Modelling to reduce nitrogen in Pukekohe (Whangamaire stream)

1 Introduction

1.1 Purpose

The purpose of this indicative environmental-economic modelling is to investigate the potential scale of impacts on commercial vegetable growing from the annual median nitrate[1] toxicity national bottom line in the National Policy Statement for Freshwater Management (NPS-FM) 2017 (6.9 mg/L) and the new NPS-FM 2020 (2.4 mg/L).

The report examines the estimated potential reduction in nitrogen loss from both on-farm mitigations and on-farm mitigations coupled with land-use change.

These results are then compared against the reductions required under the existing NPS-FM 2017 and the amended NPS-FM 2020 to determine whether the national bottom lines are likely to be met in the Pukekohe catchment, using the Whangamaire stream (one of the most impacted water bodies monitored in the catchment) as an example.

The intention of this report and the modelling exercise is to provide a high-level indication of the potential scale of impacts.

1.2 Rationale for the modelling

New Zealand is dependent on a domestic supply of fresh vegetables due to our geographic isolation and the perishable nature of many of these vegetables. New Zealand may not be able to import all the fresh vegetables needed to support the well-being of our population if domestic production should cease or decrease substantially.

However, commercial vegetable growing activity can have highly localised impacts on freshwater ecosystems. As a significant vegetable growing hub, Pukekohe is responsible for approximately 26% of New Zealand's total domestic vegetable production value (Deloitte, 2018). This modelling was undertaken to test the potential scale of impacts on commercial vegetable growing from the annual median nitrate toxicity national bottom line in the NPS-FM 2017 and 2020, and to determine whether meeting national bottom lines in the key commercial vegetable growing region of Pukekohe is achievable, without wide-spread land use change, given currently available mitigations. A reduction in access to fresh, locally grown vegetables would likely have negative public health implications. A contraction in supply would also likely lead to increasing prices, with a disproportionate effect on those more vulnerable to high food prices.

Pukekohe was modelled first to test the potential impacts of the new nitrate toxicity bottom line given its significant contribution to the domestic supply of fresh vegetables. After testing the impacts in this region, a set of criteria were developed to assess whether other areas would also be impacted by the new bottom lines and possibly lead to significant reductions in domestic vegetable supply.

[1] The term nitrate in this report has been used to refer to nitrate-nitrogen (NO_3-N)

These criteria are:

1. The catchment/area needs significant reductions in nitrogen loads to meet the national bottom lines in the NPS-FM 2020; and
2. The area is so dominated by vegetable growing that the reductions needed may not be achieved or vegetable growing may not be accommodated within the catchment without significant land use change out of vegetable growing; and
3. The area of land use change out of vegetable growing would be sufficiently large to materially affect New Zealand's supply and price of vegetables (noting that the general requirement on councils in the NPS-FM 2020 to at least maintain water quality at current states means that any large reductions in vegetable growing in one area cannot easily be compensated for by large increases in vegetable growing elsewhere).

An assessment against the above criteria indicated that the only areas that would meet all three criteria are Pukekohe and Horowhenua.

Initial results from a Freshwater Management Tool, currently being developed by Auckland Council, supports the conclusion that high nitrate concentrations in surface water correlate with areas of intensive commercial vegetable growing. Further information regarding the Auckland Council Freshwater Management Tool is included in Appendix One.

1.3 Background

During the Second World War, there were shortages of household vegetables. To meet these shortages, the Department of Agriculture established the Services Vegetable Production Scheme in 1942, which resulted in more land in the Pukekohe area being converted to vegetable production to support Allied troops in the Pacific (Baker, 1965). It was recognised at the time that the Pukekohe area was particularly well suited for vegetable growing and since then, horticultural and other agricultural land uses in the Pukekohe area have expanded (Deloitte, 2018).

The Pukekohe climate generally allows for year-round growing and supply of vegetables, including leafy greens and new season potatoes. The area is characterised by volcanic, free-draining soils which are typically classed as Land Use Capability (LUC) class 1 to 3 and are considered 'elite' or 'prime or versatile' soils (Meijer et al., 2016). LUC class 1 to 3 land have a higher ability to sustain agricultural production than classes above 4 to 8 (Lynn, et al., 2009).

Due to the presence of large areas of vegetable production, proximity to Auckland (distribution hub and population centre) and significant areas of LUC 1, 2 and 3 soils, the Pukekohe area is likely to be recognised as "critically important" under the provisions of the proposed National Policy Statement for Valuing Highly Productive Land (NPS-HPL).

1.4 Economic contribution

The estimated 2018 economic contribution of the Pukekohe horticultural industry was $261 million. This economic contribution is both direct and indirect:

- The horticulture industry directly contributes approximately $86 million each year to the regional economy (Deloitte, 2018).
- The indirect contribution, reflecting expenditure on agriculture support services, water, machinery, feed, fertiliser and seed, is $175 million each year (Deloitte, 2018).

Horticulture in the Pukekohe area directly contributes 1,458 full time equivalents (FTEs), and including both direct and indirect employment, horticulture contributes 3,090 FTEs. During 2017, the Pukekohe area accounted for nearly a quarter of the total 6,700 FTEs employed in indoor and outdoor vegetable growing in New Zealand, reflecting its importance to the country's food supply (Horticulture New Zealand, 2020). The Pukekohe area produces approximately 26% of New Zealand's total domestic value of vegetable production (particularly potatoes, carrots, onions and leafy greens) from approximately 4% of New Zealand's total hectares of fruit and vegetable production (Deloitte, 2018).

2 Whangamaire Stream

The Whangamaire Stream was selected as the focus area to illustrate the potential scale of the impacts if the NPS-FM 2020 nitrate toxicity bottom line was required to be met in the short to medium term. The Whangamaire Stream was chosen specifically because data was available on Land, Air, Water Aotearoa (LAWA) and this data indicated that this stream had the highest concentration of nitrate in the Pukekohe region. In addition, the catchment of the stream and the aquifer that feeds the stream includes a large proportion of the commercial vegetable growing in the area. It is likely that other waterbodies in the study area would also be significantly impacted by nitrogen leaching from commercial vegetable growing.

Communication with Auckland Council identified that the interactions between groundwater, surface water and flow of the Whangamaire stream are complex. A review of elevated nitrate concentrations in Franklin surface and groundwater (Meijer, et al., 2016) states that baseflow ratios indicate that the Whangamaire stream is predominately fed by groundwater from the Pukekohe volcanic aquifer, which is estimated to be 80% of the stream's flow. The review identifies that the Pukekohe volcanic aquifer records elevated nitrate concentrations of 25 mg/L[2] (Meijer, et al., 2016).

For the purposes of this modelling, the entire Pukekohe volcanic aquifer catchment area was used, due to the high proportion of flow into the Whangamaire stream coming from groundwater, compared to surface water. Focusing only on land uses in the Whangamaire stream catchment area would not address the contribution of nitrate from land uses in the groundwater catchment.

A shapefile of the Pukekohe volcanic aquifer catchment was provided by Auckland Council using data sourced from Landcare Research. Subsequently, the aquifer extent and corresponding surface water catchment area used in this modelling exercise was determined following engagement with Auckland Council.

3 Methodology

3.1 Water quality in the Whangamaire Stream

The Whangamaire Stream five-year (2013 – 2018) median total oxidised nitrogen (TON) concentration reported on the Land, Air, Water Aotearoa (LAWA) website was used as a basis for existing water quality in the Whangamaire Stream. No additional statistical analysis was undertaken on this data. The median concentration as reported by LAWA was 14 mg/L

[2] A mean nitrate concentration of 25 mg/L with a standard deviation of 1.3 mg/L for the Gun Club groundwater monitoring site, Table 6 (Meijer, et al., 2016)

(Land, Air, Water Aotearoa, 2020). Data on nitrate concentrations was not readily available and therefore TON was used in this modelling as an approximate value for nitrate[3].

Water quality encompasses a range of values supported by numerous indicators; focussing only on a handful of contaminant risks (or nitrate concentrations in this case) may bias any description of water quality. For the purposes of this report, changes to instream nitrate concentrations are assessed alone for the scenarios of varying mitigation and land use change. The model outlined in this report is therefore not a complete assessment of water quality impacts.

3.2 Estimating reductions required to meet NPS-FM 2017 and NPS-FM 2020 national bottom lines in the Whangamaire Stream

As discussed above, a concentration of 14 mg/L TON has been used to model the current instream nitrate concentration for the Whangamaire stream. In the simplest sense, to achieve the NPS-FM 2017 (6.9 mg/L) nitrate toxicity bottom line target, a 51% reduction instream would be required. To achieve the NPS-FM 2020 (2.4 mg/L) nitrate toxicity bottom line target, an 83% reduction instream would be required. Refer to Table 1 under part 5 of the Outputs and Discussion section which provides a summary of the reductions required instream to achieve national bottom line targets.

Determining what level of reduction is required from land-based leaching is complex. This model provides a very simplistic approach to determine the scale of potential reductions and impacts under the NPS-FM 2017 (6.9 mg/L) and the NPS-FM 2020 (2.4 mg/L) national bottom lines.

The modelling is based on the following key assumptions with respect to determining the scale of reductions required from land-based nitrogen sources:

- Groundwater lag-times and water quality trends of the Pukekohe volcanic aquifer are considered using an arbitrary co-efficients[4].
    - **Static nitrogen load co-efficient** – Co-efficient of 1.0 provides no reduction in annual median nitrate concentration to reflect equivalent or constant land use practices from land-based nitrogen sources to the Pukekohe aquifer. This scenario assumes that the concentration of nitrogen within the Pukekohe aquifer is constant and therefore that the concentration in surface water is not increasing or decreasing due to the groundwater lag time.
    - **Decreasing nitrogen load co-efficient –** Co-efficient of 0.8 provides a smaller degree of reduction in annual median nitrate concentration by 20% to reflect potential improvements in land use practices from land-based nitrogen sources to the Pukekohe volcanic aquifer. This scenario assumes nitrogen discharges from land to the Pukekohe volcanic aquifer are improving due to the groundwater lag time.

[3] TON equates to nitrate-nitrogen plus nitrite-nitrogen. It is expected that the nitrite-nitrogen would make up a very small proportion of total TON and therefore is a good proxy for nitrate (NO_3- N).
[4] Note: A third co-efficient was modelled but not included in this report. This co-efficient assumed worsening land use practices from land-based nitrogen sources to the Pukekohe volcanic aquifer and Whangamaire stream. A co-efficient of 1.2 was assigned for this scenario. This coefficient was not included in the final model results because the reduction required on land under this scenario was too high (93%).

- The modelling assumes that reductions that occur on land are directly proportional to the reductions that occur instream, after taking into account the co-efficient applied as described above for the decreasing and static nitrogen load co-efficients[5].
- The modelling assumes that all nitrogen lost from land uses in the catchment area have the same weight and impact instream, i.e. nitrogen lost to water (beyond the root zone) from all land in the catchment is uniform, regardless of pathway to the Whangamaire stream or Pukekohe volcanic aquifer. Table 2 in the Outputs and Discussion section provides a summary of the reductions required by land-based nitrogen sources.

It should be noted that based on the above assumptions, this modelling is simplistic and was developed to provide an indication only, of the potential scale of reductions required. Research currently underway by Auckland Council on groundwater dynamics includes variation in groundwater contribution to the Whangamaire stream, denitrification en-route and residence times. The Freshwater Management Tool being developed should provide a more robust approach to future modelling.

3.3 Land use in the Pukekohe volcanic aquifer catchment

The area used in this modelling exercise was the Pukekohe volcanic aquifer zone which was provided by Auckland Council using data sourced from LandCare Research (provided in the form of a shapefile). Land use within the Pukekohe volcanic aquifer zone was estimated using the Land Cover Database (LCDB) version 4.1 (2018) and completed by the Spatial Intelligence (Water) team at MPI. A land use classification map using the LCDB is provided in Appendix Two.

The LCDB outputs were the preferred source for land use data for the catchment area, however LCDB does not distinguish between different forms of pastoral farming within the High Producing Grassland category. To address this, high producing grassland from the LCDB was split into dairy, sheep and beef, and lifestyle property land uses, based on ratios calculated in the CoreLogic land database. Annual cropland using LCDB was also divided into rotation 1 (extensive), rotation 2 (intensive) and traditional market gardening, as defined by the AgriBusiness Group (AgriBusiness Group, 2014).

The catchment was split into the following land use categories:

- Dairy – assigned 32% of high producing grassland
- Sheep and beef (intensive finishing) – assigned 18% of high producing grassland
- Lifestyle properties – assigned 50% of high producing grassland
- Market garden (rotation 1 - extensive) – assigned 50% of annual cropland
- Market garden (rotation 2 - intensive) – assigned 45% of annual cropland
- Market garden (traditional) – assigned 5% of annual cropland
- Orchard and vineyard (modelled as kiwifruit only)
- Forestry
- Natural forest, water and grassland with woody biomass
- Settlements and roads

[5] Note this assumption was made for simplicity of the model and ease of interpretation, it is recognised that interactions will be far more complex in reality, however there is a lack of information to support including these complexities in this model at this point in time.

Refer to Table 3 (Outputs and Discussion) for a summary of land use for the Pukekohe volcanic aquifer zone and the proportion of the total for each land use.

3.4 Estimated nitrogen loss and gross margins per hectare

Nitrogen loss (kg N/ha/year) and gross margin per hectare ($/ha) for each land use was estimated using available sources. MPI expertise (environmental economists and those with knowledge of good farming practice) was used where there was limited data. Ranges for nitrogen loss per hectare for dairy, market gardening, mixed cropping and arable, sheep and beef and forestry (Benge & Clothier, 2016) were considered when estimating nutrient loss per hectare for each land use, in addition to the information sources summarised in Appendix Three. Based on the ranges provided, estimates of nitrogen losses for each land use are considered to be conservative estimates.

A comprehensive literature review on primary sector mitigation efficacy (Muller, Durie, Dooley, & Matheson, 2020) was not yet available to MPI when the scenarios for this modelling were developed. Future modelling should consider this work when developing scenarios. Based on this review, modelled impacts on gross margins are considered to be conservative estimates and reductions in nitrogen loss through the implementation of GMP are considered to be ambitious.

Appendix three contains a table of all the estimated values, the ranges for comparison and detailed references for these estimates.

3.5 Nitrogen loss reduction scenarios

Given the estimated land use areas and estimated nitrogen loss rates, mitigation and land use change modelling was undertaken to assess:

- The potential nitrogen leaching reductions that could be achieved from on-farm mitigations.
- The potential nitrogen leaching reductions that could be achieved from land use change in combination with on-farm mitigation.

Given the rationale behind this modelling, the scenarios have been developed with a focus on retaining vegetable growing in the Pukekohe area, and to assess the impacts on market gardening under various scenarios. Retaining vegetable production in Pukekohe where the land has a greater capability (LUC class 1-3) to support production than other areas is important for national food supply and food security reasons, as well as contributing to local employment. The land use change scenarios were developed to retain land in food production with lower nitrogen loss per hectare profiles (i.e. sheep and beef and orchard and vineyard land uses), as opposed to forestry, lifestyle properties or urban settlements, given the LUC (class 1-3) of the land. Refer to the rationale for the modelling under part 1 (Introduction) for more information.

The scenarios were developed using MPI's best knowledge on the efficacy, financial impact and potential for on-farm and land use change mitigations at the time. The scenarios are not based on underlying farm-systems modelling, however, the scenarios were informed by two reports: Nutrient Performance and Financial Analysis of Lower Waikato Horticulture Growers (AgriBusiness Group, 2014), and Land Use Impacts on Nitrogen and Phosphorus Loss and Management Options for Intervention (Menneer, Ledgard, & Gillingham, 2004).

Table 1 summarises the on-farm mitigation scenarios modelled, and Table 2 summarises the land use change scenarios modelled.

Table 1: Mitigation scenarios

Scenario	Industry Group	Proportion of group	Reduction in nitrogen loss (Kg N/Ha/year)	Reduction in gross margins ($/Ha)
Mitigation Scenario 1 *GMP*[a]	- Dairy - Sheep and Beef - Market Gardening - Orchard and Vineyard	100%	10%	5%
Mitigation Scenario 2 *Distributional reductions*[b]	- Sheep and Beef - Orchard and Vineyard	100%	10%	5%
	- Dairy - Market Gardening	10%	10%	5%
		60%	20%	15%
		30%	30%	25%
Mitigation Scenario 3 *Maximum Reduction*	- Sheep and Beef - Orchard and Vineyard	100%	10%	5%
	- Dairy - Market Gardening	100%	30%	25%

Note: *a*: Good management practice (GMP) was considered to achieve a 10% reduction in nitrogen loss per hectare on average, a 30% reduction in nitrogen loss per hectare was considered the upper limit that could be achieved with currently available technology.

b: This scenario includes a mix of good management practice for some land uses and mitigations which go beyond good management practice.

The use of gross margins to measure the economic impact of land use change scenarios are not suitable, and so are not reported under the land use change scenarios in Table 2. Gross margins do not reflect the capital outlay and development costs (investment in infrastructure) to convert land uses. Gross margins are also influenced by the prices for inputs and outputs which may change with changing land use and cannot be easily reflected in this static modelling exercise. An assessment of the full economic impact of land use change scenarios is recommended for any further modelling.

Table 2: Land use change scenarios

Scenario	Industry Group	Proportion of group	Reduction in nitrogen loss (Kg N/Ha/year)
Land use change Scenario 1a - *Retain market gardening, low dairy land use change*	- Sheep and beef - Orchard and vineyard	100%	10%
	- Market gardening	10%	10%
		60%	20%
		30%	30%
	- Dairy	10%	Land use change[a]
		60%	20%
		30%	30%
Land use change Scenario 1b - *Retain market gardening, high dairy land use change*	- Sheep and beef - Orchard and vineyard	100%	10%
	- Market Gardening	10%	10%
		60%	20%
		30%	30%
	- Dairy	40%	Land use change[a]
		60%	30%
Land use change Scenario 2a - *Low market gardening and dairy land use change*	- Sheep and beef - Orchard and vineyard	100%	10%
	- Market gardening - Dairy	10%	Land use change[a]
		60%	20%
		30%	30%
Land use change Scenario 2a - *High market gardening and dairy land use change*	- Sheep and beef - Orchard and vineyard	100%	10%
	- Market gardening - Dairy	40%	Land use change[a]
		60%	30%

Note: *a:* In land use change scenarios half the land was modelled as being converted to sheep and beef and the other half modelled as being converted to orchard and vineyard land uses.

4 Outputs and Discussion

4.1 Estimating reductions required to meet NPS-FM 2017 and NPS-FM 2020 national bottom lines in the Whangamaire Stream

Instream reductions

Using a median instream concentration of 14 mg/L for nitrate means that a 51% reduction in concentration would be required instream to meet the NPS-FM 2017 national bottom line (6.9 mg/L) and a 83% reduction would be required instream to meet the NPS-FM 2020 national bottom line (2.4 mg/L). Table 1 provides a summary for required instream reductions.

Table 1: Required reductions instream for the Whangamaire stream to meet NPS-FM 2017 national bottom line (6.9 mg/L) and NPS-FM 2020 national bottom line (2.4 mg/L).

Instream	
Average (5-year) Total Oxidised Nitrogen (mg/L)	14.0
Total Oxidised Nitrogen to Nitrate Toxicity (mg/L)	100%
Current Nitrate Toxicity (mg/L)	14.0
Reduction required instream to meet 6.9 mg/L Nitrate Toxicity (80% species protection) under NPS-FM 2017	-51%
Reduction required instream to meet 2.4 mg/L Nitrate Toxicity (95% species protection) under NPS-FM 2020	-83%

Land based reductions

To estimate reductions required on land to achieve the NPS-FM 2017 national bottom line (6.9 mg/L) and the NPS-FM 2020 national bottom line (2.4 mg/L) the modelling assumes that reductions that occur on land are directly proportional to the reductions that occur instream. This means variation in attributes such as location, soil type and climate are not accounted for in the modelling.

The modelling also assumes that all nitrogen lost from land uses in the catchment area have the same weight and impact instream, i.e. nitrogen lost to water (beyond the root zone) from all land in the catchment is uniform, regardless of pathway to the Whangamaire stream or Pukekohe volcanic aquifer. However, groundwater denitrification patterns are complex and variable, reflecting changes in soil structure, geochemistry and flow path (Stenger, Clague, Woodward, Morgenstern, & Clough, 2015; Rivas, et al., 2015).

Contemporary nitrogen loss is assumed at steady state, meaning any reduction in existing loss would equate to an equivalent reduction of instream median concentration by the same magnitude. This assumption is highly unlikely given the considerable groundwater contributions (80%) to instream flow of the Whangamaire stream and estimated residence time of 16-99 years on average (Meijer, et al., 2016). Considerable lag can be expected between land management actions and instream effects on nitrate concentrations. In addition, variation in the outcome of land management action can be expected due to altered climatic effects on hydrology and contaminant processes, as well as farm system and setup in future, as a result of climate change.

The modelling does not account for the complexities of groundwater lag-times and water quality trends of the Pukekohe volcanic aquifer. Given the marked residence time of the Pukekohe volcanic aquifer (Meijer, et al., 2016) any instream trends are unlikely to be indicative of ongoing on-farm activity. Hence, it is uncertain whether nitrogen discharges from land to the Pukekohe volcanic aquifer are improving, constant or worsening. To accommodate this uncertainty, an arbitrary co-efficient was used to develop two scenarios, a decreasing and a static nitrogen load co-efficient, prior to the mitigation scenarios assessed on this report. Refer to part 4.2 (Methodology), for more information on these scenarios and other assumptions to estimate reductions required from land.

Table 2 provides a summary of the required land to stream reductions required for the decreasing and static nitrogen load co-efficients.

Table 2: Required reductions on land to meet NPS-FM 2017 national bottom line (6.9 mg/L) and NPS-FM 2020 national bottom line (2.4 mg/L) targets for different water quality trend assumptions in the Whangamaire stream.

	Decreasing N-load co-efficient	**Static N-load co-efficient**
Land to stream		
Average (5-year) Total Oxidised Nitrogen (mg/L)	14.0	14.0
Steady-state adjustment from land to aquifer	0.8	1.0
Reduction required on land to meet 6.9 mg/L Nitrate Toxicity (80% species protection)	-41%	-51%
Reduction required on land to meet 2.4mg/L Nitrate Toxicity (95% species protection)	-66%	-83%

The static nitrogen load co-efficient represents the full degree of reduction required in annual median nitrate concentration (51-83% depending on NPS-FM target). The decreasing nitrogen load assumption uses an arbitrary co-efficient factor of 0.8 to reflect potential for changes in land use practices and intensity to reduce nitrogen loss to the Pukekohe aquifer and Whangamaire stream (41-66% depending on target). The decreasing nitrogen load co-efficient can be taken to indicate agricultural land uses contributing lesser nitrogen loss. This requires a smaller degree of reduction in the annual median nitrate concentration to reach the national bottom line.

There is no robust (independently audited, peer-reviewed) information for recent or historic nitrogen loss contributions from pastoral and horticultural land uses at a catchment scale for the Auckland region. The likelihood of any scenario modelled has not been considered. Further research is needed into historic and ongoing nitrogen losses.

To meet the amended NPS-FM 2020 nitrate concentration bottom line, the estimated nitrogen loss reductions that would be required on land is therefore in the range of 66% to 83%.

4.2 Land Use in the Pukekohe volcanic aquifer catchment

Land use within the Pukekohe volcanic aquifer zone was estimated using the LCDB version 4.1 (2018). A land use classification map using the LCDB is provided in Appendix Two.

The estimated area for each land use and the estimated proportion of catchment area is summarised in Table 3.

Table 3: Summary of land use in the Pukekohe volcanic aquifer zone

Land use classification	Estimated area (ha)	Estimated proportion of catchment area (%)
Dairy	710	12%
Sheep and beef - Intensive finishing	399	7%
Lifestyle properties	1,109	19%
Market Garden - Rotation 1 (Extensive)	1,155	20%
Market Garden - Rotation 2 (Intensive)	1,040	18%
Market Garden - Traditional	116	2%
Orchard and vineyard (modelled as kiwifruit)	94	2%
Forestry	25	0%
Natural forest, water, and grassland with woody biomass	112	2%
Settlements and roads	1,153	19%
Total	**5,914**	**100%**

4.3 Estimated nitrogen loss and gross margins per hectare

Nitrogen loss (kg N/ha/year) and gross margin per hectare ($/ha) for each land use was estimated using available sources and MPI expertise where there was limited data. Refer to part 4.4 (Methodology) and Appendix 3 for more information on how these estimates were formed.

It should be noted that the estimates for nitrogen loss (kg N/ha/year) and gross margins per hectare ($/ha) used in this modelling have not been validated by robust data or farm level modelling (such as Overseer analysis).

Table 4 shows the estimated land use, nitrogen loss and gross margins in the Pukekohe volcanic aquifer zone.

Table 4: Estimated land use, nitrogen loss and gross margins in the Pukekohe volcanic aquifer zone

Land use classification	Estimated area (ha)	Estimated gross margin ($/ha)	Estimated N loss (kg N/ha)	Gross Margin for catchment ($)	N loss for catchment (kg N/ha)	Gross margin per kg N lost ($/kg N)
Dairy	710	2,566	30	1,821,615	21,297	86
Sheep and beef - Intensive finishing	399	770	12	307,505	4,792	64
Lifestyle properties	1,109	-	10	-	11,092	-
Market Garden - Rotation 1	1,155	3,591	64	4,148,569	73,937	56
Market Garden - Rotation 2	1,040	4,540	65	4,720,427	67,583	70
Market Garden - Traditional	116	3,274	73	378,235	8,433	45
Orchard and vineyard (modelled as kiwifruit)	94	34,568	11	3,255,298	1,036	3,143
Forestry	25	1,000	4	25,497	102	250
Natural forest, water, and grassland with woody biomass	112	-	4	-	447	-
Settlements and roads	1,153	-	9	-	10,381	-
Total (or average)	**5,914**	**(2,478)**	**(34)[6]**	**14,657,147**	**199,101**	**(74)**

Note: land use classifications are taken from the Agribusiness Group, 2014.

Table 4 provides a baseline estimate of the number of hectares for each land use and the associated nitrogen loss and gross margin estimates per hectare. The average (mean) estimated nitrogen loss per hectare for the catchment is 34 kg N/ha/year. The average estimated gross margin per hectare is $2,478. Note that for these scenarios, orchard and vineyard (perennial crop) land use has been modelled as kiwifruit and therefore has relatively high gross margin per hectare.

Gross margin per kilogram of nitrogen lost ($/kg N) are similar across the three market gardening land uses, which are comparable to sheep and beef and slightly lower than for dairy. The higher the gross margin per kilogram of nitrogen lost, the more efficient the land use is at generating gross margins per hectare when considering nitrogen loss per hectare only. Orchard and vineyard land use (modelled as kiwifruit) has significantly higher gross margin per hectare and relatively low nitrogen loss per hectare compared to the other land uses. Optimising the scenarios to generate higher gross margins per kilogram of nitrogen loss was not done in this modelling, although could be considered in any future work. The rationale for this modelling was to investigate options to retain vegetable growing in the Pukekohe area for food security reasons and not to optimise gross margins per kilogram of nitrogen loss.

Given the baseline estimate for average nitrogen loss per hectare in the catchment is 34 kg N/ha/year, applying the land based scenario reductions required to meet NPS-FM 2017 national bottom line (6.9 mg/L) and NPS-FM 2020 national bottom line (2.4 mg/L) for the Whangamaire stream provides targets for average nitrogen loss per hectare in the catchment.

Table 5 below indicates that the average land based nitrogen loss in the catchment would need to reduce from 34 kg N/ha/year to 11 kg N/ha/year for the decreasing nitrogen load co-

[6] Average nitrogen load per hectare calculated by taking the total nitrogen load for the catchment and dividing by the total area in hectares.

efficient, or to 6 kg N/ha/year for the static nitrogen load co-efficient, to meet the NPS-FM 2020 national bottom line (2.4 mg/L) target for the Whangamaire stream.

Table 5: Required reductions on land to meet NPS-FM 2017 national bottom line (6.9 mg/L) and NPS-FM 2020 national bottom line (2.4 mg/L) targets for the Whangamaire stream.

	Decreasing N-load co-efficient	**Static N-load co-efficient**
Land to stream		
Average (5-year) Total Oxidised Nitrogen (mg/L)	14.0	14.0
Steady-state adjustment from land to aquifer	0.8	1.0
Reduction required on land to meet 6.9 mg/L Nitrate Toxicity (80% species protection)	-41%	-51%
Reduction required on land to meet 2.4mg/L Nitrate Toxicity (95% species protection)	-66%	-83%
Land based leaching		
Current average Nitrogen loss (kg N/ha)	34	34
Target Nitrogen loss (kg N/ha) to meet 6.9 mg/L Nitrate Toxicity (80% species protection)	20	17
Target Nitrogen loss (kg N/ha) to meet 2.4 mg/L Nitrate Toxicity (95% species protection)	11	6

4.4 Nitrogen loss reduction scenarios

Mitigation scenario 1 – Good management practices

This scenario assumes that all dairy, sheep and beef, market gardening and orchard and vineyard land uses can reduce nitrogen leaching per hectare through the adoption of good management practices (GMP), like reducing or changing the timing of nitrogen fertiliser inputs, and achieve a 10% reduction in nitrogen loss per hectare on average with a 5% reduction in gross margins per hectare.

Refer to part 4.5 (Methodology) for the assumptions used to derive how this scenario was modelled.

Table 6 provides a summary of the outputs for Mitigation Scenario 1. Across the Pukekohe volcanic aquifer catchment area (holding other land uses constant), nitrogen loss in the catchment could reduce by 9% from the 34 kg N/ha/year baseline average to 31 kg N/ha/year.

With all farms requiring a freshwater module of a farm plan (FW-FP) under the Action for Healthy Waterways Package, this scale of reduction could be considered realistic, although the impact instream is complex and has uncertain lag-times due to the underlying hydrology of the Pukekohe volcanic aquifer and Whangamaire stream.

Table 6: Mitigation Scenario 1 - Good Management Practices

Land use classification	**Estimated area (ha)**	**Estimated gross margin ($/ha)**	**Estimated N loss (kg N/ha)**	**Gross Margin for catchment ($)**	**N loss for catchment (kg N/ha)**
Dairy	710	2,438	27	1,730,534	19,167

Land use classification	Estimated area (ha)	Estimated gross margin ($/ha)	Estimated N loss (kg N/ha)	Gross Margin for catchment ($)	N loss for catchment (kg N/ha)
Sheep and beef - Intensive finishing	399	732	11	292,130	4,313
Lifestyle properties	1,109	-	10	-	11,092
Market Garden - Rotation 1	1,155	3,411	58	3,941,141	66,543
Market Garden - Rotation 2	1,040	4,313	59	4,484,406	60,825
Market Garden - Traditional	116	3,110	66	359,323	7,590
Orchard and vineyard (modelled as kiwifruit)	94	32,840	10	3,092,533	932
Forestry	25	1,000	4	25,497	102
Natural forest, water, and grassland with woody biomass	112	-	4	-	447
Settlements and roads	1,153	-	9	-	10,381
Total (or average)	**5,914**	**(2,355)**	**(31)**	**13,925,565**	**181,393**
Percentage Change from Base	**0%**	**-5%**	**-9%**	**-5%**	**-9%**

Mitigation Scenario 2 – Distributional reductions

This scenario assumes that sheep and beef and orchard and vineyard land uses can reduce nitrogen loss per hectare through the adoption of GMP (as in Mitigation Scenario 1).

Dairy and market gardening land uses are assumed to reduce beyond GMP where possible through farm system changes and de-intensification, such as, reducing imported high nitrogen feeds, reducing stock numbers or adopting precision agriculture technologies for more efficient irrigation and fertiliser use.

Refer to part 4.5 (Methodology) for the assumptions used to derive how this scenario was modelled.

Table 7 provides a summary of the outputs for Mitigation Scenario 2. Across the Pukekohe aquifer catchment area (holding other land uses constant), nitrogen loss in the catchment could reduce by 19% from the 34 kg N/ha/year baseline average to 27 kg N/ha/year.

Table 7: Mitigation Scenario 2 - Distributional Reductions

Land use classification	Estimated area (ha)	Estimated gross margin ($/ha)	Estimated N loss (kg N/ha)	Gross Margin for catchment ($)	N loss for catchment (kg N/ha)
Dairy	710	2,130	23	1,511,940	16,612
Sheep and beef - Intensive finishing	399	732	11	292,130	4,313
Lifestyle properties	1,109	-	10	-	11,092
Market Garden - Rotation 1	1,155	2,981	50	3,443,313	57,671
Market Garden - Rotation 2	1,040	3,768	51	3,917,955	52,715
Market Garden - Traditional	116	2,717	57	313,935	6,578
Orchard and vineyard (modelled as kiwifruit)	94	32,840	10	3,092,533	932
Forestry	25	1,000	4	25,497	102

Land use classification	Estimated area (ha)	Estimated gross margin ($/ha)	Estimated N loss (kg N/ha)	Gross Margin for catchment ($)	N loss for catchment (kg N/ha)
Natural forest, water, and grassland with woody biomass	112	-	4	-	447
Settlements and roads	1,153	-	9	-	10,381
Total (or average)	**5,914**	**(2,130)**	**(27)**	**12,597,303**	**160,843**
Percentage Change from Base	**0%**	**-14%**	**-19%**	**-14%**	**-19%**

Mitigation Scenario 3 – Maximum reductions

This scenario assumes that sheep and beef and orchard and vineyard land uses can reduce nitrogen loss per hectare through the adoption of GMP (as in Mitigation Scenario 1).

Dairy and market gardening land uses reduce nitrogen loss by 30% on average, with an associated reduction in gross margins of 25% per hectare. This scenario was modelled to illustrate what may be the upper limit of nitrogen mitigation for dairy and market gardening land uses given existing on-farm mitigation options.

Refer to part 4.5 (Methodology) for the assumptions used to derive how this scenario was modelled.

Table 8 provides a summary of the outputs for Mitigation Scenario 3. Across the Pukekohe volcanic aquifer catchment area (holding other land uses constant), nitrogen loss in the catchment could reduce by 26% from the 34 kg N/ha/year baseline average to 25 kg N/ha/year.

Table 8: Mitigation Scenario 3 - Maximum Reductions

Land use classification	Estimated area (ha)	Estimated gross margin ($/ha)	Estimated N loss (kg N/ha)	Gross Margin for catchment ($)	N loss for catchment (kg N/ha)
Dairy	710	1,925	21	1,366,211	14,908
Sheep and beef - Intensive finishing	399	732	11	292,130	4,313
Lifestyle properties	1,109	-	10	-	11,092
Market Garden - Rotation 1	1,155	2,693	45	3,111,427	51,756
Market Garden - Rotation 2	1,040	3,405	46	3,540,321	47,308
Market Garden - Traditional	116	2,456	51	283,676	5,903
Orchard and vineyard (modelled as kiwifruit)	94	32,840	10	3,092,533	932
Forestry	25	1,000	4	25,497	102
Natural forest, water, and grassland with woody biomass	112	-	4	-	447
Settlements and roads	1,153	-	9	-	10,381
Total (or average)	**5,914**	**(1,980)**	**(25)**	**11,711,795**	**147,143**
Percentage Change from Base	**0%**	**-20%**	**-26%**	**-20%**	**-26%**

Figure 2 summarises the Pukekohe volcanic aquifer catchment abatement curve for nitrogen loss per hectare under Mitigation Scenarios 1, 2 and 3.

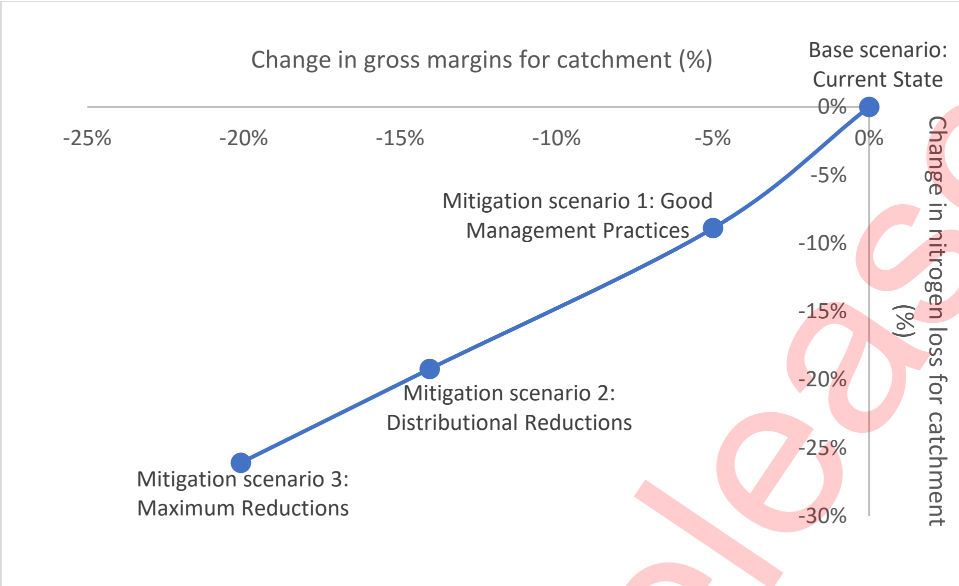

Figure 2: Abatement curve for Mitigation Scenarios 1, 2 and 3, illustrating potential catchment level reductions for nitrogen loss per hectare to the Pukekohe aquifer and Whangamaire stream by an estimated change in gross margin per hectare.

Mitigation scenario 3 indicates that the maximum reduction in nitrogen loss that is likely to be achievable from mitigation only is 26%. This suggests mitigation alone cannot achieve either the 41-66% reduction required for an annual median instream nitrate concentration of 6.9 mg/L, nor the 51-83% reduction required for an annual median nitrate concentration of 2.4 mg/L. Given this, a number of land use change scenarios have also been modelled.

Land Use Change Scenario 1 – Retain market gardening, dairy land use change

In these scenarios (1a and 1b), market gardening was retained given Pukekohe is an important growing region for fresh vegetables and supporting national food supply. Dairy, as the next highest nitrogen lost per hectare land use, after market gardening, has land use change modelled.

The use of gross margins to measure the economic impact of land use change scenarios are not suitable, and so are not reported under these scenarios. Gross margins do not reflect the capital outlay and development costs (investment in infrastructure) to convert land uses. Gross margins are also influenced by the prices for inputs and outputs which may change with changing land use and cannot be easily reflected in this static modelling exercise. An assessment of the full economic impact of land use change scenarios is recommended for any further modelling.

a) Low dairy land use change (10% of dairy hectares)

This scenario assumes that sheep and beef and orchard and vineyard land uses can reduce nitrogen loss per hectare through the adoption of GMP (as in Mitigation Scenario 1).

It is assumed that market gardening land uses can reduce beyond GMP where possible through farm system changes and de-intensification (as in Mitigation Scenario 2).

For dairy hectares, it is assumed that 10% of dairy hectares are required to change land use, with half converted to sheep and beef and the other half converted to orchard and vineyard land use. For the area remaining in dairy, 60% of the original dairy hectares are assumed achieve a 20% reduction in nitrogen loss per hectare and the remaining 30% of hectares are assumed to achieve a 30% reduction in nitrogen loss per hectare.

Refer to part 4.5 (Methodology) for the assumptions used to derive how this scenario was modelled.

Table 9 provides a summary of the outputs for Land Use Change Scenario 1a. Across the Pukekohe volcanic aquifer catchment area (holding other land uses constant), nitrogen loss in the catchment could reduce by 20% from the 34 kg N/ha/year baseline average to 27 kg N/ha/year. This scale of reduction is similar that seen in Mitigation Scenario 2.

Table 9: Land use change scenario 1a (Retain Market Gardening, Low Dairy Land Use Change)

Land use classification	**Estimated area (ha)**	**Estimated N loss (kg N/ha)**	**N loss for catchment (kg N/ha)**
Dairy	639	23	14,695
Sheep and beef - Intensive finishing	435	11	4,696
Lifestyle properties	1,109	10	11,092
Market Garden - Rotation 1	1,155	50	57,671
Market Garden - Rotation 2	1,040	51	52,715
Market Garden - Traditional	116	57	6,578
Orchard and vineyard (modelled as kiwifruit)	130	10	1,284
Forestry	25	4	102
Natural forest, water, and grassland with woody biomass	112	4	447
Settlements and roads	1,153	9	10,381
Total (or average)	**5,914**	**(27)**	**159,661**
Percentage Change from Base	**0%**	**-20%**	**-20%**

b) High dairy land use change (40% of dairy hectares)

This scenario assumes that sheep and beef and orchard and vineyard land uses can reduce nitrogen loss per hectare through the adoption of GMP (as in Mitigation Scenario 1).

It is assumed that market gardening land uses can reduce beyond GMP where possible through farm system changes and de-intensification (as in Mitigation Scenario 2).

For dairy hectares, it is assumed that 40% of dairy hectares are required to change land use, with half converted to sheep and beef and the other half converted to orchard and vineyard land use. For the area remaining in dairy, 60% of the original dairy hectares are assumed achieve a 30% reduction in nitrogen loss per hectare.

Refer to part 4.5 (Methodology) for the assumptions used to derive how this scenario was modelled.

Table 10 provides a summary of the outputs for Land Use Change Scenario 1b. Across the Pukekohe volcanic aquifer catchment area (holding other land uses constant), nitrogen loss in the catchment could reduce by 22% from the 34 kg N/ha/year baseline average to 26 kg N/ha/year.

Table 10: Land use change scenario 1b (Retain Market Gardening, High Dairy Land Use Change)

Land use classification	Estimated area (ha)	Estimated N loss (kg N/ha)	N loss for catchment (kg N/ha)
Dairy	426	21	8,945
Sheep and beef - Intensive finishing	541	11	5,846
Lifestyle properties	1,109	10	11,092
Market Garden - Rotation 1	1,155	50	57,671
Market Garden - Rotation 2	1,040	51	52,715
Market Garden - Traditional	116	57	6,578
Orchard and vineyard (modelled as kiwifruit)	236	10	2,338
Forestry	25	4	102
Natural forest, water, and grassland with woody biomass	112	4	447
Settlements and roads	1,153	9	10,381
Total (or average)	**5,914**	**(26)**	**156,115**
Percentage Change from Base	**0%**	**-22%**	**-22%**

This scale of reduction is similar to that seen in Mitigation Scenario 2 and only slightly more than Land Use Change Scenario 1a, although a considerable amount more dairy conversion is modelled under this scenario and is likely to have much higher associated economic impacts.

Dairy hectares comprise 12% of the catchment area and contribute 11% of the total nitrogen loss. The diminishing effect on reducing nitrogen loss between Land Use Change Scenario 1a and Land Use Change Scenario 1b suggests land use other than just dairy land would require land use change to achieve a significant reduction in nitrogen loss in the catchment.

Land Use Change Scenario 2 – Market gardening and dairy land use change

In these scenarios (2a and 2b), market gardening and dairy as the highest nitrogen lost per hectare land uses have land use change modelled.

Again, the use of gross margins to measure the economic impact of land use change is not suitable and has been excluded. Gross margins do not reflect the capital outlay and development costs (investment in infrastructure) to convert land uses. Gross margins are also influenced by the prices for inputs and outputs which may change with changing land use and cannot be easily reflected in this static modelling exercise.

a) *Low market gardening and dairy land use change (10% of market gardening and dairy hectares)*

The scenario assumes that sheep and beef and orchard and vineyard land uses can reduce nitrogen loss per hectare through the adoption of GMP (as in Mitigation Scenario 1).

For market gardening and dairy hectares, it is assumed that 10% of hectares for each land use is required to change land use, with half converted to sheep and beef and the other half converted to orchard and vineyard land use. For the area remaining in market gardening and dairy, 60% of the original hectares for each land use are assumed to achieve a 20% reduction in nitrogen loss per hectare and the remaining 30% of hectares are assumed to achieve a 30% reduction in nitrogen loss per hectare.

Refer to part 4.5 (Methodology) for the assumptions used to derive how this scenario was modelled.

Table 11 provides a summary of the outputs for Land Use Change Scenario 2a. Across the Pukekohe volcanic aquifer catchment area (holding other land uses constant), nitrogen loss in the catchment could reduce by 25% from the 34 kg N/ha/year baseline average to 25 kg N/ha/year. This scale of reduction is similar that seen in Mitigation Scenario 3.

Table 11: Land use change scenario 2a (Low Market Gardening and Dairy Land Use Change)

Land use classification	Estimated area (ha)	Estimated N loss (kg N/ha	N loss for catchment (kg N/ha)
Dairy	639	23	14,695
Sheep and beef - Intensive finishing	550	11	5,944
Lifestyle properties	1,109	10	11,092
Market Garden - Rotation 1	1,040	49	51,017
Market Garden - Rotation 2	936	50	46,632
Market Garden - Traditional	104	56	5,819
Orchard and vineyard (modelled as kiwifruit)	245	10	2,427
Forestry	25	4	102
Natural forest, water, and grassland with woody biomass	112	4	447
Settlements and roads	1,153	9	10,381
Total (or average)	**5,914**	**(25)**	**148,556**
Percentage Change from Base	**0%**	**-25%**	**-25%**

b) *High market gardening and dairy land use change (40% of market gardening and dairy hectares)*

The scenario assumes that sheep and beef and orchard and vineyard land uses can reduce nitrogen loss per hectare through the adoption of GMP (as in mitigation scenario 1).

For market gardening and dairy hectares, it is assumed that 40% of hectares for each land use is required to change land use, with half converted to sheep and beef and the other half converted to orchard and vineyard land use. For the area remaining in market gardening and dairy, 60% of the original hectares for each land use are assumed to achieve a 30% reduction in nitrogen loss per hectare.

Refer to part 4.5 (Methodology) for the assumptions used to derive how this scenario was modelled.

Table 12 provides a summary of the outputs for Land Use Change Scenario 2b. Across the Pukekohe volcanic aquifer catchment area (holding other land uses constant), nitrogen loss in the catchment could reduce by 44% from the 34 kg N/ha/year baseline average to 19 kg N/ha/year.

This scenario would require extensive land use change (1,088 hectares of dairying and vegetable growing), and it is expected to have marked economic consequences for the Pukekohe area and broader Auckland regional economy.

Table 12: Land use change scenario 2b (High Market Gardening and Dairy Land Use Change)

Land use classification	Estimated area (ha)	Estimated N loss (kg N/ha	N loss for catchment (kg N/ha)
Dairy	426	21	8,945
Sheep and beef - Intensive finishing	1,003	11	10,837
Lifestyle properties	1,109	10	11,092
Market Garden - Rotation 1	693	45	31,054
Market Garden - Rotation 2	624	46	28,385
Market Garden - Traditional	69	51	3,542
Orchard and vineyard (modelled as kiwifruit)	698	10	6,913
Forestry	25	4	102
Natural forest, water, and grassland with woody biomass	112	4	447
Settlements and roads	1,153	9	10,381
Total (or average)	**5,914**	**(19)**	**111,697**
Percentage Change from Base	**0%**	**-44%**	**-44%**

4.5 Compare scenarios against reductions required

All scenarios modelled were compared to the reductions required to meet the NPS-FM nitrate toxicity bottom lines. Table 13 provides a summary of each modelled scenario against both national bottom line targets.

Table 13: Summary of scenarios modelled to reduce nitrogen loss in the catchment against scenarios modelled to meet the NPS-FM 2017 6.9 mg/L nitrate concentration target (41% - 51%) and the NPS-FM 2020 2.4 mg/L nitrate concentration target (66% - 83%)

Land to Steam Reduction Targets		
	Decreasing N-load co-efficient	**Static N-load co-efficient**
Reduction required on land to meet 6.9 mg/L Nitrate Toxicity (80% species protection)	-41%	-51%
Reduction required on land to meet 2.4mg/L Nitrate Toxicity (95% species protection)	-66%	-83%
Modelled Scenarios		
	Change in gross margin for catchment (%)	**Change in nitrogen loss for catchment (%)**
Mitigation Scenario 1: Good Management Practices	-5%	-9%
Mitigation Scenario 2: Distributional Reductions	-14%	-19%
Mitigation Scenario 3: Maximum Reduction	-20%	-26%
Land Use Change Scenario 1: a) Retain Market Gardening, Dairy Land Use Change b) High Dairy Land Use Change	Not provided Not provided	-20% -22%
Land Use Change Scenario 2: a) Market Gardening and Dairy Land Use Change b) High Market Gardening and Dairy Land Use Change	Not provided Not provided	-25% -44%

The modelling shows that a large quantum of land use change in Land Use Change Scenario 2b (40% reduction in dairy and market gardening hectares) in addition to rather ambitious GMP-driven reductions in nitrogen loss results in 44% reduction in nitrogen loss for the catchment. This stresses the challenge of achieving the NPS-FM 2017 national bottom line for nitrate concentrations in the Whangamaire Stream, a 41% reduction under the decreasing nitrogen load co-efficient and a 51% reduction under the static nitrogen load co-efficient.

Even greater on-farm mitigation and land use change is expected to be required in order to achieve the newly introduced NPS-FM 2020 national bottom-line (target of 66% nitrogen loss reduction under the decreasing nitrogen load co-efficient and 83% nitrogen loss reduction under the static nitrogen load co-efficient). Equally, changes beyond Scenario 2b are needed for either NPS-FM 2017 or NPS-FM 2020 nitrate bottom lines to be achieved under the static nitrogen load co-efficient.

If median concentrations of nitrate within the Whangamaire Stream are not improving or at a steady state with the Pukekohe aquifer, and land use over the past 16-99 years[7] (Meijer, et al., 2016), has intensified, then under a more extreme scenario the reductions modelled will also be insufficient to achieve either NPS-FM 2017 or NPS-FM 2020 nitrate bottom lines.

[7] The estimated residence time.

5 Key Considerations and Limitations

There are several caveats to this modelling given the large amount of assumptions used. It is important to note these assumptions, and that the modelling exercise is to provide an indication of the scale of reductions required to achieve the NPS-FM 2017 and NPS-FM 2020 nitrate national bottom lines.

Assumptions, limitations and key considerations for this modelling are as follows:

- The Pukekohe volcanic aquifer catchment area was used for this analysis instead of the Whangamaire stream catchment area due to the large proportion of instream baseflow supplied from this aquifer (Meijer, et al., 2016) to the Whangamaire stream.
- The current state of instream nitrate is estimated from the 5-year median for TON from LAWA (Land, Air, Water Aotearoa, 2020) in the Whangamaire stream. Nitrate in mg/L is assumed to equal TON in mg/L.
- The mean residence time is estimated to be between 16-99 years (Meijer, et al., 2016) and is it not known whether nitrogen discharges from land to the Pukekohe volcanic aquifer are improving, constant, or worsening. Given this groundwater lag-times and water quality trends of the Pukekohe volcanic aquifer were represented by the decreasing nitrogen load co-efficient and static nitrogen load co-efficient. The extreme nitrogen load co-efficient has not been presented in this summary due to the very high levels of reductions required under this scenario.
- Aside from the co-efficients above, the modelling assumes that reductions that occur on land are directly proportional to the reductions that occur instream.
- The modelling assumes that all nitrogen lost from land uses in the catchment area have the same weight and impact instream, i.e. nitrogen lost to water (beyond the root zone) from all land in the catchment is uniform, regardless of pathway to the Whangamaire Stream or Pukekohe volcanic aquifer.
- The Whangamaire Stream was chosen as Pukekohe is a dominant vegetable-growing area, its instream nitrate concentration is above the proposed bottom lines (Land, Air, Water Aotearoa, 2020) and it is monitored with data available on LAWA. Other streams may have been equally suitable if these criteria can be met.
- The inclusion of currently unmonitored groundwater-fed surface water streams that originate in the Pukekohe volcanic aquifer catchment in future modelling may enable a more comprehensive overview of surface water concentrations.
- Land use classification, nitrogen leaching per hectare and gross margins per hectare are estimated. These estimates are ‘best estimates of averages’ based on available information at the time and do not reflect the distribution in farm performance, or potential to improve environmental footprint. This would be better informed by more environmental and economic data, and it is recommended that future work should consider the Muller et al literature review (Muller, Durie, Dooley, & Matheson, 2020).
- Due to the scope of this analysis, only nitrate-nitrogen has been the focus for the scenarios modelled. When assessing water quality, it is important to evaluate a range of indicators, not just nitrogen.
- GMP reductions can differ farm by farm, with some farms able to reduce nitrogen leaching significantly for no or little cost, while other farms may have very little scope to make changes. Reductions in nitrogen loss and gross margins for each scenario are proxies/ estimates for an average reduction for each land use.
- It is not well understood what level of reduction in nitrogen loss is possible (i.e. maximum attainable) through on-farm mitigation and how costly this mitigation would be, particularly for market gardening land uses. A maximum limit of 30% reduction on average for dairy and market gardening land uses was used as an estimate given currently available on-farm mitigations.

- Overseer which is used to estimate environmental losses is continually being refined and re-calibrated for both pastoral and non-pastoral land uses. Modelled results from referenced publications that use Overseer may differ due to varying versions of the model used. This has not been accounted for when forming estimates for nitrogen loss per hectare for each land use.
- Mitigation modelling by industry (DairyNZ Economics Group, 2014) indicates that the greater the nitrogen mitigation target, the higher the mitigation cost (given currently available mitigations and a short timeframe) The scenarios developed assumed that small reductions, the first 10% of reductions, are generally cost effective ('low hanging fruit' that should be targeted first) but as larger reductions are required, the cost of reduction becomes more expensive per kilogram of nitrogen reduced.
- The modelling only considers mitigation options that are currently available and does not consider continual changes or improvements in farm practices over time. The modelling focuses on what may be achievable over short timeframe (up to 20 years), while reductions may occur over a much longer period (up to 100 years).
- Changes in output/ production have not been accounted for in this mitigation or land use change modelling. Large reductions in nitrogen loss are likely to reduce output/ production provided there are no productivity gains that allow more (or the same level) of output/ production for less nitrogen loss.
- Nitrogen reduction is likely to have local economic impacts that have not been included in this modelling. Reduced output/ production from significant nitrogen mitigation or land use change will alter labour requirements and employment for those land uses. Production facilities like milk plants and pack houses may also operate under capacity with the reduced output/ production, leading to closures in the region. Full economic and social modelling could be done to assess these impacts.
- Reduced output/ production from significant nitrogen mitigation or land use change will impact on local consumers. Less supply of fresh produce (vegetables) will increase prices, leading to affordability issues, particularly for lower income households. Food security issues may arise as local produce becomes too expensive and imported produce is limited (i.e. cannot import vegetables like lettuce) (Deloitte, 2018). Full economic and social modelling could be done to assess these impacts.
- No impact of changing climate or hydrology has been considered in this modelling. More severe weather events may reduce yields leading to even larger reductions in the availability of fresh produce (vegetables) and driving up prices. A short time frame has been considered for this modelling. Long-term climate and hydrological change is not accounted for.
- Land use change from market gardening land use, from which product is predominantly consumed domestically, has been converted to land uses that export a significant proportion of production (kiwifruit, wine, beef, lamb etc.). There may be a trade-off between domestic consumption and export revenue if landowners change land use and convert to producing product for higher value export markets. Full economic and social modelling could be done to assess these impacts.
- An alternative land use scenario would be to shift some market gardening land use outside of the Pukekohe volcanic aquifer catchment area. This was not within the scope of this modelling exercise. This option may worsen water quality in other areas of the country and not all areas would be suitable due to soil (LUC) and climate conditions which may mean production is less efficient. For domestically focussed production, such as market gardening, it is important to both maximise returns for growers while also keeping consumer prices affordable. To achieve this, production in the most efficient areas with lower cartage costs is important.
- Existing debt levels have not been considered in this modelling. Highly indebted farmers may not have the available cash flow for on-farm mitigation and may not have access to additional capital if banks are not willing to lend. This would restrict many farmers from changing land use in the short term (up to 20 years).

- Restrictions or constraints on certain land uses and expensive capital outlay costs to convert the land to other productive uses may impact demand and the sale price of farms. This has not been considered in this modelling.
- There may be pressure from housing and lifestyle development in the Pukekohe area as it is close to urban centres (Auckland and Hamilton). This was not considered in this modelling.

6 Summary

This paper details an indicative environmental-economic modelling exercise which was undertaken for the Whangamaire stream (Pukekohe volcanic aquifer catchment), to determine the impacts of implementing the previous and new NPS-FM (2017 and 2020) national bottom lines for nitrate (median numeric attribute state only). The modelling focused on the importance of market gardening given the significance of the Pukekohe region to the supply local, fresh vegetables.

Two potential nitrogen reduction trends were investigated for both the previous and new median nitrate national bottom lines of 6.9 mg/L (NPS-FM 2017) and 2.4 mg/L (NPS-FM 2020). One scenario assumed improved (reduced) nitrogen loss from land use before any mitigation actions were taken, using a co-efficient of 0.8 (decreasing nitrogen load co-efficient, requiring a 41-66% reduction, depending on NPS-FM target). The other scenario assumed no change in nitrogen loss from land use, using a co-efficient of 1.0 (static nitrogen load co-efficient), requiring a 51-83% reduction (depending on NPS-FM target).

Three on-farm mitigation scenarios (including GMP, system change and de-intensification) and two land use change scenarios were modelled to reduce nitrogen loss from the land in the catchment. Outputs were compared with the identified nitrogen loss reductions required to meet the NPS-FM 2017 and 2020 national bottom lines from the static and decreasing nitrogen load co-efficients. Economic impacts were considered proxies and were determined only for on-farm mitigation scenarios for each land use on a per hectare basis. No catchment or regional economic scale economic impacts were assessed (i.e., without accounting for further costs to service providers and wider economy from altered rural productivity).

Table 13 summarises scenario outputs – the most challenging scenario (Land Use Change Scenario 2b) included a 40% reduction in dairy and market gardening land use, coupled with ambitious on-farm mitigations. This scenario was modelled to reduce nitrogen loss in the catchment by 44%, achieving the NPS-FM 2017 nitrate bottom line target (a 41% reduction) under the decreasing nitrogen load co-efficient. No scenario could deliver enough nitrogen reduction in the catchment to meet the new NPS-FM 2020 nitrate bottom line targets (51-83% reductions required). This indicates that considerable change in productive land use may be required to achieve the NPS-FM 2020 national bottom line for nitrate concentration in the Whangamaire stream.

7 Recommendations

This modelling exercise indicates that considerable change in productive land use may be required to achieve the NPS-FM 2020 national bottom line for nitrate concentration in the Whangamaire stream.

Based on this indicative environmental-economic modelling exercise, several recommendations for future modelling work have been made. The recommendations include:

- Consideration of the Literature Review on Primary Sector Mitigation Efficacy (Muller, Durie, Dooley, & Matheson, 2020) when developing additional scenarios and modelled reductions in nitrogen leaching per hectare and gross margins per hectare.
- Further research into historic and ongoing nitrogen losses from pastoral and horticultural systems in the Auckland region.
- Developing optimised scenarios to generate higher gross margins per kilogram of nitrogen loss.
- A full economic impact assessment of land use change scenarios, including capital outlay costs for converted land uses.
- Inclusion of currently unmonitored groundwater-fed surface water streams in the Pukekohe volcanic aquifer catchment to provide a comprehensive overview of surface water concentrations.
- Evaluation of a range of water quality indicators.
- Consideration of continual changes or improvements in farm practices over time by including mitigations that may be available in future and focussing on a longer time horizon.
- Consideration of local economic impacts, including reduced output/ production, labour requirements and local employment and capacity of local production facilities like milk plants and pack houses.
- Consideration of market prices for production and evaluation of affordability and food security issues.
- Consideration of trade-offs that may exist between domestic consumption and export revenue if landowners change to a land use that produces product destined for higher value export markets, rather than local consumers.

8 References

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9 Appendix

Appendix One - Freshwater Management Tool developed by Auckland Regional Council

The. Auckland Council is currently in the process of developing a Freshwater Management Tool. The Freshwater Management Tool will provide a more sophisticated assessment of water quality in the Auckland region, including major sources of waterway contamination, and can be used to test the findings from the modelling covered by this report.

The Auckland Council Freshwater Management Tool is a continuous, process-based contaminant model to deliver freshwater accounting services for the NPS-FM. The Freshwater Management Tool has been configured to represent baseline water quality for the period 2013-2017, simulating terrestrial and instream hydrological and contaminant processes continuously for 15-minute intervals throughout 5,465 sub-catchments in the region. The Freshwater Management Tool will be used to assess water quality in the Auckland Region, the major sources of contamination and identify appropriate mitigations to support implementation of the NPS-FM, regional planning and operational programmes for water quality management. Options assessed can be cost-optimised for contaminant outcomes in the Freshwater Management Tool and include a diversity of both rural and urban mitigations (e.g., stormwater devices, pastoral and horticultural devices, practice-based changes and land retirement).

Over the baseline period, horticultural land occupied 5,830 hectares (6.4%) of the broader Manukau Harbour watershed. Baseline reporting of yields, stream concentration, grading, loss and source apportionment for contaminants are undergoing independent peer-review. However, Freshwater Management Tool outputs suggest approximately 41.7% of total nitrogen (TN) loss to streams and coast are contributed by the 6.4% of horticultural land use in the Manukau Harbour watershed, disproportionately from 4,440 hectares of intensive horticulture (e.g. berryfruit, flowers, kiwifruit, vegetables, greenhouses) (Auckland Council unpublished data).

Overall, approximately 51 km of 3,085 km (2%) of waterways in the Auckland region simulated by the Freshwater Management Tool, are predicted to exceed an annual median or 95th percentile concentration of 6.9 mg/L or 9.8 mg/L respectively (NPS-FM 2017 nitrate toxicity national bottom lines). All such reaches are located in the Manukau Harbour watershed and in horticulture-rich sub-catchments of the Franklin aquifer that includes the Whangamaire Stream (refer to Figure 1).

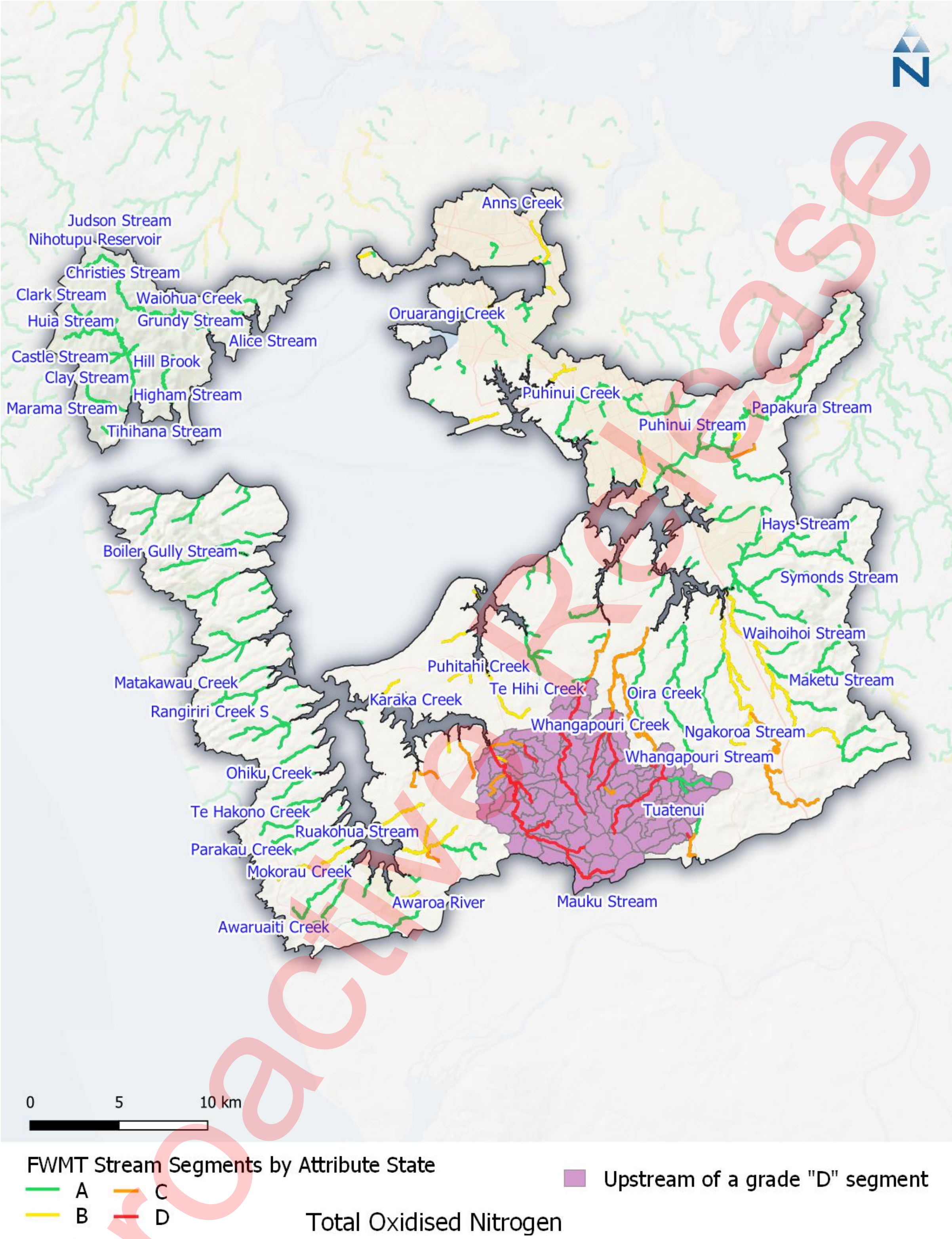
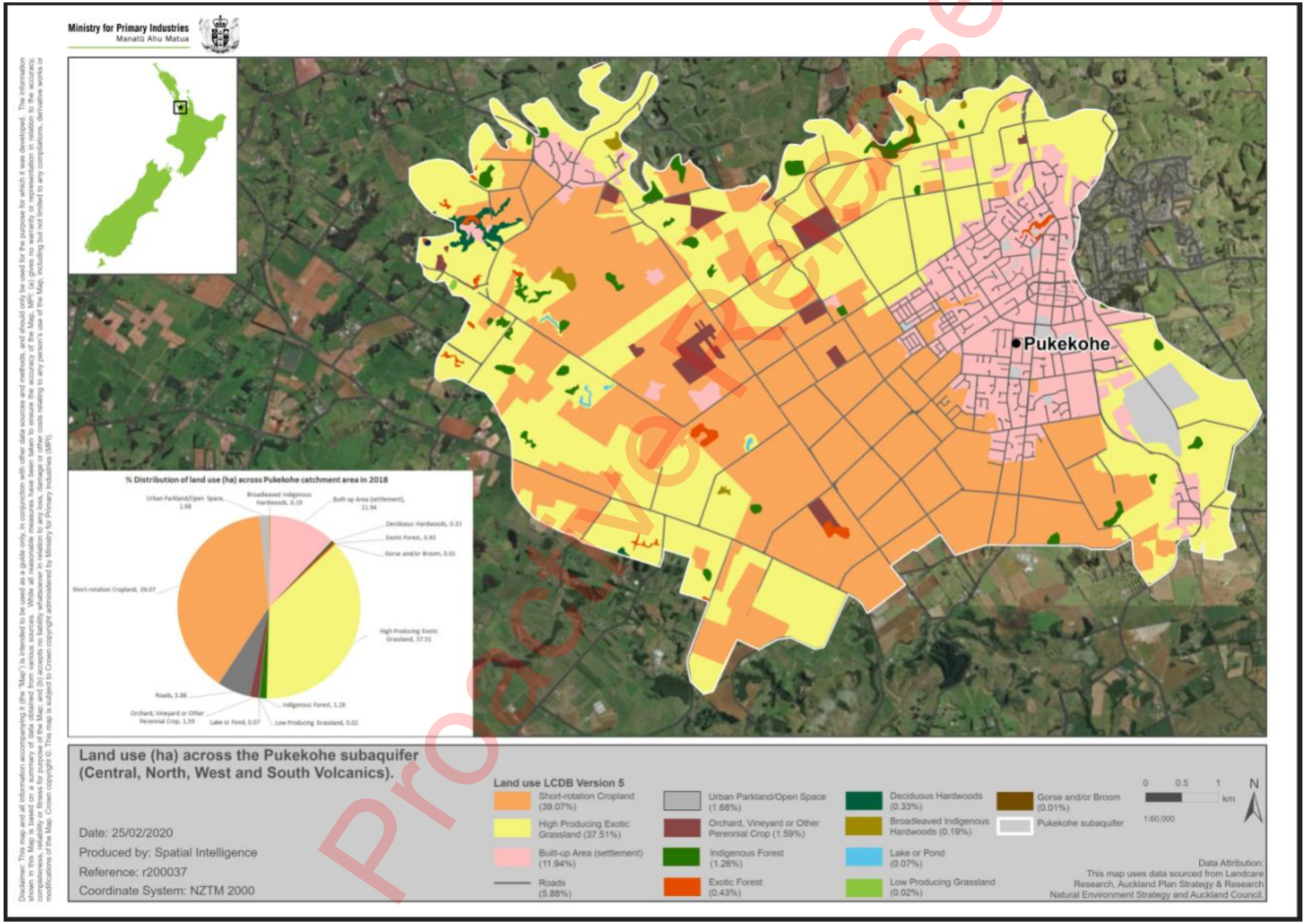


Figure 1: FWMT simulations of instream total oxidised nitrogen (TON) concentration for 2013-2017, graded under NPS-FM 2017 guidance for nitrate (undergoing peer review). All D-graded streams for TON throughout the entire Auckland region are located in the Manukau Harbour watershed, fed by the Franklin aquifer and only in horticulture-rich catchments (Bambic et al. in prep (Auckland Council, unpublished data)).

Appendix Two – Land Cover Database (LCDB) map for the Pukekohe volcanic aquifer zone



Appendix Three – Gross margin and nitrogen loss per hectare estimates and sourced figures

Land use	Modelled Gross margin/ha ($) estimate	Referenced Gross margin/ha ($)	Reference	Modelled N load/ ha (kg N/year) estimate	Referenced N load/ ha (kg N/year)	Reference
Dairy	2,566	2,566	Waipa-Franklin composite farm (DairyNZ Economics Group, 2014)	30	30	Waipa-Franklin composite farm (DairyNZ Economics Group, 2014)
Sheep and beef - intensive finishing	770	770	Sheep and Beef Farm Survey and used a 5 year average (2015-16 to 2019-20f) of gross margins per hectare for Class 5 (North Island Intensive)	12	14 to 26 5 to 39	North Island Central Sheep and Beef (Bright, Ford, & Irving, 2018) Sheep and Beef (The Agribusiness Group and The New Zealand Institute for Plant & Food Research Limited, 2016)
Lifestyle properties	-			10		MPI estimate
Market Garden - Rotation 1	3,591	3,591	Rotation 1 (AgriBusiness Group, 2014)	64	64	Rotation 1 (AgriBusiness Group, 2014)
Market Garden - Rotation 2	4,540	4,540	Rotation 2 (AgriBusiness Group, 2014)	65	65	Rotation 2 (AgriBusiness Group, 2014)
Market Garden - Traditional MG	3,274	3,274	Traditional Market Garden (AgriBusiness Group, 2014)	73	73	Traditional Market Garden (AgriBusiness Group, 2014)
Orchard and vineyard (modelled as kiwifruit)	34,568	34,568	MPI's kiwifruit monitoring data provided by Zespri (unpublished, commercially sensitive) for 2012-13 to 2016-17	11	11	Nitrogen load for Auckland Green Kiwifruit Orchard (The Agribusiness Group and The New Zealand Institute for Plant & Food Research Limited, 2016)
Forestry	1,000		MPI estimate	4	Average 3.25, max 7.1 0 to 28	Forest planted on non-agricultural land (Davis, 2014) Forestry (The Agribusiness Group and The New Zealand Institute for Plant & Food Research Limited, 2016)
Natural forest, water, and grassland with woody biomass	-			4	Average 3.25, max 7.1 0 to 28	Forest planted on non-agricultural land (Davis, 2014) Forestry (The Agribusiness Group and The New Zealand Institute for Plant & Food Research Limited, 2016)
Settlements and roads	-			9		MPI estimate