Waimea plains nitrate issues – science summary 2020 [updated 2024]

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1. Purpose of Report

Tasman District Council wishes to develop a policy response to the high nitrate-nitrogen concentrations measured in some Waimea Plains aquifers and surface water bodies. This work will build on the deliberations of the Waimea Freshwater and Land Advisory Group (Waimea FLAG) which during 2014-15 reviewed water quality management in the Waimea catchment but whose work was deferred due to Council giving priority to similar work with the Takaka FLAG.

A policy response has become more urgent with the requirement in the National Policy Statement for Freshwater Management (NPSFM 2020)[1] to set water body limits which maintain or improve water quality, alongside the recognition that nitrate concentrations in parts of the Waimea basin exceed some standards for drinking water quality and for protecting some ecological values. Council's Tasman Resource Management Plan (TRMP) Change 48 has also committed Council to working with stakeholders and land users to examine the water quality issues in the Plains in more detail and to develop management objectives and associated limits to manage water quality in the Plains.

[1] National policy statement for freshwater management | Ministry for the Environment

The current workstream comprises two parts: (1) a summary of the present state of science knowledge about the nitrate issue in the Waimea, and (2) options assessment for policy responses and action planning. This report addresses workstream (1).

2. The Nitrate Management Challenge

Nitrate-nitrogen (hereafter labelled nitrate) is the most stable and dominant form of nitrogen compound found in water environments globally. It is highly soluble so is easily flushed through landscapes. At moderate concentrations it is needed, along with phosphate and trace elements to stimulate plant growth; this is one reason the use of nitrogen fertilizers has increased markedly over recent decades, especially for dairy, arable and horticultural land uses. Increased use of nitrogen and other fertilizers allows intensification of agricultural production, whether that be more dairy cows per hectare or more vegetable production especially during the shoulder growing seasons in spring and autumn. Importantly, losses of nitrogen do not originate solely from leaching of fertilizer but from soil nutrient conversion processes and, in the case of livestock farming, from deposition of animal urine and faeces from increased livestock densities.

Nitrogen losses are a more significant problem in the environment than phosphate because nitrogen is easily leached whereas phosphate is readily – although not totally – absorbed on to soil and sediment particles. Oxidation of forms of nitrogen such as ammonium creates nitrate-nitrogen which is more stable and difficult to remove by water treatment processes. Natural processes of denitrification can reverse the oxidation process converting nitrate to nitrite and then to nitrogen gas, which is benign in the environment, however many water bodies have reasonable levels of dissolved oxygen which does not allow denitrification to occur.

Excessive concentrations of nitrate in surface waters will stimulate growth of aquatic plants and algae, leading at higher concentrations to eutrophication, including loss of oxygen from the water and die-off of aquatic life including fish and macroinvertebrates. In recreational waters, these conditions make the water unpleasant for swimming, boating and in its appearance. Higher concentrations of nitrate are directly toxic to some aquatic species. At higher concentrations still, the water poses a risk for drinking, especially by bottle-fed infants who may develop methaemoglobanaemia (blue baby syndrome, similar to the bends experienced by divers); the NZ Drinking Water Standards have a limit of 11.3 mg/l[2] nitrate-nitrogen because of this risk A recent Danish study (Schullehner at al, 2018) also suggests that nitrate-nitrogen concentrations in drinking water exceeding 0.9 mg/l over the long term may increase people's risk of colorectal cancer.

Management of nitrogen losses into water bodies (along with phosphorus, pathogens and sediments) has become a major focus of water quality management. The potential inclusion of a national 'bottom line' limit of 1 mg/l Dissolved Inorganic Nitrogen (DIN)[3] among the compulsory attributes in the NPSFM prompted thousands of submissions on the then government's 2020 *Essential Freshwater* reforms. A decision on including DIN in the national framework was deferred due to concerns both about the efficacy of national limits on a single attribute, and what any limit should be. There were many submissions advocating for limits to be tailored to local catchment conditions and community values, determined locally.

[2] mg/l = mgNO_3-N/l = g/m^3 and are used interchangeably in this summary

[3] Dissolved Inorganic Nitrogen comprises nitrate and ammonia and is the attribute which best represents the nitrogen supply readily available to aquatic primary producers, i.e. potentially causing eutrophication. Ammonia is generally low in groundwaters. DIN = NO_3-N + NH_4-N

The NPSFM continues to prescribe regional planning processes to set water quality limits alongside nationally mandated targets and limits for attributes including periphyton, and ammonia and nitrate toxicity. Thus, it is up to Tasman District Council - via the TRMP and successor plans - to decide its own water quality limits, provided they comply with NPSFM bottom lines.

3. Waimea Conceptual System Model

In order to structure this science review, it is helpful to use a 'cause and effect' conceptual model because the policy responses, and ongoing science and monitoring, will likely need to focus on interventions at both the source (land management and discharges) and in the various receiving waters (groundwater, streams and the estuary).

Figure 1 is a generic diagram of the catchment management system with the natural catchment processes shown on the left, and the RMA-guided responses on the right. Primary components of cause and effect in the socio-ecological system are human drivers alongside natural drivers. Those create cumulative inputs – varying across the catchment and through each year - which are routed via soil leaching, runoff, groundwater flow, river seepage and springflows to streams and the coast.

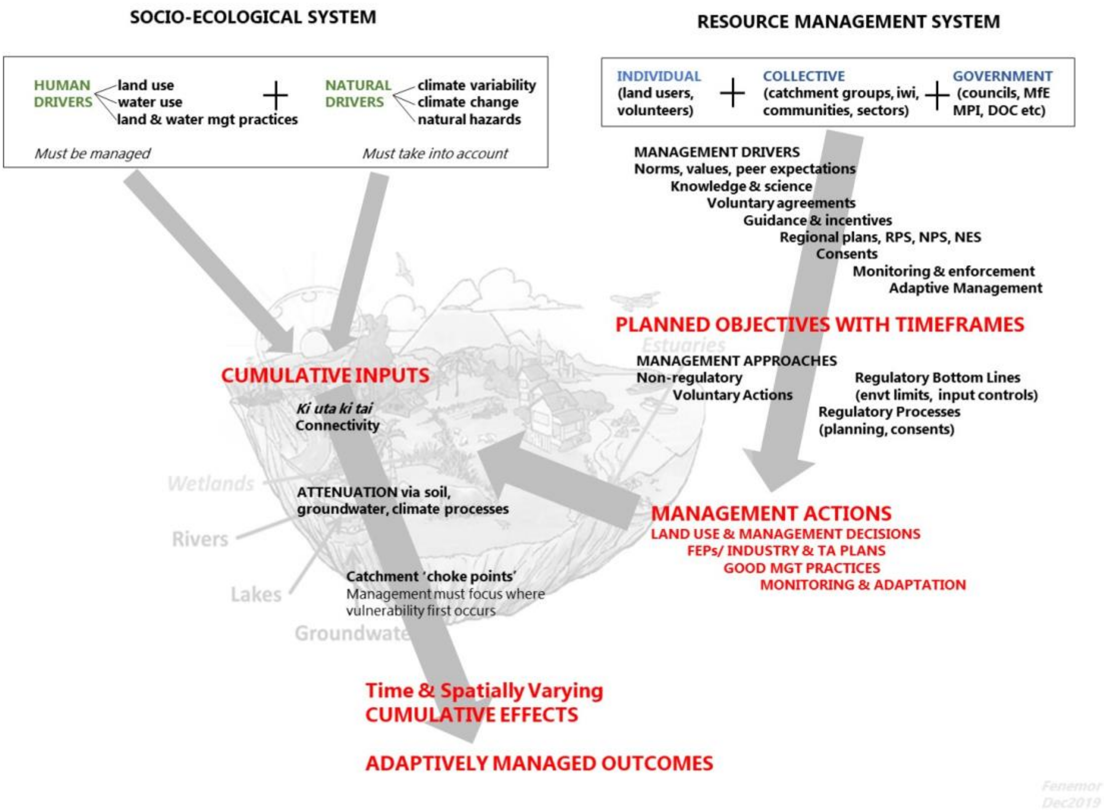

Figure 1 – conceptual catchment management system

Points in this conceptual systems model that are most relevant to this review are[4]:

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[4] Diagram and bullet points are updated from the report of the Freshwater Independent Advisory Panel for the Essential Freshwater reforms 2020 (with this section of the FIAP report drafted by A Fenemor): https://www.mfe.govt.nz/publications/fresh-water/essential-freshwater-report-of-freshwater-independent-advisory-panel

• CONNECTIVITY – Upstream water bodies affect those downstream, therefore managing connectivity is important. Catchment managers should identify 'choke points' or sensitive downstream environments such as an estuary, lake or spring, where tipping points or breaches of limits will first occur, which will not necessarily be in the upstream water body under consideration.

• SCALE – Freshwater management should focus at the catchment scale, *ki uta ki tai* (from the mountains to the sea). Although Freshwater Management Units (FMUs) may be defined for catchments or sub-catchments, planning will also need to account for differences at other scales including among water bodies and freshwater ecosystems.

• HUMAN IMPACTS – Human activities (land and water use and their management) are amenable to policy/rules/action, while natural events (mainly climate) can only be factored into management.

• CUMULATIVE EFFECTS – Collective management will be needed to achieve catchment scale outcomes because of the cumulative effects of a mosaic of land uses and practices. The same land uses applied in two different patterns will produce different downstream flows and water quality.

• ENGAGEMENT – Decisions should encourage land user engagement yet recognise the need for regulatory vs non-regulatory action, depending on the catchment and stakeholder setting. Buy-in by land users into sometimes difficult decisions requires a level of trust.

For the purpose of this review, and drawing on this system characterisation, the science knowledge is categorised into:

- <u>Sources</u>: human drivers, including land use, water use, land and water management practices
- <u>Pathways</u>: characterising flowpaths to receiving waters and their contaminant attenuation processes, including soil filtering, plant uptake, groundwater and river recharge dilution, geochemical processes
- <u>Receiving waters</u>: groundwaters, streams and surface waters where nitrate concentrations may breach ecological or water use limits, including eutrophication or drinking water limits
- <u>Whole system science</u>: integrative studies unable to be easily separated into the three categories above.

Science knowledge reviewed comprises scientific reports, journal papers, reports to Council, informal reports and datasets. Where datasets exist but have not been analysed, their existence is simply noted.

For each body of knowledge, a summary of key points relevant to potential policy responses for nitrate management is provided (implications), plus commentary on outstanding issues which may require further investigations or analysis (gaps). References are listed in date order as some build on previous work.

4. Synthesis of Existing Science Knowledge

a. Sources

Sources means the drivers of water contamination 'downstream', in this case focusing on nitrate, but at the same time recognizing that other contaminants including *E.Coli* as an indicator of pathogen contamination, phosphorus as another indicator of nutrient enrichment, sediment as an indicator of erosion processes, and potentially synthetic chemicals require monitoring and management.

The primary sources of nitrate contamination in the Waimea catchment are agricultural and livestock land uses, and associated management practices. Secondary sources are human wastewater discharges from septic tanks, as most other sewage discharges are reticulated for treatment and discharge beyond the Plains (e.g. the Regional Sewerage Scheme discharge from Bells Island to Waimea Inlet on the outgoing tide).

Dryden, G; Hosie, C; Fenemor, A; Price, R; Green, S. 2017. Land use viability, Waimea Plains. Fruition Horticulture consultancy report for Crown Irrigation Investments Limited (CIIL) and Waimea Irrigators Limited (WIL). 67p.

This work identifies opportunity for land use change to irrigation, based on current land use, soils and climate, building on the approach developed in Fenemor et al (2015). It provides guidance on the types and limits of future land uses, and hence potential future nutrient losses, which may arise following provision of water from the Waimea Community Dam, and without it.

Within the Scheme Area of around 5000 hectares, as at 2017 there are 2,616 hectares in horticultural or dairy production and a further 1,359 hectares identified as pasture. Changes in land use up to 2020 are summarised below in section 4d.

Soils characterisation uses the new mapping by Iain Campbell (2011-17) and includes a table of soil versatility ratings which indicate limitations for growing particular crops. The analysis identified 2,784 hectares as versatile for production, while moderately versatile soils cover 797 hectares. Of these areas 79% and 62% respectively are currently in horticultural or dairy production. Of the soils classed as versatile or moderately versatile currently 1,041 hectares are in pasture. While a large amount of this is on lifestyle properties, 398 hectares occurs on properties greater than 10 hectares.

The Waimea soil types map is reproduced as Figure 2 below because it is the most up-to-date available – the legend is available on TDC's GIS version. The two largest areas of versatile soils are Ranzau (sea green around Hope) and Waimea (yellow-green in Figure 2). The Ranzau soil types have lower soil moisture holding capacity and therefore require greater irrigation, but their stony content allows machinery on the ground for a greater amount of the year and these soils maintain higher soil temperature. This makes the Ranzau soils ideally suited to grapes, pipfruit and outdoor vegetables all year-round but less suited to hop and dairy production. Lower soil moisture holding capacity and lower nutrient holding capacity leads to higher inputs of both irrigation and fertiliser. The Waimea soil types generally have higher water and nutrient holding capacity and are suited to hop, grape, pipfruit and summer outdoor vegetable production. However, workability and water logging can be an issue on these soils which can limit suitability for winter vegetable and dairy production and lead to soil damage with repeated machinery movements.

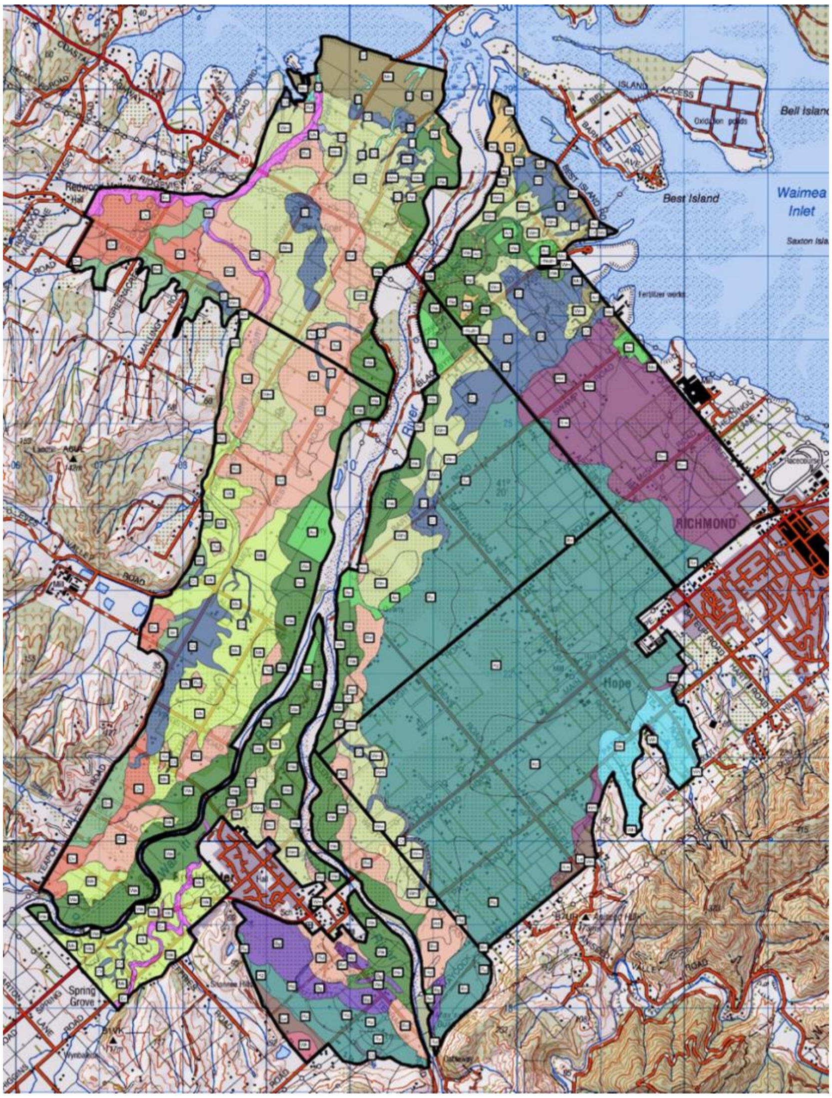


Figure 2 Waimea Plains soil mapping as updated by Iain Campbell 2011-17 (see TDC for legend)

Financial analysis combined with SPASMO soil and water allocation modelling was extended to examine the sensitivity of current and potential major land uses of the Waimea Plains – apples, grapes, hops, dairy and vegetables – with and without irrigation from the Waimea Community Dam. Results show that without high reliability water provided by the dam, crop yield reductions (excluding dairy which can bring in feed) are in the range 8-30% during dry summers such as 1972/73 and 2000/01, with even greater yield reductions on soils with low water holding capacity such as the Ranzau and Redwood soils. However over the modelled 1972-2013 period, average yield reductions are much lower, in the range 0.8 – 3.5%. Worst hit land uses would be grapes, apples and vegetables. Land uses with highest Net Present Value, based on the last 5 years of returns (to 2017), are hops, apples and vegetables in that order.

Implications: Despite the higher N losses modelled and reported in Fenemor et al (2015) for vegetables using SPASMO, this financial analysis suggests that favoured land uses for expansion post-dam would be hops, apples and vegetables. Expansion of these land uses is constrained by the amount of versatile land in small lifestyle blocks and the relatively small area of currently unirrigated land in economic blocks. There has been some expansion of hops on Waimea, Dovedale and Motupiko soils but generally the Waimea Plains are considered too windy for hop growing (Greg Dryden, pers. comm).

Gaps: When updated SPASMO or other nutrient modelling is undertaken, other potentially dominant or leaky land use/soil combinations could be included.

This report contains the most recent land use and soils maps, available as GIS layers at TDC. It is suggested that Council instigate a programme of 5-yearly land cover mapping to maintain datasets available for the types of N-loss and financial modelling contained in this report, which would inform ongoing policy development and implementation.

Agribusiness Group 2015. Nutrient Performance and Financial Analysis of Horticultural Systems in the Waimea Catchment. Report by S.Ford for Horticulture NZ and Waimea FLAG. 23p. https://www.hortnz.co.nz/assets/Natural-Resources-Documents/Nutrient-Performance-and-Financial-Analysis-of-Horticultural-Systems-on-the-Waimea-Plains-Final-May-2015.pdf

The objective of the study was to collect primary physical, financial and environmental data from growers in the Waimea Catchment, to provide representative models of horticultural systems and to analyse the impact of mitigation practices on the environmental and economic performance of the farms. Twelve growers were interviewed across vege growing, pipfruit, kiwifruit and vineyard land uses. Preliminary results were presented to the Waimea FLAG (Freshwater and Land Advisory Group) in 2015 as a contribution to understanding what changes in land management may be possible to reduce nutrient losses in the Waimea Plains.

The report includes the following useful excerpt from an Environment BOP report (Meneer et al ND) on vegetable growing as a source of leached N:

> *The main factors responsible for nitrate leaching in these systems are: high N use (fertiliser and manure), frequent cultivation, relatively short periods of plant growth, low nutrient use efficiency by many vegetable crops, and crop residues remaining after harvest (Di and Cameron, 2002a).*
>
> *Compared to other agricultural systems, market gardens are the most intensively fertilised and cultivated production systems - hence their propensity to leach N. N application rates used in vegetable crops can be as high as 600 kg N ha^{-1} yr^{-1} (Wood, 1997). Large application rates are used to ensure maximum growth because vegetable crops have sparse root systems that are inefficient at recovering applied fertiliser. Also, vegetables typically have short growing periods and are also grown over winter when plant growth and N uptake is slow (Haynes and Francis, 1996; Haynes, 1997). Therefore, the recovery of applied N by vegetable crops is often less than 50%, and can be as low as 20% (Di and Cameron, 2002a). Consequently, a large quantity of fertiliser N remains in the soil surface layers and is susceptible to leaching during rainfall or irrigation. Additionally, following crop harvest large amounts of plant residues are usually incorporated into the soil which, following decomposition, release mineral N into soil. The amount of mineral N derived from fertiliser and crop residue that is present in the soil after harvest can be as high as 200-300 kg N ha^{-1}, and is the major source of leached N, indicating that fertiliser N management strategies are the key to nitrate leaching intervention in these systems.*

Pipfruit systems are relatively high users of Nitrogen (175 kg N / ha) in the growing years of the crop (years 1 to 3). Once the crop reaches its mature size then very little Nitrogen fertiliser (40 kg N / yr) is used, although this small amount used is critical for the next year's yield.

Kiwifruit has a relatively high requirement for Nitrogen fertiliser annually (120 kg N / ha), primarily during the growth phase of the vines in spring.

Grapes use a relatively small amount of Nitrogen fertiliser during the growing of the young vines (65 kg N / ha) then once the vine is mature very little (14 kg N / ha).

In this study, three mitigation techniques to reduce N losses were modelled using OVERSEER on either Ranzau or Waimea soils (as appropriate for the crop) and produced the N losses of Table 1:

Mitigation M1 – Limiting N application so that no application of N exceeds 80 kg N / ha per month (with status quo irrigation).

Mitigation M2 – Reduce the amount of N applied to the crop in 10% increments from 0 to 30% (with status quo irrigation).

Mitigation M3 – Apply only the amount of water which is required by the crop as determined from the OVERSEER 6.1.3 model (with status quo N applications).

Table 1: Whole Orchard N leaching results (kg N / ha / annum)

	Status Quo	**M1**	**M2 - 10%**	**M2 - 20%**	**M2 - 30%**	**M3**
Vegetables (Onions > Cabbage > Lettuce > Squash)	24	24	22	21	19	23
Pipfruit (40ha apples, 34 is mature orchard)	24	24	23	23	22	17
Kiwifruit (15ha with 12 ha mature orchard)	37	37	35	34	32	35
Vineyard (50ha with 42ha mature vines)	6	6	6	5	5	5

Capping N applications to 80 kg/ha/month (M1) had no effect on the total amount of N leaching because no grower was applying more than that anyway. Reducing the amount of N applied in increments of 10% (M2) had more effect on N losses for vegetables [2-5 kg/ha/yr less] and kiwifruit [2-5 kg/ha/yr less] but little or no impact on pipfruit [1-2 kg/ha/yr less] and grapes [0-1 kg/ha/yr less]. Vegetables and kiwifruit are relatively high users of Nitrogen fertilisers while pipfruit and grapes are relatively low. Reducing irrigation to only that required (M3) has a significant impact for pipfruit – modelled on Ranzau soils - but little impact otherwise.

Gross margins ($/ha) are presented in the report. Of the three mitigations, only M2 impacts farm financial results but the reductions are severe. For vegetable production, a 50% loss for the 10% reduction in N application increases to 134% at the 30% reduction. For pipfruit, the losses are 18% increasing to 83%. For kiwifruit, 21% increasing to 118%, and for vineyard production, 9% increasing to 28% at the 30% fertilizer reduction.

Implications: Results indicate that reducing N applied will reduce losses but is a blunt tool with financial consequences for all crops modelled. The modelling is based on various assumptions in OVERSEER 6.1.3 which average and simplify actual farm practice, e.g. monthly data inputs only, assumptions about whether only the crop or entire area is being fertilised, assumptions about monthly irrigation water applied, and no ability to model slow release fertilizers or more organic approaches. Until OVERSEER is better tailored and validated for horticultural crops, these results should be used only in a relative sense rather than believing the absolute N losses modelled. Gross margin analysis is a useful but blunt tool for evaluating financial consequences of potential mitigations.

Gaps: There would be value in more refined modelling of N losses from the Waimea land uses which are seen as higher N leachers, using either SPASMO, APSIM or improved versions of OVERSEER.

Rainham, D. 2015. Investigating Soil nitrate movement under intensive vegetable production on the Waimea Plains, Tasman. Agfirst Consultants report for R Conning and M O'Connor. December. 18p. [permission given by Robbie Conning and Mark O'Connor to cite this report]

This small trial monitored nitrate movement based on 8-9 samples each from suction cup soil water samplers under a cauliflower crop at one site each on Ranzau stoney clay loam (Rz) and Waimea clay loam (Y). Sampling occurred over the 160 day autumn to spring growing period after planting in March and April 2015 respectively. A control plot at each site had no fertilizer applied while normal fertilizer practices applied at the adjacent plot. Nitrate loss was calculated as the difference between N concentrations in soil water for the standard plot compared with the control.

Results showed that N leached past the root zone whether fertilizer N was applied or not: 62 kg/ha on Ranzau soil and 72 kg/ha on Waimea soil. Adding N fertilizer increased leaching losses with an additional 59 kg/ha leached from Ranzau but only an additional 18 kg/ha from the heavier Waimea soils. Fig 7 indicates for the Ranzau trial, fertilizer applications of 155 kg/ha at planting and side dressing of 80 kg/ha 45 days after planting with most leaching occurring in the first half of the growing cycle late March-early May. Fig 8 indicates for the Waimea trial fertilizer applications of 80 kg/ha 6 days after planting then 2 dressings of 250 kg/ha 32 and 60 days after planting with the small amount of leaching occurring late in the growing cycle August-September. Despite less than half the amount of N being applied on Ranzau soil than on Waimea in this trial, two thirds more N was leached from the Ranzau plot.

Implications: The study shows that despite N being regarded as highly mobile in soil because of its solubility, market gardening leaves considerable N in the soil over winter, which results in ongoing N losses even if no more fertilizer is applied. However the residual soil N is insufficient to produce a marketable cauliflower crop without further fertilizer. Reducing N losses especially from light stoney soils like the Ranzau requires smaller fertilizer applications early in the growing cycle.

Gaps: The influence of rainfall on leaching rates is not clear from the report despite rainfall having been measured as well as irrigation. Because the methodology estimates N losses from difference in soil N concentrations between control and treatment plots, it is possible that heavy rainfalls may have leached slugs of N past the suction cups without detection. Some form of continuous soil moisture sampling would overcome this.

However, these types of field trials are relatively inexpensive compared with full-scale lysimeter trials collecting leachate from the base of the soil profile. Trials that continue through a full hydrological year, and linked to modelling of leachate losses using SPASMO, APSIM or OVERSEER would provide better knowledge of leaching processes and enable improved N loss estimation across major land uses of the Waimea Plains.

In November 2014 it was reported to FLAG that Dean Rainham was carrying out a benchmarking project surveying a much wider group of growers to gather information on practices pertaining to nutrient use and irrigation (11 growers, 14 crops (7 vege, 7 fruit), 6 soil types), but I understand the Agribusiness report for HortNZ summarised above is the outcome – at smaller scale - of that work.

Shaw, J. 1997. Land use survey – Hope/Ranzau area of the Waimea Plains. Tasman District Council report, November. 47p.

This is a well crafted and extensive student project for TDC which surveyed and interviewed 244 land users across 2089ha [1981ha effective] of the eastern Waimea Plains (mostly the area of the Ranzau soils). One aim was to map land use in 9 categories: dairy (13% by area), horticulture (31%), market gardening (10%), agriculture (25%), forestry (7%), lifestyle block (4%), cropping (5%), uncultivated (buildings, driveways etc; 4%) and other (1%). Previous land use(s) are also recorded, indicating a decline in cropping from 13 to 5%, a decline in agriculture from 34 to 25%, a decline in market gardening from 12 to 10%, an increase in horticulture from 15 to 31% and in lifestyle blocks (including septic tanks) from 1 to 4%.

The study also determined patterns of fertilizer use, crop management practices which may affect N loss, water source and use of irrigation, sewage disposal, and animal grazing systems. 188 of 244 respondents used fertilizer, most applying twice a year in spring and autumn and many basing applications on soil tests from Ravensdown. Page 13 is a pie chart of total fertilizer by type, totalling 262 t/yr of which most include N. Fig 2 of the report maps fertilizer usage as <1 t/ha, 1-2 t/ha and >2t/ha with 33% of the area using >2t/ha (dairy, horticulture and market gardening). Market gardening uses by far the most substantial amounts of fertilizer at 493 kg/ha compared with horticulture at 155 kg/ha and the rest lower. One nursery with plants in planter bags was calculated as applying the equivalent of 40 t/ha.

Land used for crops was mainly in continuous use with little fallowing. At this time, most irrigators had little idea how much water they were using but irrigated 'when needed' within their allocations. The report suggests – without any detail - an allocation system for fertilizer similar to that for water, and guidance on land management activities which should be promoted and discouraged.

<u>Implications:</u> This is a useful snapshot from 27 years ago of changing land use and fertilizer practices. It highlights the intensification of land use in the eastern Waimea Plains and the large amounts of fertilizer used by market gardening (vege growing) compared to all other land uses.

<u>Gaps:</u> There is no substitute for interviews using a well-defined set of questions to map actual activities. With some additional rigour in the survey design, this approach could be repeated say every 10 years alongside land cover mapping in order to link land use with management practices, for use in modelling and policy refinement. It would also be a way to raise awareness and provide information on good management practices (GMPs). The complete spreadsheet of interview responses in Appendix 2 is a useful data source against which future surveys could be compared. Any repeat survey should ideally cover the whole plains, but with limited resources could be tailored to areas upstream of the most vulnerable receiving waters including the confined aquifers and spring-fed streams.

Simmonds B and M Westley. 2020. Waimea Plains nitrate supplementary data: land-use, soil and groundwater. TDC Operations committee report, summary report ROCCCC20-02-4 and presentation. February. 26p, 9p & 20p. [soils component]

Council staff completed soil sampling and analysis at 80 sites during winter 2017 and 2018 on the eastern Waimea Plains to analyse soil properties beneath four main land uses (market garden, pasture, pipfruit and viticulture) and to link these with locations of high nitrate groundwater such as the Ranzau/Bartlett Road area [groundwater commentary is provided below under Pathways].

Soil samples were taken at near-surface (7-17.5cm) and subsurface depths (30-40cm) to measure soil nitrate, other soil fertility indicators (e.g. Olsen P, sulphate-S), soil carbon, total nitrogen and estimates of mineralisable organic nitrogen. Only N results are mentioned here.

In topsoil samples, market garden sites had higher soil nitrate (and other nutrient) levels and lower soil organic matter levels, nitrogen storage and potentially mineralisable nitrogen compared to pasture, pipfruit and viticulture.

In subsoil samples, mean nitrate levels were three to four times higher under market gardens compared to pasture, pipfruit and viticulture (Figure 3). Subsoils were stony and permeable making them prone to excessive drainage and leaching. The subsoil depth is also close to the rooting depths of some vegetable types grown on the Waimea Plains and therefore potentially represents a depth limit for vegetable nutrient uptake. This makes high subsoil nitrate levels a concern as plants will not be able to take up this nitrate which increases the risk of it leaching to groundwater.

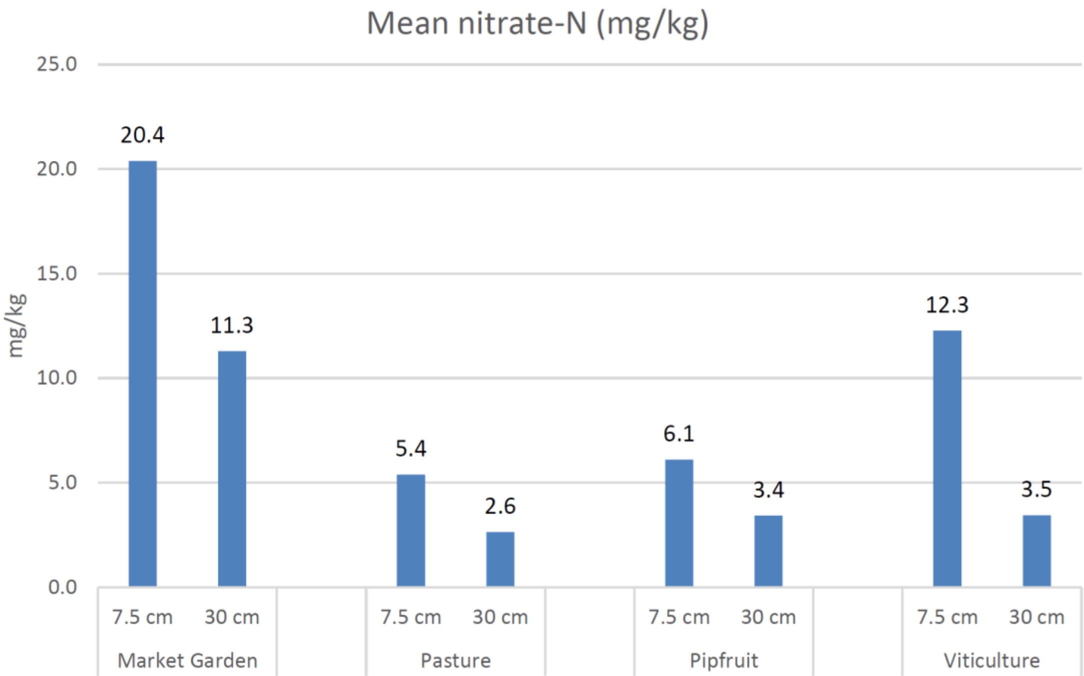


Figure 3 – mean soil nitrate, topsoil and subsoil for 4 land uses

Soil sampling results indicate that the risk for nitrate leaching in the study area is likely to be elevated under market gardening. Market gardens appeared to receive more frequent and/or higher fertiliser nitrogen inputs compared to the other systems. The lack of soil organic matter, coupled with well-drained soil properties and high nitrate levels (particularly at subsoil depths) makes market gardening a higher risk land use for nitrate leaching on the Waimea Plains, when compared to pipfruit, pasture and viticulture.

Implications: Market gardening is identified as needing particular attention for N-loss reduction. The report outlines some N-loss mitigations useful for policy consideration. These include efficient use of irrigation to reduce soil drainage losses, avoidance of fertilizing before rain, slow-release fertilizers, matching fertilizer to crop needs, allowing for crop residues and soil N when N budgeting, use of deep-rooted cover crops, use of soil carbon amendments such as biochar and increased organic matter.

Gaps: This method appears useful for identifying N-loss risk. It could be expanded to a wider range of soil-crop combinations. For example, the question has been asked why groundwater N concentrations west of the Waimea River are lower than on the eastern side, down-gradient of market gardening. Factors causing this would likely include the heavier soils (more retentive of N), the shorter duration of market gardening in some western areas, and the greater dilution provided by higher flow rates though the underlying Appleby Gravel Unconfined Aquifer.

At the September 2014 FLAG meeting, HortNZ acknowledged that managing soil organic carbon/matter is one of the key things to consider in managing nitrate. The comment was made that for vegetable growing a major source of nitrogen leaching is from cultivation, and consequential N-mineralisation. This points to methods such as biochar, organics, compost, and no-till to improve N retention through carbon adsorption. HortNZ has funded lysimeter studies in Canterbury, Pukekohe, Pukekawa, Hawkes Bay and elsewhere to measure nitrate leaching, so information from those studies should be relevant as input data for modelling and policy development.

b. Pathways

Stanton DJ and J L Martin. 1975 Nitrate levels in subsurface waters of the Waimea Plain, Nelson. NZ Journal of Marine and Freshwater Research, 9:3, 305-309, DOI: 10.1080/00288330.1975.9515570

This is the first published evidence for high nitrate concentrations in groundwaters of the Waimea Plains, dating back to 1969-72. 122 wells were sampled ranging in depth from 2.5 to 35m. Four had nitrate exceeding 30 mg/l (with 50 mg/l occurring in one well), fifteen in the range 30-20 mg/l, 46 between 20 and 10 mg/l, 57 below 10 mg/l and only four below 1 mg/l. In comparison the Wairoa River at the gorge had 0.07 and the Wai-iti 0.5-2 mg/l.

The authors' Fig 1 shows a nitrate plume directed northwards and centred on Main Road Hope between Edens and Ranzau Roads (>30 mg/l), with no results west of the Waimea River included within the 10 mg/l contour.

Implications: This work was carried out prior to characterisation of the separate aquifers underlying the Plains (see Dicker et al 1992) so the plume mapped in the authors' Fig 1 combines data from all well depths but many wells in the shallower Hope aquifers. The high concentrations mapped at this early date would suggest sources not solely linked to the historic piggery at Aniseed Valley Road/Haycock Road.

Gaps: This work was the genesis of ongoing nitrate surveys summarised below, and which should be continued, on a 5-yearly basis.

NMRC, NCC and TDC. 1990. Waimea Basin – water resource and water supplies. Summary report on reticulated supplies by J Wareing, P Dougherty, N Tyson & A Fenemor. July. 12p.

This regional council report provided a summary of Waimea water resources and water reticulation schemes existing in 1990. Reticulation schemes comprised the Maitai Dam (1987), the upper Roding River (1940), the decommissioned Reservoir Creek supply to Richmond (1886-1968?), the lower Queen Street wellfield (Lower Confined Aquifer; 1968), the Waimea supply (Appleby Gravel Unconfined Aquifer; 1976), Hope/Brightwater supply (AGUA;1976), Wakefield water supply (AGUA; 1973) and Neimann Creek supply (surface water; 1970).

On water quality, the report notes that the lower Queen St supply has nitrate exceeding 10 mg/l and has shown an upward trend for the previous 10 years (1980-90). A single water quality analysis for each supply is included in s8.2 and shows a May 1986 concentration in the Richmond supply of 14 mg/l nitrate-nitrogen [which exceeds the current drinking water standard of 11.3 mg/l].

Implications: Dilution of Richmond's lower Queen St supply with Waimea supply water is mentioned as a potential solution, and this has now happened. The TDC proposal to supply pumped groundwater from a new Clover Road West wellfield to interconnected Waimea Plains water supply schemes would provide a better quality water source (at least for N), with Wairoa-Waimea river flow depletion reduced by flow releases from the new Waimea Community Dam.

Gaps: Integrated modelling of river and groundwater flows alongside water quality (starting with nitrate) will enable more holistic management of land use versus drinking water. This needs to include assessment of areas not reticulated with water supplies meeting the NZ Drinking Water Standards, so that those can either be priorities for reticulation of for land use management to achieve NZDWS compliance in source groundwaters.

Dicker, M.J.I.; Fenemor, A.D.; Johnston, M.R. 1992. Geology and Groundwater Resources of the Waimea Plains, Nelson. Geological Bulletin, DSIR Geology and Geophysics, 59 pp.

Fenemor, A.D. 1988. A Three-dimensional Model for Management of the Waimea Plains Aquifers, Nelson. Publication No. 18 of DSIR Hydrology Centre, 133 pp.

Fenemor, A.D. 1989. Groundwater modelling as a tool for water management: Waimea Plains, Nelson. Journal of Hydrology (New Zealand) 28(1):17-31.

Taken together, these three publications provide the seminal hydrogeological and geohydrological understanding of the water resources of the Waimea Plains. Dicker et al summarises and extends the thesis work of Michael Dicker from 1980 and the Fenemor publications summarise the first groundwater flow model developed for the Waimea basin. The MODFLOW 3D model was used in management simulations to predict the aquifer response to three irrigation schemes, two of which (Waimea East and Redwood Valley) were subsequently built. It was also used to set allocation limits for water extraction from the aquifers in the first comprehensive Waimea Basin Water Management Plan (Nelson Catchment Board 1986) based on system response modelled for the 1982/83 drought (a 32 year drought as of 2023). Versions 2 and 3 of the Waimea flow model by Timothy Hong (GNS) and now Julian Weir (Aqualinc) update the flow modelling using more recent data, and provide simulations of river and aquifer responses to water rationing, with and without the Waimea Community dam water releases.

The publications above describe the major aquifers of the plains as the Appleby Gravel unconfined aquifer (AGUA), the Upper Confined Aquifer and the Lower Confined Aquifer (LCA) with the Hope Minor Confined and Unconfined Aquifers (HMCUA) occurring on fans along the Barnicoat Range. The AGUA which is up to 15m deep at the coast is fed from river recharge and rainfall infiltration with recharge calculated for the 1977-78 year as around 1200 l/sec. In comparison the UCA winter throughflow was 110 l/sec and LCA 58 l/sec. Recharge to the UCA and LCA is from river infiltration in the reach around Brightwater Bridge and about 50% from rainfall recharge in the eastern Waimea Plains via the Hope fan gravels. The UCA depth ranges from 18m deep near Wairoa Gorge to 32m deep near Bartlett Road where its upper confining layer is ruptured providing a hydraulic connection there with the AGUA. The LCA ranges from 30m near Wairoa Gorge to 50m deep extending an unknown distance beyond the end of Rabbit Island.

Dicker et al contain a summary and contour maps of nitrate in each aquifer in 1978 and 1986. Neimann Creek had 6.3$\pm$ 0.7 mg/l compared with Pearl Creek at 1.4$\pm$1.5 mg/l indicating the predominant UCA source for Neimann compared with AGUA water in Pearl Creek. The AGUA had mean N concentrations in 1978 and 1986 from 8 wells of 2.7 and 5.7 mg/l respectively. In the HMCUA mean nitrate was 11.1 and 10.5 mg/l respectively between 1978 and 1986. In the UCA the respective averages were 10.5 and 12.2 and in the LCA 9.5 and 9.6 mg/l. The average seepage velocity in the LCA was calculated as 0.92m/day while the movement of nitrate in this aquifer gave about 0.7 m/day, providing validation for the flow modelling in Fenemor (1988). Dicker et al also discuss oxygen isotope and tritium results as indicators of rainfall versus river recharge.

Implications: The sources, pathways and discharge of water from each aquifer are important to understand as carriers of contaminants including nitrate.

Gaps: More detailed work to differentiate the HMCUA from the UCA may help understanding of nitrate pathways into the aquifers – methods could include geophysics, more detailed well logging, isotope and geochemical analyses. Although of less concern for nitrogen management, better understanding of the coastal connection of the LCA to the sea, including seawards of Rabbit Island, would allow better risk management for seawater intrusion, especially with sea level rise.

Stewart, M.K., Stevens, G., Thomas, J.T., van der Raaij, R. and Trompetter, V., 2011. Nitrate sources and residence times of groundwater in the Waimea Plains, Nelson. Journal of Hydrology (New Zealand), pp.313-338.

Stewart, M.K. 2011. Improved understanding of groundwater movement and age in the aquifers of the Waimea Plains. GNS Science Consultancy Envirolink Report 2011/55. 10p.

Isotope research by C Taylor and M Stewart utilising tritium and oxygen isotopes assisted in defining the aquifers reported in Dicker et al 1992. These two more recent publications by M Stewart cover similar ground and use ^{15}N, ^{18}O and ^{3}H (tritium) isotopes, CFC and SF_6 contamination to help define the sources of nitrate-contaminated groundwaters.

Tritium measurements in well water give mean residence times for groundwaters, with the youngest waters in the area south of Hope, where nitrate concentrations are highest, and increasing ages to the south, west and north. Fitting a piston flow model to the isotope and CFC data suggest that well waters comprise mixes of water with wide variability in age. The CFC data cannot be relied upon as the authors consider the samples are contaminated from agrichemical sources.

The age distributions produce a nitrate input history for the Upper and Lower Confined Aquifers suggesting inputs starting from the 1940s. The contamination is carried northwards, affecting wells on the scale of decades.

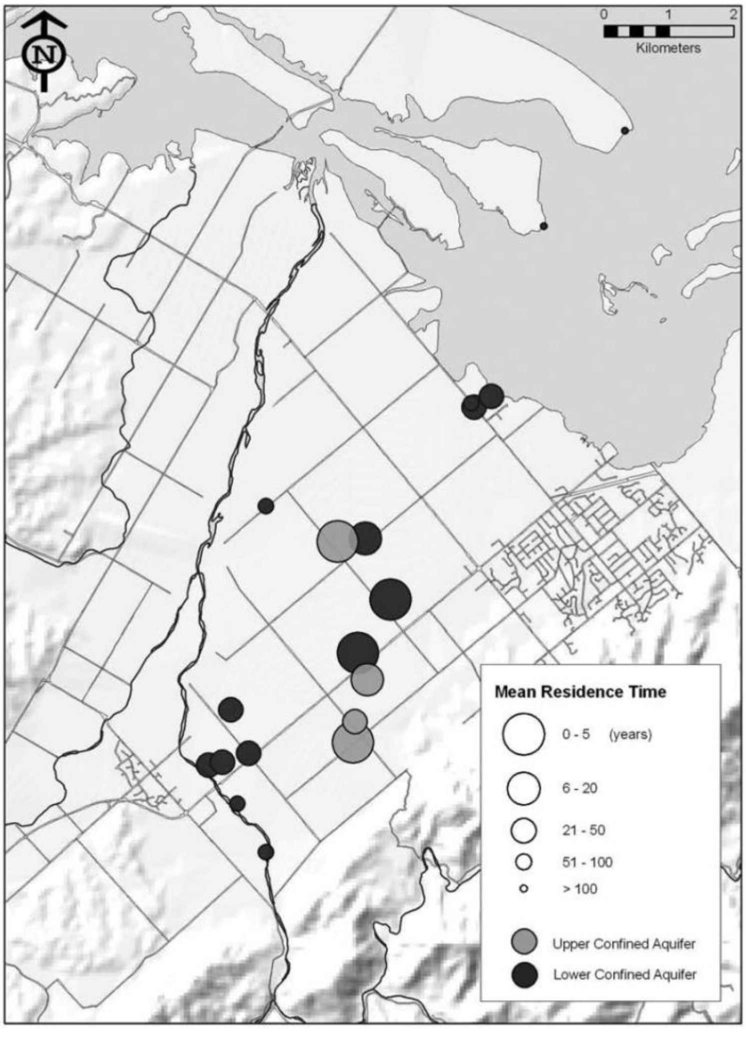


Figure 4 – Groundwater age UCA and LCA (Fig 7 from Stewart et al 2011)

Tritium sampled between 1972 and 2005 gives well-defined mean residence times for the LCA of 8 months at Ranzau Road, 33 years at Lower Queen St, 110 years at Bells Island and >150 years at Rabbit Island (Figure 5). Further west in the LCA the river-source water is up to 70 years old, confirming that the nitrate in the LCA is arriving via the Hope fan gravels.

Water in two Hope aquifer bores was recent at 0.5 and 0.1 years old, and in two AGUA wells was 2 and 1.1 years old. UCA water was 36 years old in an upstream bore but only 4.5 years old in monitoring bore WWD37 indicating a Hope aquifer source of more recent water between the two.

Interestingly, the paper models future nitrate concentrations based on an assumed history of inputs and continuing inputs at current levels. In the UCA WWD37 is projected to level off at about 10 mg/l after 2020 while in the LCA WWD208 at Ranzau Road is projected to level off at 9 mg/l after 2018, and the Richmond LCA water supply to fall to 11 mg/l in 2020 and decline slowly thereafter.

Implications: The wide age distributions found in single well samples confirms that in some wells the groundwater originates from a combination of rainfall recharge (via the Hope Aquifers along the Barnicoat Range when water tables are high) and river recharge from further south. This applies especially to long-term monitoring bores WWD37 for the UCA and WWD208 for the LCA both in Ranzau Road.

The ability of the isotope results (e.g. Fig 5a-c in the Stewart paper) to identify contaminant sources as from animal wastes versus fertilizer, or water sources as rainfall or rivers is not particularly convincing, perhaps confirming the mixed sources in many wells.

Gaps: The modelled future nitrate concentrations should be compared over coming years with measured data from ongoing nitrate and land use surveys. This would allow the reliability of the model assumptions to be checked or adjusted.

Spencer M J. 1981. Waimea Plains nitrate survey – summer 1981. Nelson Catchment Board internal report.

Fenemor, A.D. 1987. Water quality of the Waimea Plains aquifers 1971-1986. Nelson Regional Water Board. December. 40p.

Edie, N. 1995. Groundwater quality survey Waimea Plains (1986-1994). Tasman District Council report. January. 30p.

Ware, P. 2000. The Spatial and Temporal Distribution of Nitrate Within the Groundwater System of the Waimea Plains: Submitted in Partial Fulfilment of the Degree of Bachelor of Science, with Honours at the University of Otago, Dunedin, New Zealand.

Stevens G. Groundwater Quality in Tasman District 2010. TDC State of the environment report R10003. October. 53p. http://www.tasman.govt.nz/document/serve/State%20of%20the%20Environment%20Report%20-%20Groundwater%20Quality%20in%20Tasman%20District%202010.pdf?path=/EDMS/Public/Other/Environment/EnvironmentalMonitoring/WaterMonitoring/Groundwater/000000186335

Stevens, G. 2017. Waimea groundwater nitrate synoptic survey. TDC Environment & Planning committee report 17-06-05. June. 24p.

Simmonds B and M Westley. 2020. Waimea Plains nitrate supplementary data: land-use, soil and groundwater. TDC Operations committee report, summary report ROCCCC20-02-4 and presentation. February. 26p, 9p & 20p. [Groundwater component]

Westley, M. 2023. Waimea Groundwater Quality Survey 2021. Tasman District Council technical report, 83p.

Nitrate surveys have been systematically carried out across the Waimea Plains since 1986, although surveys by Stanton and Martin (1975) and Spencer (1981) provided unstructured data on high nitrates in wells even earlier. Alongside the geohydrological understanding of the aquifers, the surveys provide a time series of nitrogen movement from land uses to wells and receiving waters down the plains. The surveys were undertaken in 1986 (63 sites), 1994 (64 sites), 1999 (82 sites), 2005 (93 sites), 2016 (130 sites) and 2021 (149 sites). These synoptic surveys are typically undertaken during the summer months and are in addition to the Council's quarterly State of the Environment (SoE) monitoring programme for groundwater.

Groundwater nitrate concentrations below 1.6 mg/l are most likely a result of natural processes. Concentrations higher than 3.5 mg/l are almost certainly indicative of human influence (Daughney and Reeves 2005). Concentrations exceeding 11.3 mg/l do not meet the New Zealand Drinking Water Standard Maximum Acceptable Value (MAV) for nitrate. Treatment options for the removal of nitrate from groundwater are very expensive.

Comparison of the 1978 and 1986 surveys found steady concentrations of nitrate in the LCA (averaging 9.6 mg/l in 1986), increasing levels in the UCA (12.6 mg/l), decreasing levels in the HMCUA (10.5) and increasing levels in the AGUA and spring-fed streams (5.6). The 1994 survey noted no decrease in groundwater nitrate concentrations apart from within the Appleby Gravel Unconfined Aquifer. In the other aquifers nitrate concentrations remained elevated and in numerous instances exceeded the New Zealand Drinking Water Standard. The 1999 survey concluded that elevated nitrate concentrations continue to occur along flow paths in the Lower Confined Aquifer and Upper Confined Aquifer, confirming that the principal source of nitrate to the aquifer systems occurs in the Hope area where groundwater recharge to both the confined aquifers occurs. The 2005 survey noted the persistence of high nitrates in some areas over the past 30 years; 35% of bores sampled in 2005 had nitrate exceeding 11.3 mg/l, however, apart from the LCA near the coast and AGUA near SH60 between Bartlett and Blackbyre roads, concentrations overall were either decreasing or showing no appreciable change.

Much of the Waimea Plains continues today to have low nitrate concentrations in the groundwater. However, nitrate concentrations have risen where the UCA discharges into the AGUA (Bartlett Road/Blackbyre Road/State Highway 60 and Ranzau/Bartlett Road areas – red symbols in Figure 6) with measured concentrations rising from 24 mg/l in 2016 to 30 and higher in 2021. These have increased since the 2005 survey when the highest concentrations occurred in the Aniseed Valley/Paton Road area of the UCA but have now fallen. The UCA (and dispersed historic piggery plume) merges into the AGUA near Bartlett Road and Ranzau Road. Some leakage from the UCA to the underlying LCA also occurs (around Ranzau Road) when the UCA passes over the LCA resulting in elevated nitrate concentrations observed in the LCA down gradient of this location.

Of the 137 bores/wells sampled in 2021, 39 sites (28%) were above the Drinking Water Standard of 11.3 mg/l and 42 sites (31%) were between 5.6 and 11.3 mg/l. Samples where nitrate concentrations are above 50% of MAV underlie the horticultural and agricultural areas on the Plains, confirming input from present-day activities into all four aquifers. Pesticide residues detected in the seven bores that were sampled in 2018 were well below the pesticide MAVs. Nitrate is the main indicator contaminant requiring action.

The snapshot surveys raise the question of how variable are nitrate concentrations over shorter than annual timescales. These studies show that nitrate levels respond quickly to rainfall infiltration in AGUA bores, especially during winter, but these nitrate signals are damped in the confined aquifers. As an example, nitrates in UCA bore WWD37 are stable, while earlier data there show a decline in nitrate from ~25 mg/l in the late 1980s to a steady concentration of ~11 mg/l since 2012. It is possible this represents the last of the historic piggery leachate reaching Ranzau Road (WWD37) in 2012. In contrast, AGUA wells surrounded by market gardening confirm that larger rainfall events are flushing soil nitrate into the unconfined aquifer.

The Westley (2023) report contains useful comparative maps of nitrate plumes across the three main aquifer units across all surveys. These are reproduced in Figure 7a-c and show in yellow, orange and red the groundwaters exceeding the NZ Drinking Water MAV. Together with identification of up-gradient contributing land uses, these maps help to identify land areas for action, and how some may have changed over time.

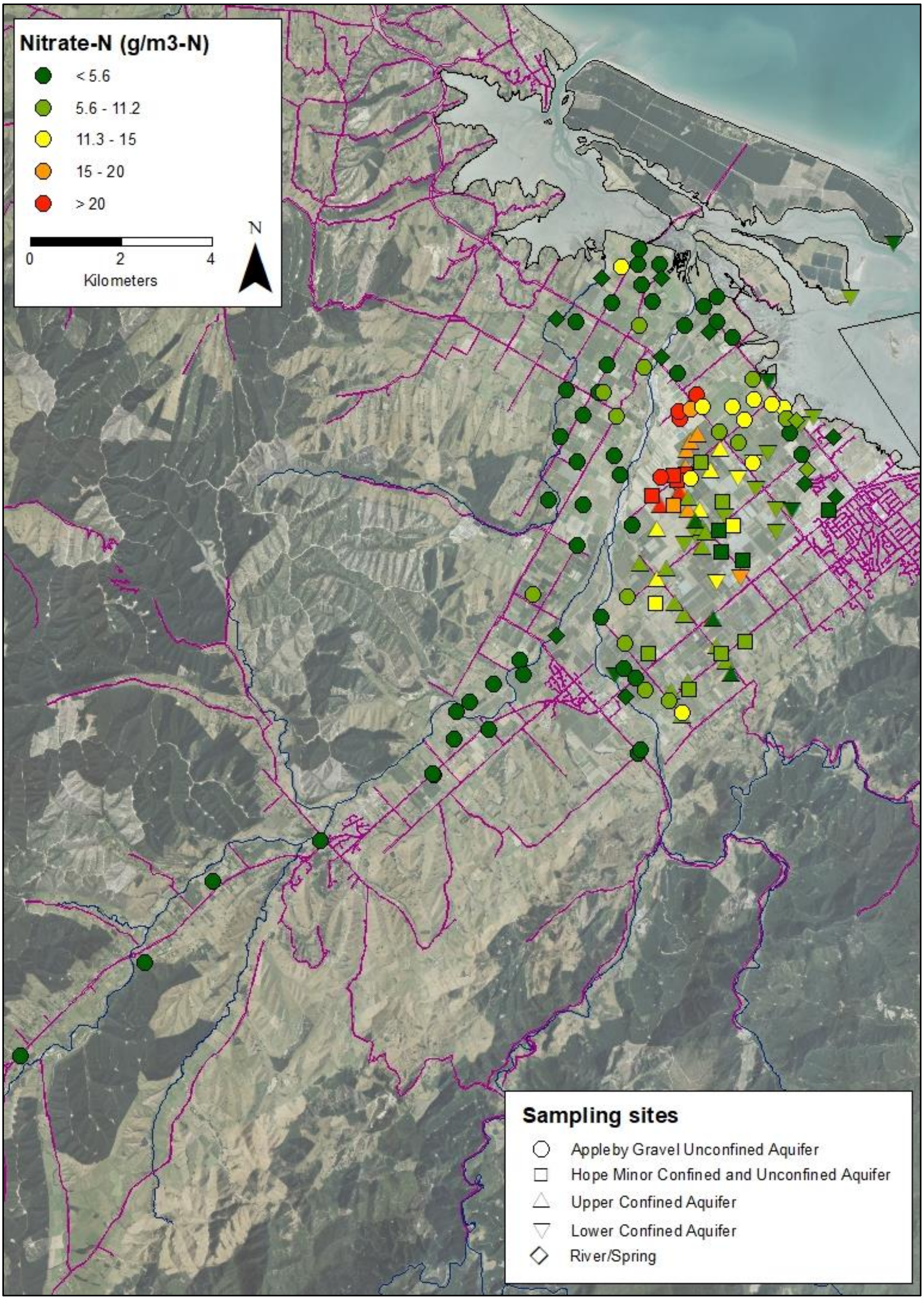
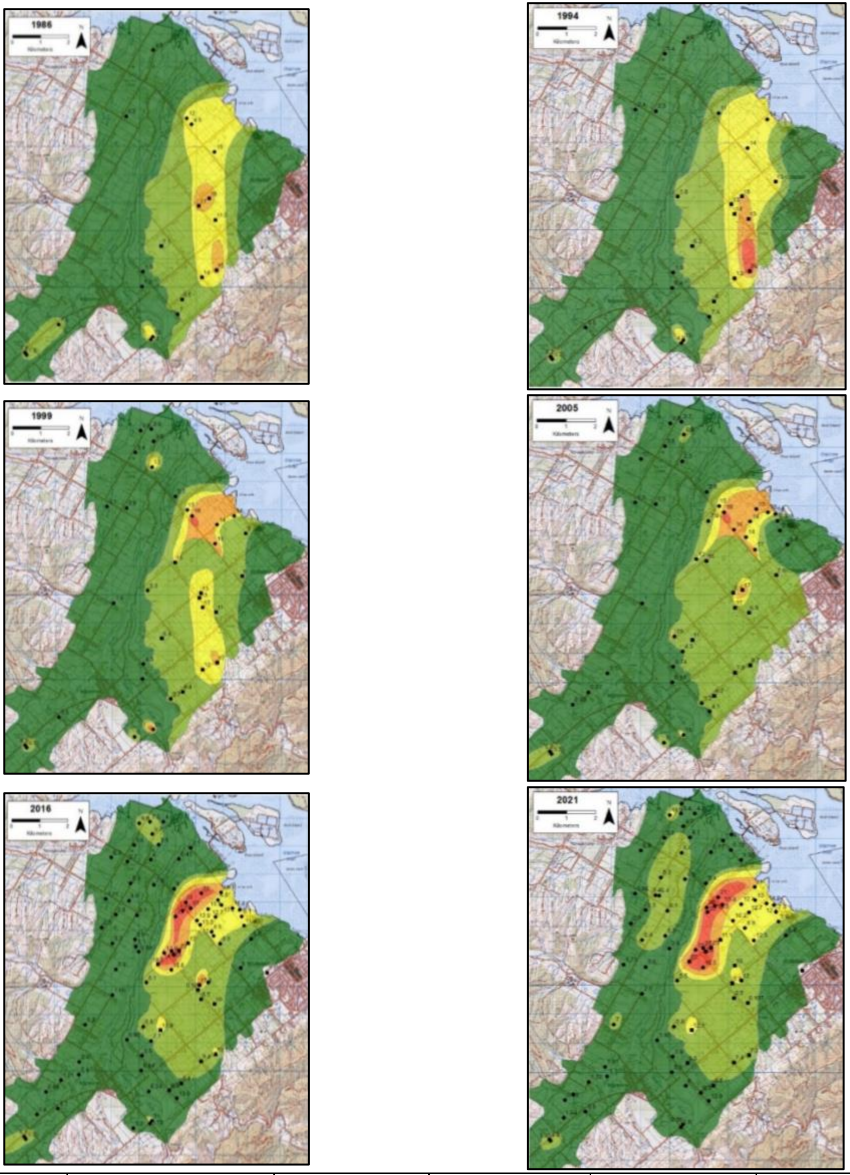
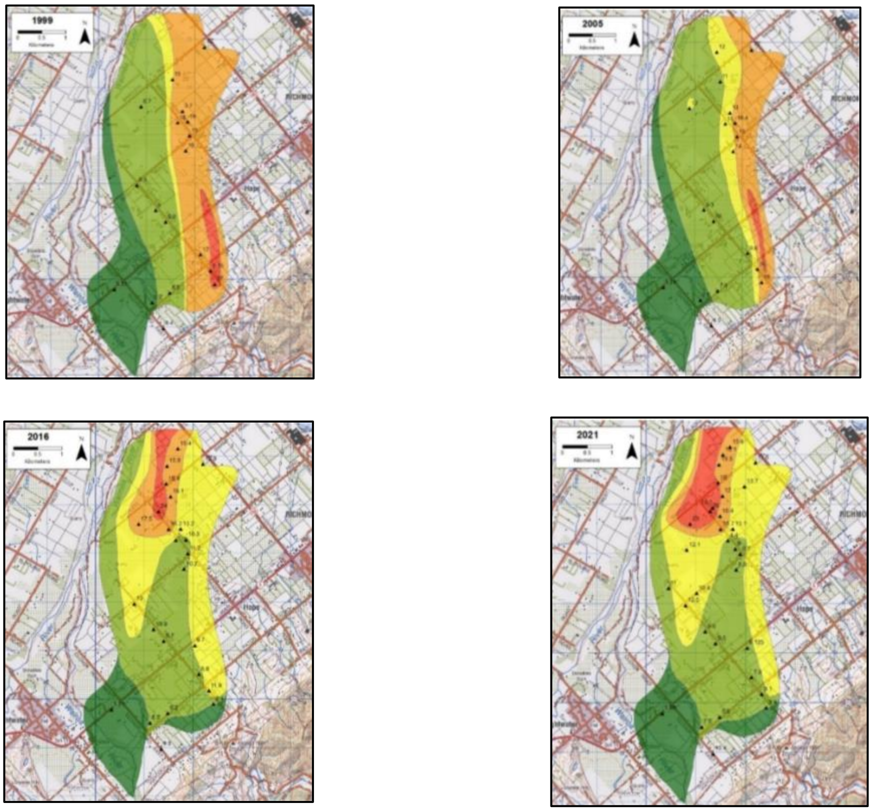


Figure 5 –Distribution of nitrate-N across the Waimea Plains from 2021 survey. Yellow, orange and red highlights concentrations measured above the MAV, in increasing order.



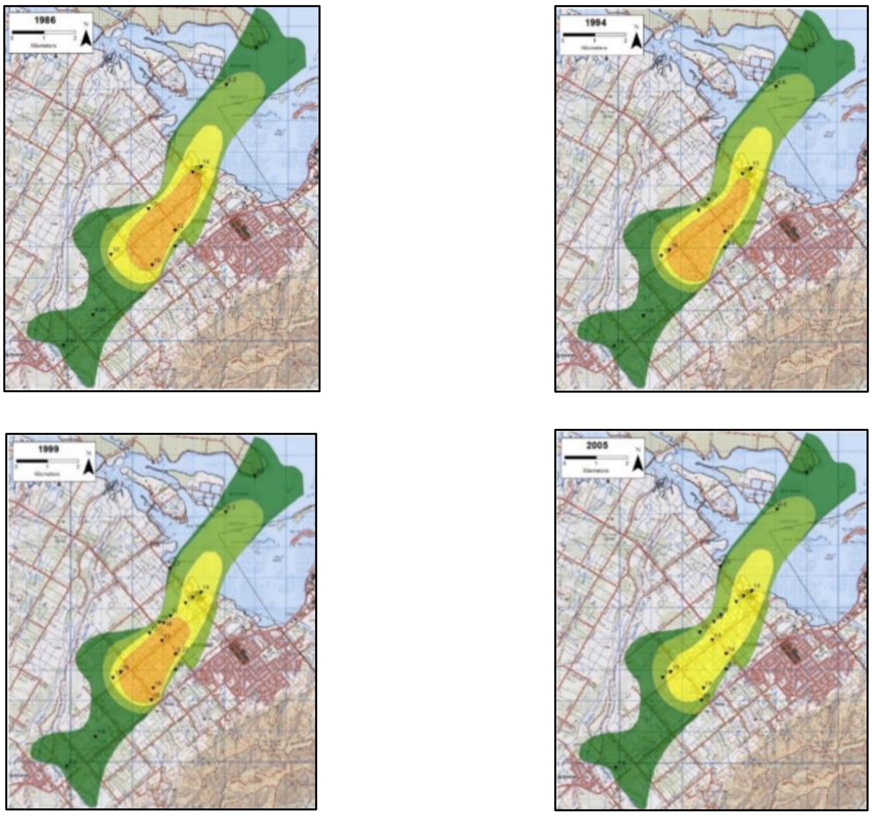
Legend					
Nitrate-N (g/m3-N)	*< 5.6*	*5.6 – 11.2*	*11.3 -15*	15.1 – 20	> 20

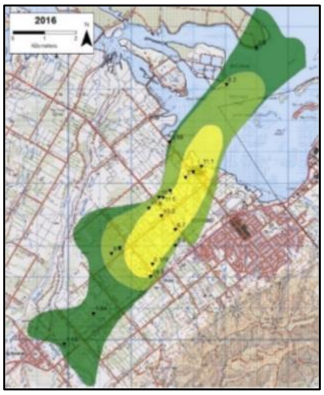
Figure 7a: AGUA and HU nitrate-N contours from 1986, 1994, 1999, 2005, 2016 and 2021 investigations.

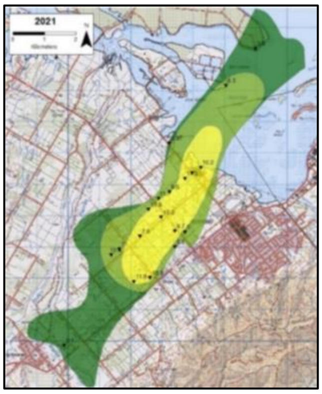


Legend					
Nitrate-N (g/m3-N)	*< 5.6*	*5.6 – 11.2*	*11.3 -15*	*15.1 – 20*	*> 20*

Figure 7b: UCA nitrate-N contours from 1986, 1994, 1999, 2005, 2016 and 2021 investigations.







Legend					
Nitrate-N (g/m3-N)	< 5.6	5.6 – 11.2	11.3 -15	15.1 – 20	> 20

Figure 7c: LCA nitrate-N contours from 1986, 1994, 1999, 2005, 2016 and 2021 investigations.

Implications: Recent data confirm the leaching of nitrogen from highly fertilised land uses affecting the recharge areas of the UCA and LCA and directly affecting water quality in the unconfined AGUA. As concentrations exceed the drinking water limit, policy should be directed towards reducing them and/or ensure availability of alternative potable supplies especially for any households with bottle-fed infants.

The monthly data suggest that the connectivity between the AGUA and underlying UCA in the Ranzau/Bartletts/Blackbyre/SH60 area is more widespread than earlier hydrogeological interpretation would have suggested. The data suggest that the historic contamination has likely passed and this is supported by the fact that pig effluent is highly mineralizable so that after 30+ years from the time of discharge, it should have substantially degraded. Therefore, what we see as the nitrate signature in these wells is caused by local and upstream intensive land uses, particularly market gardening (vege growing). The lack of fluctuation in WWD37 nitrate concentrations will be due to the mixing of multiple sources of nitrate and variable transit times for recharge water – a blend of rainfall and river sources - to reach this confined part of the aquifer. Higher nitrate levels will exist in the top of the aquifer with mixing down the depth of the aquifer occurring gradually as groundwater flows down-gradient; pumping water from a fully screened well will mix stratified water as it is sampled.

Gaps: It has been proposed that piezometers be installed up-gradient and down-gradient of the historic piggery to check whether high nitrates are still coming from that area, potentially from residual buried waste. Before that is considered further, it would be useful to carry out more intensive (monthly) sampling of existing wells in the vicinity, and to evaluate the geochemistry (following up on the suggestion of Selva Selvarajah (email to B Simmonds 20 Feb 2020) that Magnesium may be an indicator of the historic contaminant source, and that its similar pattern in WWD37 to nitrate suggests the historic plume has largely dissipated). The difficulty with piezometer installation is the high variability of aquifer geology especially upgradient of the old piggery where clay-bound outwash from the hill could complicate interpretation of groundwater sampling results – this would likely mean that more than 2 piezometers (upstream/downstream) would be needed to find sites representative of aquifer conditions.

I have spoken with Tony Zwart who owned the Stratford piggery property after it ceased being a piggery. While the piggery was in operation he also made compost for market gardening on Aniseed Valley Road by combining sawdust with the pig effluent (a 2:1 mix) in the effluent collection pit at the NW corner of the property. When the piggery closed, he reports the empty compost pit was returned to its original contour by filling it in with soil. As this pit does not appear to be directly upgradient of the well on the property with high nitrate, this lends weight to the notion that the nitrate plume originates from broader-scale land use.

Regarding the monthly monitoring, it may help inform understanding of the leaching loss mechanisms locally to develop a water balance model relating AGUA water level and nitrate responses to land use and effective rainfall (rain minus ET). This would require data on the land use activities (crop locations, fertilizer and irrigation use), some of which is provided by the Rainham survey summarised earlier and may also be available via Craig Hornblow (Agfirst). The model could then be used to investigate what management practices might achieve nitrate concentrations less than NZDWS limit of 11.3 mg/l. This work could also be carried out on a larger scale with the proposed linking of a nutrient loss model (eg SPASMO or OVERSEER) with the existing groundwater flow model, discussed below – the advantage of that is that upstream land use effects on nitrates can be better accounted for. If the nitrate sensor can be confidently calibrated, its redeployment in the same area would provide useful fine-scale data for improving understanding of the processes and lags in N leaching, and for the modelling.

The mapped plots of progress of the nitrate plumes for each aquifer as shown in the Westley 2021 survey report are a useful visualisation of nitrate levels over 35 years. It would be informative to see overlaid plots using exactly the same wells available in all surveys to better judge the plume movement without the distortions caused by adding new wells into the contouring. Overall, the surveys suggest that migration of nitrate through the aquifers is happening more slowly than flow modelling has suggested.

BioGro who certify organic produce have indicated (B Simmonds, pers.comm) that having high N levels in groundwater has the potential to compromise the certifiable organic status of the crop, which limits access to high value domestic and overseas markets. If BioGro became aware of contaminant issues in groundwater used for irrigation, they would be duty bound to test the irrigation and impose any relevant limits for contaminants. They would be looking to UK, US, EU for guidance on those permitted limits, as these are the key markets.

Former orchardist David Easton who takes irrigation water from a well with high nitrates next to WWD163 (**Error! Reference source not found.**) has indicated that high nitrate delays apple colouring despite it maturing. Dean Rainham and Craig Hornblow, AgFirst, have commented that especially during dry years with more irrigation required, the high N in irrigation water equates to 60-80 kgN/ha/yr being applied at a time when the crop does not need nitrogen. Higher N appears to mobilise Mg in the soil, affecting fruit maturity and storage quality. Mitigations include addition of K fertilizer and use of bark mulch to absorb N. Neither has been particularly effective, so an alternative water supply might be required. Thus, high N in irrigation water adds to the monitoring and mitigation required on orchards in that area.

Fenemor A, Weir J 2016. Waimea Community Dam: Peer Review of Waimea Plains Hydrology underpinning the proposal. Landcare Research contract report LC2659 for Tasman District Council. September. 53p. https://www.tasman.govt.nz/my-council/projects/waimea-community-dam/document-library/?path=/EDMS/Public/Other/Tasman/Projects/WaterAugmentationProjects/Water_for_Waimea_Basin/LandcareResearchGroundwaterHydrologyPeerReview2016

Weir J. 2024. Waimea Plains Groundwater Model - Model Documentation. Aqualinc Research report WL22006 for Tasman District Council. 292p.

While not addressing water quality, these reports (along with the GNS modelling report of Hong and Zemansky 2009) summarise the hydrological basis for river flows and aquifer water levels with and without the Waimea Community Dam. Flow releases from the dam maintaining a 1100 l/sec minimum flow in the lower Waimea River every summer combined with increased groundwater pumping and improved reliability (freedom from rationing) will modify the contributions of river infiltration to the aquifers, particularly the AGUA and spring-fed streams in the lower catchment. Generally, as river flows increase, river recharge to groundwater increases (Figure 6). Similarly, as groundwater levels drop, river recharge to groundwater increases. Dam releases will improve water quality during summer in the lower Waimea River and potentially in the spring-fed streams as well, through dilution from the increased river flow.

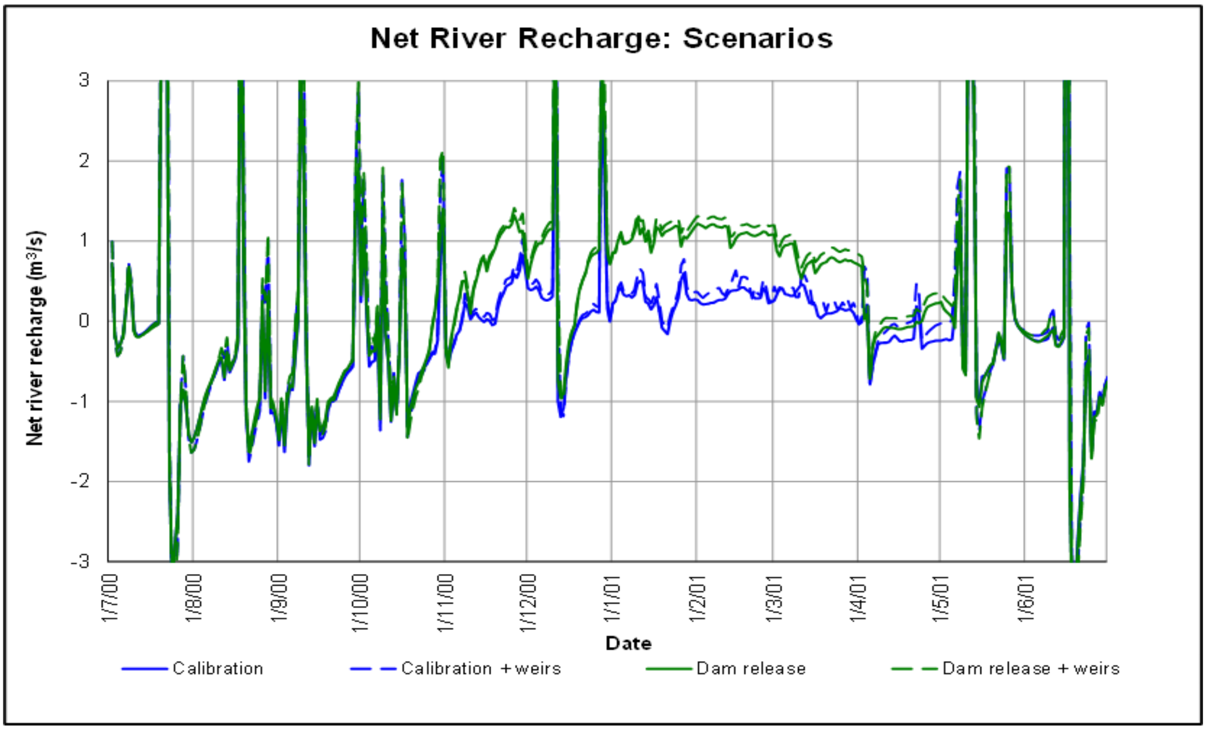


Figure 6 – Modelled increased groundwater recharge from Wairoa-Waimea river with dam releases

The 2016 review also summarises the projected effects of climate change to 2090 which, among other effects, will likely change the range of crops able to be grown, and also the nutrient losses. For 1990–2040, annual mean air temperatures may rise by 0.9°C; for 1990–2090 mean temperatures could increase by 2°C. The days of frost are expected to decline markedly which may affect fruit set for some horticultural crops. Sea level rise of 0.8m is expected by 2090; in the absence of tidegates, this would modify the aquatic ecosystems of the lower reaches of Pearl, Neimann and Borck creeks to more saline-tolerant for some 500-1000m inland (Figure 7).

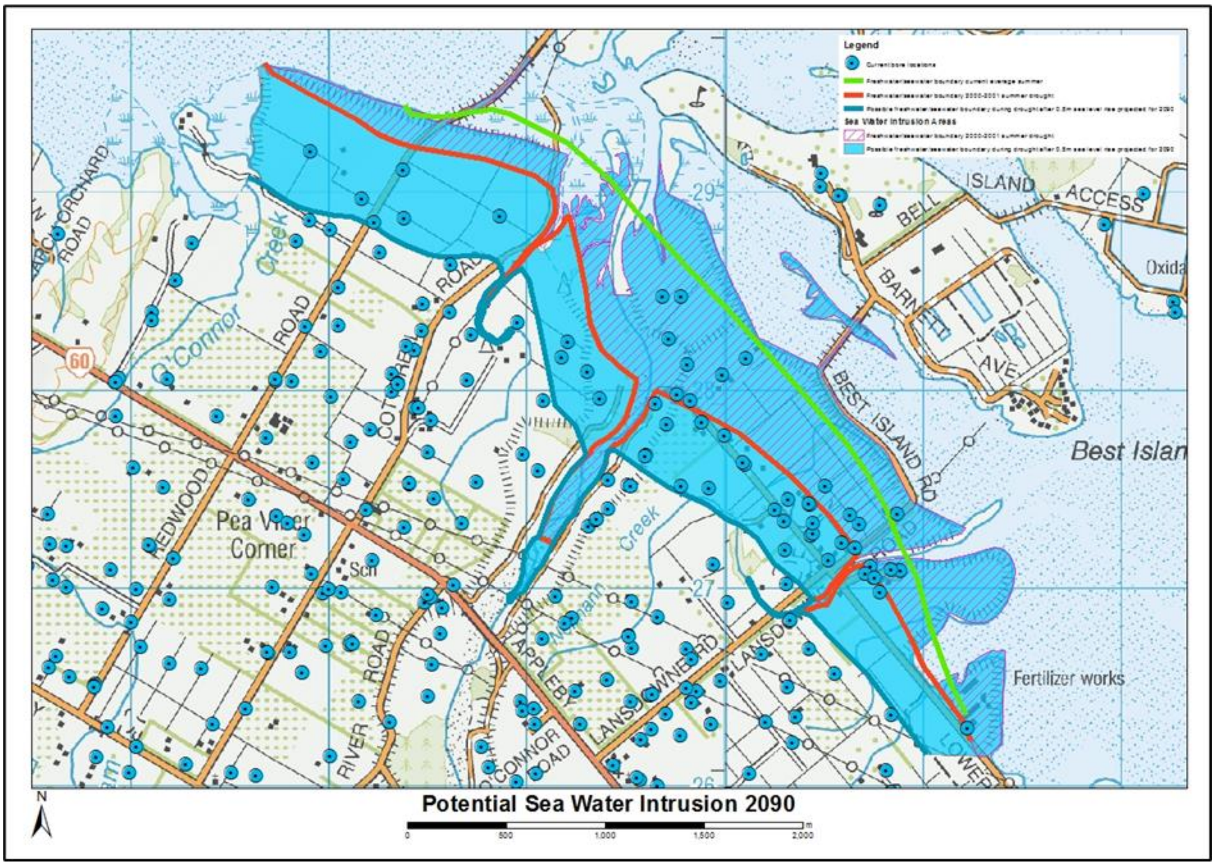


Figure 7 - Waimea river mouth showing three locations for freshwater–seawater interface: average summer currently (green), during 2001/01 drought (red) and during 2000/01 drought conditions as a worst case if they occurred in 2090 after 0.8-m rise in sea level (blue).

The 2016 report notes that given the types of farming systems currently on the Waimea Plains, there is limited scope for technology improvements in irrigation efficiency, given the already widespread use of microsprinklers and drippers (see the commentary on the SPASMO modelling later which concludes that for current crops the addition of irrigation creates little increased N leaching, and in the case of apples, less).

Of relevance to nitrate concentrations is the Waimea Community Dam release of water to maintain much higher minimum river flows during summer. The Aqualinc (2024) modelled scenarios indicate that historical groundwater pumping predicted to have reduced Pearl and Neimann creeks by 20-30 l/s (each) during dry periods would no longer occur thereby providing more summer dilution of nitrates. Maintaining a minimum flow of 1,100 l/s at Nursery by augmenting gorge flows is predicted to raise groundwater levels over the plains during very dry periods (a 50-year drought) by up to 0.8 m, near the rivers. Shallow groundwater levels are predicted to be maintained at least 0.1 m higher over a width of approximately 0.5-2 km out from the Waimea and Wairoa rivers. This is estimated to increase the volume of water stored in groundwater by approximately 0.8 million m^3 also providing some additional dilution of nitrates, albeit offset by land use intensification facilitated by availability of extra irrigation.

Implications: This report and modelling reports from Aqualinc (2024) and GNS (e.g. Hong and Zemansky 2009) document modelled changes in Waimea Plains hydrology expected after commissioning of the Waimea Community dam. Increased groundwater pumping combined with increased Waimea river flows especially during dry summers may change the attenuation (N reducing) characteristics of the aquifers primarily through increased local dilution, although nett effects are expected to be small. The 2016 report points to the need to consider longer term effects of climate change on the crops able to be grown on the Plains alongside expected sea level rise effects on coastal receiving waters (spring-fed streams, lower Waimea River and Waimea Inlet).

Gaps: The Waimea groundwater model is proposed to be developed in future years to include modelling of nitrate transport, not as an integrated water quality process model, but more likely through a loose linkage with N inputs generated by SPASMO, APSIM or OVERSEER for various land use and land management scenarios. This should be a priority in Council's LTP as it will enable more informed modelling of various land use and management scenarios which can in turn inform policy development. However there is sufficient knowledge from existing approaches (see commentary below on the SPASMO modelling) not to delay policy development while awaiting linked modelling.

Lovett, A. and Rissmann, C. 2018. Evaluation of the physiographic method for the Tasman Region. Land and Water Science Report 2018/01. 26p.

The physiographic method, developed in Southland, seeks to explain 'how' and 'why' water quality varies across a region by identifying the gradients driving key landscape processes that govern water quality outcomes and risk (Rissmann et al., 2016). While land use is a prerequisite for poor water quality outcomes, it is the inherent physical, chemical and biological characteristics (attributes) of a landscape that are often responsible for a larger proportion of the variation in water quality outcomes. Such attributes include soil drainage class affecting denitrification, soil permeability gradients affecting transmission pathways, and hydrological gradients affecting flowpaths. The fundamental premise of the physiographic approach is that spatial variation in water composition (quality and hydrochemistry) can be understood by identifying and mapping the spatial coupling between process signals in water and landscape attributes. TDC has stated an interest in the potential for the physiographic approach to determine the origin of non-point source contaminants at a paddock scale.

This report is a scoping exercise focused on data needs and potential of the method for the Waimea catchment. In addition to existing flow, water quality, soil and land use datasets, the authors recommend collection of headwater quality data from hill and alpine catchments of varying geology and soils, plus 6 surface water and 6 shallow groundwater quality samples.

Implications: The value of the physiographic approach appears to be for characterising cause and effect for flows and water quality across broad-scale relatively uncharacterised catchments. It lends itself to regional scale mapping where hydrochemical signatures can be differentiated and attributed to landscape characteristics including soils and underlying geology. I have doubts of its value in an already highly researched catchment such as the Waimea but would see some worth in trialling it in a data-poor catchment such as the Aorere.

Gaps: The physiographic approach draws heavily on geochemistry for linking landscape attributes with water quality. Hydrogeochemistry is an area of investigation which should be looked at for its potential to better refine knowledge of aquifer connectivity and N attenuation, for example via denitrification. As a start, mining existing data such as from the NGMP and SOE sites and from earlier research may help improve our conceptual model of cause and effect, which will in turn improve modelling and policy development. This work is currently (2023) being carried out by GNS in an Envirolink-funded project.

c. Receiving Waters

TDC and Tasman Environmental Trust. 2004. Pearl Creek, Tasman District. Booklet on history, ecology and restoration by Ann Sheridan. 7p.

This information booklet describes the history of use of Pearl Creek for access to the Waimea pa near the present-day Appleby School, the aquatic species in the creek (which then included giant kokopu), and the restoration project which started with a planting project in the mid 1980s.

Implications: A useful information source on the history and values of Pearl Creek.

Gaps: -

Hickey C. 2013. Updating nitrate toxicity effects on freshwater aquatic species. NIWA Envirolink report HAM2013-009. 34p. https://envirolink.govt.nz/assets/Envirolink/1207-ESRC255-Updating-nitrate-toxcity-effects-on-freshwater-aquatic-species-.pdf

Hickey, C.W. (2015). Hardness and Nitrate toxicity – site-specific guidelines for spring-fed streams in the Waimea and Motupipi river catchments and Waikoropupū Springs. No. HSJ15201. NIWA report to Tasman District Council, pp. 7.

Dr Hickey has updated the ANZECC guidelines and the 2009 ECan guidelines for nitrate concentrations which would cause acute or chronic toxicity effects on freshwater species, but including only 2 NZ native species, juvenile inanga and mayflies. "Grading" concentrations are median values equivalent to ANZECC trigger values and "Surveillance" values are 95th percentile concentrations; gradings are NOEC (no observed effect) concentrations for all relevant species.

Of relevance to Waimea spring-fed streams is the observation that the original nitrate toxicity guidelines are for low hardness water, which has toxic effects at lower concentrations than high hardness water. However there was insufficient information to modify the recommended toxicity thresholds at the time of this report.

The recommended toxicity guidelines were those included in the 2017 NPSFM:

Guideline Type	Grading Nitrate concentration (mg NO_3-N /L)	Surveillance Nitrate concentration (mg NO_3-N /L)	Description of Management Class
Chronic – high conservation value systems (99% protection)	1.0	1.5	Pristine environment with high biodiversity and conservation values.
Chronic – slightly to moderately disturbed systems (95% protection)	2.4	3.5	Environments which are subject to a range of disturbances from human activities, but with minor effects.
Chronic – highly disturbed systems (90% protection)	3.8	5.6	Environments which have naturally seasonally elevated concentrations for significant periods of the year (1-3 months).
Chronic – highly disturbed systems (80% protection)	6.9	9.8	Environment which are measurably degraded and which have seasonally elevated concentrations for significant periods of the year (1-3 months).
Acute	20	30	Environments which are significantly degraded. Probable chronic effects on multiple species.
Method of comparison	Annual median	Annual 95th percentile	

In his 2015 memo for TDC, Dr Hickey calculates hardness-specific nitrate guidelines for Borck, Neimann and Pearl creeks at which time (2015) their median nitrate concentrations were 5.6, 3.3 and 2.9 mg/l respectively.

In the decisions gazetted in the NPSFM 2020, the national bottom line is raised from the current 80% protection level to 95% protection.

If it were permissible to adjust the NOF guidelines for hardness, Hickey (2015) calculates that the median limits for 95% protection would be 16, 21 and 16 mg/l respectively.

Implications: Neimann Creek and Borck Creek have the highest nitrate concentrations, and in relation to nitrate toxicity are currently subject to the NPSFM bottom line of 2.4 mg/l, below the cited median concentration for all 3 spring-fed streams. This means that rather than simply focussing on managing these streams for periphyton and algae, the new toxicity (species protection) limits must also be complied with. Neimann Creek water is relatively hard but there is no ability yet discussed for Council to be able to adjust the national bottom line limit to allow for the effect of water hardness in reducing toxicity.

Gaps: Council may wish to advocate to MfE to allow adjustments to toxicity based on water hardness, as indicated in Hickey (2015)

Young RG, Doehring K, James T 2010. River Water Quality in Tasman District 2010. State of the environment report for Tasman District Council. Cawthron report 1893. 165 p. plus appendices.

James, T. and Kroos, T. 2011. The Health of Freshwater Fish Communities in Tasman District 2011. Tasman District Council State of the Environment Report #11001. September. 145p. http://www.tasman.govt.nz/document/serve/State%20of%20the%20Environment%20Report2011.pdf?path=/EDMS/Public/Other/Environment/EnvironmentalMonitoring/WaterMonitoring/Fish/000000204290

Maps: http://www.tasman.govt.nz/document/serve/State%20of%20the%20Environment%20Report%202011%20-%20Appendix.pdf?path=/EDMS/Public/Other/Environment/EnvironmentalMonitoring/WaterMonitoring/Fish/000000204291

James T. 2011. Tasman's Natural Swimming Holes and Beaches - Popularity and Effects on the Recreational Experience. TDC state of the environment report #11002. http://www.tasman.govt.nz/document/serve/TasmanSwimmingAreaSurveyReport2011.pdf?path=/EDMS/Public/Other/Environment/EnvironmentalMonitoring/WaterMonitoring/SurfaceWater/RecreationalSwimmingWater/000000191956

James, T and McCallum. 2015. State of the environment report – River water quality in Tasman District 2015. Tasman District Council report. 383p.

Young R, Wagenhoff A, Holmes R, Newton M, Clapcott J. 2018. What is a healthy river? Prepared for Cawthron Foundation. Cawthron report 3035. 45p.

These SoE reports summarise water quality data, including for the Wairoa, Wai-iti, Waimea rivers and spring-fed streams, and including nitrogen concentrations. As stream water quality in the lower Waimea catchment during baseflow conditions is heavily governed by groundwater return flow, the water quality and freshwater ecosystem health of these water bodies is dependent on groundwater quality and in turn on upstream land use activities.

The reports also review the values associated with surface water bodies, including recreational uses, which will affect the limits and targets to be set.

The Cawthron report outlines the definition for freshwater ecosystem health now modified and adopted as a fundamental tenet governing the 22 attributes to be prescribed for use by the NPSFM 2020. In summary FEH comprises:

1. Water quality – the physical and chemical measures of the water, such as temperature, dissolved oxygen, pH, suspended sediment, nutrients and toxicants.
2. Water quantity – the extent and variability in the level or flow of water.
3. Habitat - the physical form, structure and extent of the waterbody, its bed, banks and margins, riparian vegetation and connections to the floodplain.
4. Aquatic life – the abundance and diversity of biota including microbes, invertebrates, plants, fish and birds.
5. Ecological processes – the interactions among biota and their physical and chemical environment such as primary production, decomposition, nutrient cycling and trophic connectivity.

In addition, limits may be set through regional plans to maintain or enhance other values including cultural values, recreation, landscape and production values.

<u>Implications:</u> Nitrate is but one parameter affecting both freshwater ecosystem health and other water body values. From a science perspective, it is desirable to prioritise as far as possible, attributes which are integrative measures of the chosen values. For example, parameters such as Macroinvertebrate Community Index (MCI), Fish Index of Biotic Integrity (IBI) and periphyton. The NPSFM mandates the use of particular attributes and prescribes national bottom lines for most. Those include nitrate toxicity as discussed above and potentially in future Dissolved Inorganic Nitrogen (DIN) of which nitrate is a primary component. DIN and Dissolved Reactive Phosphorus (DRP) together affect periphyton growth and should be considered together. Existing water quality data and expected national regulations together suggest the need for policy to reduce nitrates especially in spring-fed streams.

<u>Gaps:</u> -

James, T 2020. Neimann Creek Restoration Work. Summary report, May 2020. Tasman District Council, 8p.

This report is a summary of riparian and instream restoration work carried out during January-May 2020 to improve the environment along Neimann Creek. The work included sediment and aquatic weed removal by dredging, fish recovery during dredging, poisoning of willow regrowth, planting of *Carex secta*, removal of flow restrictions including an upstream culvert and aquatic habitat enhancement including anchoring logs to the banks, placing of straw bales to create eddies and a floating wetland.

The report also summarises continuous monitoring of dissolved oxygen in January 2020 for comparison with 2019 data. Of surprise were the lower daily minima downstream of the spring source of the creek, when it was expected the spring source would have lower D/O. This may be due to rotting vegetation in the creek and/or inflow of low D/O groundwater along the upper stream reach. Lack of shading exacerbates low D/O.

Among the recommendations, author Trevor James suggests a tide gate be reinstalled at lower Queen St, a sediment trap to allow further sediment removal, and oxygenation near the source. A funding application made by ESR to test the efficacy of woodchip denitrification walls (WDWs) at the springhead of Neimann Creek was unsuccessful in 2020. Estimated construction cost is $150,000 and expected life 30 years.

Implications: This work highlights the importance of a whole-stream approach to improving the values of spring-fed streams such as Neimann, Borck and Pearl Creeks. Riparian improvement is needed alongside water quality improvement to improve freshwater ecosystem health.

Gaps: The denitrification wall project would be hugely valuable as both a research opportunity and actual mitigation if it can be installed in such a way that it filters most of the high-N springflow. Constructing a woodwaste bund in a form of wetland may be one way to do this. Given the lack of SLMACC funding in 2020, other funding sources are needed for its construction, as a priority.

TDC Nitrate Monitoring Results to Feb 2024 for spring-fed streams, analysis by A Fenemor, data from Jon McCallum TDC

Table 6 of the NPSFM 2020 sets bottom line limits for nitrate toxicity in rivers and streams, calculated as limits on the annual median and 95th percentile of measured data

Table 6 – Nitrate (toxicity)

Value (and component)	Ecosystem health (Water quality)	
Freshwater body type	Rivers	
Attribute unit	mg NO_3 – N/L (milligrams nitrate-nitrogen per litre)	
Attribute band and description	Numeric attribute state	
	Annual median	Annual 95th percentile
A High conservation value system. Unlikely to be effects even on sensitive species.	≤1.0	≤1.5
B Some growth effect on up to 5% of species.	>1.0 and ≤2.4	>1.5 and ≤3.5
National bottom line	2.4	3.5
C Growth effects on up to 20% of species (mainly sensitive species such as fish). No acute effects.	>2.4 and ≤6.9	>3.5 and ≤9.8
D Impacts on growth of multiple species, and starts approaching acute impact level (that is, risk of death) for sensitive species at higher concentrations (>20 mg/L).	>6.9	>9.8

This attribute measures the toxic effects of nitrate, not the trophic state. Where other attributes measure trophic state, for example periphyton, freshwater objectives, limits and/or methods for those attributes may be more stringent.

Analysis of nitrate-N measurements is compared with the bottom line below, with bold data in the RH column showing current exceedances:

	Period of Records, number of samples n	Mean NO_3-N, mg/l	Median NO_3-N, mg/l	Latest full year's annual median NO_3-N, mg/l
Pearl Creek	2011-2021 (n=18)	3.3	2.9	**2.5**
Neimann Creek	2012-2024 (n=103)	3.4	2.5	**2.6**
Borck Creek	2009-2024 (n=124)	5.5	5.5	**3.6**

Results are seasonally variable, tending higher in winter in Borck Creek but higher in summer in Neimann, and unclear for Pearl Creek. The Neimann lag probably reflects delayed throughflow from the confined aquifer upstream.

d. Whole system science

Fenemor, A.D; Lilburne, L; Young, R.A.; Green, S.; Webb, T. 2013. Assessing Water Quality Risks and Responses with Increased Irrigation in the Waimea Basin. Landcare Research contract report LC1246 for the Waimea Water Augmentation Committee, Tasman District. 42p.

This report takes a source to sink (cause and effect) view of nitrate management in the Waimea Plains by modelling nitrate losses spatially across multiple soil-crop combinations, estimating potential N-attenuation in the aquifers below the soil zone, and evaluating potential receiving water limits.

SPASMO modelling shows that full irrigation within the Lee Dam service zone could increase nitrogen concentrations entering groundwaters by 23% and in a hypothetical worst case by up to 50% if the entire plains were converted to irrigated market gardening. These increases are mitigated (diluted) by increased drainage rates to groundwater of 6% and 19% respectively caused by the increased irrigation.

Nitrogen is diluted and dispersed within the aquifers ('groundwater attenuation'), meaning that this load will not reach sensitive receiving waters such as springs and the lower river with this level of increase in *concentration*. Groundwater attenuation of around 50% in the unconfined aquifer and 0–40% in the confined aquifers is likely to reduce the impact in down-gradient receiving waters. In the river, water quality is expected to improve when the water augmentation scheme is operating, because of the dilution offered by the uncontaminated flow releases from the dam.

This study suggests that the 'choke point' where land use intensification – and indeed current land use – most affects desired water quality outcomes is in the spring-fed streams. Given the influence of localised runoff and stock access (especially at Neimann Creek which has the highest nitrates), the following recommendations are made:

- By the time the Lee Dam is operational, ensure stock access and runoff into Neimann and Pearl Creeks is prevented
- The water permits required of all irrigators within the Lee Dam service zone should require as a condition of grant the implementation of relevant Good Management Practices that minimise the loss of nitrogen, phosphorus and other contaminants to groundwaters.
- The numeric objectives suggested in Table 13 of this report should be considered for implementation in plan changes for Waimea basin water management, with the proviso that the suggested nitrate toxicity limits for the spring-fed streams be treated as interim pending further evaluation of the effects of water hardness in setting appropriate limits.
- For the spring-fed streams, pending the outcome of further work on relevant nitrogen toxicity limits it is suggested that there shall instead be no increase in the annual 5-year moving average of nitrate-nitrogen concentrations.
- For confined aquifer groundwaters where the legacy plume of poor water quality is still passing through, it is similarly suggested that the limit shall instead be no increase in the annual 5-year moving average of nitrate-nitrogen concentrations
- If an increase does occur in any of the annual 5-year moving average of nitrate-nitrogen concentrations described above, the Council will need to decide whether to implement additional mitigation options either through another plan change or changes to the Nutrient and Irrigation Management Plans for upgradient properties.

The suggested receiving water limits in this report were updated in the 2015 report for Waimea FLAG, taking into account water hardness effects on nitrate toxicity, however those updated recommendations have been superseded by gazetted nitrate toxicity 'bottom lines' in the 2020 NPSFM.

For the purpose of setting management objectives and limits, the report includes a 'traffic light' table (Table 11) of uses and values for various Waimea minimum flows.

Implications: This document was presented to Waimea FLAG and forms a useful systems view of the science and policy components needing consideration for future management of Waimea nitrates. The uses and values assessment of Table 11 may be a useful starting point for deciding management objectives now that the 1100 l/sec minimum flow for the river is a commitment.

Gaps: Work to refine N-loss modelling using SPASMO, OVERSEER or APSIM would be improved with better validation of leaching losses and better definition of soil parameters, as would further information on geochemistry to assess denitrification potential in the aquifers (both recommended above). However, in my opinion, this systems modelling already forms an adequate basis for policy development.

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

This project for MPI compiles and interprets modelled data to understand how different irrigation water allocations and reliabilities of supply affect production, profit, and nutrient leaching responses for irrigated apples, grapes, outdoor vegetables (market gardening) and dairy land uses of the Waimea Plains. The production and profit assessments are not discussed further in this summary.

Of relevance to nitrogen leaching, the modelling examines the effects of varied weekly irrigation allocation limits but with full reliability of supply up to those weekly limits (0, 7, 14, 21, 28, 35 mm/week and unlimited) for both a 'with dam' (i.e. no water rationing) scenario as well as a 'no dam' scenario (with major water use restrictions during dry summers).

Because nitrate leaching is more sensitive to soil type than to whether or not a crop is irrigated, there is little difference in leaching rates for the 'no rationing' vs 'with rationing' scenarios. Perhaps surprisingly, for some irrigated crops, leaching is lower than for the dryland equivalent because of the efficiency of plant uptake of nutrients in a fully watered situation. The example of apples is shown in Figure 8.

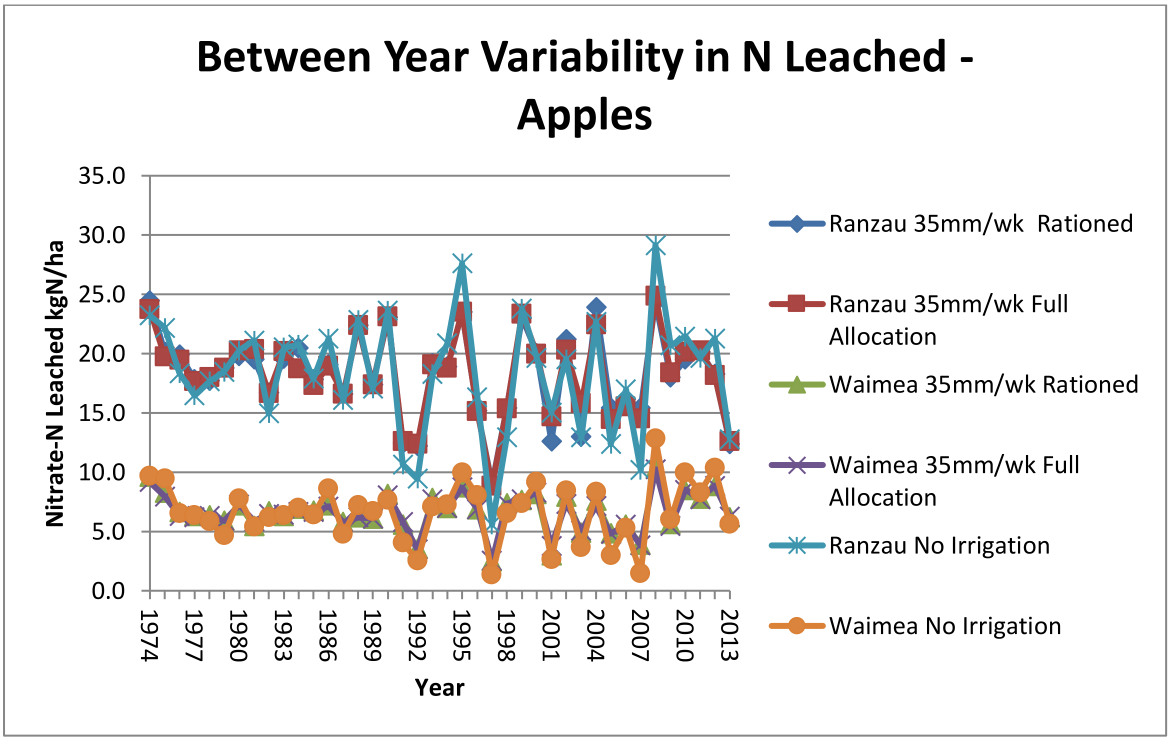


Figure 8 - Year to year variation in N leaching from apples for Ranzau and Waimea soils 1974-2013 with no irrigation, rationed irrigation and full (no rationing) irrigation (Fig 26 in source report)

The report concludes that management of irrigation water allocation and nitrate losses on Ranzau soils needs to be a focus when setting catchment limits.

It also includes a more detailed review of mitigation options for reducing N losses than that referred to in the report for Waimea FLAG which follows.

Implications: The report is useful for evaluating the effects of improved water availability on N losses after the Waimea Community Dam is operational. Results should be considered alongside those in the following report for Waimea FLAG.

Gaps: -

Fenemor AD, Price R, Green, S. 2016. Modelling the Source and Fate of Nitrate-Nitrogen Losses from Waimea Plains Land Uses. Landcare Research report LC2459 for the Waimea Freshwater and Land Advisory Group, Tasman District Council, 32p. http://www.tasman.govt.nz/document/serve/LC2459_Waimea_Nitrate_Modelling_FINAL.pdf?path=/EDMS/Public/Meetings/FreshwaterLandAdvisoryGroups/WaimeaFLAG/2015/2015-07-19/000000459971

Fenemor A, Green S, Price R 2023. Modelling of Nitrate Losses and Impacts from Waimea Plains Rural Land Uses. Manaaki Whenua -- Landcare Research Envirolink Report LC4215 for Tasman District Council. 41p. LandCare Report (envirolink.govt.nz)

These two modelling reports extended the previous (2013 and 2015) research to assess nitrate leaching losses using the SPASMO model, initially for 40 years of daily climate data to 2013 using 2013 land uses, and later for 48 years to 2020 using 2020 land uses. The 2016 report modelled specific farm system and soil combinations, informed by the Waimea FLAG, i.e. for apples, grapes, outdoor vegetables, and dairy farm systems on the four major soil series of the Waimea Plains. Results were discussed with Waimea FLAG at their 18 June 2015 meeting and 19 August 2015 meetings. The 2023 report added modelling of N losses from hops, kiwifruit and nurseries and refined the modelling for outdoor vegetables. Results and implications of the 2023 report were discussed at a meeting of growers organised by TDC and HortNZ on 20 November 2023.

Note that this modelling is not attempting to reproduce N losses over past years (as practices have changed over that time); rather, it is an average of 40-48 years of simulated data based on current practices and aggregated for current (2013 or 2020) land use pattern. The modelling predicts N losses for the past 48 years as if current land uses and management practices had existing unchanged over that time.

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 (new total 1077ha), 9% in outdoor vegetable production (768ha), 73% in hops (83ha), and up to 175% in nursery production (313ha). These increases were balanced by decreases of 14% in the area of berries (new total 99ha), 58% less area in dairying (259ha), 9% less land in kiwifruit (59ha), and 2% less in pasture.

The 2016 report includes the following map (Figure 9) which shows the likely spatial limits to further market gardening expansion because of the breeze from Wairoa Gorge (which mitigates frost risk), lower frosts and suitable soils:

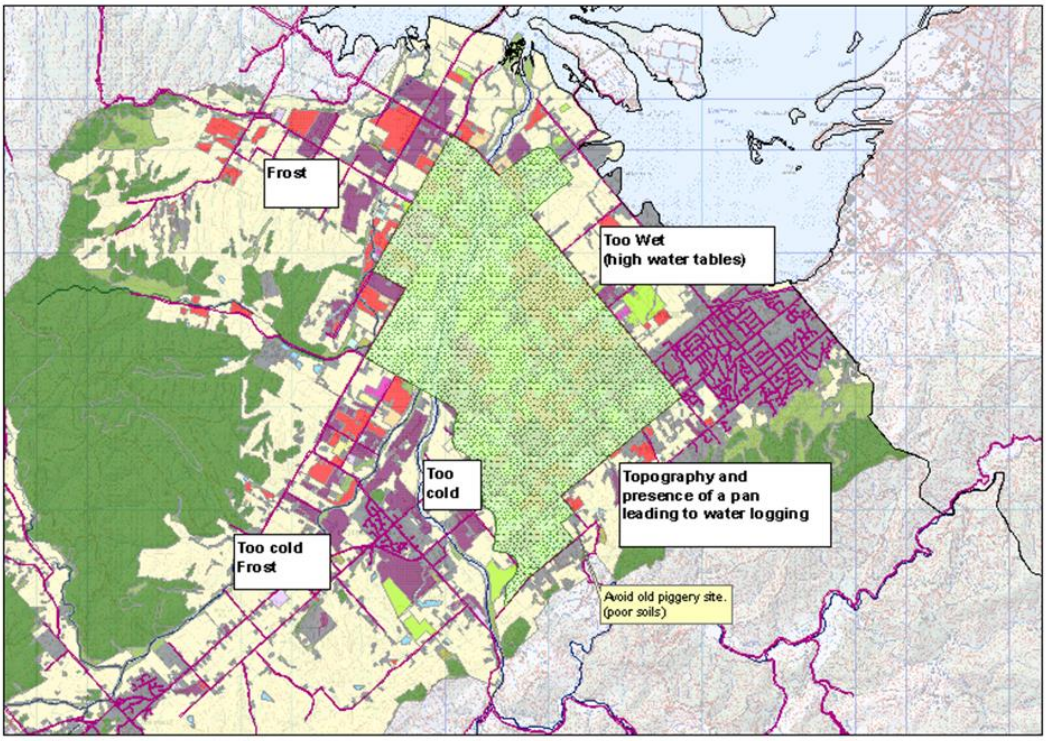


Figure 9 – Potential market gardening area (dappled green)(Pierre Gargiulo, pers comm 2015)

Averaged SPASMO-modelled nitrate losses summarised for six Waimea catchment land uses and four soil groups in kgN/ha/yr (assuming irrigation where needed, with no water rationing) are summarised from the 2023 work in the table below for 1973-2020.

Land use / farm system	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)	**28 ± 5**	**13 ± 4**	**15 ± 3**	**7 ± 1**		
Dairy pasture 1450kgMS/ha/yr	**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] (also applied to olives, small nuts)	**17 ± 4**	**8 ± 2**	**11 ± 2**	**4 ± 1**		
Outdoor vegetables: spinach-cabbages-lettuces	44 ± 8	15 ± 4	14 ± 4	6 ± 2		
Outdoor vegetables: onions, caulis, lettuces, greens	129 ± 31	94 ± 30	60 ± 23	32 ± 16		
Outdoor veges averaged[d]	**86 ± 19**	**54 ± 16**	**37 ± 13**	**19 ± 9**		
Hops	**34 ± 7**	**22 ± 7**	**27 ± 8**	**9 ± 3**		
Kiwifruit[e]	**17 ± 7**	**8**	**11**	**4**		
Nursery[f]	**37 ± 8**	**29 ± 10**	**24 ± 7**	**15 ± 5**		

Lifestyle blocks, other pasture and non-agricultural land uses[g]	**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.

Highest loss rates on the Waimea Plains are from dairy and outdoor vegetable production, followed by nurseries, hops, pipfruit, kiwifruit and grapes. The table shows that the most sensitive plains soils for nitrate leaching are Ranzau, followed by Waimea and Wakatu, which are similar, then Richmond soils.

Soil water-holding capacity is a much greater determinant of nitrogen losses than irrigation. As an example, **Error! Reference source not found.** shows leaching from the averaged market gardening system in which fully irrigated average losses are 86 for Ranzau soils compared with 54 kgN/ha/yr on Waimea soils.

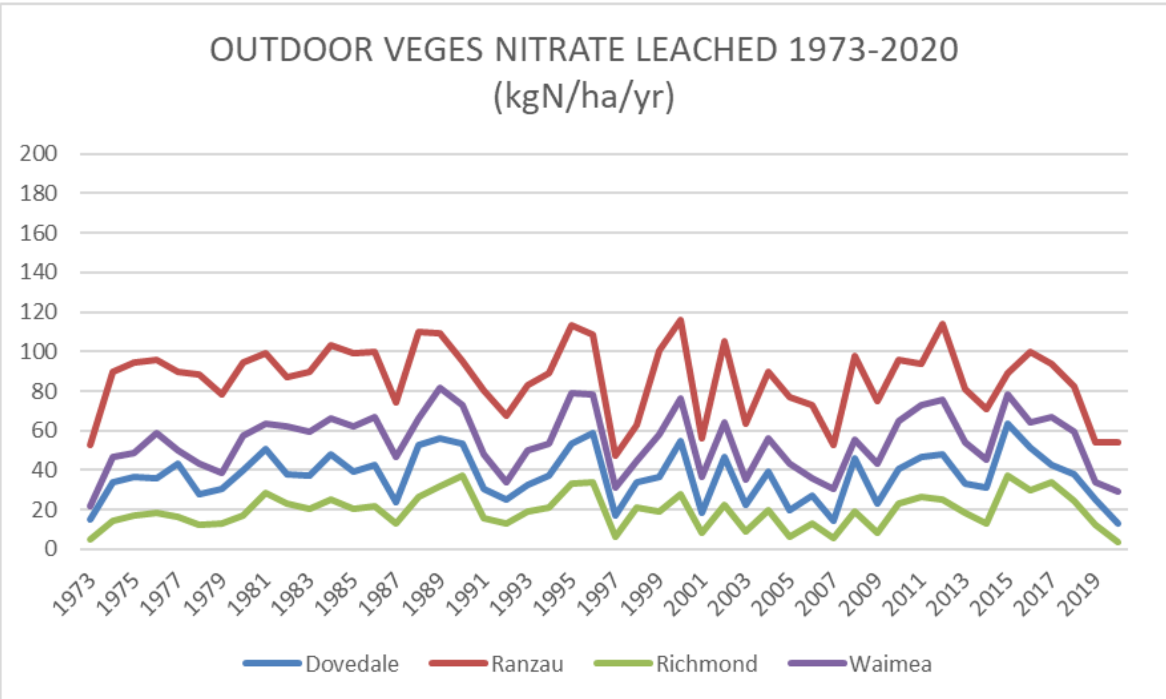


Figure 14. Year-to-year variation in N leaching (kg N/ha/yr) from average of the two outdoor vegetable scenarios for four soil groups, 1973–2020. Average losses are 86 kg N/ha/yr (Ranzau), 37 (Dovedale), 54 (Waimea), and 19 (Richmond).

Figure plots monthly nitrate losses for Ranzau soils, showing that the most vulnerable months for nitrate losses are the winter months June to October.

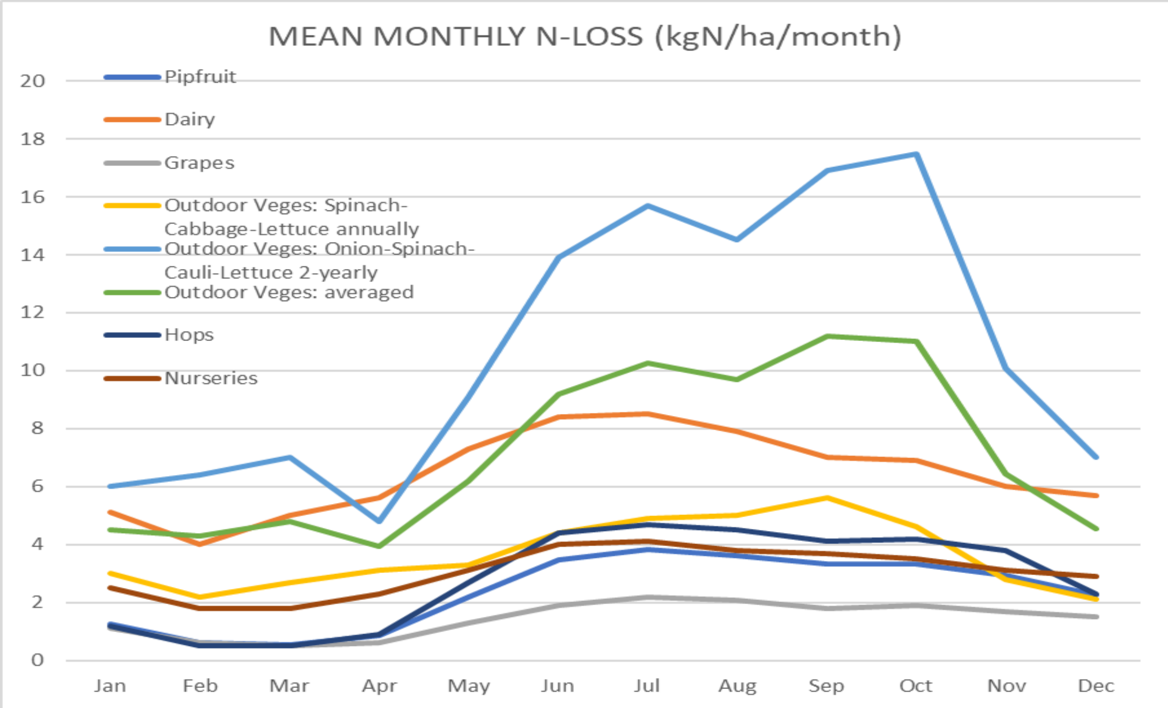


Figure 15. Mean monthly nitrate loss (kg N/ha/month) for major Waimea Plains farm system proxies on Ranzau soil group, 1973–2020. (Similar patterns but lower losses apply on other soil groups.)

Figure 15 shows that both outdoor vegetable growing regimes have high nitrate losses, particularly the onion-spinach-cauli-lettuce rotation with its high N fertilizer applications for onions in early spring and brassicas in late autumn.

The 2016 modelling showed there is little difference between nitrate losses for the same land use with or without irrigation; however, irrigation allows more intensive land use, which may produce higher nutrient loads overall depending on the land uses being intensified.

Total modelled nitrate loss from the 40600 ha of the lowland Waimea catchments for 2020 land uses was 324 tonnes per year. Outdoor vegetables, pipfruit, dairy, grapes, and nurseries are the top five sources of nitrate load[5] leaching to waters within the Waimea Plains.

Below the crop root zone, N losses may be attenuated (lowered) as the contaminant plume is carried through the aquifer(s). The 2013 report evaluated potential attenuation between the root zone and down-gradient surface water, suggesting possible attenuation of 60% in the unconfined aquifer, negligible attenuation in the Hope Aquifers and UCA, and around 40% for the LCA. This report proposes assuming 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.

Assuming no attenuation, groundwater flow tube analysis in 2016 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 0.44-0.48 g/m^3 for 200–562 hectares converted. For the spring-fed Neimann Creek, equivalent increases in nitrate concentration would be 0.54-1.06 g/m^3, increasing the risk of exceeding acceptable aquatic ecosystem limits, depending on what values those

[5] Load (kg/yr or t/yr) = N loss rate (kgN/ha/yr) multiplied by area of that land use (ha) and represents the accumulated loss from 'upstream' at a specified receiving water location such as Pearl Creek or the Waimea Inlet

limits are ultimately based. 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.

Figure 10 shows the intensity of SPASMO-modelled current nitrate losses for the 2020 land-use mapping. Land parcels (cross-hatched) overlying the groundwater flow tubes intersecting with Neimann and Pearl Creeks pose the greatest risk to water quality in those vulnerable receiving waters.

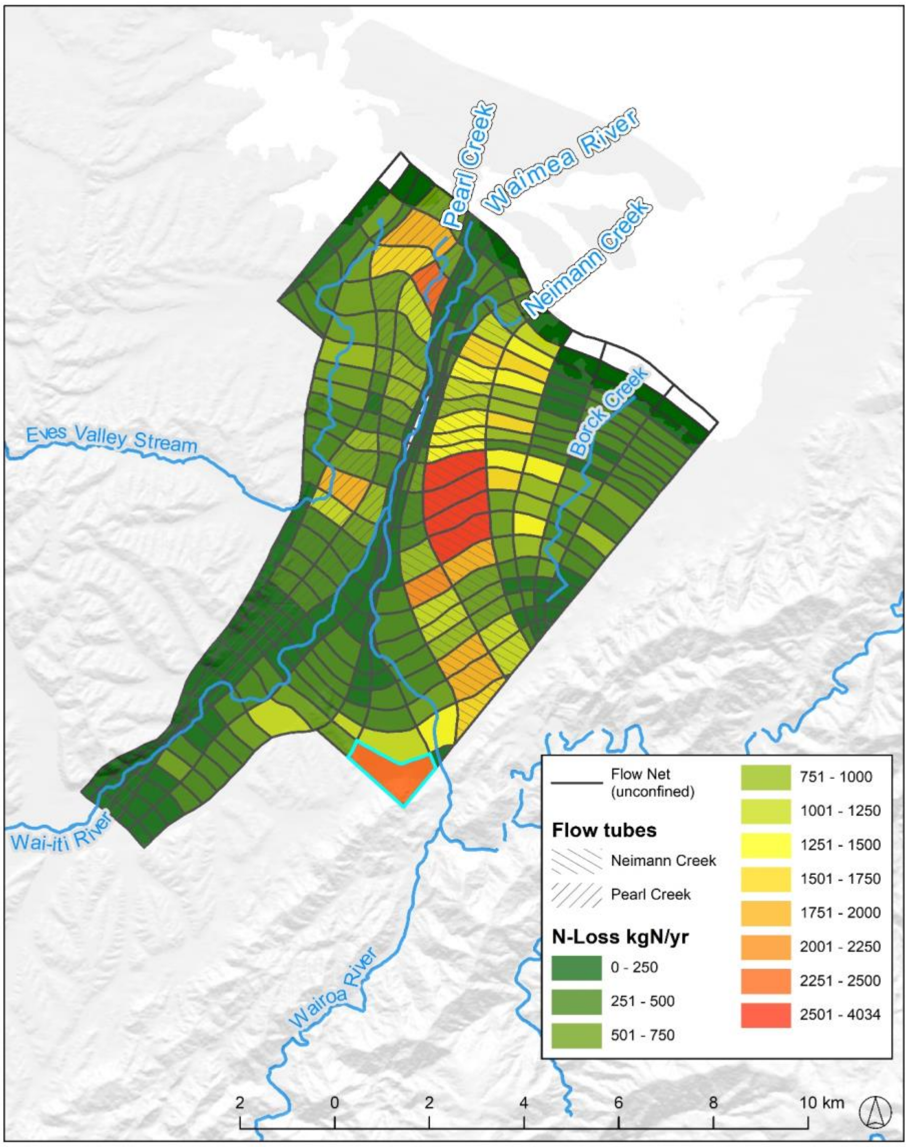


Figure 10. Nitrate losses by unconfined aquifer flow net cell for current land use (cross-hatching shows land areas contributing nitrate to Neimann and Pearl Creeks).

In relation to possible receiving water limits, median[6] nitrate concentrations in both streams exceed the nitrate toxicity national bottom line of 2.4 g/m^3 in the NPSFM 2020 (median in both springs is 2.90

[6] Important note: the NPSFM2020 national bottom line for nitrate toxicity is an <u>annual</u> median, i.e. the median of samples taken within a year, whereas the median concentrations quoted here are <u>multi-year</u> medians due to the low number of samples taken

mgN/l). In addition, nitrate concentrations exceed the NZ Drinking Water Standard MAV of 11.3 mgN/l, particularly in the Appleby/Blackbyre Road area. Under the requirements of the NPSFM 2020, the TDC is required to set limits in its proposed regional plan by December 2027 to reduce nitrate losses from current land uses to meet these standards for groundwater and spring-fed streams.

The question arises whether changes to land management practices (such as fertilizer regimes) would reduce N losses sufficiently to meet receiving water limits. The 2016 report includes a brief summary of actions which could be undertaken on pastoral and horticultural farm systems to reduce N losses. The 2023 modelling compared current modelled scenarios with pipfruit and vegetable scenarios with different fertilizer regimes. Results showed smaller than expected reductions in N loss, with potential effects on crop yield and quality, suggesting that reductions in areas of outdoor vegetable growing on Ranzau soils are also needed if receiving water limits for nitrate are to be achieved.

Implications: These modelling studies are a useful source to sink conceptualisation of the causes and effects of N losses across the Plains.

Gaps: This work applies to land uses in 2020, since which there has been further market garden and nursery development. The NPSFM 2020 also imposed more stringent limits than proposed in the report for nitrate toxicity as water hardness is not a mitigating factor in the toxicity bottom lines. Given the Government's intention to review the NPSFM, it is suggested that TDC again advocate for nitrate toxicity limits which take into account the mitigating effects of water hardness; while this would allow for better science-based N-toxicity limits, the limits needed to reduce eutrophication in spring-fed streams would still require reductions in up-gradient N losses.

e. Datasets not reported above

Current TDC Waimea water quality monitoring sites (J McCallum, TDC, pers.comm. as at 2016)

Site_name	Easting	Northing	Programme	Frequency
GW 32 - TDC	1613959	5425351	GNS NGMP	Quarterly
GW 802 - Waiwest	1611246	5426481	GNS NGMP	Quarterly
GW 114 - TDC Roadside	1610324	5419792	SOE Groundwater	Quarterly
GW 1392 - Spring Grove	1605907	5417667	SOE Groundwater	Quarterly
GW 37 - Gardner	1611852	5423288	SOE Groundwater	Quarterly
GW 997 - McCliskies	1609013	5427614	SOE Groundwater	Quarterly
GW 127	1610671	5423814	Waimea Plains Nitrate Supplementary Data	Monthly
GW 163	1611537	5424174	Waimea Plains Nitrate Supplementary Data	Monthly
GW 274	1611269	5425658	Waimea Plains Nitrate Supplementary Data	Monthly
RW Borck @ 400m ds Queen St	1614660	5425096	SOE River Water	Monthly
RW Neimann Ck @ 600m us Lansdowne Rd	1611931	5427410	SOE River Water	Monthly

each year. The most recent data (Pearl had 4.1 mg/l in 2021, Neimann a median from 4 samples of 4.0 mg/l in 2022 and Borck had 4.9 mg/l in 2022) would exceed the N-toxicity bottom line even more than the multi-year medians indicate.

RW Pearl Ck	1610884	5428577		Quarterly 2013-2016
RW Reservoir Ck @ 20m d-s Salisbury Rd	1616813	5424118	SOE River Water	Monthly
RW Wai-iti @ 400m d-s Waimea W Rd	1608584	5420756	SOE River Water	Monthly
RW Waimea @ SH60 Appleby	1610882	5426854	SOE River Water	Monthly
RW Wairoa @ SH6	1610100	5419408	SOE River Water	Monthly

Nutsford D. 2020. Tasman District Stream Delineation. GIS delineation of Tasman District streams for which LiDAR data exists. Morphum Environmental advisory note #1 and GIS layers, January to Trevor James. 7p

TDC GIS layers: full or partial land use maps for 2001/2002, 2005/2006, 2010/2011, 2013/2014 and 2015/2016 plus from A.Becher a 'heatmap' of Waimea Farm Types (>10) from AgriBase 2019 to indicate Nitrate leaching by farm system and septic tanks, and an infiltration susceptibility map.

TDC Microbial Source Tracking data register from T.James describing faecal data origins as human or ruminant or wildfowl or gull (or not)

TDC holds soils data and GIS maps for each of the 5 zones mapped by I Campbell and shown in Figure 2 with a report available for each zone: Redwood Valley, Waimea West, Brightwater, Waimea East and Lower Queen Street. Landcare Research has carried out further soil mapping to increase S-Map coverage on versatile lands. In the Waimea this comprises approximately 1,400 ha from Spring Grove inland to Belgrove, including Wakefield. The work is a south-ward continuation of Waimea Plains survey area for which results have not yet been reported.

On-site wastewater systems: Most on-site wastewater systems are permitted activities so Council only holds limited information. FLAG July 2014 notes report potentially up to 789 on-site wastewater systems within the water management Zones. Using on-site wastewater nitrate removal and leaching data from Environment Waikato, Bay of Plenty and the US, the onsite systems are estimated to contribute up to 2kg/ha/yr, which can be compared to the current TRMP permitted activity level for bird and animal effluent of 200kg/ha/yr. They may cause localised impacts but their contribution compared with land use diffuse sources is small.

5. Conclusions

What does existing science knowledge tell us to inform an effective policy response to the high nitrate concentrations in Waimea Plains waters? What further science is needed?

These conclusions can be drawn from this review:

- It is helpful to use a 'cause and effect' conceptual model because the policy responses, and ongoing science and monitoring, will likely need to focus on interventions at both the source (land management and discharges) and in the various receiving waters (groundwater, streams and the estuary).
- The primary sources of nitrate contamination in the Waimea catchment are agricultural and livestock land uses, and associated management practices. Secondary sources are human wastewater discharges from septic tanks, likely only 1-2% of primary loads

- Financial analyses based on returns over the 5 years to 2017 suggest that favoured land uses for expansion post-dam would be hops, apples and vegetables, but N loss monitoring and modelling show that the land uses with highest N losses are (from highest to lowest) dairy and outdoor vegetable production, followed by nurseries, hops, pipfruit, kiwifruit and grapes
- The most sensitive plains soils for nitrate leaching are the stony soils with lower water-holding capacity, i.e. Ranzau, followed by Waimea and Wakatu, which are similar, then Richmond soils. Soil water-holding capacity is a much greater determinant of nitrogen losses than presence or absence of irrigation.
- Water quality surveys since 1975 confirm the history of movement of a plume in groundwater of elevated nitrate from the confined aquifer recharge areas near the closed piggery in the Aniseed Valley Road/Patons Road area progressing northwards. Overall concentrations are slowly declining, however rising concentrations are now found where the UCA discharges into the AGUA (Bartlett Road/Blackbyre Road/State Highway 60 and Ranzau/Bartlett Road areas. Elevated nitrate concentrations are also present between Ranzau Road and the Waimea Estuary where the UCA passes over the top of the LCA. These elevated concentrations exceed the NZ Drinking Water Standard, and are affecting apple maturation when used for orchard irrigation.
- Monthly groundwater nitrate data suggest that the connectivity between the shallow AGUA and underlying UCA in the Ranzau/Bartletts/Blackbyre/SH60 area is more widespread than earlier hydrogeological interpretation would have suggested. The data suggest that the historic contamination from the piggery closed in the 1980s has likely passed and that the nitrate signature in these wells is caused by local and upstream intensive land uses, particularly market gardening (vege growing).
- Spring-fed streams Pearl Creek, Neimann Creek and Borck Creek are receiving waters for high N groundwaters. Neimann and Borck creeks have the highest nitrate concentrations, but all three streams have median concentrations exceeding the nitrate toxicity bottom line of 2.4 mg/l set in the NPSFM 2020, despite their high water hardness being a recognised mitigating factor which may have justified a higher local toxicity limit. This means that rather than simply focussing on managing these streams for periphyton and algae, nitrate concentrations will need to be reduced to achieve compliance with the toxicity (species protection) limits.
- Modelling in 2016 of various scenarios of converting pasture to outdoor vegetable production (market gardening) predicted that nitrate concentrations in Pearl Creek could increase the 2020 median of 2.9 by 0.44-0.48 g/m^3 for 200–562 hectares converted. For Neimann Creek, equivalent increases in nitrate concentration would be 0.54-1.06 g/m^3 on top of its current median coincidentally also 2.9, both of which would increase the exceedance of NPSFM aquatic ecosystem limits.
- 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.
- In summary, it is suggested here that action should focus on (a) areas up-gradient of receiving waters where current nitrate concentrations exceed the NZ Drinking Water Standard in groundwaters (11.3 mgN/l) or the NPSFM2020 nitrate toxicity bottom line (2.4 mgN/l), and (b) areas where there are upward trends in nitrate likely to exceed 50% of MAV (5.6 mgN/l). The surveys confirm that priority areas (a) are the eastern Waimea Plains primarily the Ranzau Gravel

soils extending from Haycock Road north to SH6 at Appleby and Neimann Creek, and priority areas (b) are the same area plus an area west of the Waimea River extending north from River Road/Waimea West Road towards Pearl Creek.

- The review concludes that there is already sufficient science information to adequately inform development of a policy response for managing nitrates on the Waimea Plains. Development of the Council's Nutrient Management Approach and an Action Plan should be the priority now rather than awaiting additional information collection and research.
- Continuing monitoring and rerunning a N-loss Model (SPASMO or APSIM) based on present-day land use mapping and further potential land use scenarios after the Waimea Community Dam is commissioned would help to support and refine policy interventions and management.

6. Acknowledgements

Thanks to Joseph Thomas, Trevor James, the late Bernard Simmonds, Glenn Stevens, Melanie Westley, Anette Becher for providing information, data and feedback, and to Lisa McGlinchey and Rochelle Selby-Neal for their extensive reviews of the 2020 draft report.

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