Manaaki Whenua
Landcare Research

Modelling of nitrate losses and impacts from Waimea Plains rural land uses

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Modelling of nitrate losses and impacts from Waimea Plains rural land uses

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Summary

Project and client

Tasman District Council (TDC) commissioned Manaaki Whenua – Landcare Research to evaluate nitrate losses from various land uses, and to better understand the consequences in aquifers and downstream surface waters under current and potential future land-use patterns

The project models nitrate-nitrogen contaminant losses to groundwater and to the downstream waters of the Waimea Plains, Tasman, for land uses mapped in 2020, and for current management practices assessed from a horticultural land-user survey by Horticulture New Zealand (HortNZ). This updates earlier research on nitrate losses modelled for the years 1974–2013 using the SPASMO model of Plant & Food Research Ltd, and reported by Fenemor et al. (2016). This report stands alone, but for completeness should be read in conjunction with the earlier report.

Objectives

The results are intended to support TDC in setting freshwater quality limits for the Waimea catchment, as required under the National Policy Statement for Freshwater Management 2020 by December 2024. The results may also help industry and land users to determine what changes in fertiliser and land management practices may be required to achieve potential water quality limits. Nitrogen is the focus because nitrate concentrations exceed aquatic toxicity and/or periphyton limits for spring-fed streams and drinking-water standards in some aquifers.

Methods and results

Modelling of nitrate–nitrogen ('nitrate') leaching losses was carried out using daily inputs to the SPASMO model. The results are reported for the 48 years 1973–2020 for pipfruit, dairy, grapes, outdoor vegetables, hops, kiwifruit, and nursery land uses on the four major soil groups of the Waimea Plains. Table S1 summarises the modelled nitrate losses.

Table S1. Summary of modelled nitrate losses

	Pipfruit	Dairy	Grapes	Outdoor veges	Hops	Kiwifruit	Nurseries	Lifestyle blocks*	Forest & scrub**
Average N-NO_3 loss kg N/ha/yr	16	60	10	49	23	10	26	10.7	2.5
Range	7–28	26–77	4–17	19–86	9–34	4–17	15–37	-	-

* Represents SPASMO modelled losses for extensive sheep & beef farming.

** An average value adopted from the literature.

The highest rates of loss on the plains part of the Waimea catchment, according to the SPASMO modelling, are from dairy and outdoor vegetable production, followed by nurseries, hops, pipfruit, kiwifruit and grapes. 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. Analysis of monthly nitrate losses shows that the vulnerable months for losses are the winter months June to October. As reported in Fenemor et al. 2016, for a given land use, soil water-holding capacity has the greatest influence on nitrogen losses.

Modelling the effect on nitrogen losses of the late application of fertiliser on apples did not show the expected increase in nitrate loss. Modelling of lower rates of use of nitrogenous fertiliser on outdoor vegetables did reduce nitrogen losses, but to a lower extent than expected. These scenarios showed the over-riding influence of soil characteristics ('leakiness') in governing leaching.

The total modelled nitrate loss from the 40,600 ha of the lowland Waimea catchment is 324 tonnes per year, compared with 287 tonnes per year calculated in Fenemor et al. 2016. The difference is due both to changes in land use and to improved modelling of current farm systems. Outdoor vegetables, pipfruit, dairy, grapes, and nurseries are the top five sources of nitrate load leaching to waters within the Waimea Plains.

Groundwater flow tube analysis of modelled nitrate losses for 2020 land uses gave a nitrate concentration of 2.75 g/m^3 in the spring-fed Pearl Creek west of the river mouth, which is close to measured median value from 2011-2016. In the spring-fed Neimann Creek of the eastern plains, this groundwater flow tracking gave a concentration of 8.73 g/m^3, more than twice the measured median value from 2011-2022, suggesting there may be further nitrate load to come from recent upstream changes of land use.

Conclusions

Measured median nitrate concentrations exceed nitrate toxicity national bottom lines prescribed under the National Policy Statement for Freshwater Management 2020 by around 20%, and in some localities, such as Appleby, groundwater nitrate concentrations exceed drinking-water standards. This indicates that reductions in current loads from land uses contributing flow to those streams and aquifer localities will be needed, and that there is no 'headroom' for further intensification of land uses.

1 Introduction

Tasman District Council (TDC) is required under the National Policy Statement for Freshwater Management 2020 (NPSFM 2020) to set catchment objectives and limits for water quality across all freshwater management units, including the whole Waimea catchment, in a proposed regional plan to be publicly notified by December 2024. TDC's work includes consideration of potential policy and rules that could apply to land uses and management practices likely to be causing excess contaminant concentrations or loads in receiving waters such as the Waimea aquifers, spring-fed streams, and Waimea Inlet.

By way of context, a review of over 50 years of monitoring across the Waimea Plains (Fenemor 2020) focused on nitrate-nitrogen ('nitrate') has shown that some intensive land uses across the Waimea Plains will require specific attention, because nitrate concentrations in parts of the Waimea aquifers and spring-fed streams exceed national bottom line limits.

Modelling of nitrate leaching losses, their attenuation within the Waimea aquifers, and assessment of concentrations reaching the spring-fed Neimann and Pearl Creeks (Figure 1) was reported to TDC in Fenemor et al. 2016 for land uses mapped as at 2013. Following discussion of the modelling at a public meeting on the nitrate issues, and in discussion with horticulturists whose land uses comprise a major proportion of the Waimea Plains, it was agreed to update the modelling with better information on current land uses, land management, and fertiliser regimes. The updated information comprised a 2020 land-use survey carried out by TDC in the summer of 2019/20, and a survey of a sample of horticulture producers funded by HortNZ and carried out by Mike Nelson of Fruition Horticultural Consultants (Nelson & Dryden 2022), with input from Stuart Ford of the Agribusiness Group.

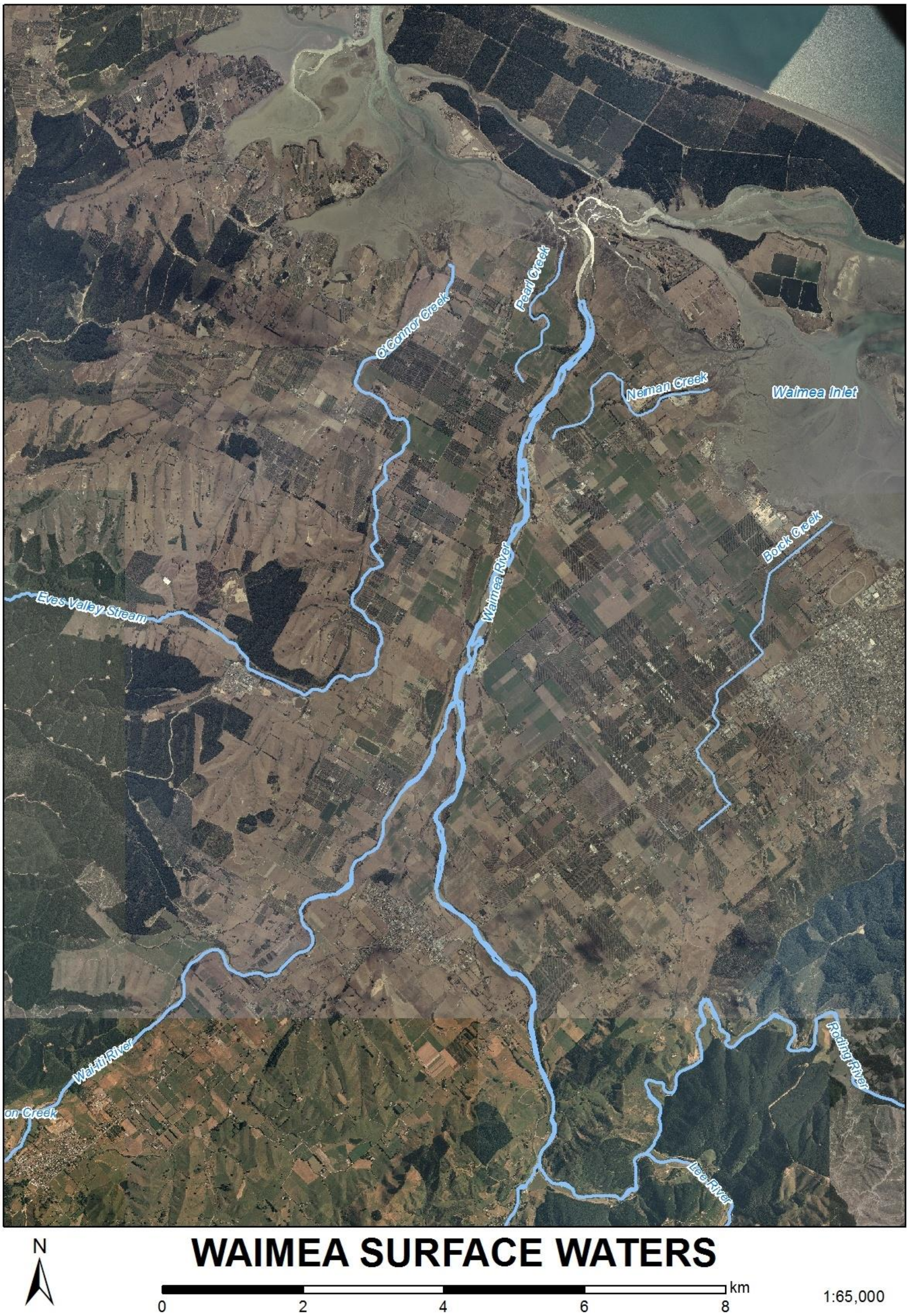

Figure 1. Receiving surface waters of the Waimea basin (from Fenemor et al 2013).

TDC has commissioned this updated modelling work to evaluate nitrate losses from various land uses, and to better understand the water quality and aquatic ecosystem consequences in aquifers and downstream surface waters under current and potential future land-use patterns. The project was funded under Envirolink grant 2212-TSDC180 (http://www.envirolink.govt.nz/).

2 Approach taken

2.1 Overview

The modelling carried out in 2022-23 replicates the approach used in 2015 but updates the farm systems modelled with current data ('farm system proxies') and extends the period for which nitrate leaching losses were modelled to cover the years 1970–2020.[1] The Plant & Food Research SPASMO model (Green et al. 2012) has been further upgraded to accommodate repeated multi-year cycles of crops, specifically for outdoor vegetable production.

Modelled results have been applied in this project to create catchment maps of nitrate losses to groundwater for current land use. Steady-state maps of groundwater flow direction ('flow nets') from Fenemor 1988 have been superimposed to calculate aggregated nitrate losses into the spring-fed Neimann and Pearl Creeks. Receiving waters for leached contaminants are the three aquifers, plus the Waimea River, spring-fed streams, and the Waimea Inlet (Figure 1).

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 can be placed on projected concentrations for assumed future land uses.

2.2 What is a farm system proxy?

A proxy is a description of a farm system in terms of areas of specific crops and age profiles, where relevant, plus fertiliser and production assumptions. The latter are expressed as the type of fertiliser used, its application rate, and the day of the year applied for each crop. Each scenario is run in the SPASMO model repeatedly for each year of the daily climate records simulated (1970–2020).

Section 3 of Fenemor et al. 2016 contained a summary of the 2015 farm systems identified as representative of pipfruit orcharding, dairying, winegrowing, and outdoor vegetable production. In this updated work these representative farm systems are described as proxies, as described in section 4, because they describe averaged management regimes for each type of land use.

[1] Because of the time required for model outputs to stabilise, results are presented for 1973–2020 rather than 1970–2020

Because of concern that the earlier system descriptions may not accurately reflect current practice, especially fertiliser regimes, the updated proxies are derived from horticultural grower surveys (Nelson & Dryden 2022) and from information provided by Sustainable Winegrowers (E. Massey, pers. comm.) and some individual growers. Where updated data were not available, the previous proxies have been re-used and provide a basis for a comparison of 2015 vs 2022 results.

2.3 What is a model scenario?

A model scenario predicts nitrate losses from each combination of crop, climate, and soil type. The crop component is the land use or farm system proxy described above and detailed in section 4. The climate component is the daily record of rainfall (and irrigation, where applicable) and climate parameters for specified zones of the Waimea Plains. An initial proposal was to separate the plains into two climate zones, because annual rainfall in the northern area, as represented by the Nelson Airport record, is less than along the southern area around Brightwater and Wakefield (c. 990mm vs c. 1,200 mm). However, due to the need to run double the number of scenarios with two climate components, and a limited budget, we have reverted to the single representative climate site from Hope used in the 2015/16 work (NIWA's VCSN site 20302).

The soil type component comprises the predominant soil types expressed in terms of their average hydraulic parameters, water-holding capacity or total available water (TAW = FC – WP)[2], with soil types grouped where those properties are similar within a group (see Table 3 in Fenemor et al. 2015). We model the same soil groups as in 2015/16. The same soil hydraulic parameters are used, except that Ranzau very stony silt loam now uses parameter values available from the National Soils Database (as opposed to local data), as shown in Table 1. Soils are shown in Figure 2.

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[2] FC is field capacity at which the soil moisture store is full; WP is wilting point for the crop beyond which the plant can no longer extract water from the soil profile; thus TAW is the total available water accessible to the plant within the soil profile when the soil moisture store is full

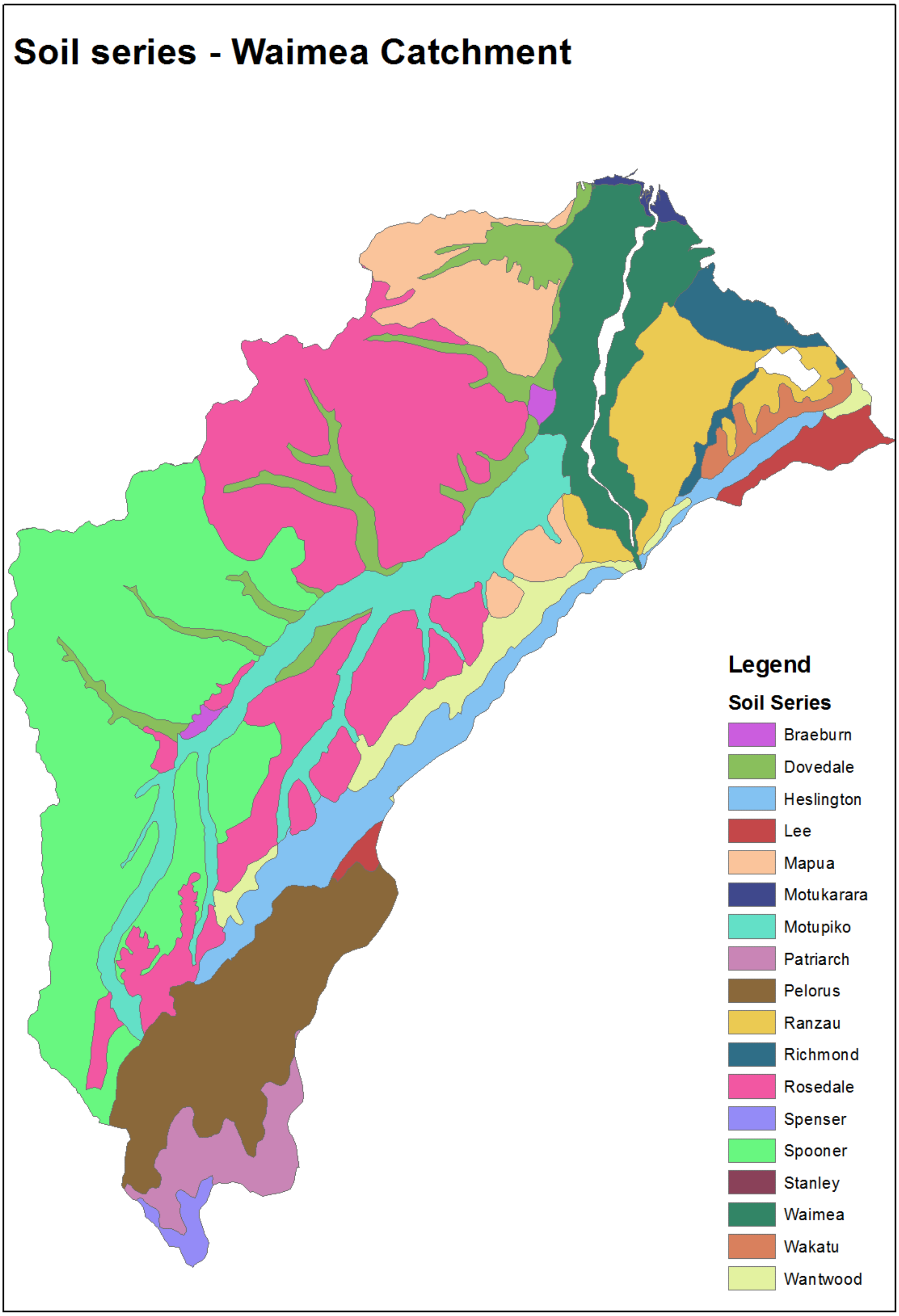

Figure 2. Soil series of the Waimea lowland catchment

Table 1. Soil groups and hydraulic parameters for 1 m soil depth

Soil #	Soil group	Saturated soil water content (mm)	Field capacity (FC, mm)	Stress point (SP, mm)	Wilting point (WP, mm)	Total available water (TAW = FC – WP, mm)	Plant-available water (PAW = FC – SP mm)
1	Dovedale silt loam (& Wakatu)	338	208	136	84	124	72
2	Ranzau very stony silt loam[3]	378	275	204	143	130	71
3	Richmond silt loam (& Heslington)	430	343	239	146	198	104
4	*Waimakariri deep silt loam*[4]	*475*	*278*	*142*	*70*	*208*	*136*
5	Waimea silt loam & sandy loam; (& Motupiko)	399	287	188	112	175	99

In summary, the heavier Richmond and Waimea soils will hold more water. The stony, gravelly Ranzau soil has lower water-holding capacity so it requires irrigating more often and leaches more nitrogen.

3 Waimea catchment land use, 2020

TDC completed an updated land-use survey for the Waimea lowland catchment in early 2020. Aerial photography analysis was combined with on-the-ground field checking and peer review by TDC staff. Minor adjustments were subsequently made to update land mapped as dairy in the Wai-iti Valley to hops and pasture. The summary table below from our MPI report (Fenemor et al. 2015) shows the changes in areas for consideration of the primary land uses (crop or farm systems) to model. Land use from 2020 is mapped in Figure 3.

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[3] Note that for the pre-existing kiwifruit simulation result provided by Zespri and used in this study, the Ranzau soil modelled was the Ranzau stony silt loam with SAT = 408, FC = 149, SP = 78, and WP = 38.

[4] The Waimakariri loam (italicised) was used as an earlier heavy soil proxy for the Waimea soil group; as it was modelled it has been included here

Table 2. Land-use areas, Waimea lowland catchment, 2020 and 2013

Land-use class	2013 area (ha)	2020 area (ha)	Primary soil classes	Comments on this class
Pipfruit, other tree crops	893	896	Ranzau (41%), Waimea (29%), Dovedale (9%)	Predominantly apples. Other tree crops include stonefruit, hazelnuts and macadamias (26 ha in 2020), and avocados (1 ha)
Berries	114	99	Waimea (87%), Ranzau (8%)	Raspberries, boysenberries
Dairy	615	259	Waimea (52%), Richmond (38%), Ranzau (7%)	Commercial-scale dairy farms (5 farms in 2013; 3 in 2020)
Grapes, olives	1,003	1,077	Waimea (35%), Ranzau (33%), Motupiko (10%)	Predominantly grapes; also olives (46 ha in 2020). Both have lower irrigation water demands
Outdoor vegetables	705	768	Waimea (49%), Ranzau (46%)	Commercial vegetable production rotations on owned and leased land
Hops	48	83	Motupiko (78%), Waimea (19%)	Commercial hops production
Kiwifruit	65	59	Waimea (81%), Ranzau (17%)	Commercial kiwifruit production
Nursery	114	313	Waimea (55%), Motupiko (22%), Ranzau (9%)	Comprises horticultural nurseries on leased land as well as permanent nursery production
Glasshouses	30	30	Waimea (52%), Ranzau (35%), Richmond (5%)	Permanent structures for commercial production of vegetables, and floriculture
Pasture	12,350	12,138	Rosedale (24%), Motupiko (17%), Mapua (12%)	Includes sheep & beef, grassed surfaces of lifestyle blocks
Scrub	2,159	2,170	Pelorus (29%), Spooner (12%), Motupiko (9%)	Includes riparian shrublands including willows
Forest	19,797	19,833	Spooner (42%), Rosedale (27%), Pelorus (15%)	Predominantly exotic pine plantings
Non-agricultural	2,691	2,855	Ranzau (25%), Waimea (14%), Motupiko (12%)	Includes buildings, roads, urban, industrial areas, curtilage
Water	61	61	Rosedale (23%), Mapua (19%), Motupiko (16%)	Rivers, significant streams, ponds, reservoirs
TOTAL AREA	**40,645 ha**	**40,645 ha**		

Comparison of 2020 and 2013 land-use areas shows that in the intervening 7 years the major changes have been increases of 7% area in viticulture, 9% in outdoor vegetable production, 73% in hops, and up to 175% in nursery production. These increases were balanced by decreases of 14% in the area of berries, 58% less area in dairying, 9% less land in kiwifruit, and 2% less in pasture.

Loss of productive land (e.g. the Richmond West urban development) is indicated by the 6% increase in non-agricultural land use. A caveat for the 175% increase indicated for nursery production is that some nursery land, particularly in the 2013 survey, may have been miscategorised from aerial photography as young orchard. This example highlights the potential inaccuracies in the land-use mapping, especially of different horticultural crops, which will in turn affect the spatially aggregated nitrate losses.

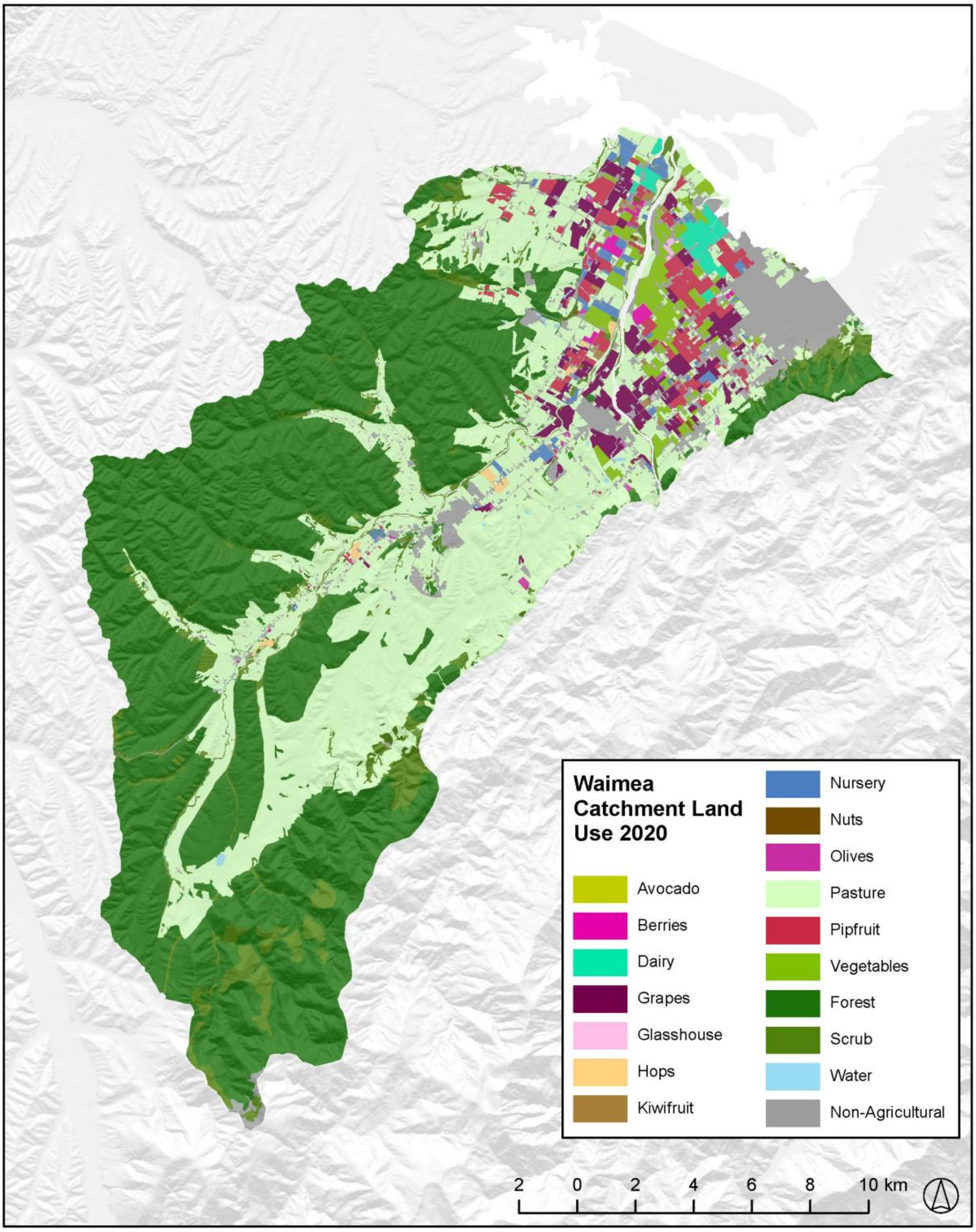

Figure 3. Land use, Waimea lowland catchment, 2020

4 Farm system proxies for modelling

This section details the modelling assumptions used for each farm system proxy and scenario simulated using the SPASMO model. Each farm system proxy requires data on crop type and age (where relevant), targeted production yield and fertiliser and management regimes. The scenario parameters are then selected and summarised in grey text for each farm system proxy.

4.1 Pipfruit proxy

Fruition surveyed Waimea Plains apple growers on their crop management regimes. They received responses from nine growers, representing 421 ha (58% of the area) of apples (Nelson & Dryden 2022). Averaging those responses, their recommended proxy is:

- for mature pipfruit orchard: assume a yield of 70 t/ha and annual nitrogen (N) application using CAN (calcium ammonium nitrate) each March at 25 kg N/ha
- for young pipfruit plantings: assume plant growth but no crop yield and annual N application between spring and mid-summer of 72 kg N/ha.

Scenario Group #1: We assume 90% of the pipfruit area is mature crop and 10% young plantings. The SPASMO model has been run for all five soil groups, and pipfruit on Cotterell and Māori soils has been assigned as having most similar N loss rates to Waimea soil. This scenario applies fertiliser in March for a mature orchard and October for a young orchard.

Scenario Group #2: Some pipfruit growers report they have been delayed from March to as late as May by weather or other management factors in fertilising mature orchard crops. This scenario applies fertiliser in May instead of March to evaluate how much delaying application into the wetter late autumn period could increase N losses.

4.2 Dairy proxy

There are approximately 650 dairy cows farmed in the central Waimea Plains on three farms. The dairy farm system has been based on data from Dairy NZ (2012) and for local farms (M. Langford and M. King, pers. comm.).

The model farm is 80 ha, with 2.75 cows/ha and a herd of 220 cows, with a targeted annual milk solids (MS) production of 1,450 kg MS/ha/yr and an average annual dry matter (DM) production of 16,000 kg DM/ha/yr.

When drought occurs, the farm first uses its own supplements, none of which are assumed to have been sold off the property. Bought-in DM supplements are limited to a maximum of 750 kg DM/ha/yr. 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 20% 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 one cow per hectare, with the remainder wintered outside the plains. Younger stock are preferentially wintered off. There are only approximately 60 cows winter milking on the Waimea Plains.

The fertiliser regime assumes 150 kg N/ha applied as five 30 kg/ha applications (including any minor contribution from dairy shed effluent application to the pasture).

Scenario Group #3: Dairying occurs predominantly on the heavier soil groups, Waimea and Richmond. The SPASMO model has been run for dairying on all five soil groups.

4.3 Grapes proxy

Sustainable Winegrowers NZ (SWNZ) have provided vineyard statistics for Nelson–Tasman but they are not available separately for the Waimea catchment. The SWNZ figures identify that Nelson vineyards apply 4.6 kg N/ha/yr (Ed Massey, pers. comm., 21 July 2022). These nitrogen results need to be treated with a degree of caution because it was the first year of including them in the SWNZ analysis. They compare with national average N fertiliser application rates of 4.3 and 5.2 kg N/ha/yr from other SWNZ sources. SWNZ also cites measured N losses in a Marlborough vineyard study (led by Steve Green) of 3-7 kg N/ha/yr, which compare with SPASMO-modelled 4.3–18.3 kg N/ha/yr from the previous Waimea modelling for grapes, and a national average N loss of 8 kg N/ha/yr (Clothier and Green, 2017).

For the grapes proxy 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 for the previous modelling with Phillip Woollaston of the former 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.

The fertiliser regime has been rounded to assume an average application of 5 kg N per year, noting that in some vineyards this is applied as an ‘organic’ form and would range from 0 to 20 kg N/ha/yr.

Scenario Group #4: Grapes are grown predominantly on the Ranzau and Waimea soil groups but have been modelled for all five soil groups. Pinot Noir and Sauvignon Blanc have been modelled separately because they represent the range of production yields for all varieties.

4.4 Outdoor vegetables proxy

It is challenging to derive a representative farm system proxy for outdoor vegetable growing because the combination of vegetable crops and management regimes varies from grower to grower. To achieve more representative proxies for outdoor vegetable growing than those used in the 2015/16 work, HortNZ commissioned the grower survey reported by Nelson and Dryden (2022).

For modelling purposes, all other farm system proxies use a recurring annual fertiliser regime, which is valid for permanent cropping such as orchards and vineyards. However, vegetable growing is carried out on rotations of more than 1 year, across different land parcels and with occasional fallowing of land.

Two combinations of outdoor vegetable crops have been identified as representative from the grower survey: (1) lettuces, leafy greens (e.g. spinach), and cabbages, and (2) cauliflowers and onions. To enable modelling on a recurring cycle across the 50 years of climate data, group (1) has been represented as an annual cycle and group (2) as a 15-month rotation, plus a 9-month lettuce then spinach crop to enable a 2-year recurring cycle for modelling purposes.

Four scenarios have been modelled, comprising one each of average practice reported by growers, and the second two for comparison using the standard fertiliser recommendations from the Nutrient management guideline for vegetable crops in New Zealand (Reid & Morton 2019).

Scenario Group #5: The SPASMO model has been run for winter lettuce, yielding 30 t/ha, followed by leafy greens (spinach), yielding 15 t/ha, then summer cabbage, yielding 60 t/ha[5] (but refer Table 3). This scenario is run for all five soil groups, with Redwood soils assigned as most similar to Waimea. As shown in Table 3, annual N application totals 240 kg N/ha, which compares with the average application rate assumed in the earlier work (Fenemor et al. 2016) at 400 kg N/ha/yr.

Scenario Group #6: Same as scenario #5 but with annual N application per nutrient management manual of 195 kg N/ha (see Table 3).

Scenario Group #7: The second outdoor vegetable modelled proxy comprises a 2-year cycle of cauliflowers yielding 45 t/ha, followed by onions (80 t/ha fresh), then lettuce / leafy greens, as per Scenario #5. This scenario is run for all five soil groups, with the onions crop grown May to January, the brassicas February to July, and the lettuces August to April. (In order to compare scenarios 5–8, Table 3 starts in August, which is mid-cycle for onions.) Fertiliser requirements per crop equate to 292.5 kg N/ha for onions, 368.4 kg N/ha for brassicas, and 197 kg N/ha for lettuces/leafy greens.

[5] An earlier simulation assumed a yield of 90 t/ha but the modelled yield achieved in the model was only 80 T/ha (using fertilizer application rates recommended at www.yara.co.nz). 90 t/ha is a winter cabbage yield. Scenario #5 targets a yield of 60 t/ha as this is the expected yield for summer cabbage.

Scenario Group #8: Same as Scenario #7 but with annual N application per nutrient management manual (see Table 3). Fertiliser requirements per crop equate to 108 kg N/ha for onions, 369 kg N/ha for brassicas, and 153 kg N/ha for lettuces / leafy greens.

Table 3. Outdoor vegetable crop and fertiliser recurring management regime assumed for SPASMO modelling

SCENARIO	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	TOTAL Kg N/ha/yr
Scenario #5		Lettuces		Harvest		Leafy greens sown			Cabbages		Harvest	Fallow	
N/ha applied	30	30	42			36		30	30	42			240
Scenario #6 N/ha applied	12	18	27			36		30	30	42			195
Scenario #7, year 1			Onions (ctd)			Harvest			Brassicas			Harvest	
Scenario #7, year 2		Lettuces		Harvest			Leafy greens				Onions sown		
Scenario #7 N/ha applied, year 1	60	81		38			26	81	90	81	90		547
Scenario #7 N/ha applied, year 2	30	30	41			36		30	30	36		78	311
Scenario #8 N/ha applied, Year 1		27		27			24	95	95	81	74		423
Scenario #8 N/ha applied, year 2	12	18	27			36		30	30	27		27	207

4.5 Hops proxy

Hops are an increasingly popular crop, although so far mostly in the upper Motueka Valley rather than the Waimea Plains. The fertility guide from the Hop Research Centre reports US data suggesting that typical first-year nitrogen requirements are 85 kg N/ha, increasing to 110–170 kg N/ha in subsequent years. Fruition reports that annual nitrogen use on hops in Tasman District averages 165 kg N/ha, split approximately as follows:

September	25kg/ha
October	33kg/ha
November	33kg/ha
December	41kg/ha
January	33kg/ha

Scenario Group #9: The SPASMO model has been run for all five soil groups, assuming the five nitrogen applications reported above, in the form of ammonia and nitrate, making a total annual application of 165 kg N/ha/yr.

4.6 Kiwifruit proxy

The Agribusiness Group (2015) reported a nitrogen loss value of 37 kg N/ha/yr for kiwifruit on the Waimea Plains using the Overseer model and assuming 120 kg N/ha/yr of fertiliser input. However, N loss rates of less than half that amount are shown from more recent SPASMO modelling of kiwifruit reported by Zespri, as shown in Table 4.

Table 4. Modelled long-term nitrogen loss rates in the Tasman region. SPASMO model inputs consider five predominant soil types in the region, average long-term rainfall of the region (1,031 mm), and addition of nitrogen fertiliser at a rate of 120 kg N/ha/yr.

Soil type	Nitrate loss Kg N/ha/yr		
	HW*	G3**	Weighted by variety (ha)***
Average	15.3	7.8	**11.8**
Maximum	31.2	12.0	**22.1**
Minimum	5.2	1.3	**3.4**
Bishopdale_silt_loam	31.2	12.0	**22.1**
Kairuru_silt_loam	9.8	8.3	**9.1**
Mapua_fine_sandy_loam	11.3	9.4	**10.4**
Ranzau_stony_silt_loam	19.0	8.1	**13.8**
Onahau_fine_sandy_loam	5.2	1.3	**3.4**

* Considering a mean regional productivity of 6,600 TE/ha, dry matter of 17.0 %, and tray weight of 3.6 kg/TE (TE is tray equivalent).

** Considering a mean regional productivity of 15,200 TE/ha, dry matter of 18.1 %, and tray weight of 3.3 kg/TE.

*** Values weighted by the green (223) and gold (200) ha in Tasman region, as per 2018.

Scenario Group #10: The SPASMO model results for the Ranzau soil group have been adopted, and, because the nitrogen losses are most similar to those for the grapes proxy, the grapes results have been applied pro rata to estimate kiwifruit N losses for the other soil groups.

4.7 Outdoor nursery proxy

The largest apple tree nursery grower across the plains advises that the average N application on their planted land has been 31.5 kg N/ha/yr, excluding allowance for fallowed land (G. Simpson, pers. comm.). They also use cover crops for 2 years between tree crops. A typical average regime is:

- year 1: no nursery planting; cover crops sown; no fertiliser applied to cover crops
- year 2: year 1 trees planted; nitrogen fertiliser is applied via fertigation through a dripline irrigation system from October to March, 186 kgN/ha total applied
- year 3: year 2 trees have N fertiliser applied via fertigation through a dripline irrigation system from October to March, 50 kgN/ha total applied.

Scenario Group #11: The SPASMO model simulations for young apple trees have been applied for outdoor nursery production, recognising that the result is a long-term average N loss.

4.8 Lifestyle blocks proxy

Lifestyle blocks have widely varying land uses, but generally of low intensity unless leased out for commercial use. Some are fertilised using organic products (e.g. Fertilizer NZ reports that their popular liquid fertilizer, Actavise, has 8% nitrogen), while some lifestyle blocks are not fertilised at all. We have assumed N loss rates (as in the previous work) to be similar to those from extensive sheep & beef grazing on the equivalent area.

Scenario Group #12: Extensive sheep & beef with the same N loss assumed across all soil types. As reported in Fenemor et al. 2016, we assigned annual nitrate-N losses of 10.7 kg N/ha/yr.

4.9 Other rural land uses

It has not been viable to model other crops with only small areas planted individually. We have assumed that berryfruit, olives, and small nuts have similar losses to pipfruit.

The land uses described in Table 2 as forest or scrub are mostly beyond the alluvial plains but do form part of the hydrologically contributing lowland catchment draining to the rivers, streams, and estuary. We have assumed the same annual N loss rate as in the earlier work (i.e. 2.5 kg N/ha/yr lost from forest and scrub land across all soil groups).

Nitrogen losses from urban stormwater have not been modelled in this study and are likely to be of less relevance as urban areas mostly drain to the north into the Waimea Inlet rather than to the aquifers and spring-fed streams of the Waimea Plains.

5 SPASMO nutrient-loss modelling, assumptions, and uncertainty

As described in Fenemor et al. 2016, all water and nutrient calculations have been carried out using Plant & Food Research's SPASMO model (Green et al. 2008, 2012). A brief summary of the SPASMO model is provided in section 4 of Fenemor et al. 2016. Further detail on the complexity of the model and the way in which crop phenology is modelled can also be found in Green at al. 2012, where SPASMO modelling is described for the Ruataniwha Plains.

However, it should be noted that since 2012 the SPASMO model has been further refined to simulate more realistically the drying off and feed import scenarios for dairy farms on the Waimea Plains. In order to simulate multi-year market gardening rotations, the model was run continuously for each annual crop sequence, then the two years' results were merged in alternate years. To validate the changes, calculated outputs for nitrate loss and soil water drainage were compared for both versions of the model and produced very similar results, even with a further 6 years (2015–2020) of climate data included.

Similar assumptions and uncertainties are used to those described in earlier work (Fenemor et al. 2016), albeit with improved farm system proxies and a longer climate data set this time. This modelling approach and GIS-based apportionment of nitrate losses across the plains provides a basis for evaluating changes in potential water quality outcomes for any specified policy option. More reliance should be put on the comparative scale of the modelled changes between options, rather than on the absolute modelled nitrate losses.

SPASMO has been verified for pipfruit and grapes in other regions, but ideally further lysimeter validation is needed to check its results and those of Overseer across a range of Waimea land uses, especially outdoor vegetable and hops production. Based on past validation research (eg Hardie et al 2022: Norris et al 2022), we consider that the SPASMO model adequately predicts actual nitrate leaching losses for the range of land uses and soils simulated, and that the assumed loss rates for land uses not directly simulated by SPASMO are valid as averages (e.g. lifestyle blocks where dryland sheep & beef has been used as the correlate; forestry and scrubland where a default loss has been adopted).

Because SPASMO calculates nutrient accumulation and losses cumulatively in the soil profile, the first 3 years of simulations (1970–73 inclusive) are ignored, because within this period the modelled nutrient processes are gradually stabilising from their initial conditions. As a result, the N losses reported below represent mean values for the 48 years 1973–2020 rather than the total daily climate period simulated (1970–2020).

6 SPASMO modelled nitrate-nitrogen leaching responses

The SPASMO model calculates nutrient losses below the root zone via leaching and runoff, including calculating N transformations within each soil layer. Losses due to runoff on the flat lands of the Waimea Plains are negligible and in the model they re-enter the soil N store at the land surface.

This section of the report summarises nitrate-N leaching losses *averaged* over the 48 years 1973–2020 inclusive, for apples, dairy, grapes, outdoor vegetables, hops, kiwifruit, nurseries, lifestyle blocks, and forest/scrub, on four soils (Tables 2 & 3). The 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, as described in Fenemor et al (2015)).

The effects of restricted irrigation water availability on production and N losses were reported in that earlier study (Fenemor et al. 2015) and showed little difference in annual

N leached for 100% water supply reliability compared with fully rationed irrigation scenarios. This is because N leaching is most strongly driven by rainfall events: land users generally avoid over-irrigation, which would lead to significant additional leaching. However, irrigated land will usually be farmed more intensively, and may have larger reservoirs of nutrients able to be flushed through when heavy rainfalls do occur.

Table 5 summarises the average modelled nitrate-N leaching losses for 1973–2020, summarised for primary Waimea catchment land uses (farm system proxies) in 2020, and for the four main soil groups. Table 6 breaks these modelled N losses down to monthly averages for the Ranzau soil group, so that the time of year for higher and lower loss rates can be seen. Figure 4 plots those monthly nitrate losses, and shows that the vulnerable months for nitrate losses are the winter months June to October.

Figures 5-11 plot the annual variability over 48 years in modelled nitrate leaching losses for current farm system proxies for pipfruit, dairy, grapes, outdoor vegetables (market gardening), hops, kiwifruit, and tree nurseries. Note that the vertical axes showing nitrate losses are 0–100 kg N/ha/yr for all farm systems except dairy and outdoor vegetables, where the scale is 0–200 kg N/ha/yr.

The figures show the distinct variability in leaching rates on permeable stony soils like the Ranzau soil group, with much lower nitrate loss rates on the heavier soils such as the Richmond group.

Table 5. Mean modelled nitrate-N losses from SPASMO modelling for 1973–2020, summarised for primary Waimea catchment land uses and four soil groups, kg N/ha/yr

Land use / farm system / scenario #	Ranzau soil	Waimea & Motupiko soils	Wakatu & Dovedale soils	Richmond & Heslington soils	Proxy soil for sheep & beef	Proxy soil for forest & scrub
Pipfruit – young	37 ± 8	29 ± 10	24 ± 7	15 ± 5		
Pipfruit – mature	27 ± 5	11 ± 3	14 ± 3	6 ± 1		
Pipfruit[b] (also applied to berries, avocados) #1	**28 ± 5**	**13 ± 4**	**15 ± 3**	**7 ± 1**		
Dairy pasture 1450kgMS/ha/yr #3	**77 ± 17**	**73 ± 20**	**63 ± 15**	**26 ± 11**		
Grapes – Sauvignon Blanc	17 ± 4	8 ± 2	10 ± 2	4 ± 1		
Grapes – Pinot Noir	17 ± 4	8 ± 2	11 ± 3	4 ± 1		
Grapes[c] #4 (also applied to olives, small nuts)	**17 ± 4**	**8 ± 2**	**11 ± 2**	**4 ± 1**		
Outdoor vegetables: spinach-cabbages-lettuces #5	44 ± 8	15 ± 4	14 ± 4	6 ± 2		
Outdoor vegetables: onions, caulis, lettuces, greens #7	129 ± 31	94 ± 30	60 ± 23	32 ± 16		
Outdoor veges averaged[d]	**86 ± 19**	**54 ± 16**	**37 ± 13**	**19 ± 9**		
Hops #9	**34 ± 7**	**22 ± 7**	**27 ± 8**	**9 ± 3**		
Kiwifruit[e] #10	**17 ± 7**	**8**	**11**	**4**		
Nursery[f] #11	**37 ± 8**	**29 ± 10**	**24 ± 7**	**15 ± 5**		
Lifestyle blocks, other pasture and non-agricultural land uses[g] #12					**11**	
Forest, scrub						**2.5**

a Note that in the equivalent table in Fenemor et al. 2016 N losses were reported as medians not means, as here. Mean values are slightly higher than the medians.

b Pipfruit nitrate losses were calculated assuming orchard has 10% young trees and 90% mature.

c Grapes nitrate losses were calculated based on respective varietal yields, so Pinot Gris losses are similar to Sauvignon Blanc (total 70% of area) and Chardonnay and other varieties are similar to Pinot Noir (30% of area).

d Average of N losses from both outdoor vege scenarios #5 and #7 (not a weighted average, as the areas represented by each vegetable growing rotation are not known).

e Kiwifruit N losses were previously assumed to be most similar to those of pipfruit, but SPASMO data from Zespri for Ranzau stony silt loam leached 11 kg N/ha/yr for G3 and 23 kg N/ha/yr for the HW varietal. We have averaged those two loss rates, then scaled results for other soils using the most similar proxy (grapes).

f N leached from nurseries is assumed to be the same as modelled for young pipfruit.

g Lifestyle block N losses were generalised as extensive sheep & beef land use, as per previous work in Fenemor et al. 2016.

Table 6. Mean monthly N losses for the Ranzau soil group for each farm system, kg N/ha/month, with months exceeding 4 kg N/ha/month highlighted yellow

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pipfruit: mature	1.1	0.5	0.4	0.7	2.1	3.4	3.8	3.6	3.3	3.3	2.9	2.2
Pipfruit: young	2.5	1.8	1.8	2.3	3.1	4.0	4.1	3.8	3.7	3.5	3.1	2.9
Pipfruit	**1.2**	**0.6**	**0.5**	**0.9**	**2.2**	**3.5**	**3.8**	**3.6**	**3.3**	**3.3**	**2.9**	**2.3**
Dairy	**5.1**	**4.0**	**5.0**	**5.6**	**7.3**	**8.4**	**8.5**	**7.9**	**7.0**	**6.9**	**6.0**	**5.7**
Grapes: Pinot Noir	1.2	0.6	0.5	0.6	1.3	1.9	2.1	2.0	1.8	1.9	1.6	1.5
Grapes: Sauvignon Blanc	1.1	0.6	0.5	0.6	1.3	1.9	2.2	2.1	1.8	1.9	1.7	1.5
Grapes	**1.1**	**0.6**	**0.5**	**0.6**	**1.3**	**1.9**	**2.2**	**2.1**	**1.8**	**1.9**	**1.7**	**1.5**
Outdoor veges: spinach-cabbage-lettuce	3.0	2.2	2.7	3.1	3.3	4.4	4.9	5.0	5.6	4.6	2.8	2.1
Outdoor veges: onion-spinach-cauli-lettuce	6.0	6.4	7.0	4.8	9.1	13.9	15.7	14.5	16.9	17.5	10.1	7.0
Outdoor veges: average	**4.5**	**4.3**	**4.8**	**4.0**	**6.2**	**9.2**	**10.3**	**9.7**	**11.2**	**11.0**	**6.5**	**4.6**
Hops	**1.2**	**0.5**	**0.5**	**0.9**	**2.7**	**4.4**	**4.7**	**4.5**	**4.1**	**4.2**	**3.8**	**2.3**
Kiwifruit	N/A											
Nurseries	**2.5**	**1.8**	**1.8**	**2.3**	**3.1**	**4.0**	**4.1**	**3.8**	**3.7**	**3.5**	**3.1**	**2.9**
Lifestyle blocks	N/A											

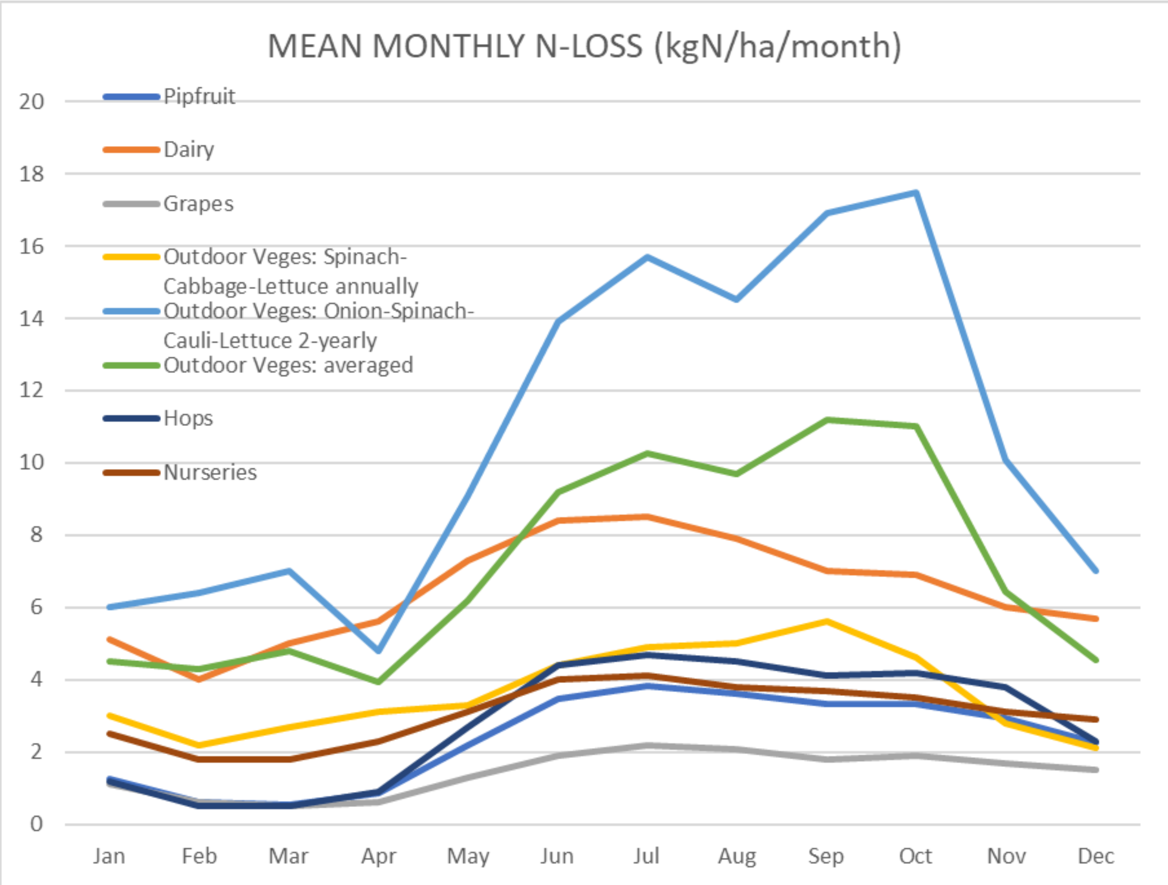

Figure 4. Mean monthly nitrate loss (kg N/ha/month) for major Waimea Plains farm system proxies on Ranzau soil group, 1973–2020. (Similar patterns but lower losses apply on other soil groups.)

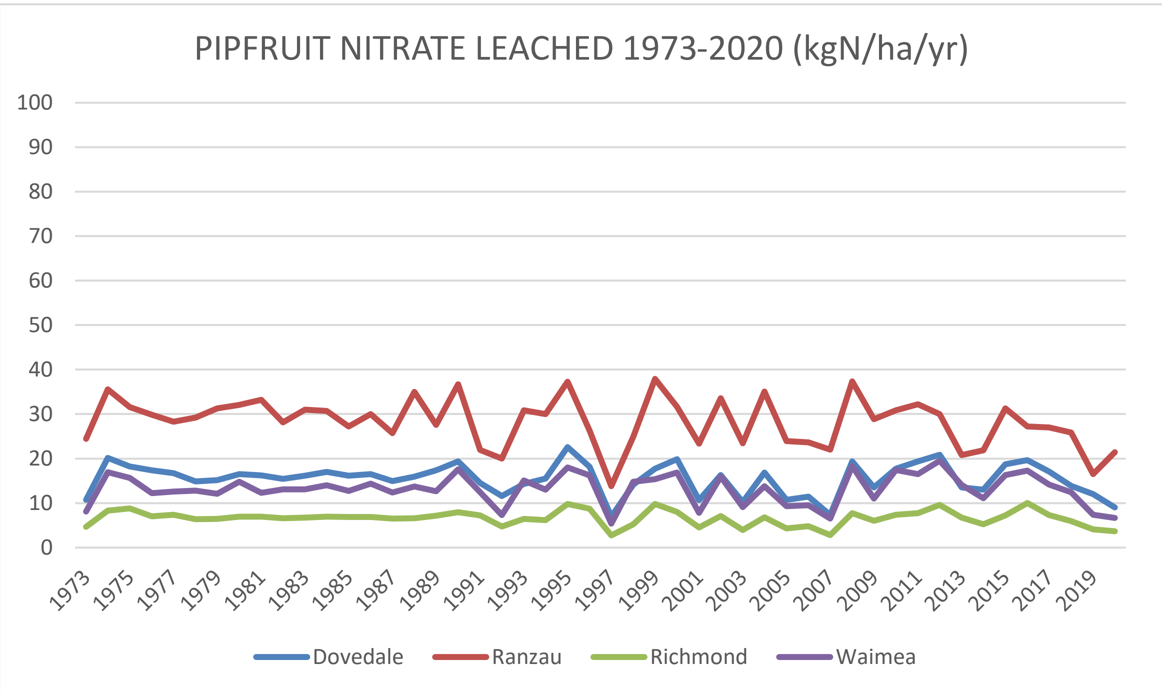

Figure 5. Year-to-year variation in N leaching (kg N/ha/yr) from pipfruit for four soil groups, 1973–2020. Average losses are 28 kg N/ha/yr (Ranzau), 15 (Dovedale), 13 (Waimea), and 7 (Richmond).

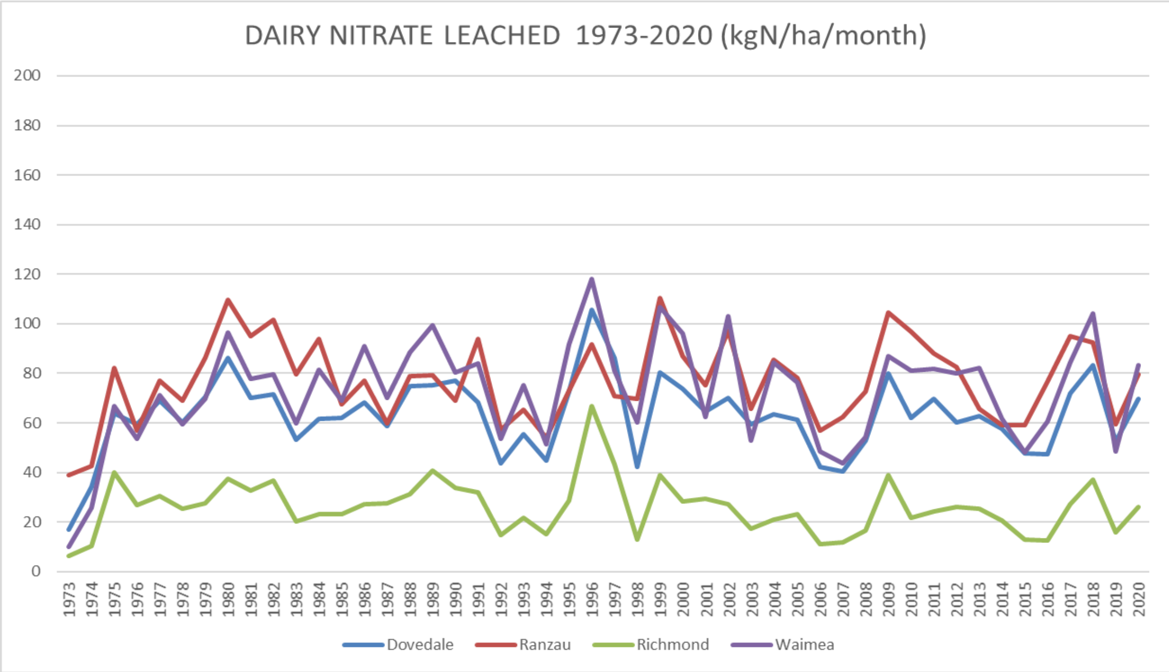

Figure 6. Year-to-year variation in N leaching (kg N/h/month) from dairy farming producing 1,450 kg MS/ha/yr for four soil groups for 1973–2020. Average losses are 80 kg N/ha/yr (Ranzau), 63 (Dovedale), 73 (Waimea), and 28 (Richmond). Note: vertical scale is 0–200 not 0–100.

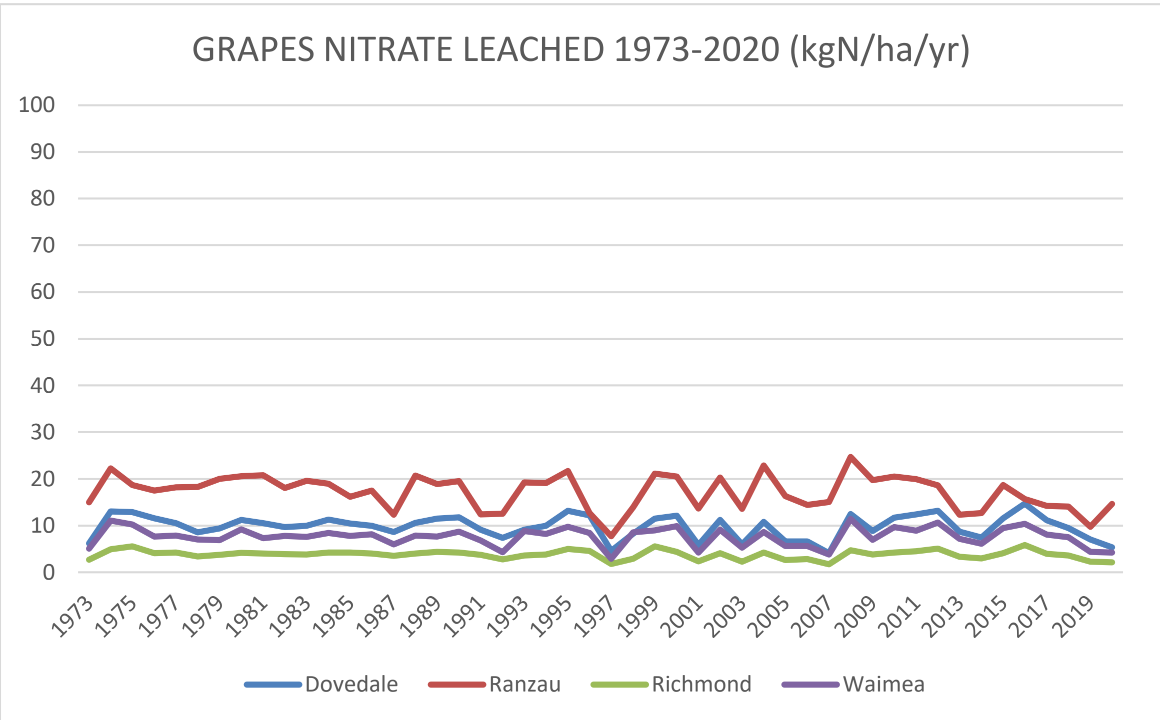

Figure 7. Year-to-year variation in N leaching (kg N/ha/yr) from grape vineyards for four soil groups for 1973–2020. Average losses are 17 kg N/ha/yr (Ranzau), 10 (Dovedale), 8 (Waimea) and 4 (Richmond).

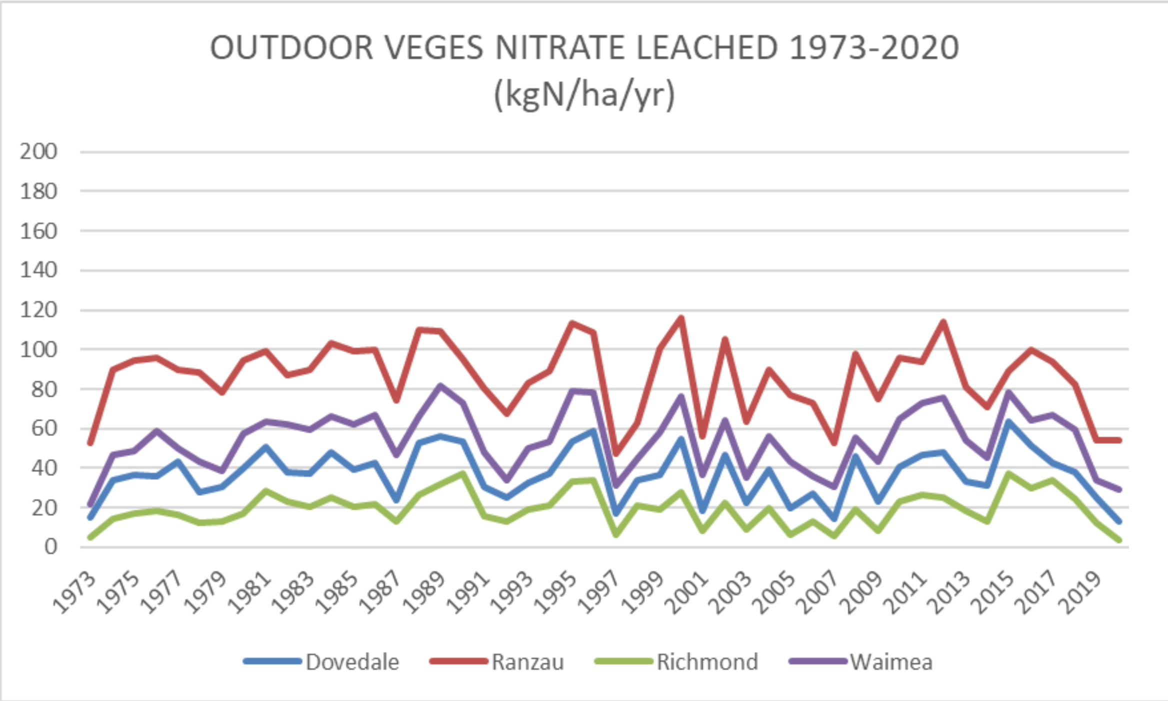

Figure 8. Year-to-year variation in N leaching (kg N/ha/yr) from average of the two outdoor vegetable scenarios for four soil groups, 1973–2020. Average losses are 86 kg N/ha/yr (Ranzau), 37 (Dovedale), 54 (Waimea), and 19 (Richmond). Note: vertical scale is 0–200 not 0–100.

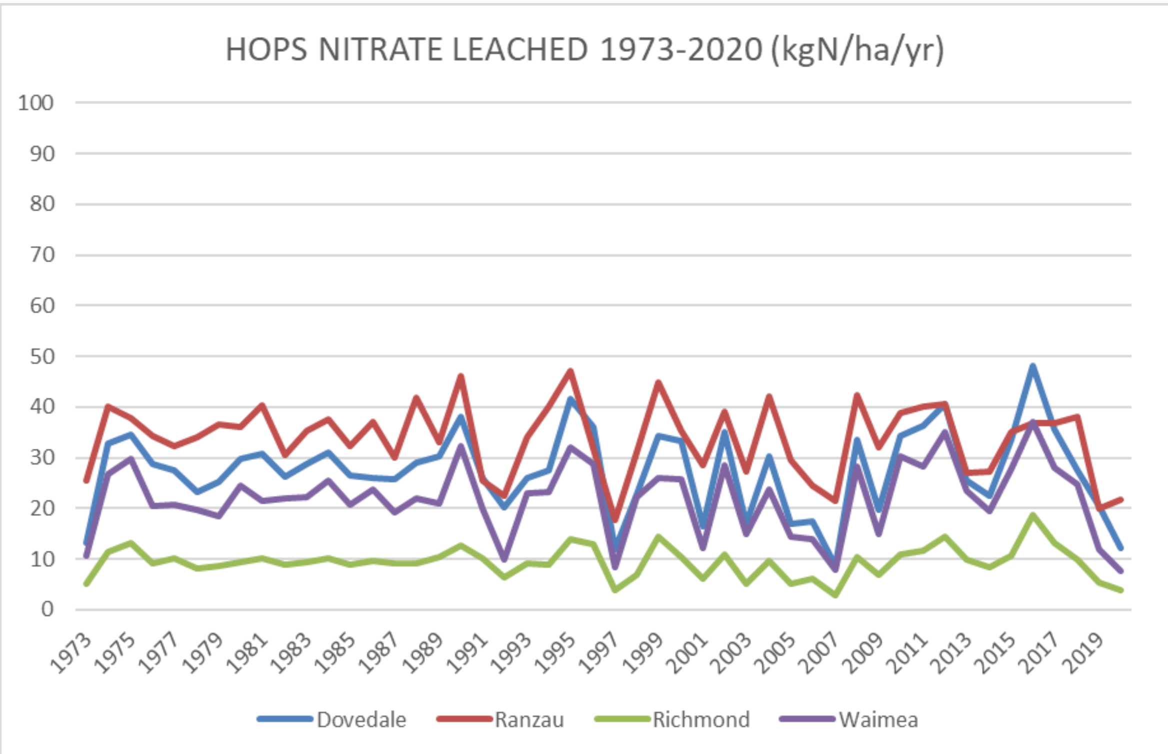

Figure 9. Year-to-year variation in N leaching (kg N/ha/yr) from hops for four soil groups, 1973–2020. Average losses are 31 kg N/ha/yr (Ranzau), 23 (Dovedale), 18 (Waimea), and 8 (Richmond).

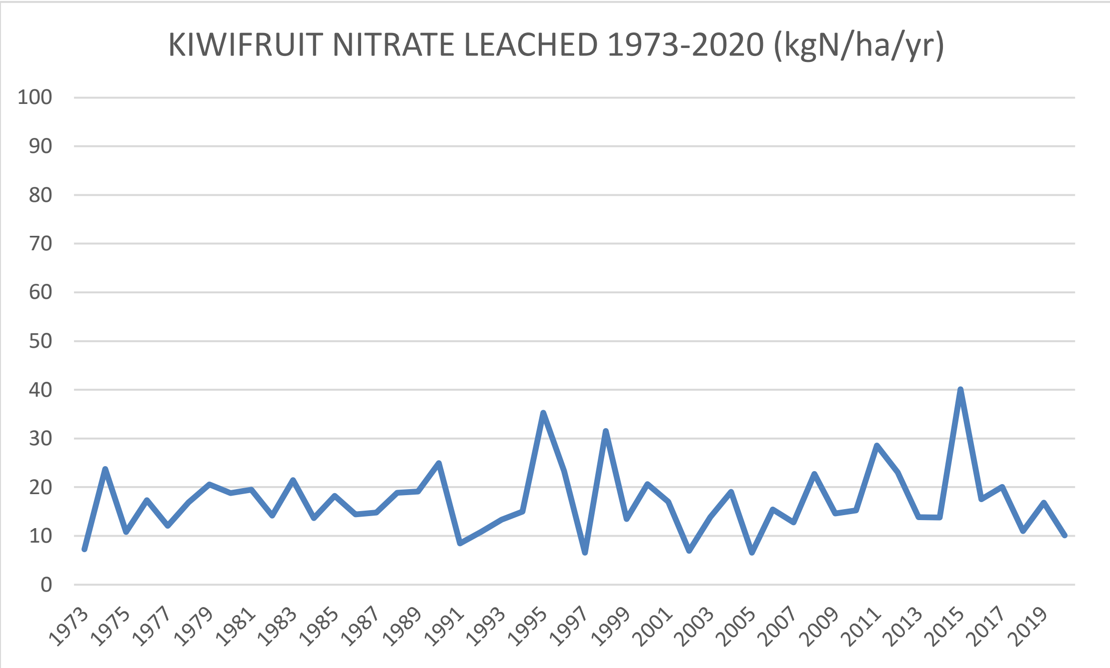

Figure 10. Year-to-year variation in N leaching (kg N/ha/yr) from kiwifruit for Ranzau soil group, 1973–2020. Average losses are 17 kg N/ha/yr (Ranzau).

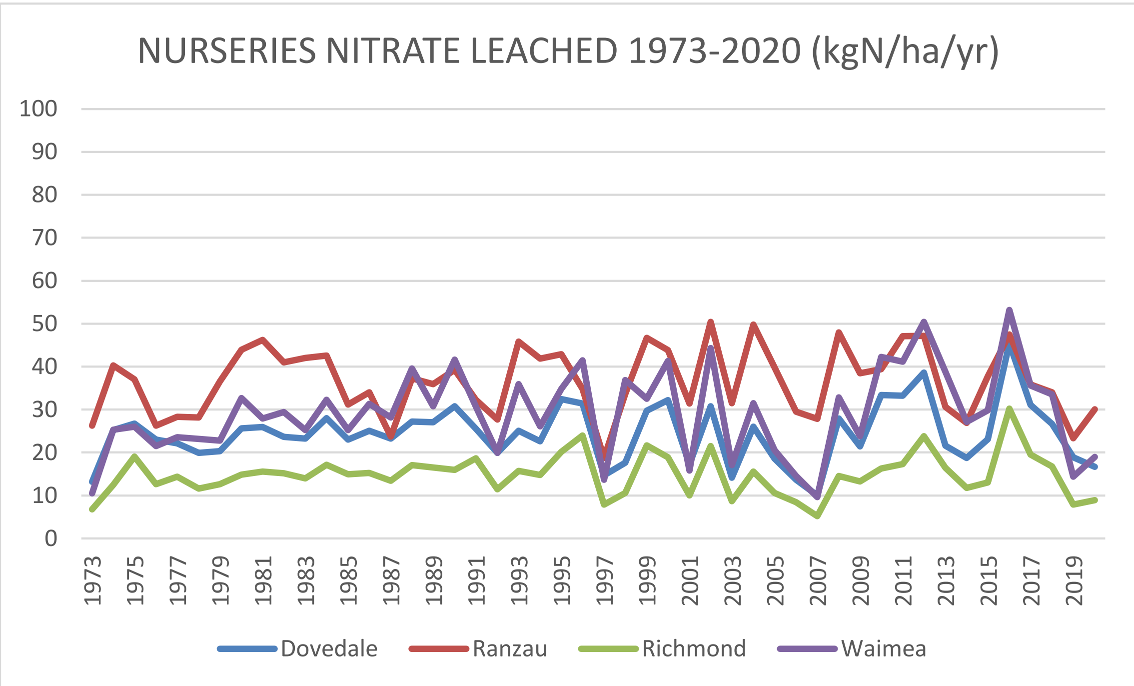

Figure 11. Year-to-year variation in N leaching (kg N/ha/yr) from tree nurseries (assumed same as young apples) for four soil groups, 1973–2020. Average losses are 36 kg N/ha/yr (Ranzau), 24 (Dovedale), 29 (Waimea), and 15 (Richmond).

7 Nitrate loss pattern from current land uses

Plotting the nitrate losses by land use and soil type for the combinations shown in Table 7 produces the map below (Figure 12). Note that both Table 7 and Figure 12 describe the Waimea lowland catchment, being the total catchment area below Wairoa Gorge which contributes water flows to the Waimea Inlet. The Waimea Plains portion of the 406 km^2 Waimea lowland catchment is approximately 20% of the Waimea lowland catchment at its north-eastern end. The upper 320 km^2 portion of the Waimea catchment not shown in Figure 12 is largely DOC estate and contributes little nitrogen to the downstream waters.

Total calculated nitrate loss below the soil root zone for the Waimea lowland catchment shown in Table 7 is 324 t/yr. This compares with the 287 t/yr calculated for 2013 land use in the 2016 report (Table 3 in Fenemor et al. 2016). However, this apparent increase is not entirely due to increased land-use intensity; it is also due to improvements in the modelling of N loss for existing land uses. Note, for example, that the area of dairy land has decreased (Table 2) yet the areas of grapes and market gardening have increased.

The top eight largest contributors, by land use, <u>for the whole lowland catchment</u> are pasture (including lifestyle blocks) and non-agricultural land cover (e.g. urban, roads), forest and scrub, vegetables, pipfruit, dairy, grapes, nurseries, and hops. The first two categories dominate the overall N losses because they comprise 91% of the Waimea lowland catchment, despite being predominantly foothills rather than plains. Thus vegetables, pipfruit, dairy, grapes, and nurseries are the top five sources of nitrate load leaching to waters <u>within the Waimea Plains</u>, in that order.

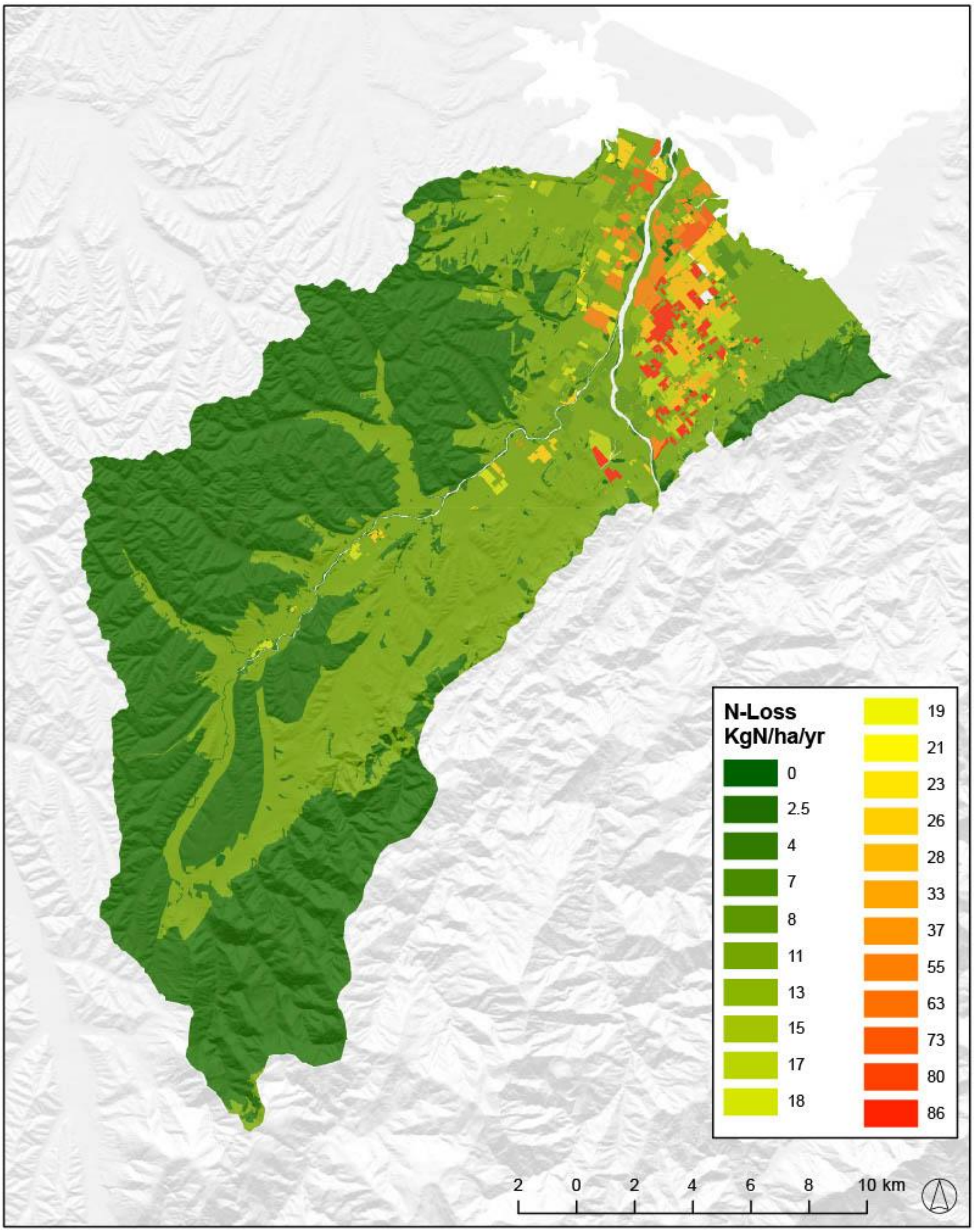

Figure 12. Modelled nitrate losses (kg N/ha/yr), by land use, for the Waimea lowland catchment.

Compared with modelled N losses for the 2013 land uses on the Waimea Plains, the top four modelled N loss increases - in terms of load lost - are from vegetables, pipfruit, nurseries and hops. Vegetable N losses have increased mainly because of changes in the crop mixes modelled, as well as the 9% increased area in vegetable production. Pipfruit N losses have increased solely because of increases in SPASMO-modelled loss rates arising from better data on the fertiliser regime used for apples. N losses from nurseries have increased because of the 175% increase in area mapped for nursery production between 2013 and 2020, but with lower modelled losses per hectare, because in the previous work their loss rates were assumed to be the same as for outdoor vegetables, whereas now we have used modelled loss rates for young apple trees. Hops N losses have increased because of both increased area planted, and better data on their fertiliser regime.

The top three soil series from which the N originates (same as for the 2013 land uses) are Ranzau (19% of lowland catchment N losses), Waimea (17%) and Rosedale (15%). The first two are the primary Waimea Plains horticultural soils. However, in terms of localised impact it is the nitrate loss rates, accumulated N loads and proximity to receiving waters that are important to understand. The highest loss rates according to the SPASMO modelling are dairy and market gardens, followed by nurseries, hops, pipfruit, kiwifruit, and grapes (Table 5). Table 5 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.

Table 7. Mean annual nitrate-N loads, by land use and soil series, kg N/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										34								34
Berries	14	16					21			234					1128			1413
Dairy		5				139	0			1565	2590				10007			14306
Forest & scrub	12	1271	1529	1434	1279	51	857	2681	9071	4	14	14269	400	21671	161	70	226	54998
Glasshouse*							0			0	0				0	0		0
Grapes	68	1098			321		879			6036	47				3043	239	12	11743
Hops	32	2					1444								356			1834
Kiwifruit										169	3				381			553
Nursery		430				200	2090			1047	226				4989			8982
Nuts		31	1							133		5			113			283
Olives		60	34		5		75			140		0			50		29	393
Lifestyle, pasture & non-agricultural	1294	14069	15000	672	17628	707	27818	2	534	11547	5158	34457	789	5526	10557	3272	11038	160072
Pipfruit	68	1285	1		583	0	303			10204	559	64		2	3275	107	4	16455
Vegetables			0		14	502	207			30883	199				20706	30		52541
Total kg N/yr	**1488**	**182673**	**16565**	**2106**	**19830**	**1599**	**33701**	**2683**	**9605**	**61996**	**8796**	**48795**	**1189**	**27199**	**54766**	**3718**	**11309**	**323612**

* Assumed self-contained

8 Comparison of land management SPASMO simulations

Some SPASMO modelling scenarios have been run to compare N losses under different management regimes, especially varied fertiliser applications and timings. Original scenarios are shown italicised in Table 8 for comparison.

Table 8. Average 1973–2020 modelled nitrate-N losses from SPASMO modelling and standard deviations summarised for additional fertiliser management options, kg N/ha/yr

Land use / farm system / scenario #	Ranzau soil	Waimea & Motupiko soils	Wakatu & Dovedale soils	Richmond & Heslington soils
Pipfruit mature (90% of Scenario #1)	*27 ± 5*	*11 ± 3*	*14 ± 3*	*6 ± 1*
Pipfruit mature, with March N application delayed to May #2	27 ± 5	11 ± 3	15 ± 3	6 ± 1
Outdoor vegetables: spinach, cabbages, lettuces #5	*44 ± 8*	*15 ± 4*	*15 ± 4*	*6 ± 2*
Outdoor vegetables: spinach, cabbages, lettuces, with winter lettuce N application reduced from 101 to 57 kg N/ha #6	42 ± 8	14 ± 4	14 ± 4	6 ± 2
Outdoor vegetables: onions, caulis, lettuces, spinach #7	*129 ± 31*	*94 ± 30*	*60 ± 23*	*32 ± 16*
Outdoor vegetables: onions, caulis, lettuces, spinach, with lower N applications for onions (108 not 292 kg N/ha) and lettuces/spinach (153 not 197) #8	112 ± 26	74 ± 24	49 ± 18	22 ± 11

Comparison of Scenario #1 for young pipfruit with Scenario #2 for mature pipfruit shows that young orchards lose more nitrogen than in later years when mature. Higher application rates of nitrogenous fertiliser on young trees mean that on average, median N losses from young trees are 81% higher than from a mature orchard. (In Table 4 these losses have been aggregated for a pipfruit orchard assuming 10% young trees and 90% mature.)

Scenario #2 was designed to evaluate the effect on N losses of delaying autumn fertilising from March to May. By May pipfruit trees have lost their leaves, so uptake of nutrients would be expected to be lower than in March. However the SPASMO simulations show little increase in N losses for the later autumn fertiliser regime, perhaps because the relatively low application rate of 25 kg N/ha of CAN (calcium ammonium nitrate) allows retention in the soil profile.

Scenarios #5 and #6, and #7 and #8, were designed as pairs to evaluate the effects of changing N fertiliser regimes from the average of current practice for the two outdoor vegetable proxies to the practices recommended in the HortNZ nutrient management manual (Reid & Morton 2019).

Reducing winter lettuce N fertiliser from 101 kg N/ha to 57 from scenario #5 to #6 showed only a marginal reduction in nitrate losses, and the reduction was only on the Ranzau and Waimea soils, not the heavier soils. Given the small reduction in N losses, any loss of lettuce yield and quality resulting from lower N fertilizer application becomes a more important factor; conversely, the area of winter lettuces grown on permeable soils may need to be reduced if lower losses are required.

Reducing N fertiliser on onions and lettuces, however, showed a larger reduction in what are already high nitrate losses for all soil groups. Reductions ranged from 13% on Ranzau soils to 21% on Waimea soils, to 31% on heavier Richmond soils. Nitrate losses remained very high for the Ranzau soils, exceeding 100 kg N/ha/yr, and showing the difficulty of producing this second outdoor vege combination of onion-cauliflower-lettuce-spinach on these leaky soils without contamination in groundwater or spring-fed streams exceeding national water quality bottom lines.

9 Modelling nitrate reaching receiving waters

In the earlier work of Fenemor et al. (2016) recommendations were made for numerical water quality objectives that could apply to protect or maintain specified values within the Waimea catchment and Waimea Inlet. These comprised water quality limits for nitrate-N, dissolved reactive phosphorus and *E. coli*, covering water bodies of the Waimea River, spring-fed streams, and the Waimea Inlet (Table 4 in Fenemor et al. 2016).

Since then the NPSFM2020 has been gazetted. It sets bottom-line national limits for attributes including nitrate toxicity in rivers and lakes, and directs a limit-setting process under which regional and unitary councils must set limits in their regional plans, to be publicly notified by December 2024. This report does not address appropriate limits beyond those previously addressed in Fenemor et al. 2016.

In order to manage the environmental effects of nitrate losses, we need to understand the attenuation (reduction in nitrate) between the base of the soil profile along the flow path and the sensitive receiving waters. This must be followed by consideration of potential water quality limits, to be achieved in each receiving water body. In the previous work (Fenemor et al. 2016) it was suggested that 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.

In this work we have updated only the current-state groundwater flow tube analysis of Fenemor et al. 2016 as a method for assessing the effects of land-use change on nitrate concentrations reaching Pearl and Neimann Creeks. Work by TDC on improved understanding of groundwater flow paths, including transient changes in flows within and between aquifers and receiving waters is under way with calibration of the Stage 3 Waimea groundwater flow model already completed (Weir, 2023) and with plans to add a nitrogen transport component to this model; details of the flow system are not described further in this report.

Figure 13 shows the intensity of SPASMO-modelled current nitrate losses for the 2020 land-use mapping. Land parcels overlying the groundwater flow tubes intersecting with Neimann and Pearl Creeks pose the greatest risk to water quality in those vulnerable receiving waters. No analysis has been completed for Borck Creek (average nitrate 2011–2022 of 6.2 g/m^3) because that stream is both spring- and surface-water-fed, receives considerable urban stormwater at moderate to high flows, and is less affected by rural land use.

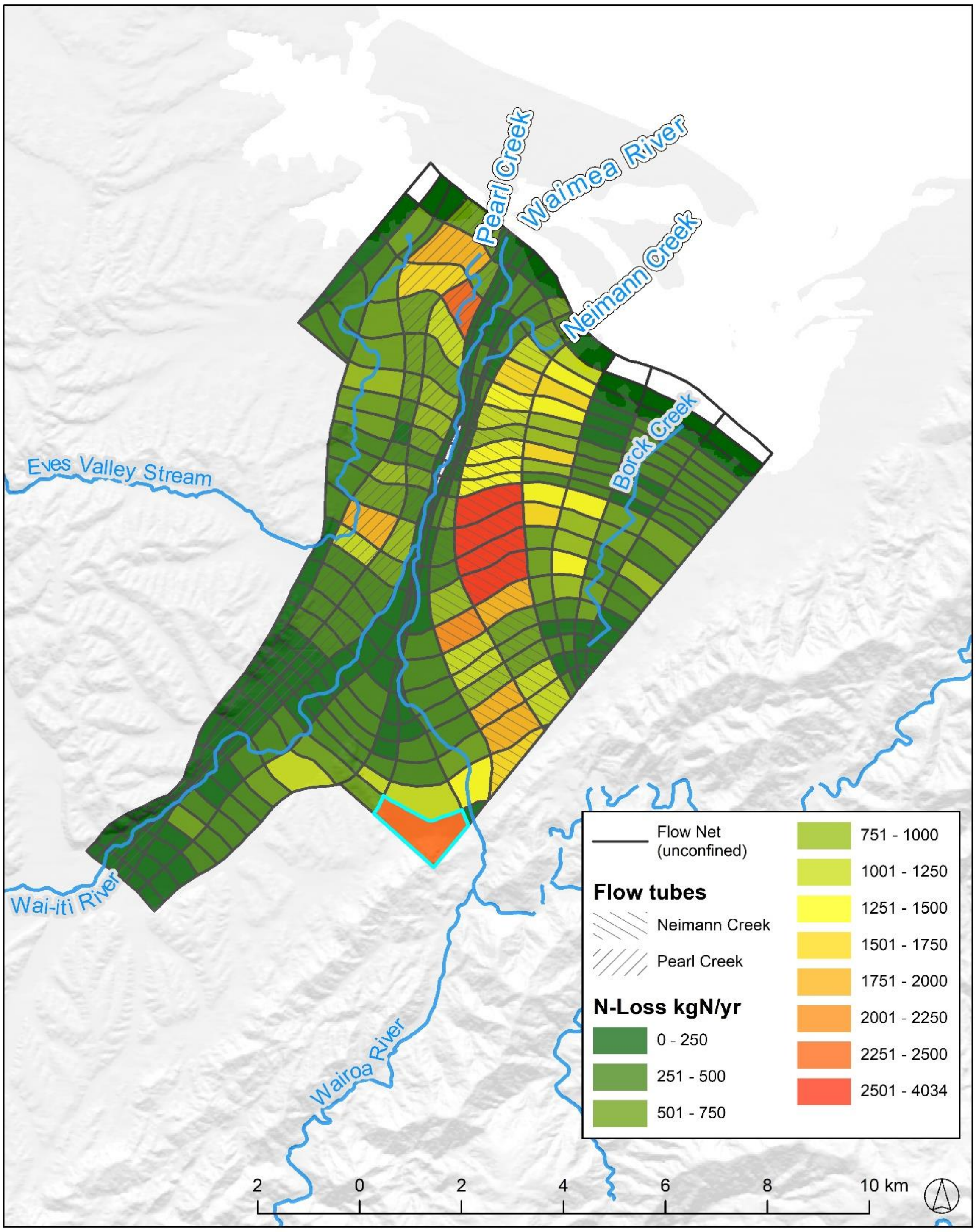

Figure 13. Nitrate losses by unconfined aquifer flow net cell for current land use (cross-hatching shows land areas contributing nitrate to Neimann and Pearl Creeks).

Assuming no attenuation of nitrate, Table 9 summarises the modelled nitrate concentrations that are being delivered for current land uses at Pearl Creek and Neimann Creek. The match between calculated and recent measured concentrations is good for Pearl Creek west of the Waimea River. For Neimann Creek east of the river the calculated nitrate concentrations from upstream land uses are higher than indicated by measured concentrations. If the modelled losses are realistic, then this difference suggests there is an increasing load of nitrate to come at Neimann Creek.

Median nitrate concentrations in both streams exceed the nitrate toxicity national bottom line of 2.4 g/m^3 in the NPSFM 2020. In addition, nitrate concentrations exceed the NZ Drinking Water Standard, particularly in the Appleby/Blackbyre Road area. Under the requirements of the NPSFM 2020, the TDC will be required to set limits in its proposed regional plan by December 2024 to reduce nitrate losses from current land uses to meet these standards for groundwater and spring-fed streams. The type of analysis presented in this report will help to identify which land uses and soil types to focus on, and what mitigations might be possible within the receiving waters themselves.

Table 9. Modelled nitrate discharges at spring-fed streams for current land use

	Pearl Creek (mean flow c. 265 L/sec[a])			**Neimann Creek (mean flow c. 166 L/sec)**			**TDC bore GW802**
Land-use scenario	Calculated average contributing nitrate load, kg N/yr	Calculated nitrate concentration, g/m^3	Measured (mean, median) nitrate concentration (2011–16, n = 19)[b], g/m^3	Calculated average contributing nitrate load, kg N/yr	Calculated nitrate concentration, g/m^3	Measured (mean, median) nitrate concentration (2011–22, n = 91)[c], g/m^3	Measured (mean) nitrate concentration (2011–22)[d], g/m^3
Current land use 2020	17.6	2.73	3.26, 2.90	33.6	8.43	3.61, 2.90	2.51
Previous analysis for 2013 land use	13.4	2.05		22.1	5.56		

[a] Mean flow retained from that used in 2013 to allow comparison of calculated concentrations.

[b] Averaged from all available TDC data.

[c] Averaged from all available TDC data.

[d] From Westley, M 2023. *Technical Report – Waimea Groundwater Quality Survey 2021*. Tasman District Council, Table 2

Note, however, that the following caveats apply to this assessment.

- It has been assumed there is no attenuation (loss) of nitrate between the base of the soil profile and the arrival of nitrates at the spring-fed streams. A primary cause of reductions of nitrate concentrations in groundwaters is denitrification, which occurs in anoxic (reducing) conditions; these aquifers have not been found to have sufficiently low dissolved oxygen for denitrification to be likely (Westley, 2023). 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 (as Neimann flows also come from the upper confined aquifer). Without this dilution accounted for, the modelled nitrate concentrations in the streams will be worse than they may be in reality.

- It is assumed that the groundwater 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.

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12 Supporting Datasets

Eighteen spreadsheets summarising the SPASMO model results for scenarios modelled in Tables 5 and 8 and a spreadsheet of the flow net calculations in Table 9 are available upon request, and stored at MWLR at T:\Hamilton\Projects P-T\Spatlab Shared\Projects\SL2022\SL2206_WaimeaPlains_NitrateLosses\Documents\Release .