



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

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

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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/m³ for 200–562 hectares converted. For the spring-fed Neimann Creek, equivalent increases in nitrate concentration would be 0.54 to 1.06 g/m³, 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/yr¹ 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.

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: 1383 instead of 1500 kgMS/ha/yr. 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.).

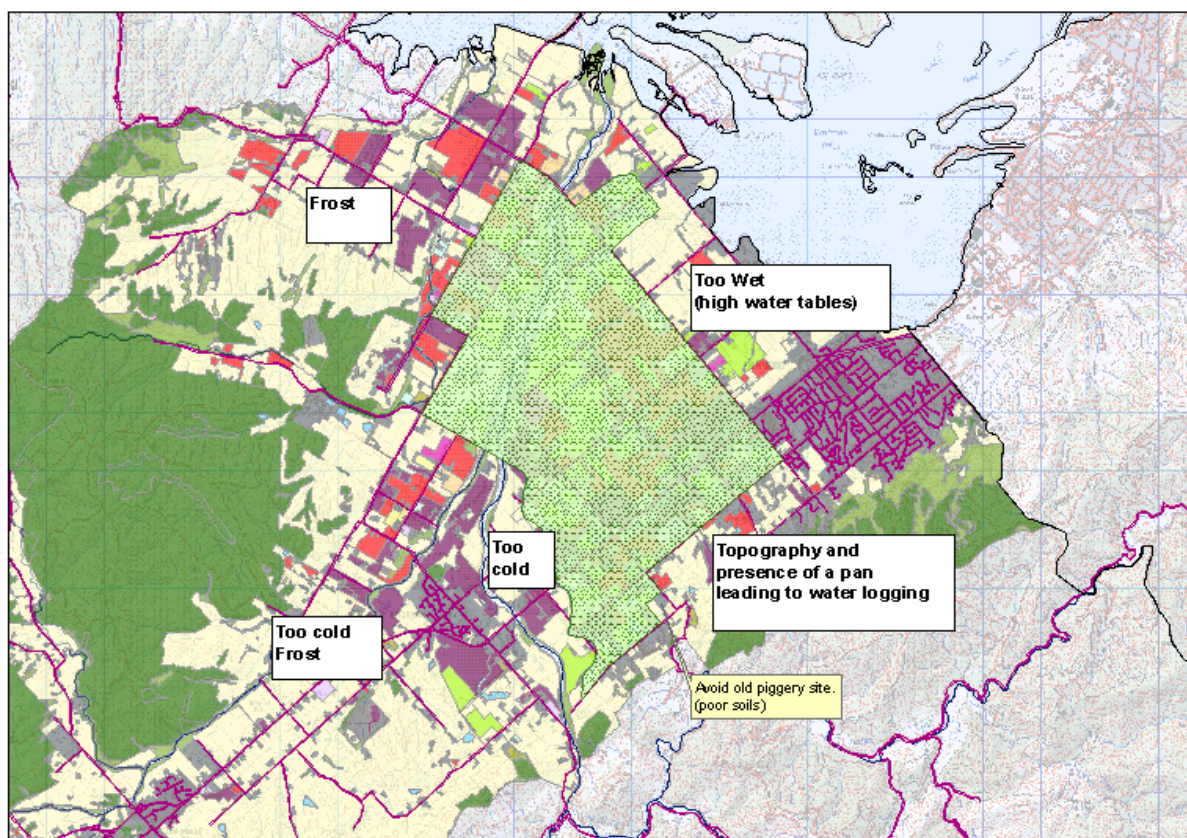


Figure 1 Potential market gardening area (dappled green)(Pierre Gargiulo, via Glenn Stevens TDC)

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.

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 et 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

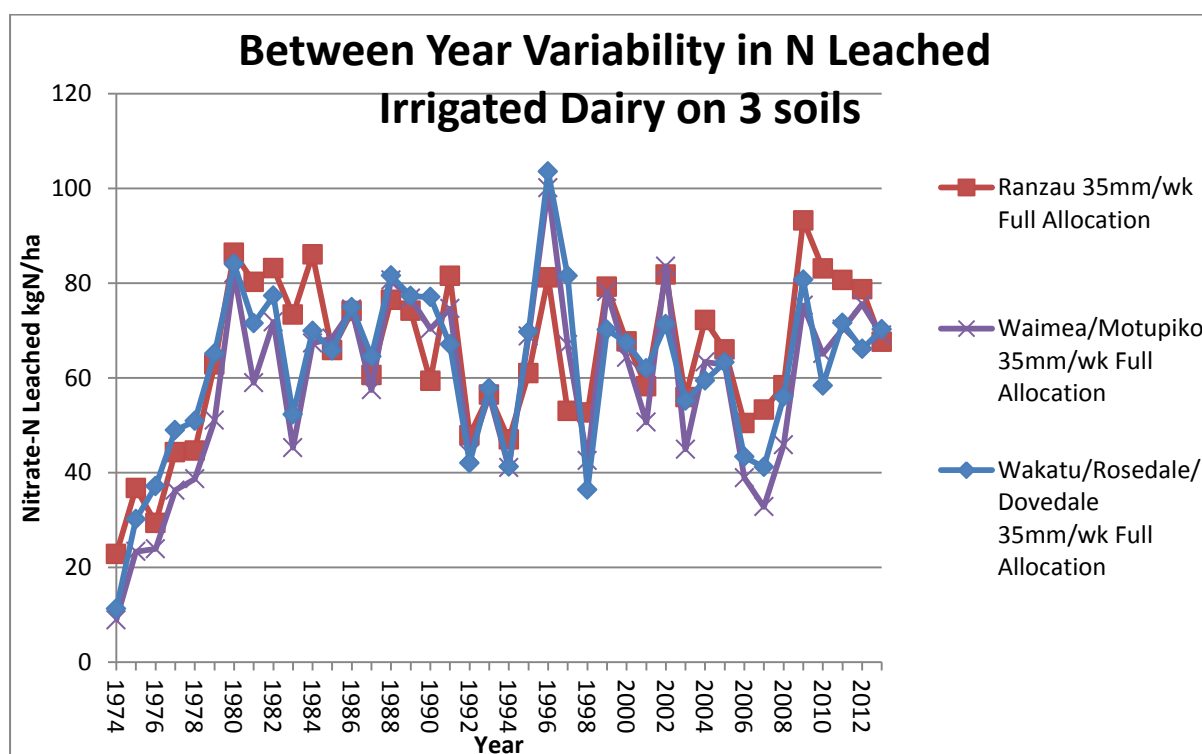


Figure 2 Year to year variation in N leaching from fully irrigated dairy farming for 3 soil groups. Average losses are 69 (Ranzau), 63 (Waimea) and 66 kgN/ha/yr (Wakatu). Modelled losses for 1974-78 are subject to model initialisation errors and have not been included in averages.

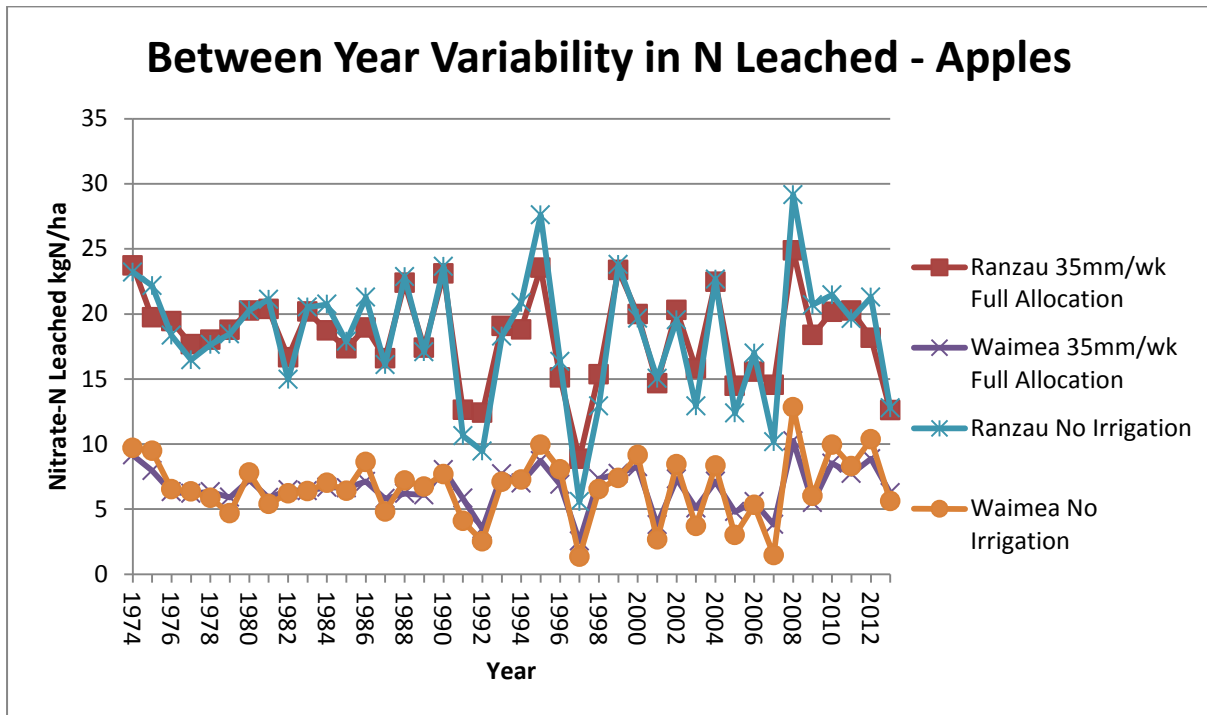


Figure 3 Year to year variation in N leaching from apples for Ranzau and Waimea soils. Fully irrigated average losses are 18 kgN/ha/yr (Ranzau) and 7 kgN/ha/yr (Waimea).

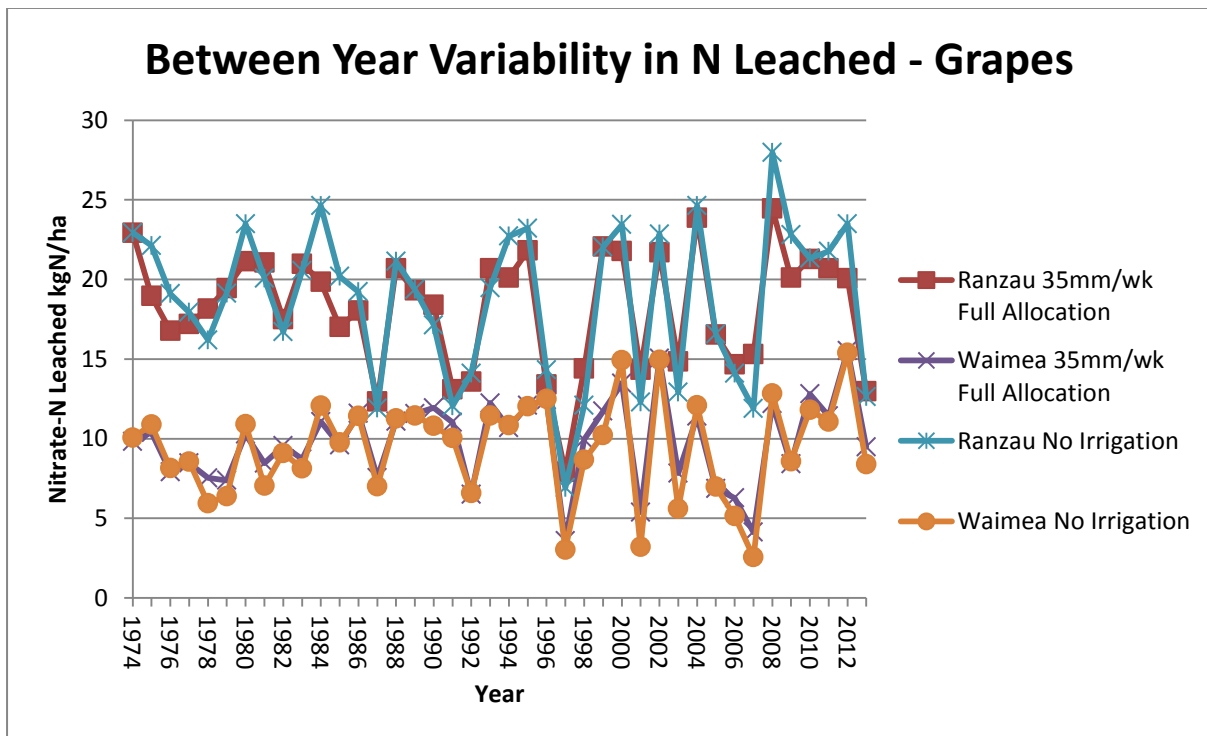


Figure 4 Year to year variation in N leaching from grapes for Ranzau and Waimea soils. Fully irrigated average losses are 18 kgN/ha/yr (Ranzau) and 10 kgN/ha/yr (Waimea).

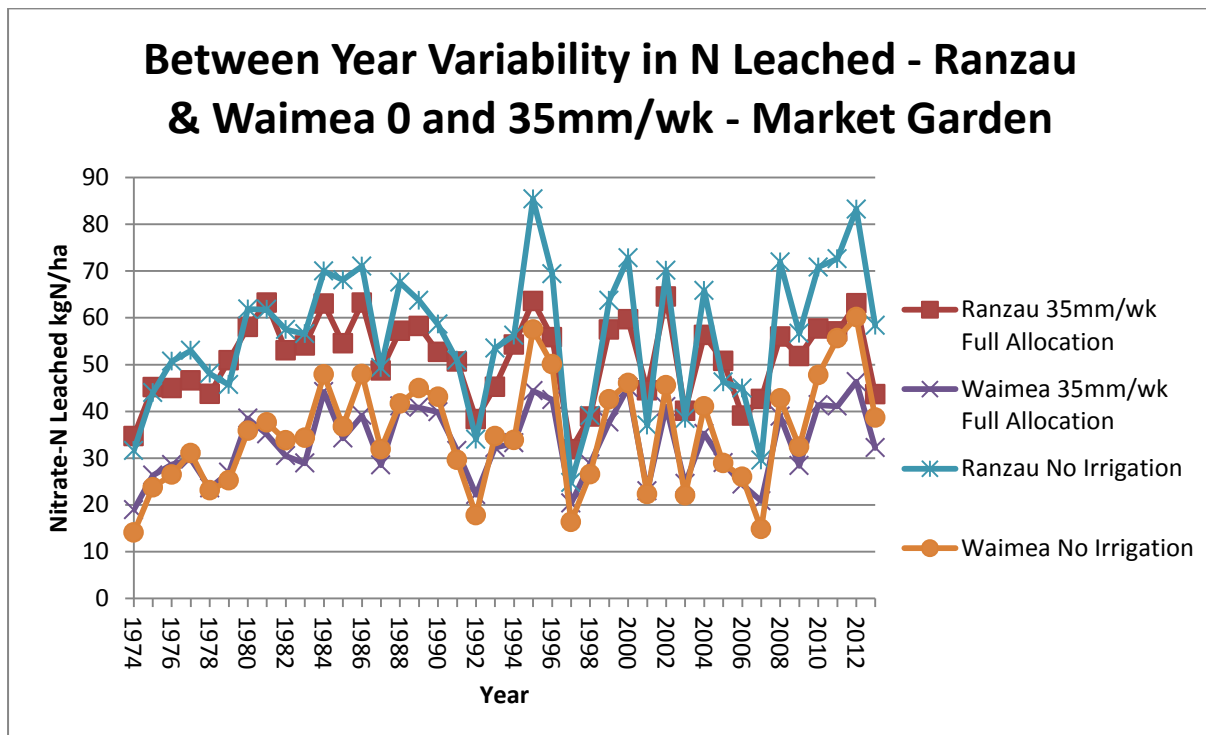


Figure 5 Year to year variation in N leaching from overall market garden for Ranzau and Waimea soils. Fully irrigated average losses are 51 (Ranzau) and 33 kgN/ha/yr (Waimea).

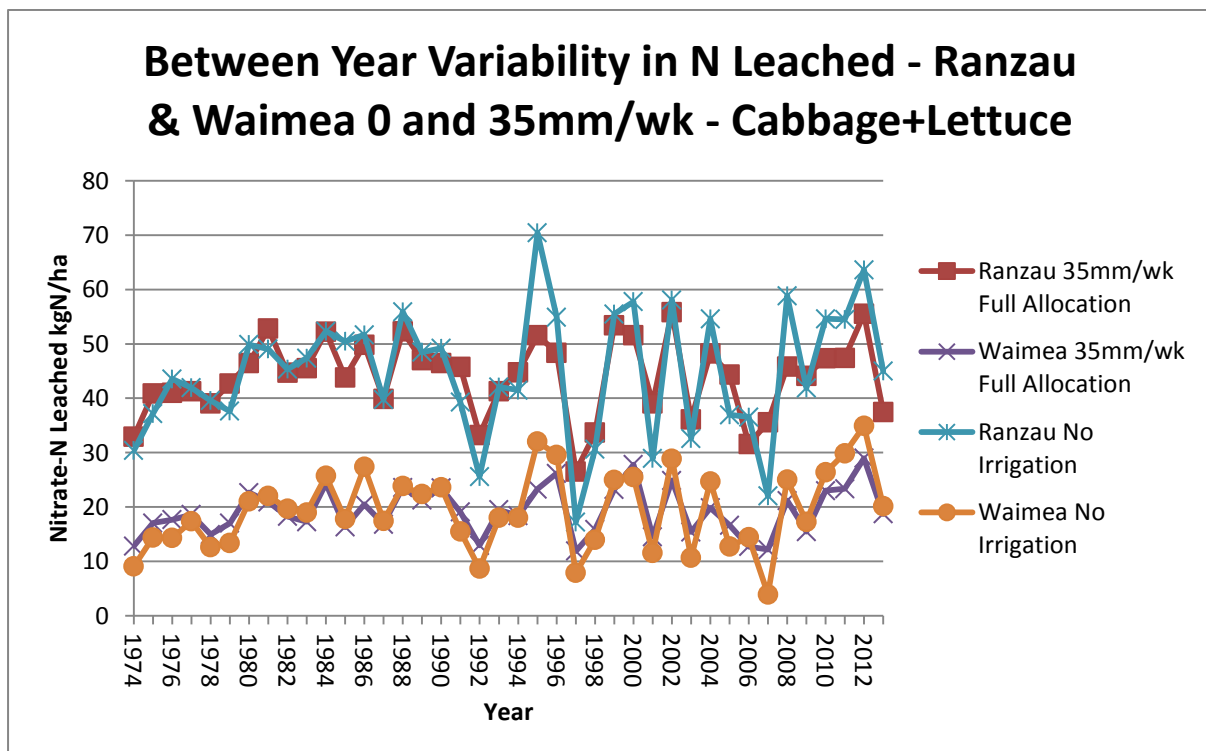


Figure 6 Year to year variation in N leaching from a cabbage/lettuce sequence for Ranzau and Waimea soils. Fully irrigated average losses are 44 (Ranzau) and 19 kgN/ha/yr (Waimea).

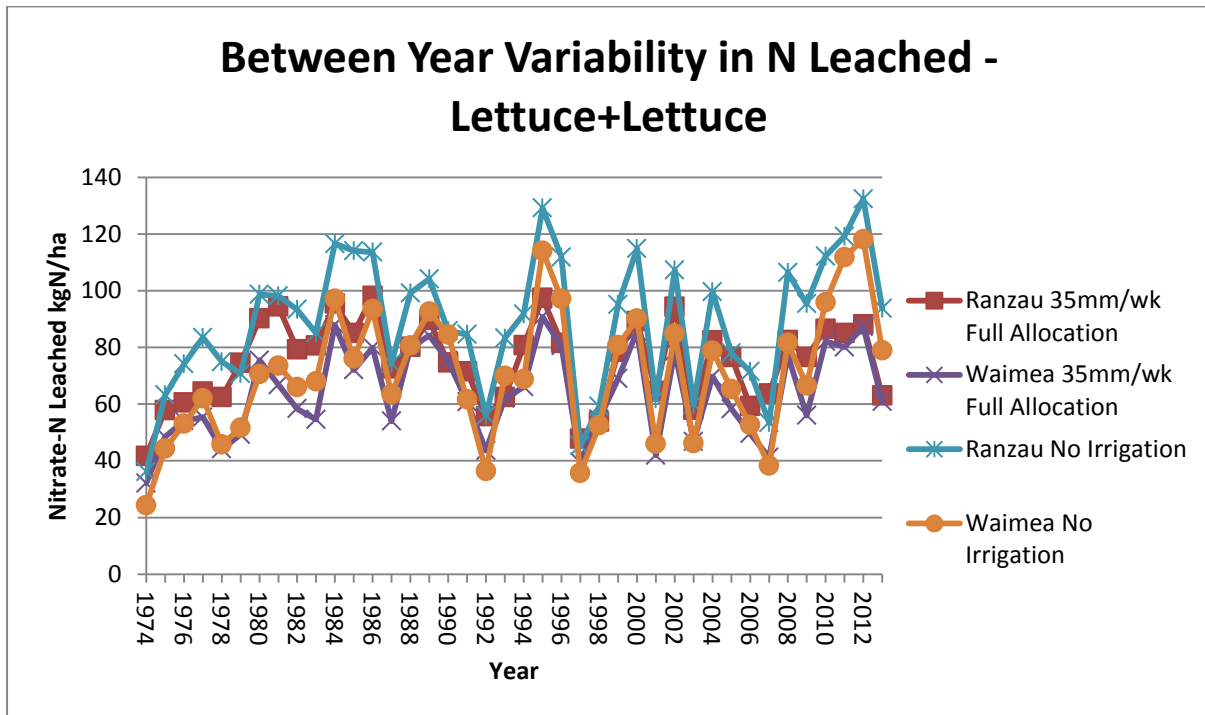


Figure 7 Year to year variation in N leaching from a lettuce/lettuce sequence for Ranzau and Waimea soils. Fully irrigated average losses are 75 (Ranzau) and 64 kgN/ha/yr (Waimea).

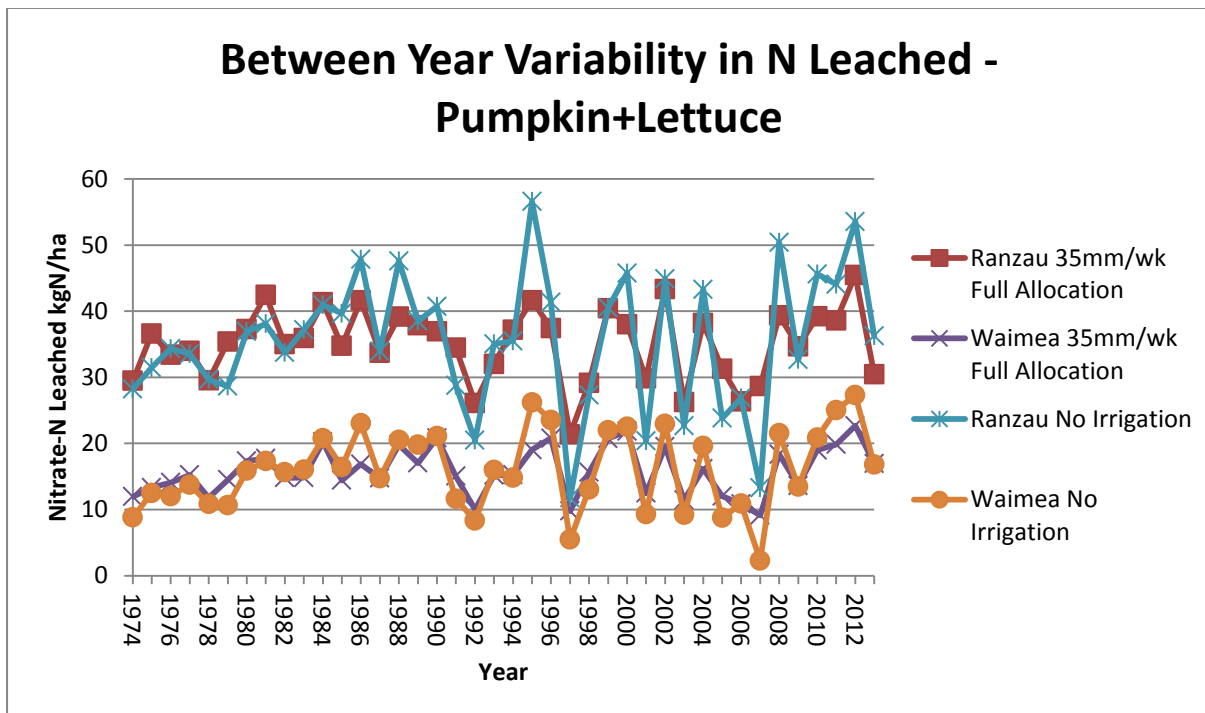


Figure 8 Year to year variation in N leaching from a pumpkin/lettuce sequence for Ranzau and Waimea soils. Fully irrigated average losses are 35 (Ranzau) and 16 kgN/ha/yr (Waimea).

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.

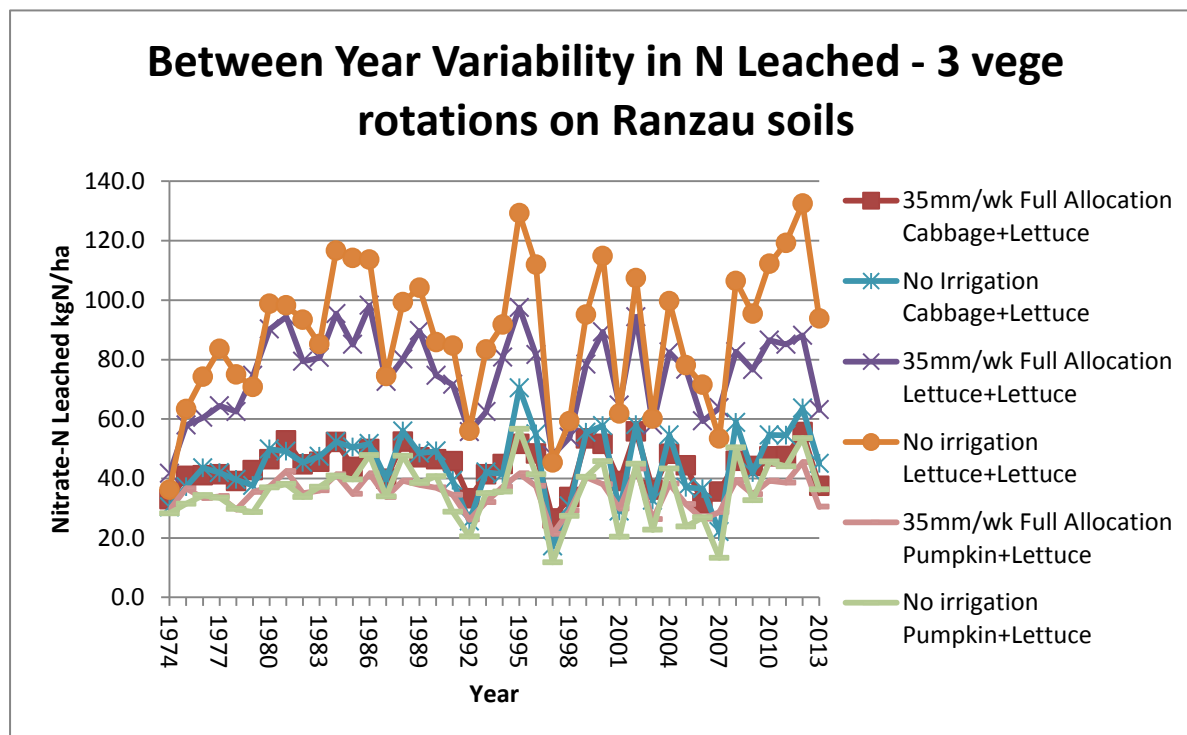


Figure 9 Year on year variability of nitrate losses from market gardening on Ranzau soils under various irrigation scenarios.

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.

Modelled Nitrate-Nitrogen Losses, Waimea lowland catchment

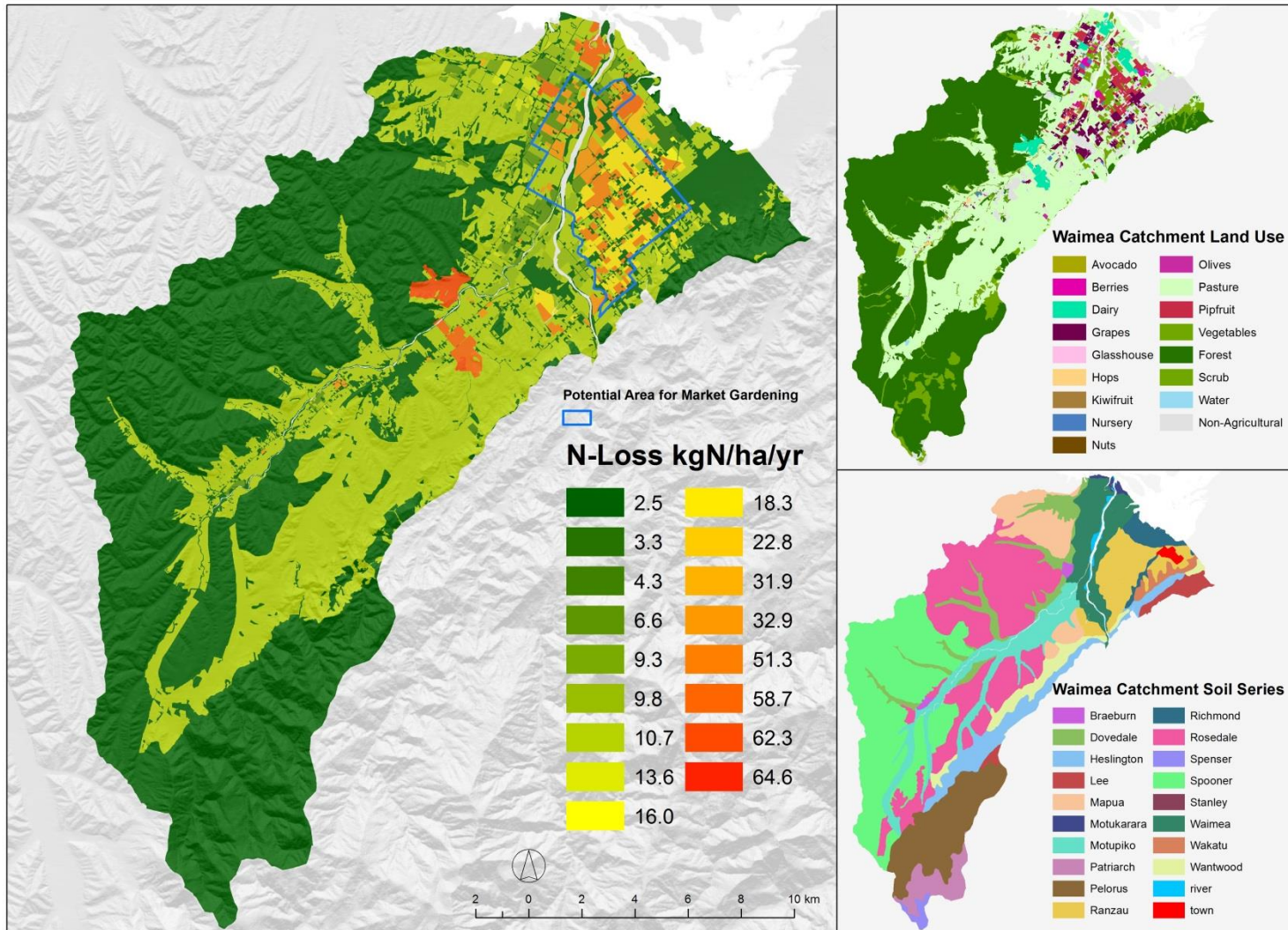


Figure 10 Modelled nitrate losses, land use and soil series for the Waimea lowland catchment.

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

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

Waterbodies	Objectives				Limit macroalgal blooms in the Waimea Inlet
	Safe for swimming	Safe drinking water	Limit risk of nitrate toxicity	Control freshwater periphyton growth	
Waimea River	95 th percentile values of <i>E. coli</i> shall be <260 /100mL	N/A	Annual average NO ₃ -N shall be <2.4 mgN/L and annual 95 th 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 95 th percentile shall be <10 mg/L**	Dissolved reactive phosphorus concentrations <0.026 mg/L	
Groundwater	N/A	No <i>E. coli</i> detected; 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 = $e^{0.9518 \cdot \ln(\text{Hardness})} - \text{Constant}$, 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 CaCO₃/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).

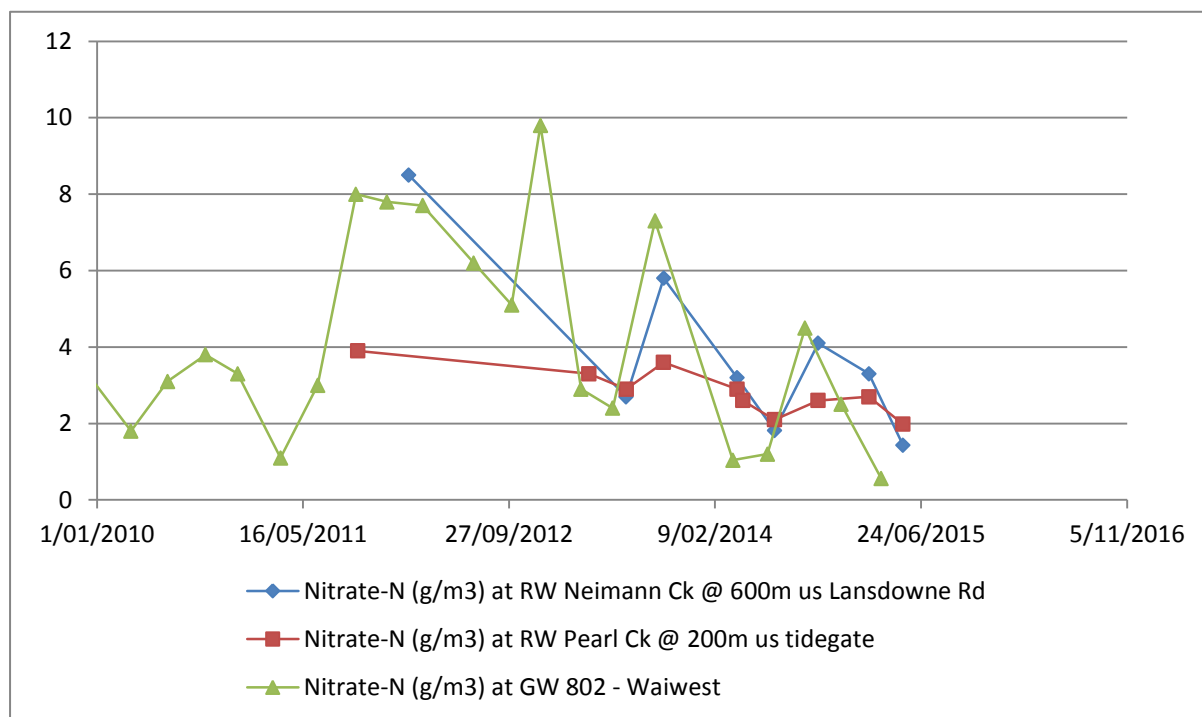


Figure 11 Measured nitrate concentrations (g/m^3) since 2010 in Pearl and Neimann creeks and well 802 upstream of Neimann Creek (Glenn Stevens, TDC, pers. comm.).

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.

Modelled Nitrate-Nitrogen Losses under Current Land Use, Waimea lowland catchment

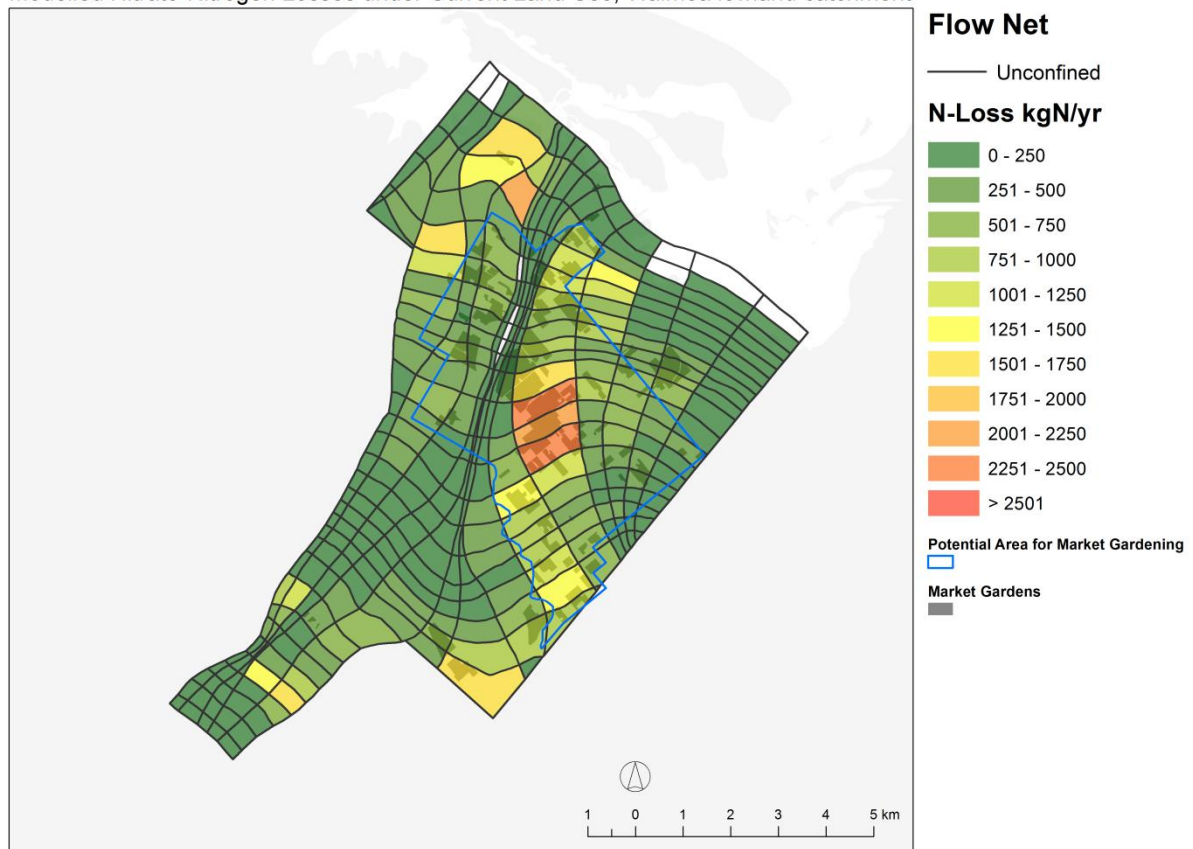


Figure 12 Nitrate losses by flow net cell for current land use.

Modelled Nitrate-Nitrogen Losses with additional 200ha Vegetables, Waimea lowland catchment

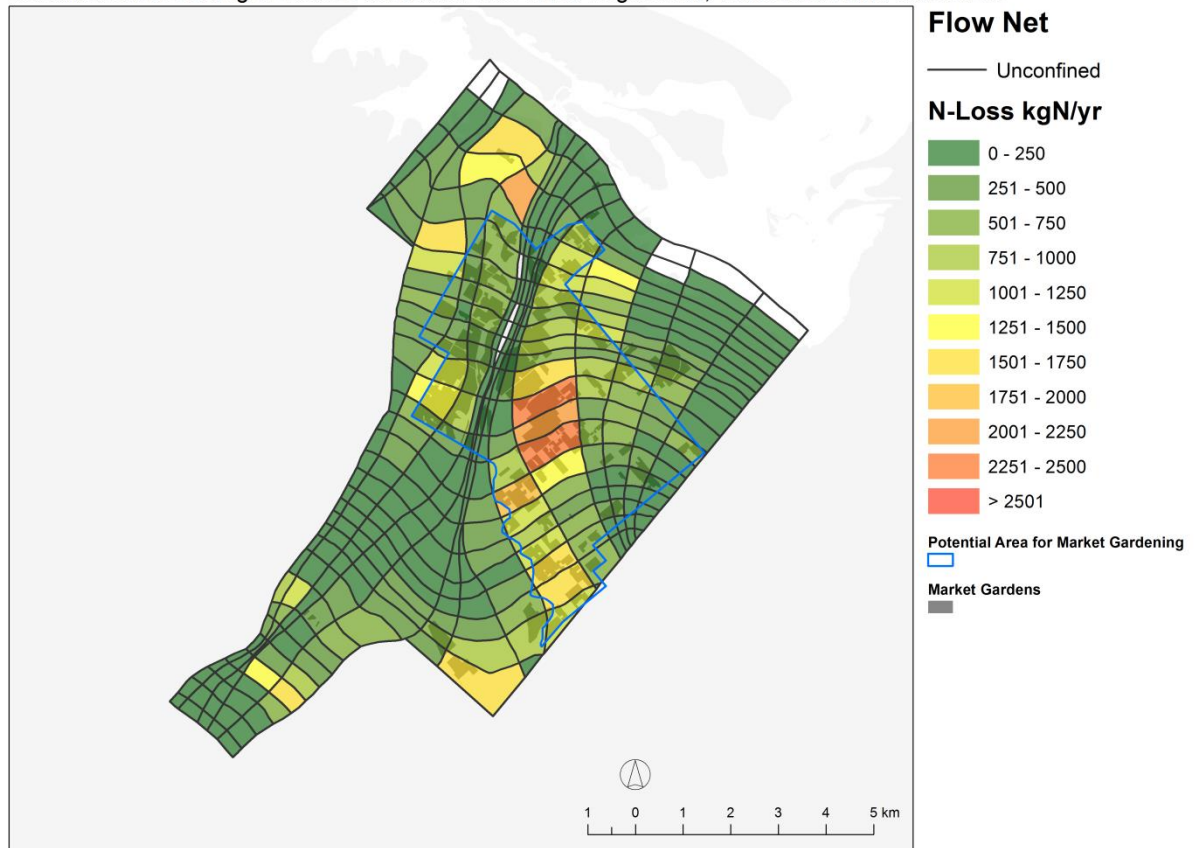


Figure 13 Nitrate losses by flow net cell for current land use plus 200 ha outdoor vegetable growing (with all vegetable growing shaded).

Modelled Nitrate-Nitrogen Losses with additional 316ha Vegetables, Waimea lowland catchment

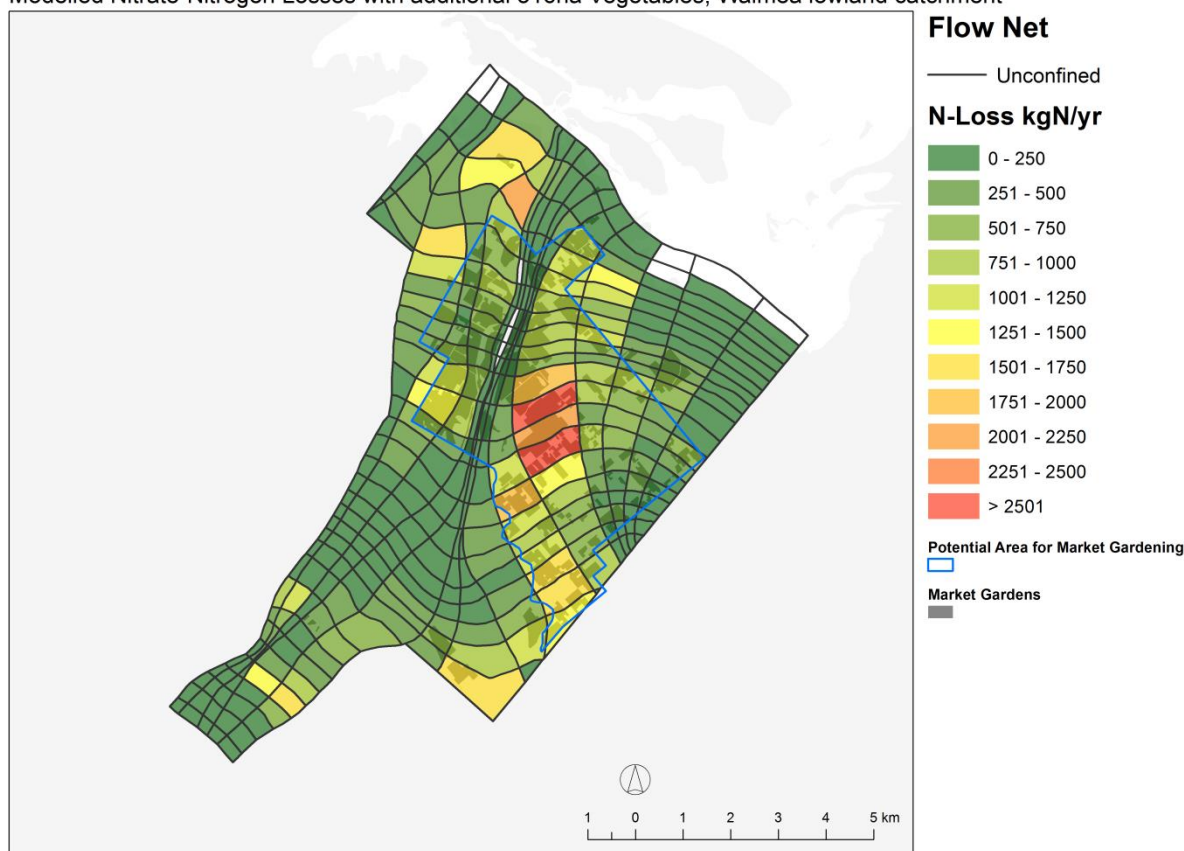


Figure 14 Nitrate losses by flow net cell for current land use plus 318 ha outdoor vegetable growing (with all vegetable growing shaded).

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/m³ 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/m³. 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

Market gardening scenario	Pearl Creek (mean flow ~ 278 l/sec)			Neimann Creek (mean flow ~ 166 l/sec)			GW802
	Calculated average contributing nitrate load, kgN/yr	Calculated nitrate concentration, g/m ³	<u>Measured</u> nitrate concentration (2011–15, n=8), g/m ³	Calculated average contributing nitrate load, kgN/yr	Calculated nitrate concentration, g/m ³	<u>Measured</u> nitrate concentration (2011–15, n=10), g/m ³	<u>Measured</u> nitrate concentration (2011–15, n=14), g/m ³
Current Land Use	13.4	2.05		22.1	5.56		
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	2.86	25.0	6.29	3.86	4.79
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.

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