulo, Ewers Ltd, pers. comm.).

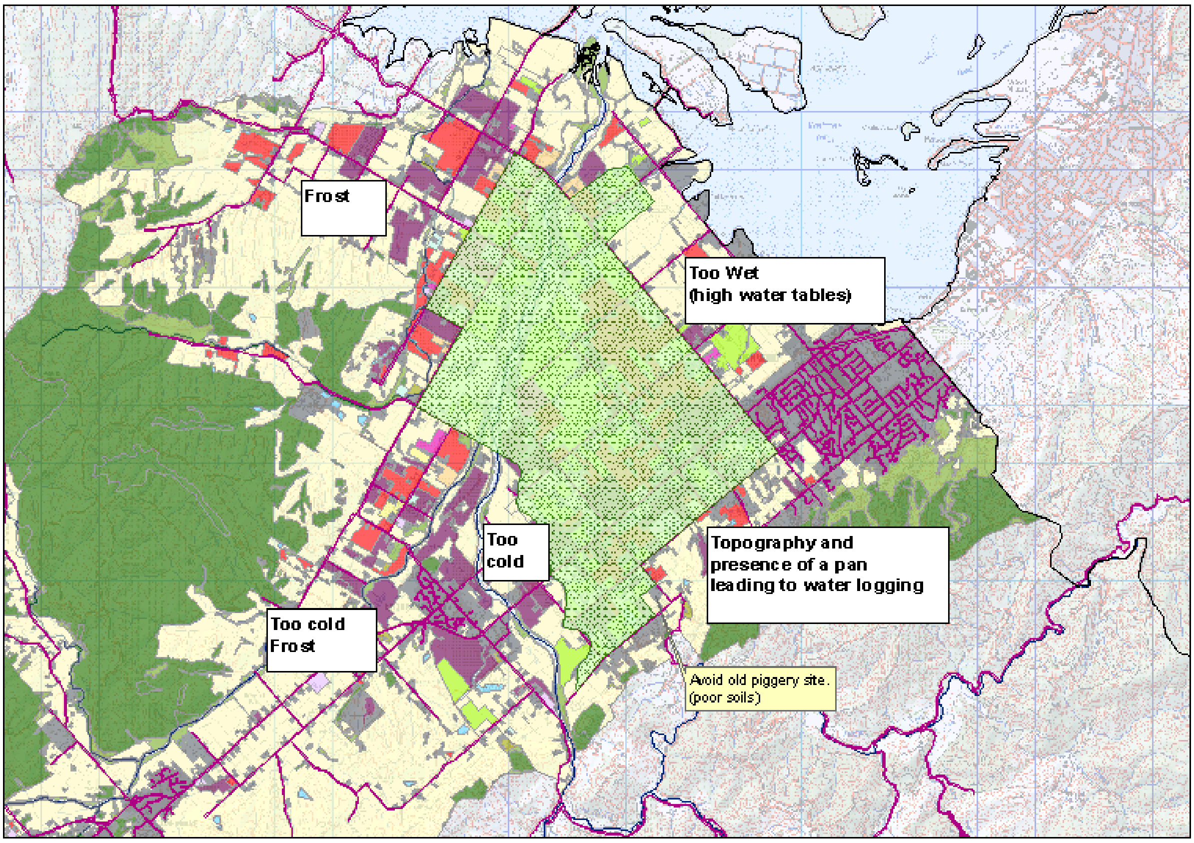

**Figure 1** Potential market gardening area (dappled green)(Pierre Gargiulo, via Glenn Stevens TDC)

The design market garden for SPASMO modelling is an owner-operated self-contained outdoor operation with 45 ha available for planting. In a 12-month cycle this 45 ha has 45 ha of winter lettuces; in Spring/Summer 15 ha are rested (grazed pasture) or – as assumed for this modelling – a further lettuce crop planted, and there are 15 ha of cabbages and 15 ha of pumpkins. For modelling purposes this comprises a two-crop annual cycle, either lettuce/lettuce, lettuces/cabbages, or lettuce/pumpkins.

At six heads per crate, market returns have averaged $8.50/crate for winter lettuces, $5.85/crate for summer lettuces, $4.00/crate for cabbage, and $0.60/kg for pumpkins.

The fertilizer regime, as suggested following the Waimea FLAG April 2015 meeting is shown in Table 1(a) and projected yields in Table 1(b).

**Table 1(a)** Outdoor vegetables fertilizer regime

| Crop | | N | P | K |
|---|---|---|---|---|
| Lettuces | Planting | 47 | 34 | 90 |
| | 6 wks later | 61 | 25 | 73 |
| | 2 wks from harvest | 117 | 8 | 21 |
| | Total | 225 | 67 | 184 |
| Cabbages | Planting | 61 | 41 | 132 |
| | 6 wks later | 57 | 23 | 65 |
| | 2 wks from harvest | 57 | 23 | 65 |
| | Total | 175 | 87 | 262 |
| Pumpkins | Planting | 32 | 22 | 58 |
| | 4 wks later | 25 | 13 | 34 |
| | Total | 57 | 35 | 92 |

We note that the N and P applied to lettuces seems high compared with fertilizer company recommendations.[2]

**Table 1(b)** Outdoor vegetables projected yields for model calibration

| Product | Gross production (t/ha) | Harvested | TOTAL harvested (t/ha) |
|---|---|---|---|
| Lettuce | 15 | 70% | 10.5 |
| Pumpkin | 25 | 90% | 22.5 |
| Cabbage | 65 | 60% | 39.0 |
| Fallow/ Green Crop | 0 | 0% | 0.0 |

The difference between gross production and harvested allows for losses, either unharvested parts of a crop or whole unharvested paddocks, and uses actual data from a Waimea grower for brassicas and pumpkins, and an estimate for lettuce.

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[2] http://www.yara.co.nz/crop-nutrition/crops/other-crops/lettuce-crop-programme/ This recommendation totals 167 kgN/ha

## 4 SPASMO Crop Production and Nutrient Loss Modelling

All water and nutrient calculations have been carried out using Plant & Food Research's SPASMO model (Green et al. 2008, 2012). This model considers the movement of water, solute (e.g. N and P), pesticide, dissolved organic matter (i.e. dissolved organic carbon (DOC) dissolved organic nitrogen (DON)) through a one-dimensional soil profile, as well as overland flow of sediment and nutrients.

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. SPASMO includes components to predict the carbon and nitrogen budgets of the soil. These components allow for a calculation of plant growth and uptake of N, 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, and the returns of dung and urine from grazing animals (Rosen et al. 2004). 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 $g/m^3$ and kg/ha, respectively. All calculations are run on a daily basis and the results are presented on a per hectare basis.

For modelling each farm or crop system, each farm type is specified by a production target (e.g. dairy is represented by kg of milk solids per ha, horticulture is represented by kg of product per hectare). For each model run, the input parameters for SPASMO were adjusted to achieve the expected yields and production volumes identified by growers, Fruition Horticulture and Plant & Food Research based on local experience and research results.

Further detail on the complexity of the model and the way in which crop phenology is modelled can be found in Green at al. (2012), where SPASMO modelling is described for the Ruataniwha Plains. However, it should be noted that the SPASMO model was considerably further refined for this project to simulate multiple market gardening rotations and to simulate more realistically the drying off and feed import scenarios for dairy farms on the Waimea Plains.

## 5 Assumptions and uncertainty

The modelling and GIS-based apportionment of nitrate losses across the plains provides a basis for anticipating changes if certain policy options are put in place. More reliance should be put on the scale of the modelled changes rather than on the absolute modelled nitrate losses, because the following assumptions have been made:

- There is no attenuation (loss) of nitrate between the base of the soil profile and the arrival of nitrates at the spring-fed streams. If the Waimea Community Dam is supplying additional river flow in summer, there will be some dilution from additional river flow losses to the unconfined aquifer, which we expect will affect Pearl Creek flows and to a lesser extent Neiman Creek flows. Without this dilution accounted for, the modelled nitrate concentrations in the streams will be worse than they may be in reality.
- The flow tubes adequately represent average groundwater flow directions from upstream land use to the springs. Groundwater flow directions change subtly in

response to pumping patterns, especially between summer and winter. Non-horizontal groundwater flows between confined and overlying unconfined aquifers also vary. However, at the scale of the analysis completed here over the whole Waimea Plain, we think the flow directions are generally correct.

- The SPASMO model adequately predicts actual nitrate leaching losses for the range of crops and soils simulated, and the assumed loss rates for land uses not directly simulated by SPASMO are valid (e.g. lifestyle blocks where dryland sheep and beef has been used as the correlate; forestry where a default loss has been adopted). SPASMO has been verified for pipfruit and grapes in other regions, but ideally lysimeter monitoring is needed to check its results and those of OVERSEER across a range of Waimea land uses, especially market gardening.

# 6 SPASMO modelled Nitrate-Nitrogen Leaching Responses

Besides calculating production, the SPASMO model also calculates nutrient losses below the root zone via leaching and runoff, including calculating nitrogen transformations within each soil layer. Losses due to runoff on the flat lands of the Waimea Plains are negligible.

This section of the report summarises nitrate-nitrogen leaching losses *averaged* over the 40 years 1974–2013 inclusive, for apples, grapes, outdoor vegetables, and dairy, on four soils (Tables 2 & 3). Results in these tables assume full irrigation water availability with no rationing (i.e. the ‘with dam’ full reliability scenario in the TRMP water allocation rules).

Figures 2–9 plot the annual variability in modelled nitrate leaching losses for the four land uses on their predominant soils.

Modelling carried out in the partner study for MPI (Fenemor et al. 2015) for the ‘no dam’ fully rationed irrigation scenario showed little difference in annual nitrogen leached for the full reliability compared with fully rationed irrigation scenarios, as shown for apples, grapes, and vegetables in Figures 3–9. This is because nitrogen leaching is most strongly driven by rainfall events, while land users generally avoid over-irrigation, which would lead to significant additional leaching. However, irrigated land will usually be farmed more intensively, and will have larger reservoirs of nutrients able to be flushed through when heavy rainfalls do occur.

**Table 2** Average modelled nitrate-nitrogen losses from SPASMO modelling summarised for six Waimea catchment land uses and four soil groups, kgN/ha/yr

| **Land Use/ Farm System** | **Ranzau soil** | **Waimea & Motupiko soils** | **Wakatu & Dovedale soils** | **Richmond & Heslington soils** | **Proxy soil for S&Beef includes all other soils** | **Proxy soil for Forest & scrub** |
|---|---|---|---|---|---|---|
| Dairy pasture | 68.8 | 63.4 | 65.6 | 24.0 | | |
| Apples (also applied here to berries, hops, kiwifruit, avocados) | 18.3 | 6.6 | 9.3 | 3.1 | | |
| Grapes (also applied to olives, small nuts) | 18.3 | 9.8 | 13.6 | 4.3 | | |
| Outdoor vegetables (also applied to nurseries, non-sealed glasshouses) | 51.4 | 33.0 | 31.9 | 16.0 | | |
| Other pasture/lifestyle block/non-agricultural (assumes extensive sheep & beef land use) | | | | | 10.7 | |
| Forest, scrub | | | | | | 2.5 |

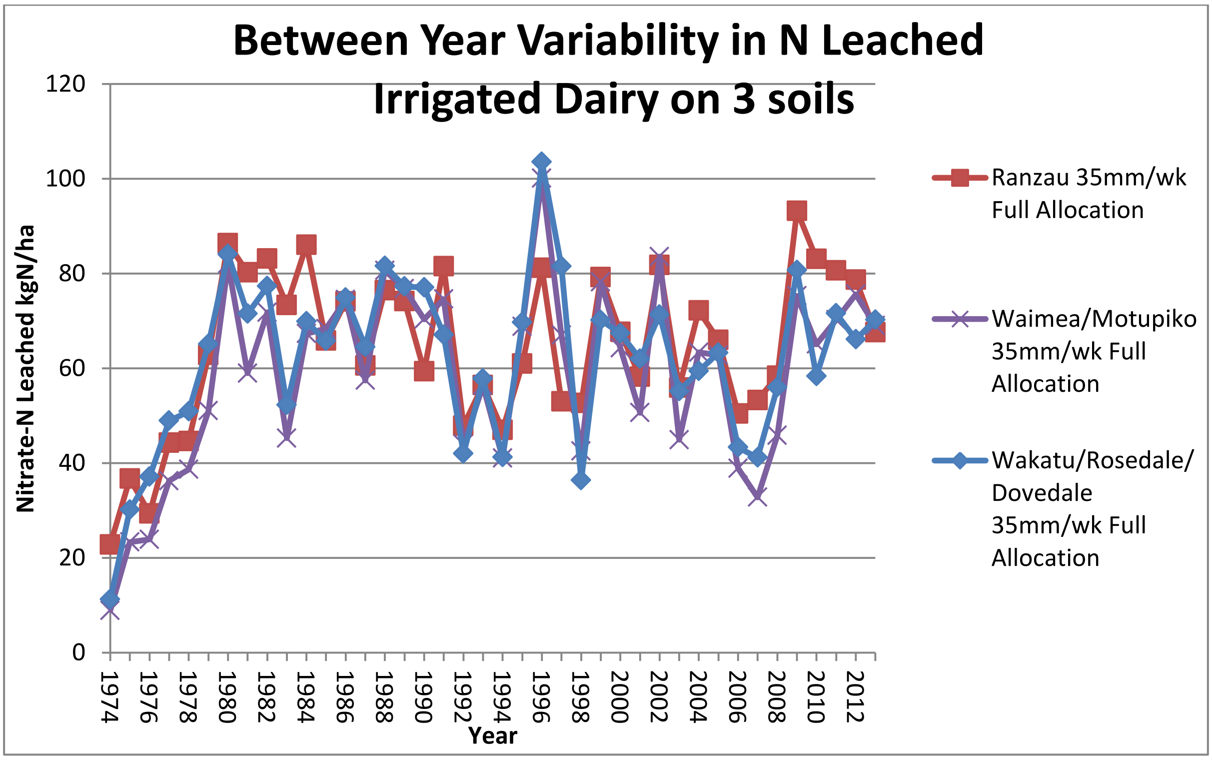

**Figure 2** Year to year variation in N leaching from fully irrigated dairy farming for 3 soil groups. Average losses are 69 (Ranzau), 63 (Waimea) and 66 kgN/ha/yr (Wakatu). Modelled losses for 1974-78 are subject to model initialisation errors and have not been included in averages.

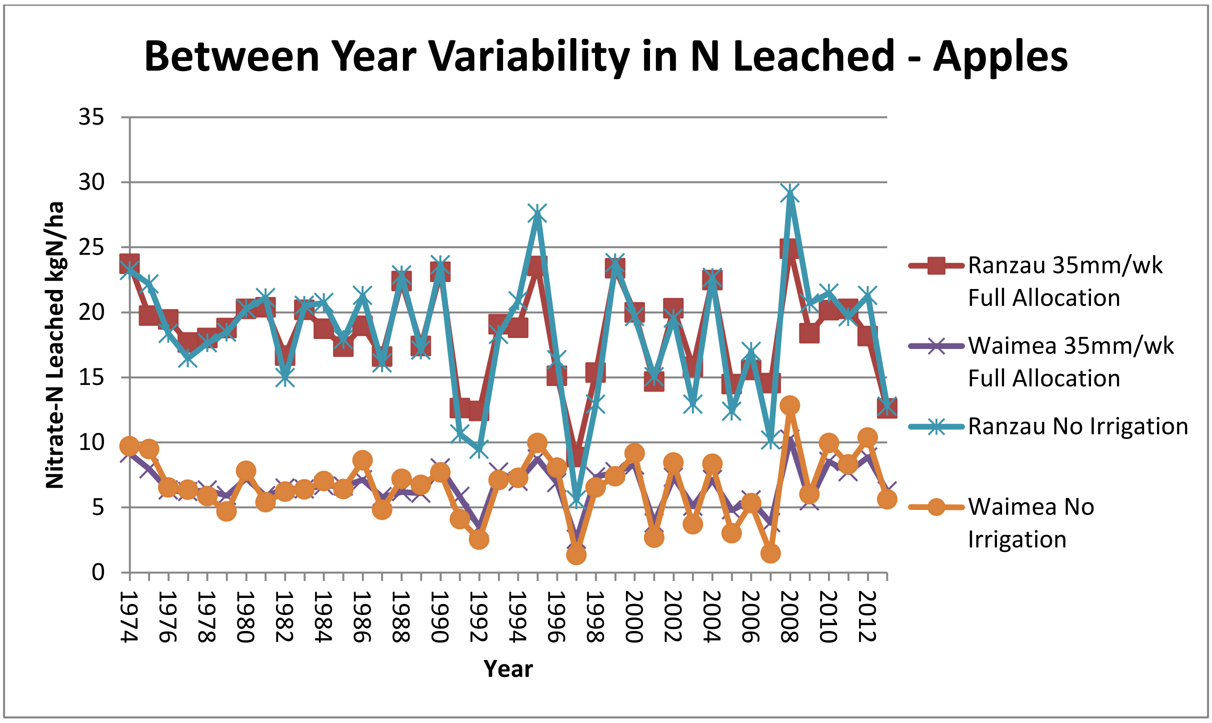

**Figure 3** Year to year variation in N leaching from apples for Ranzau and Waimea soils. Fully irrigated average losses are 18 kgN/ha/yr (Ranzau) and 7 kgN/ha/yr (Waimea).

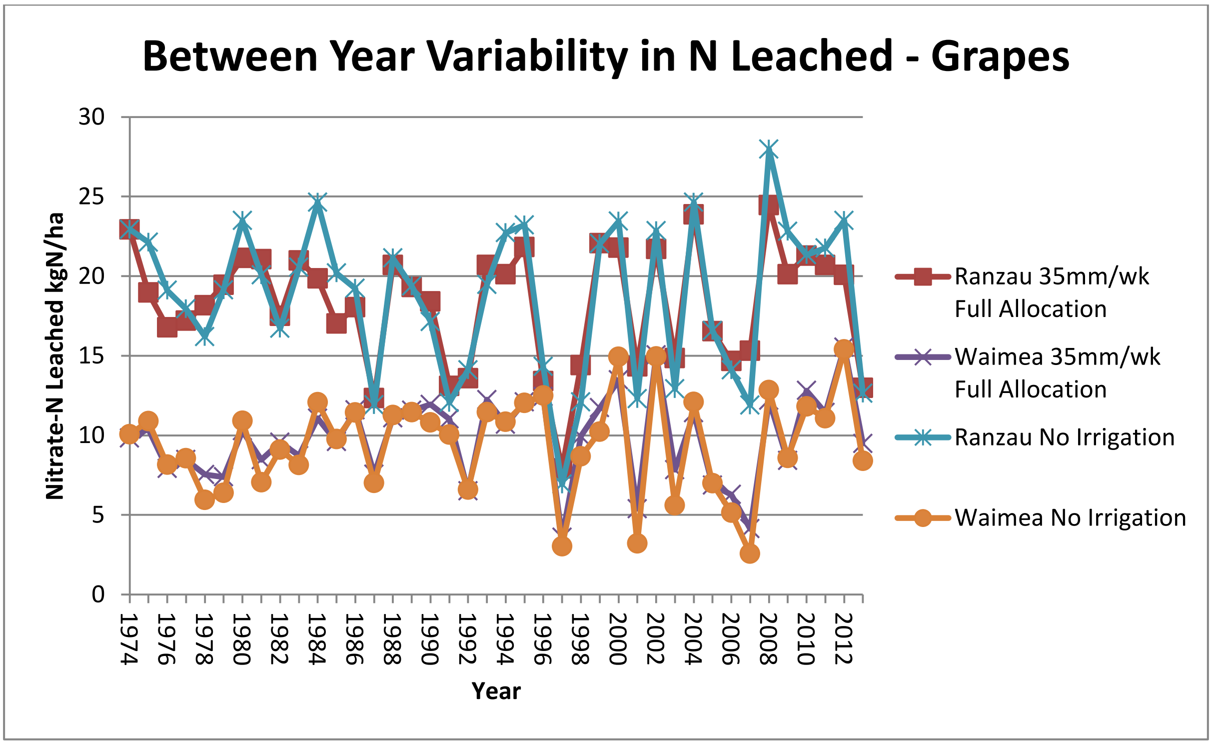

**Figure 4** Year to year variation in N leaching from grapes for Ranzau and Waimea soils. Fully irrigated average losses are 18 kgN/ha/yr (Ranzau) and 10 kgN/ha/yr (Waimea).

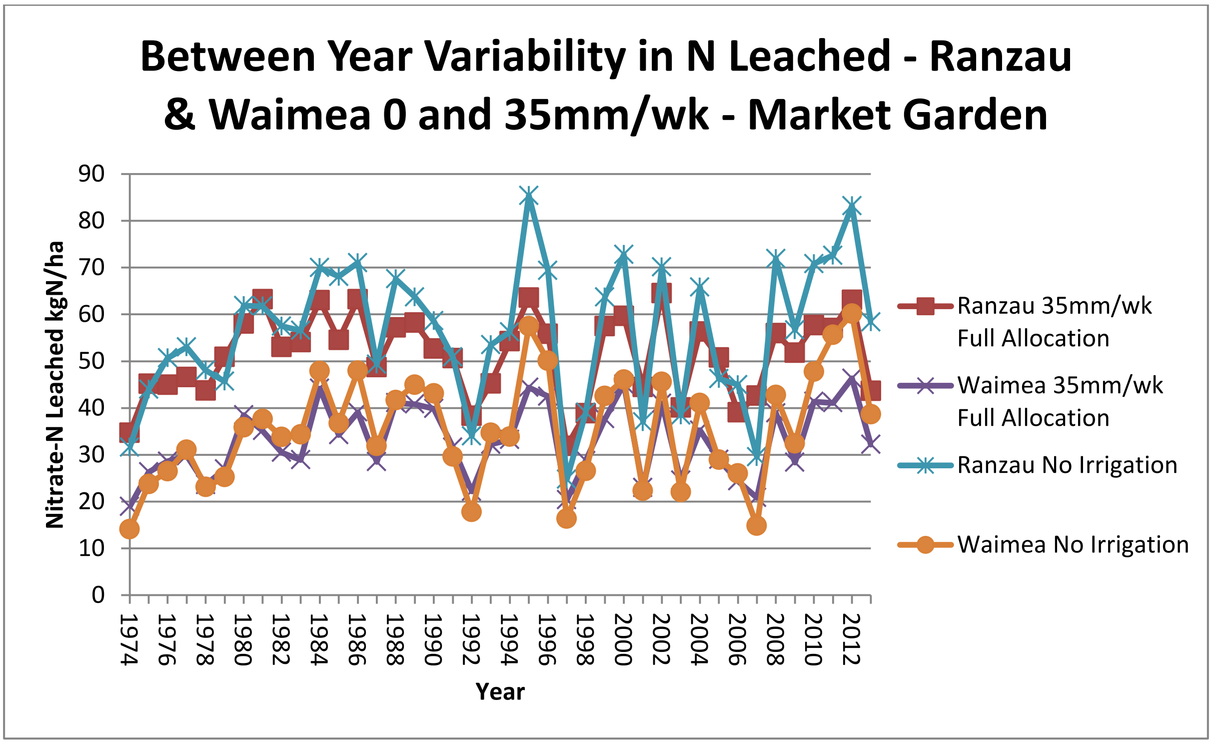

**Figure 5** Year to year variation in N leaching from overall market garden for Ranzau and Waimea soils. Fully irrigated average losses are 51 (Ranzau) and 33 kgN/ha/yr (Waimea).

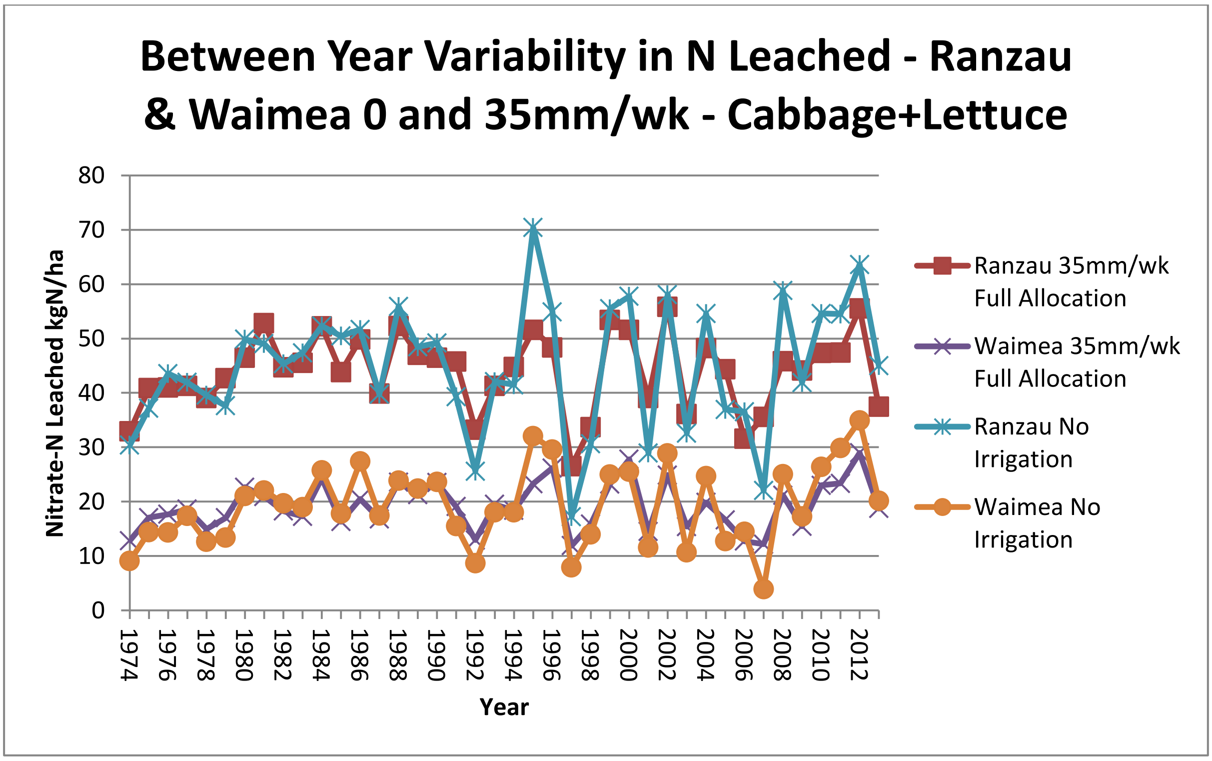

**Figure 6** Year to year variation in N leaching from a cabbage/lettuce sequence for Ranzau and Waimea soils. Fully irrigated average losses are 44 (Ranzau) and 19 kgN/ha/yr (Waimea).

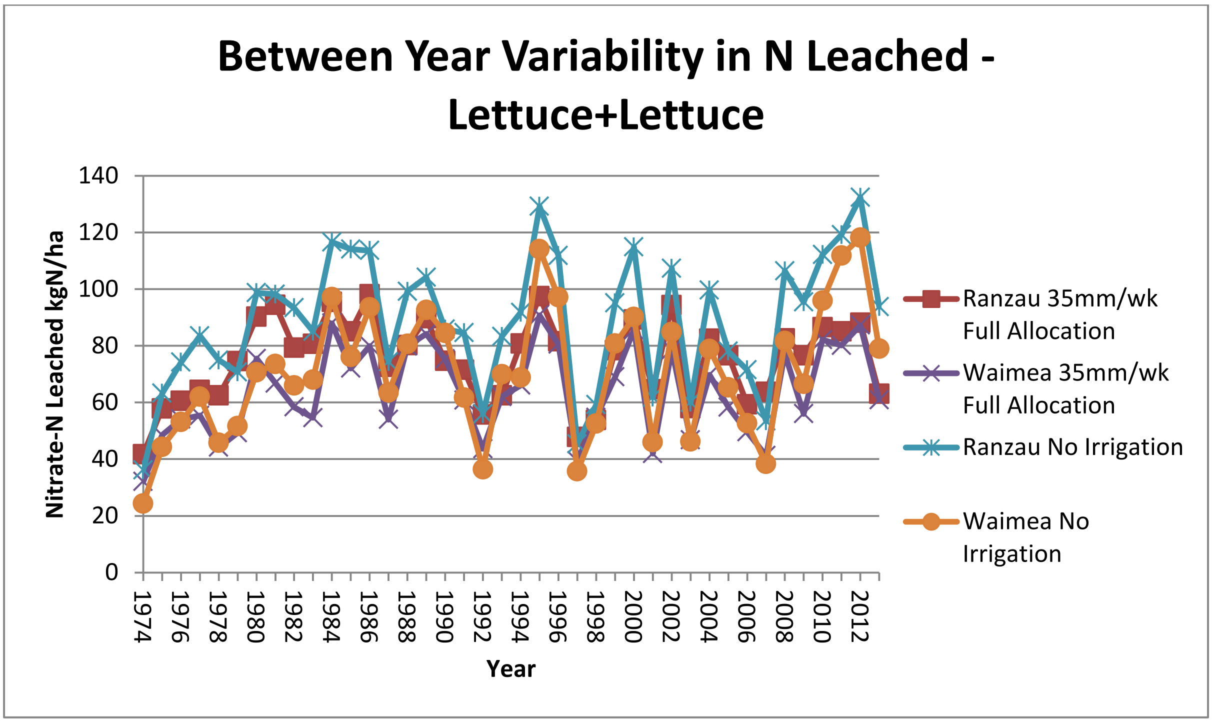

**Figure 7** Year to year variation in N leaching from a lettuce/lettuce sequence for Ranzau and Waimea soils. Fully irrigated average losses are 75 (Ranzau) and 64 kgN/ha/yr (Waimea).

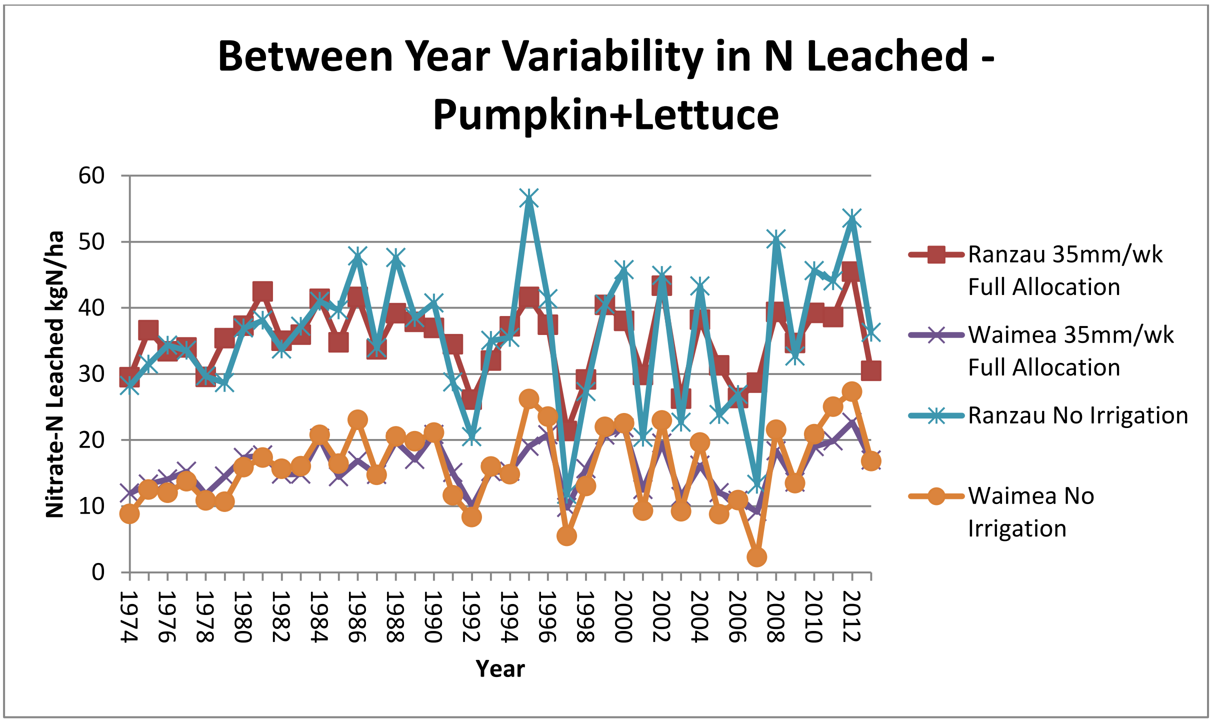

**Figure 8** Year to year variation in N leaching from a pumpkin/lettuce sequence for Ranzau and Waimea soils. Fully irrigated average losses are 35 (Ranzau) and 16 kgN/ha/yr (Waimea).

Finally, Figure 9 compares the leaching rates across the three outdoor vegetable crop combinations modelled, for Ranzau soil only as that soil has the higher leaching rates. The plot shows that the Lettuce/Lettuce combination has particularly high nitrate losses compared with the Cabbage/Lettuce and the Pumpkin/Lettuce combination.

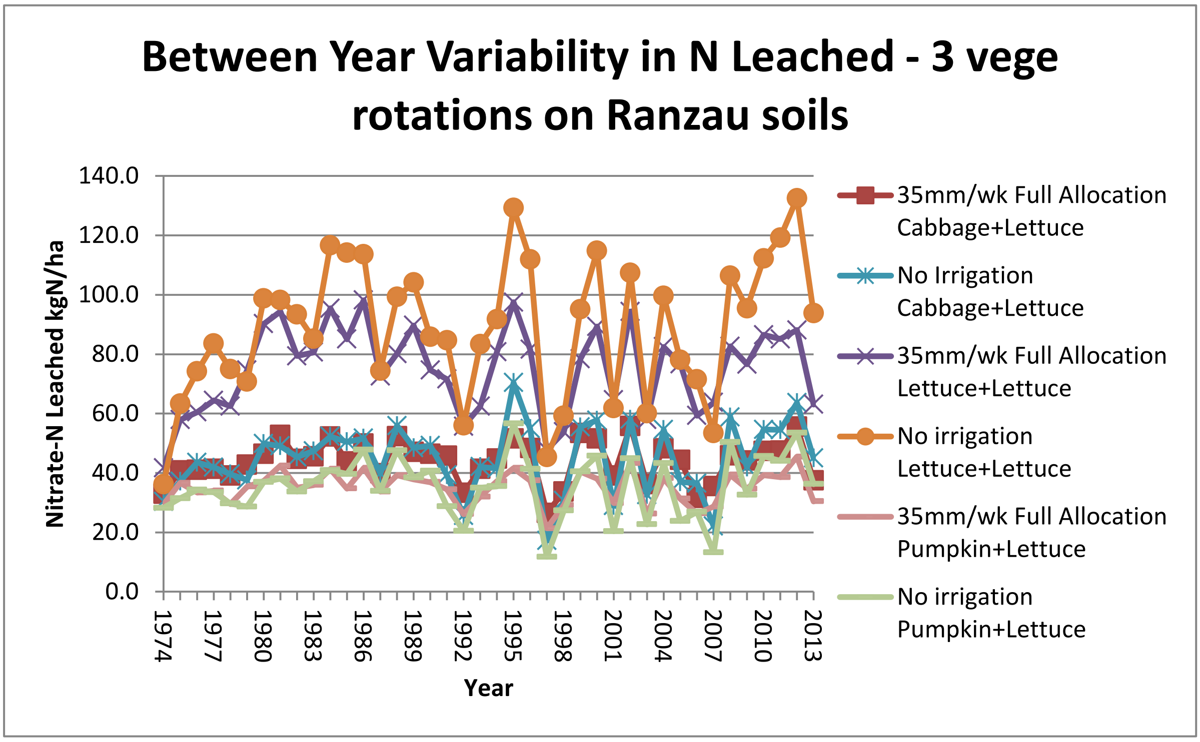

**Figure 9** Year on year variability of nitrate losses from market gardening on Ranzau soils under various irrigation scenarios.

## 7 Nitrate Loss Pattern from current Land Uses

Plotting the nitrate losses by land use and soil type for the combinations shown in Table 3 produces the map below (Fig. 10).

Total calculated nitrate loss below the soil root zone for the Waimea lowland catchment is 287 tonnes per year. The top six largest contributors by land use are pasture, forest, dairy, outdoor vegetables, grapes, and pipfruit. The top three soil series from which the nitrogen originates are Rosedale, Ranzau, and Waimea.

However, in terms of localised impact, it is the nitrate loss rates and proximity to receiving waters that are important to understand. Highest loss rates according to the SPASMO modelling are dairy, outdoor vegetables, grapes, and then apples (Table 3). Table 3 shows that the most sensitive plains soils for nitrate leaching are Ranzau, followed by Waimea and Wakatu, which are similar, then Richmond soils, which are less prone to leaching.

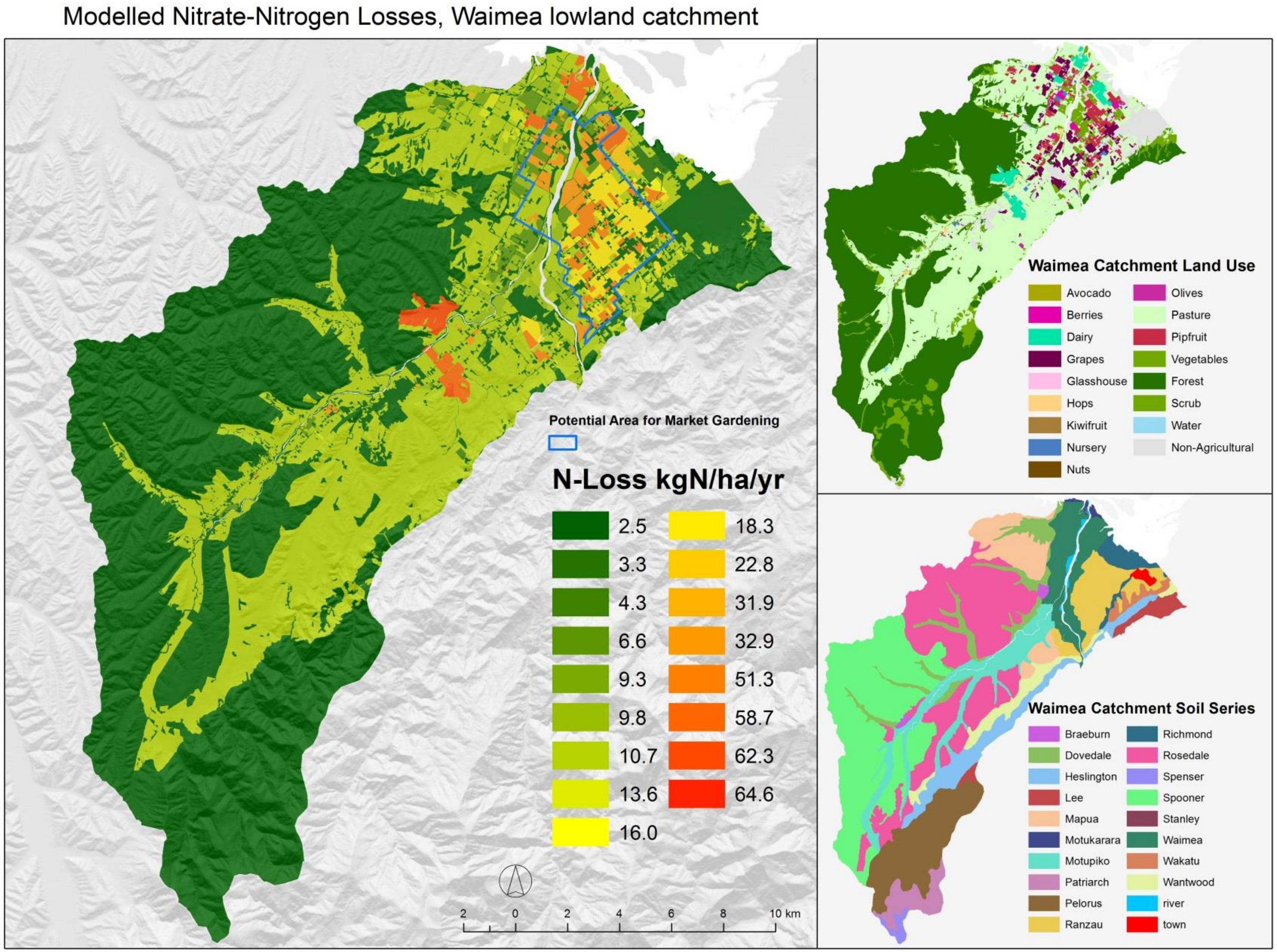

**Figure 10** Modelled nitrate losses, land use and soil series for the Waimea lowland catchment.

**Table 3** Mean annual nitrate-nitrogen loads by land use and soil series, kgN/yr

| ***Land Use*** | **Braeburn** | **Dovedale** | **Heslington** | **Lee** | **Mapua** | **Motukarara** | **Motupiko** | **Patriarch** | **Pelorus** | **Ranzau** | **Richmond** | **Rosedale** | **Spenser** | **Spooner** | **Waimea** | **Wakatu** | **Wantwood** | **Total For Land Use** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Avocado* | | | | | | | | | | 23 | | | | | | | | **23** |
| *Berries* | 7 | | | | | | 13 | | | 112 | 99 | | | | 480 | | | **711** |
| *Dairy* | | 4393 | | | 2045 | 741 | 6561 | | | 25 | 1610 | 7829 | | | 11 105 | | | **34 309** |
| *Forest* | 8 | 898 | 1038 | 1076 | 963 | | 309 | 2569 | 7466 | 1 | | 13 773 | 246 | 21 027 | 15 | 6 | 96 | **49 492** |
| *Glasshouse ** | | | | | | | 0 | | | 0 | 0 | | | | 0 | 0 | | **0** |
| *Grapes* | 84 | 1336 | | | 395 | | 1011 | | | 5915 | 61 | | | | 3484 | 299 | 13 | **12597** |
| *Hops* | 10 | 1 | | | | | 199 | | | | | | | | 107 | | | **317** |
| *Kiwifruit* | | | | | | | 3 | | | 218 | 3 | | | | 342 | | | **566** |
| *Non-Agricultural* | 50 | 421 | 152 | 2 | 329 | 11 | 916 | 0 | | 2020 | 636 | 317 | 185 | 59 | 1050 | 455 | 125 | **6727** |
| *Nursery* | | 135 | | | | | 944 | | | 1331 | 111 | | | | 1602 | | | **4122** |
| *Nuts* | | 39 | 2 | | | | | | | 144 | | 7 | | | 89 | | | **282** |
| *Olives* | | 75 | 37 | | 7 | | 78 | | | 48 | | 0 | | | 62 | | 32 | **339** |
| *Pasture* | 1082 | 11 901 | 14 360 | 666 | 15 927 | 749 | 22 191 | | 535 | 4699 | 2684 | 30 811 | | 5277 | 9434 | 1314 | 10 513 | **132 141** |
| *Pipfruit* | 35 | 798 | 1 | | 285 | 0 | 224 | | | 7203 | 181 | 45 | | 1 | 1560 | 89 | 2 | **10 424** |
| *Scrub* | 4 | 334 | 493 | 359 | 316 | 45 | 495 | 114 | 1,614 | 5 | 14 | 368 | 154 | 663 | 226 | 65 | 130 | **5399** |
| *Vegetables* | | | 0 | | 9 | 8 | 82 | | | 18 761 | 397 | | | | 10 266 | 26 | | **29 550** |
| **Total kgN/yr** | **1280** | **20 329** | **16 084** | **2103** | **20 277** | **1553** | **33 026** | **2684** | **9614** | **40 503** | **5796** | **53 150** | **585** | **27 027** | **39 822** | **2253** | **10 912** | **286 999** |

* *assumed self-contained*

# 8 Modelling Nitrate reaching Receiving Waters

In order to manage the environmental effects of nitrate losses, an understanding is first needed of the attenuation (reduction in nitrate) between the base of the soil profile along the flow path to sensitive receiving waters. This is followed by consideration of potential water quality limits, which should by met for each receiving water body.

Relevant receiving waters for management of water quality are the three aquifers, the Wai-iti, Wairoa, and Waimea rivers, the spring-fed streams Pearl Creek and Neimann Creek, other streams, including Borck Creek near Richmond and O'Connor Creek at Appleby, as well as the Waimea Inlet.

The following table (Table 4) was a first attempt to provide a scientific basis for water quality limits for receiving water bodies in the Waimea Plains. Further work has since been carried out adjusting upwards the nitrate toxicity limits initially proposed in Table 4 because of the higher water hardness in the spring-fed streams (Hickey, 2015). The revised limits are incorporated into Table 4.

**Table 4** Recommended numeric objectives associated with maintaining various values within the Waimea Catchment and Waimea Inlet (updated from Fenemor et al. 2013)

| | **Objectives** | | | | |
|---|---|---|---|---|---|
| **Waterbodies** | Safe for swimming | Safe drinking water | Limit risk of nitrate toxicity | Control freshwater periphyton growth | Limit macroalgal blooms in the Waimea Inlet |
| Waimea River | 95th percentile values of *E. coli* shall be <260 /100mL | N/A | Annual average $NO_3$-N shall be <2.4 mgN/L and annual 95th percentile shall be <3.5 mg/L | Dissolved reactive phosphorus concentrations <0.026 mg/L | Total N load to Waimea Inlet from all sources <610 tonnes/year (equivalent to <50 $mgN/m^2/day$) |
| Spring-fed streams | N/A | N/A | Annual average $NO_3$-N shall be <7 mgN/L and annual 95th percentile shall be <10 mg/L** | Dissolved reactive phosphorus concentrations <0.026 mg/L | |
| Groundwater | N/A | No *E. coli* detected;<br>Nitrate-nitrogen concentration <11.3 mg/L | * | * | |

* Concentrations in groundwater need to be considered in relation to limits on the spring-fed streams

** Nitrate toxicity guideline limits shown are the more conservative levels calculated from Pearl and Borck Creeks measured water hardness and calculated in Hickey (2015) as Hardness-specific nitrate-N guideline = $e^{0.9518*Ln(Hardness)}$ - Constant, where 0.9518 is the slope of the hardness relationship (from Rescan 2012), hardness is the measured value, and the Constant is a factor to adjust from the "NOF nitrate standards" reference hardness value of 13 mg $CaCO_3$/L for annual median and 95th percentile concentrations.

It is evident from comparing Table 4 with measured nitrate concentrations that the more sensitive receiving waters for nitrate are the confined aquifers, where some wells have nitrates above drinking water guidelines, and the spring-fed streams where nitrate levels are close to nitrate toxicity recommendations and may exceed future periphyton-related limits (although as Figure 11 shows, nitrate levels have been declining).

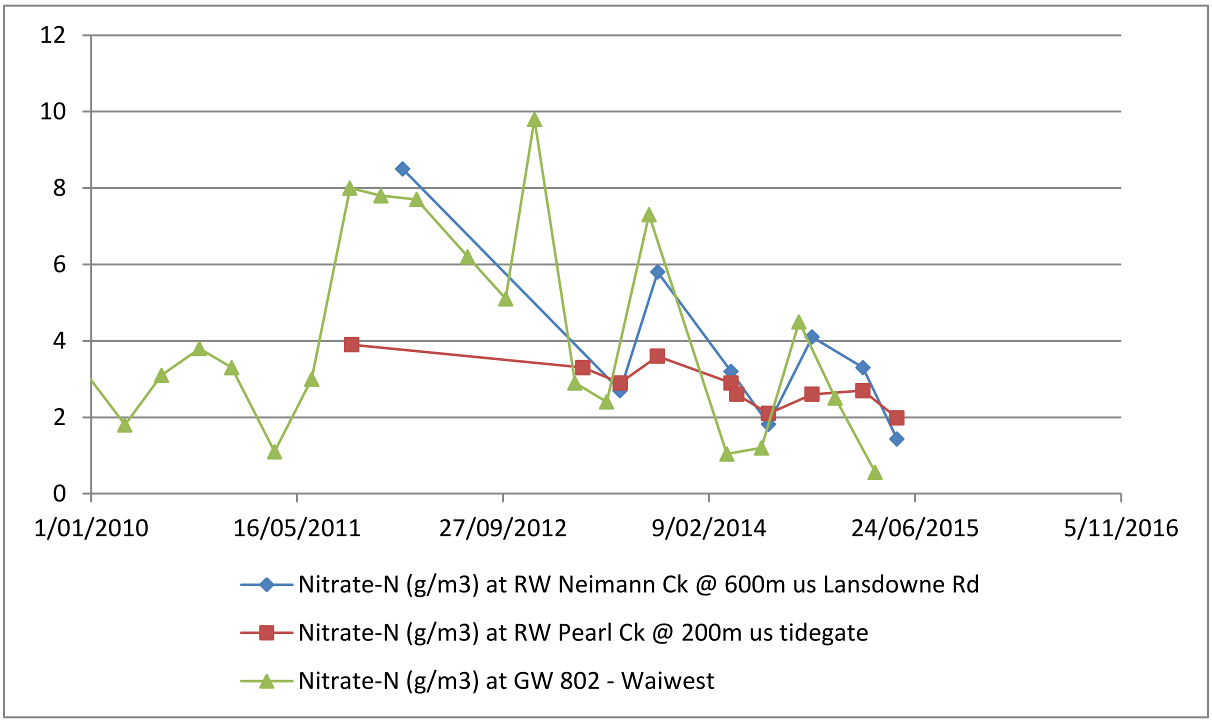

**Figure 11** Measured nitrate concentrations (g/m$^3$) since 2010 in Pearl and Neimann creeks and well 802 upstream of Neimann Creek (Glenn Stevens, TDC, pers. comm.).

Potential attenuation of nitrate before it reaches any surface water was evaluated in the earlier study for WWAC. The results suggested possible attenuation of 60% in the unconfined aquifer, negligible attenuation in the Hope Aquifers and UCA, and around 40% for the LCA. The previous work (Fenemor et al. 2013) concluded:

> *Physically, more attenuation would be expected in the unconfined aquifer than the confined ones. This is because of the exchange of relatively clean river recharge with groundwater near the major rivers, and the input of less enriched waters from hillslope recharge. In the Hope and two fully confined aquifers, most of the recharge is originating from rainfall and irrigation via the overlying contaminating land uses; the only dilution is the proportion of river recharge reaching the LCA and a small contribution of less enriched recharge from the eastern hill slopes.*

A conservative assumption would be that attenuation in the confined aquifers is negligible, and in the unconfined aquifer attenuation is caused only by dilution of river water recharging the adjoining aquifer. If the Waimea Community Dam is releasing water that recharges the unconfined aquifer during summer, this may have a diluting effect on flows from Pearl and Neiman Creeks, but that would need to be investigated using the TDC’s Waimea groundwater model.

In the meantime, we have completed a flow tube analysis as a method for assessing the effects of land use change on nitrate concentrations reaching Pearl and Neimann creeks. Figure 12–14 show modelled nitrate losses for scenarios of increasing market gardening within the blue bounded area of Figure 1.

As discussed at the June 2015 FLAG meeting, areas assumed converted to market gardening exclude any area currently in permanent crops (orchard, grapes) and have been chosen sequentially from the largest blocks first. The additional 200 ha of Figure 13 correspond to all blocks larger than 3.4 ha being converted, while the additional 318 ha of Figure 14 correspond to all blocks of 1ha or more being converted within that blue boundary.

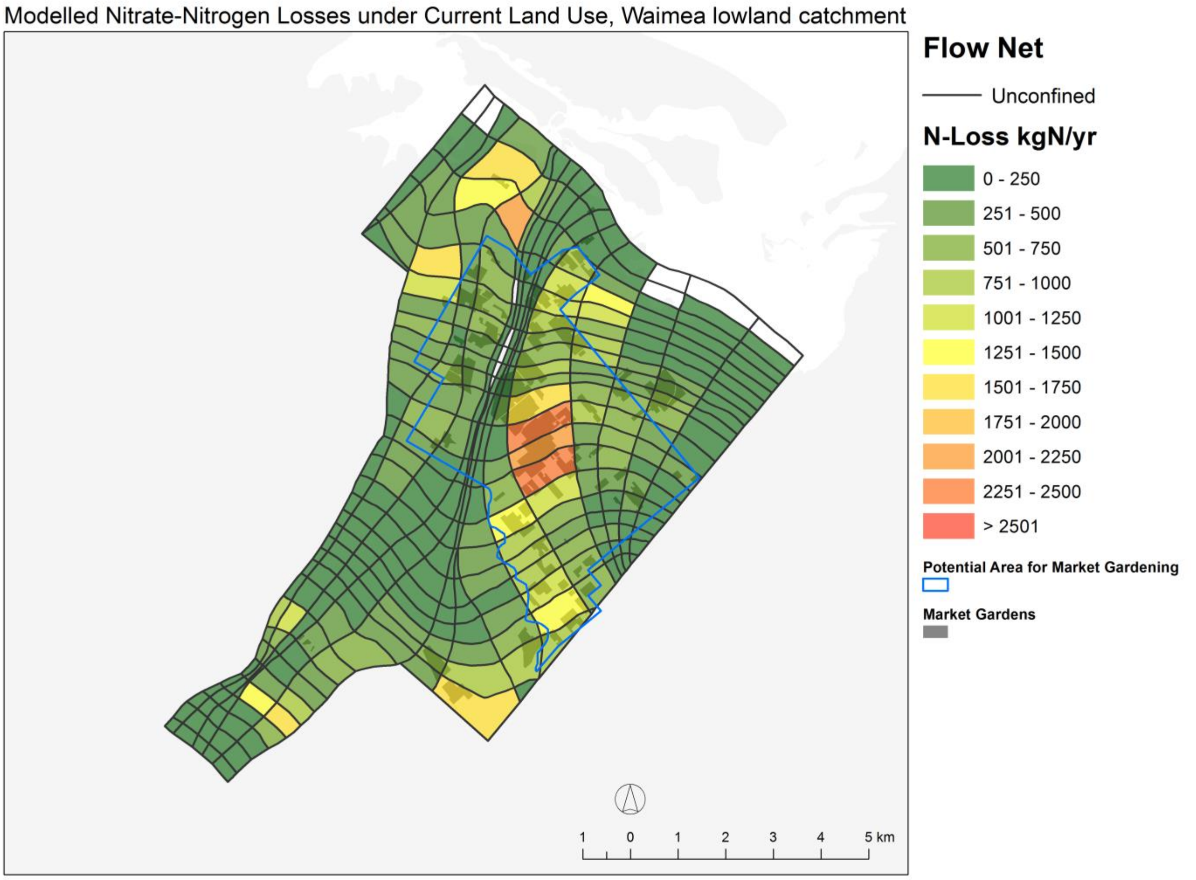

**Figure 12** Nitrate losses by flow net cell for current land use.

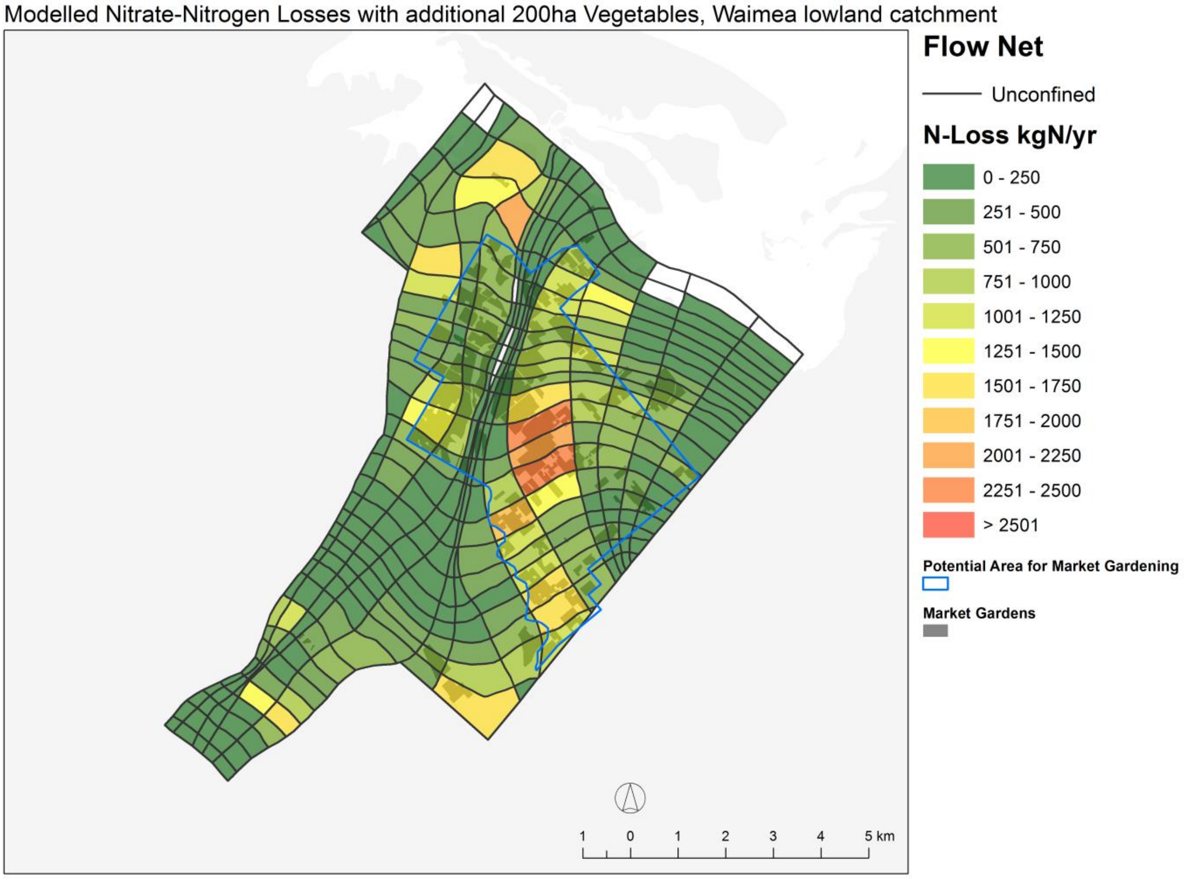

**Figure 13** Nitrate losses by flow net cell for current land use plus 200 ha outdoor vegetable growing (with all vegetable growing shaded).

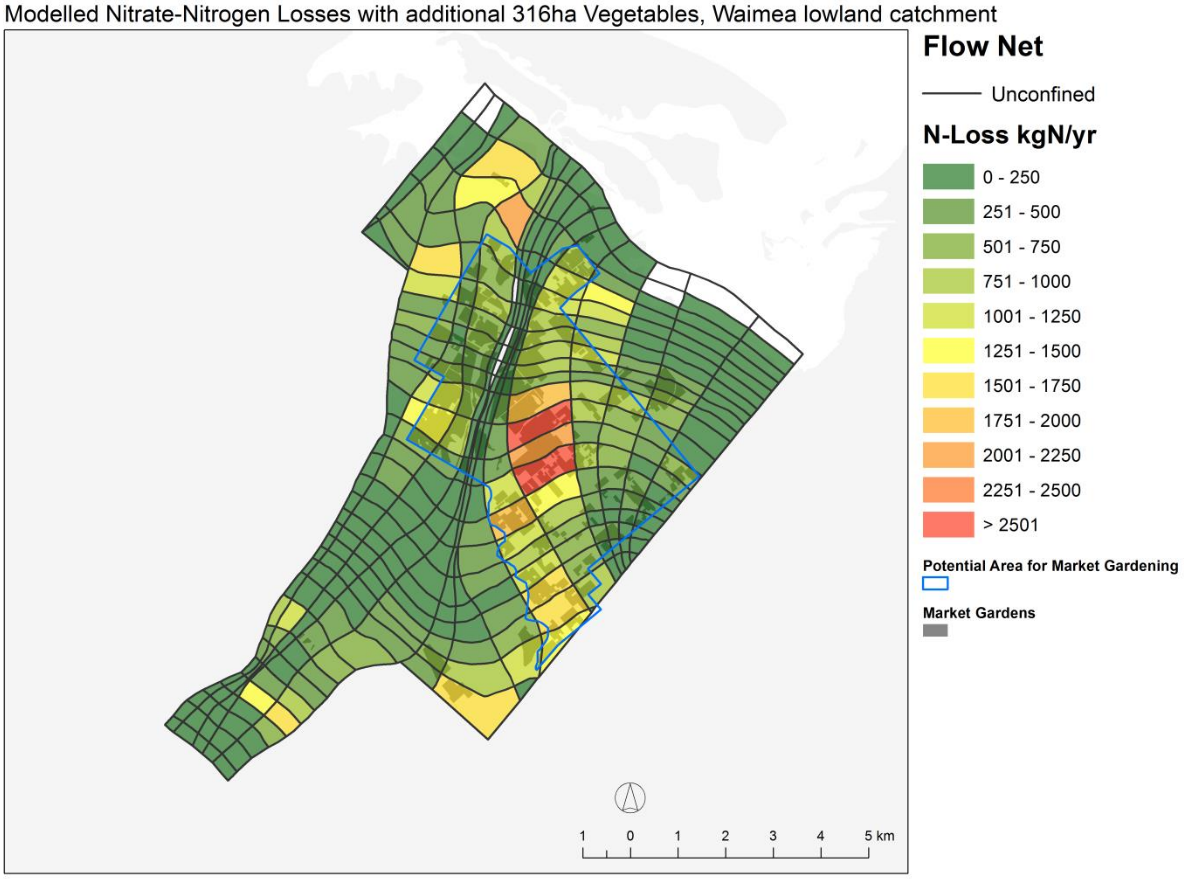

**Figure 14** Nitrate losses by flow net cell for current land use plus 318 ha outdoor vegetable growing (with all vegetable growing shaded).

Assuming no attenuation of nitrate, Table 5 summarises the modelled nitrate concentrations that would be delivered for these and other scenarios at Pearl Creek and Neimann Creek. The match between calculated and recent measured concentration at Pearl Creek is excellent but the predicted concentrations in Neimann Creek exceed recent measured concentrations (although they are similar to earlier higher nitrate concentrations there).

The main benefit of these numbers is to show the sensitivity of changes in nitrate in these streams to changes in land use, in this case increases in market gardening. The table should help assess the effects of land use intensification on nitrate concentrations in spring-fed streams.

Table 5 shows that nitrate concentrations in the spring-fed Pearl Creek could increase by 0.44 to 0.48 g/m$^3$ for 200–562 additional hectares converted from pastoral land use to outdoor vegetable production. For the spring-fed Neimann Creek, equivalent increases in nitrate concentration would be 0.54 to 1.06 g/m$^3$. Resulting nitrate concentrations would slightly increase the risk of exceeding acceptable aquatic ecosystem limits, depending on which values the FLAG and community decide those limits should be based.

**Table 5** Modelled nitrate discharges at spring-fed streams for various market garden expansion scenarios

| | Pearl Creek (mean flow ~ 278 l/sec) | | | Neimann Creek (mean flow ~ 166 l/sec) | | | GW802 |
|---|---|---|---|---|---|---|---|
| **Market gardening scenario** | **Calculated average contributing nitrate load, kgN/yr** | **Calculated nitrate concentration, g/m$^3$** | **Measured nitrate concentration (2011–15, n=8), g/m$^3$** | **Calculated average contributing nitrate load, kgN/yr** | **Calculated nitrate concentration, g/m$^3$** | **Measured nitrate concentration (2011–15, n=10), g/m$^3$** | **Measured nitrate concentration (2011–15, n=14), g/m$^3$** |
| Current Land Use | 13.4 | 2.05 | 2.86 | 22.1 | 5.56 | 3.86 | 4.79 |
| Current plus 47ha (>5ha blocks) | 16.0 | 2.45 | | 23.8 | 5.98 | | |
| Current +200ha (>3.4ha blocks) | 16.3 | 2.49 (+0.44) | | 24.3 | 6.10 (+0.54) | | |
| Current+264ha (>2ha blocks) | 16.3 | 2.50 | | 25.0 | 6.29 | | |
| Current+318ha (>1ha blocks) | 16.5 | 2.52 | | 25.6 | 6.44 | | |
| Current+562ha (all eligible blocks) | 16.5 | 2.53 | | 26.3 | 6.62 | | |

# 9 Summary of Mitigation Methods

The Waimea FLAG discussed workable on-farm methods for reducing nitrogen losses, as well as policy methods that could be applied through a nutrient management plan change to the Tasman Resource Management Plan.

As a starter for discussion, the following summarises mitigation methods from Fenemor et al. (2015):

### Pastoral options to reduce nitrogen losses

- Time fertilizer applications to maximise plant uptake
- Reduce or limit N fertilizer applied
- Livestock improvement for efficient feed utilization
- Riparian buffer plantings, stock exclusion and tracks kept away from any running water
- Feed pads, stand-off pads, barns where effluent can be collected
- Lower stocking and production rates
- Use of N inhibitors
- Wetlands for intercepting runoff
- Limit autumn grazing, e.g. through wintering off at less vulnerable locations
- Improved irrigation efficiency to reduce drainage losses

### Horticultural options to reduce nitrogen losses

- Limit each fertilizer application, e.g. to less than 80 kgN per month
- Reductions in N applied
- Improved irrigation application efficiency
- Side dressings of fertilizer post-planting
- Winter cover crops when ground is fallow
- Soil and leaf testing including deep soil N testing
- Irrigation scheduling to maintain soil moisture between wilting point and field capacity – using soil moisture monitoring
- Tailor crop types to leaching vulnerability
- Variable rate fertilizer and irrigation application to match crop demand
- Accounting for all organic, effluent and glasshouse nutrient disposal to reduce fertilizer applied
- Improved fertilizer technologies, e.g. prills, coatings.

# 10 References

Fenemor AD 2013. Summary of hydrology and water management bases for decisions on Waimea water management, with and without water augmentation. Landcare Research contract Report LC1647 to inform Tasman District Council plan change C47. 25 p.

Fenemor AD 1988. A three-dimensional model for management of the Waimea Plains Aquifers, Nelson. Hydrology Centre Publication No. 18. Lower Hutt, DSIR. 133 p.

Fenemor A, Green S, Dryden G, Samarasinghe O, Newsome P, Price R, Betts H, Lilburne L 2015. Crop production, profit and nutrient losses in relation to irrigation water allocation and reliability – Waimea Plains, Tasman District: final report. MPI Technical Paper No: 2015/36. Landcare Research. 65 p. http://www.mpi.govt.nz/document-vault/9899

Fenemor AD, Lilburne L, Young RA, Green S, Webb T 2013. Assessing water quality risks and responses with increased irrigation in the Waimea Basin. Landcare Research Report LC1246 for the Waimea Water Augmentation Committee, Tasman District. 42 p.

Green SR, Clothier BE, van den Dijssel C, Deurer M, Davidson P 2008. Measurement and modelling the stress response of grapevines to soil-water deficits in their rootzones. In: Ahuja L ed. Modeling the response of crops to limited water: Recent advances in understanding and modeling water stress effects on plant growth processes. Soil Science Society America Monograph. Pp. 357–386.

Green S, Manderson A, Clothier B, Mackay A 2012. SPASMO modelling of water and nutrients using a GIS framework to estimate catchment loads. Client report prepared for Hawke’s Bay Regional Council, Report number PFR SPTS No. 6846, Plant and Food Research. Included as Appendix 1 in Rutherford K 2012. Modelling the effects of land use on nutrients entering the Tukituki River, Hawke’s Bay. Report prepared for Hawke’s Bay Regional Council, NIWA Client Report number HAM2012-077. Auckland, National Institute of Water & Atmospheric Research.

Hickey, C. 2015. Hardness and Nitrate toxicity – site-specific guidelines for spring-fed streams in the Waimea and Motupipi river catchments and Waikoropupu Springs. Memo to J. Thomas, Tasman District Council, 19 May 2015.

Rescan 2012. EKATI Diamond Mine: Site-Specific Water Quality Objective for Nitrate, 2012. Project #648-116-01. Prepared for BHP Billiton Canada Inc. by Rescan Environmental Services Ltd, Yellowknife, Northwest Territories. pp. 57.

Rosen MR, Reeves RR, Green SR, Clothier BE, Ironside N 2004 Prediction of groundwater nitrate contamination after closure of an unlined sheep feedlot in New Zealand. Vadose Zone Journal 3: 990–1006.