Kiwifruit and Dairying Effects on Shallow Groundwater

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Working with our communities for a better environment
E mahi ngatahi e pai ake ai te taiao

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Executive Summary

This study was initiated to examine how the development of kiwifruit orchards affects nutrient levels (particularly nitrate) in shallow groundwater in comparison to dairying. The study was incorporated as 'in-kind' support with a Sustainable Farming Fund (SFF) project which was examining nitrogen and water use in Hort16A (gold) kiwifruit.

The study sites were at Kelly Road, Maketu, and included a kiwifruit orchard and a dairy farm about to be converted to a kiwifruit orchard. At each site five bores were drilled to around 6 metres and the water quality was monitored for three years.

The key finding of the study is that nutrient exports are considerably less from kiwifruit than from dairying as summarised in the table below.

Calculated nutrient export from a kiwifruit orchard and a dairy farm in Kelly Road, Maketu.

	Phosphorus kg/ha/yr	Nitrogen kg/ha/yr
Kiwifruit	0.27 – 0.42	5.8 – 9.2
Dairy	0.8 – 1.26	24 - 38

This finding was corroborated for nitrate exports from a range of coastal and central Bay of Plenty soils using the SPASMO model. The model predicted leaching losses typically less than 15 kg/ha for irrigated and non-irrigated orchards with low fertiliser use (67 kg N/ha) and high fertiliser use (134 kg N/ha).

Based on the above it is suggested that kiwifruit growing could be an alternative land use to lower nutrient inputs in sensitive catchments. For example, climate change with lesser frost days, may work in favour of kiwifruit expansion into the Rotorua lakes catchments in the future.

An assessment could be undertaken to examine the feasibility of establishing a kiwifruit/avocado or other horticultural activities around Rotorua in the future. If feasible the economics of land use change could follow. This may provide an alternative to dairying if nutrient loss reduction is not possible for the dairy industry in the lakes catchments.

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Chapter 1: Introduction

In the early 2000's Environment Bay of Plenty reported the effects of land application of dairy effluent on groundwater (Environment Bay of Plenty, 2002). Three sites were studied in the vicinity of oxidation ponds to determine the effects of seepage from ponds on groundwater nitrogen levels and also determine the effects of spray irrigation of effluent. In conjunction with this, a survey was carried out to determine the extent of nitrate contamination of groundwater in the Bay of Plenty.

The survey showed that, when compared to the New Zealand drinking water standard, there were acceptable nitrate levels in the groundwater in dairying areas at the production levels of the late 1990's. Rotorua lake sites were not included in the survey but it was noted that increases in nitrate leaching was causing eutrophication of certain lakes (e.g. Rotorua and Rotoiti).

In the areas where the land use was mixed there was significant nitrate contamination. Figure 1 shows that the greatest impact was found in the low-lying area around Maketu, but this could have been caused by multiple land uses. However, one of the oxidation ponds was from this area and the results indicated that effluent ponds could transmit high concentrations of nitrogen to groundwater.

This study was initiated to examine how the development of kiwifruit orchards affects nutrient levels (particularly nitrate) in shallow groundwater in comparison to dairying. The key features of the study are outlined below;

(i) The study site was on Kelly Road, near Maketu, and groundwater bores were installed on two nearby properties. One was a kiwifruit orchard and the other a dairy farm about to be converted to a kiwifruit orchard. The predominant land use in the area was kiwifruit growing.

(ii) The study was also incorporated as 'in-kind' support with a Sustainable Farming Fund (SFF) project which was examining nitrogen and water use in Hort16A (kiwi gold) kiwifruit. HortResearch were the research provider for the project with project partners Seeka Kiwifruit Industries. The objective of the SFF project (03/092) was stated as follows.

> *"To ensure the economic and environmental sustainability of the ZESPRI™ GOLD kiwifruit ('Hort16A'), industry New Zealand growers must comply with the global trend for increased environmental accountability through mechanisms such as EUREP-GAP (now renamed GlobalGAP). These protocols require that orchard inputs, such as irrigation and nitrogen (N) fertilisers, are applied based on demonstrated need and are demonstrably safe for the environment. Specific information about the water and nitrogen balances in kiwifruit orchards is essential for fulfilment of these protocols."*

The SFF project aimed to give specific information for kiwifruit grown in the Bay of Plenty region. The modelling component of the project would also allow findings from the field site to be applied to other growing regions.

(iii) Some 'Soil Plant Atmosphere Model' (SPASMO) scenarios were run by a HortResearch scientist to assess the likely impact of different fertiliser application rates on nitrate leaching from kiwifruit orchards on local Bay of Plenty soils.

(iv) The project also provided information for a 'what if' scenario, i.e. what if climate became more favourable for kiwifruit development in the Rotorua lakes district? Would kiwifruit horticulture be a land use with low nutrient loss to groundwater and the lakes?

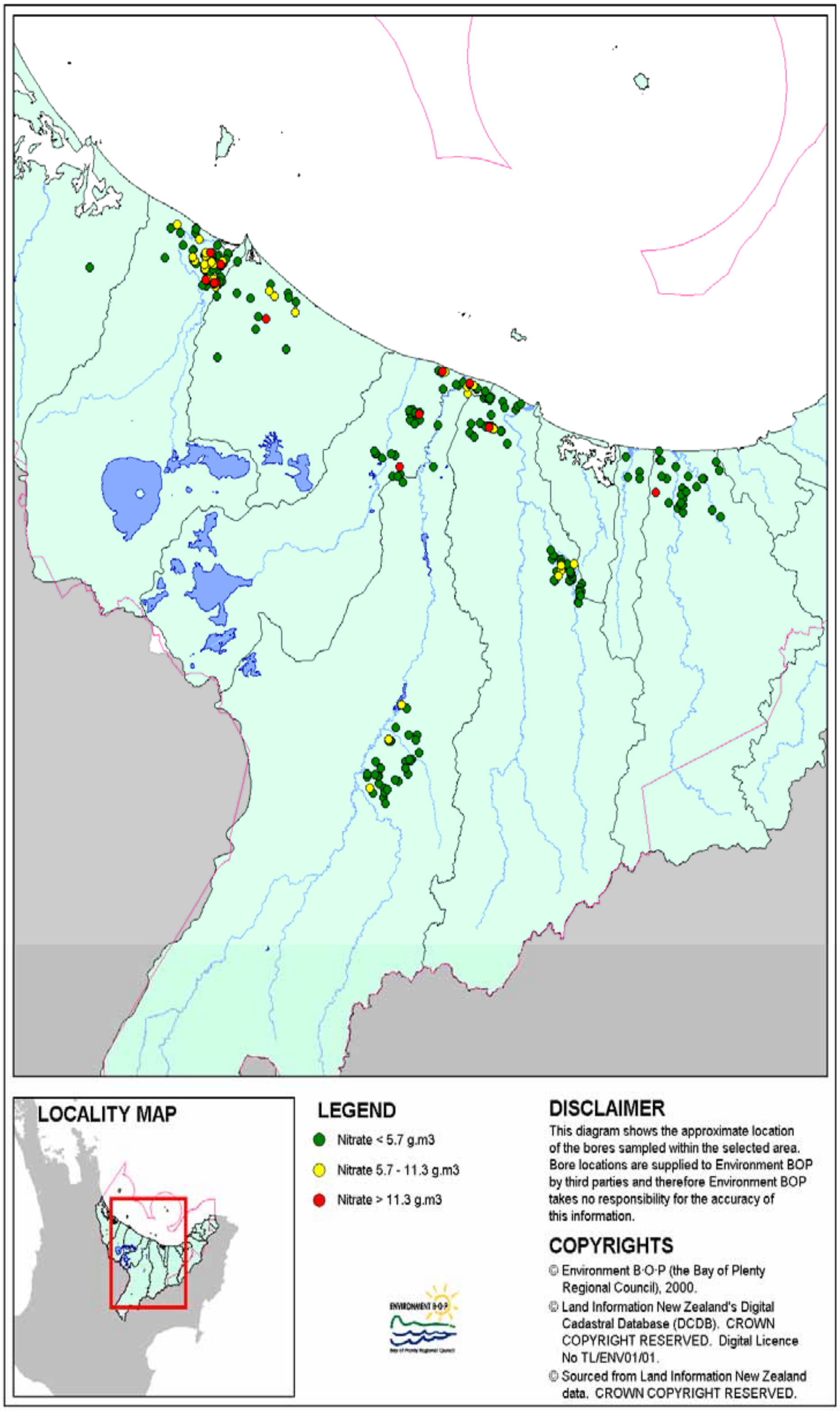


Figure 1 Nitrate levels at survey sites for the study reported in Environment Bay of Plenty, 2002 (Environmental Report 2002/09).

Chapter 2: Methods

2.1 Sites

Five sites were established on a kiwifruit orchard and five on a dairy farm. Groundwater monitoring bores were drilled to around 6 metres and screened at the bottom. The soil types present were a sandy loam, a loamy sand and a silt loam underlain by peat.

2.2 Soil Types

2.2.1 Kiwifruit orchard

The soil type was Paengaroa sandy loam/Te Puke sandy loam. These soils are situated on gently undulating to undulating terraces near sea level with coarsely textured soils which are especially suited to citrus and subtropical fruit.

Waipumuka sandy loam

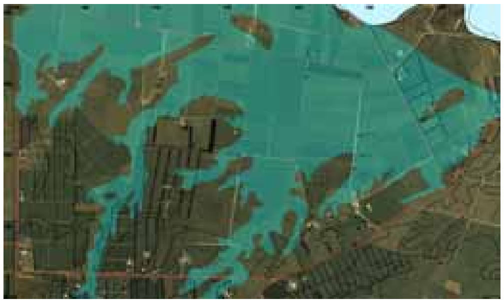
Paengaroa sandy loam

Paengaroa sandy loam/Te Puke sandy loam

2.2.2 Kiwifruit/dairy

The soil types were Paengaroa loamy sand, Waipumuka sandy loam and Raparapahoe silt loam with the Paengaroa loamy sands and Waipumuka sandy loam on the same level as the kiwifruit orchard. The Raparapahoe silt loam was on the poorly drained flats with a moderately high water table and subject to runoff from higher areas. This area merged into Maketu Peat closer to Maketu Township but was underlain and interspersed with peat.

In the latter soil (Raparapahoe silt loam) three of the bores (8, 9, and 10) were at this poorly drained lower level. Bores 6 (Paengaroa loamy sand) and 7 (Waipumuka sandy loam) were on the ash soil.



Raparapahoe silt loam

Paengaroa loamy sand

2.3 Monitoring

Monitoring was carried out at about monthly intervals for three years with the water level in each bore measured and samples taken for nutrient and other analyses.

Staff at Sinclair Knight Merz Limited plotted the groundwater level data and also mapped the groundwater surface (Figure 2). This shows that the direction of flow was to the north east to the drainage system around Maketu Estuary.

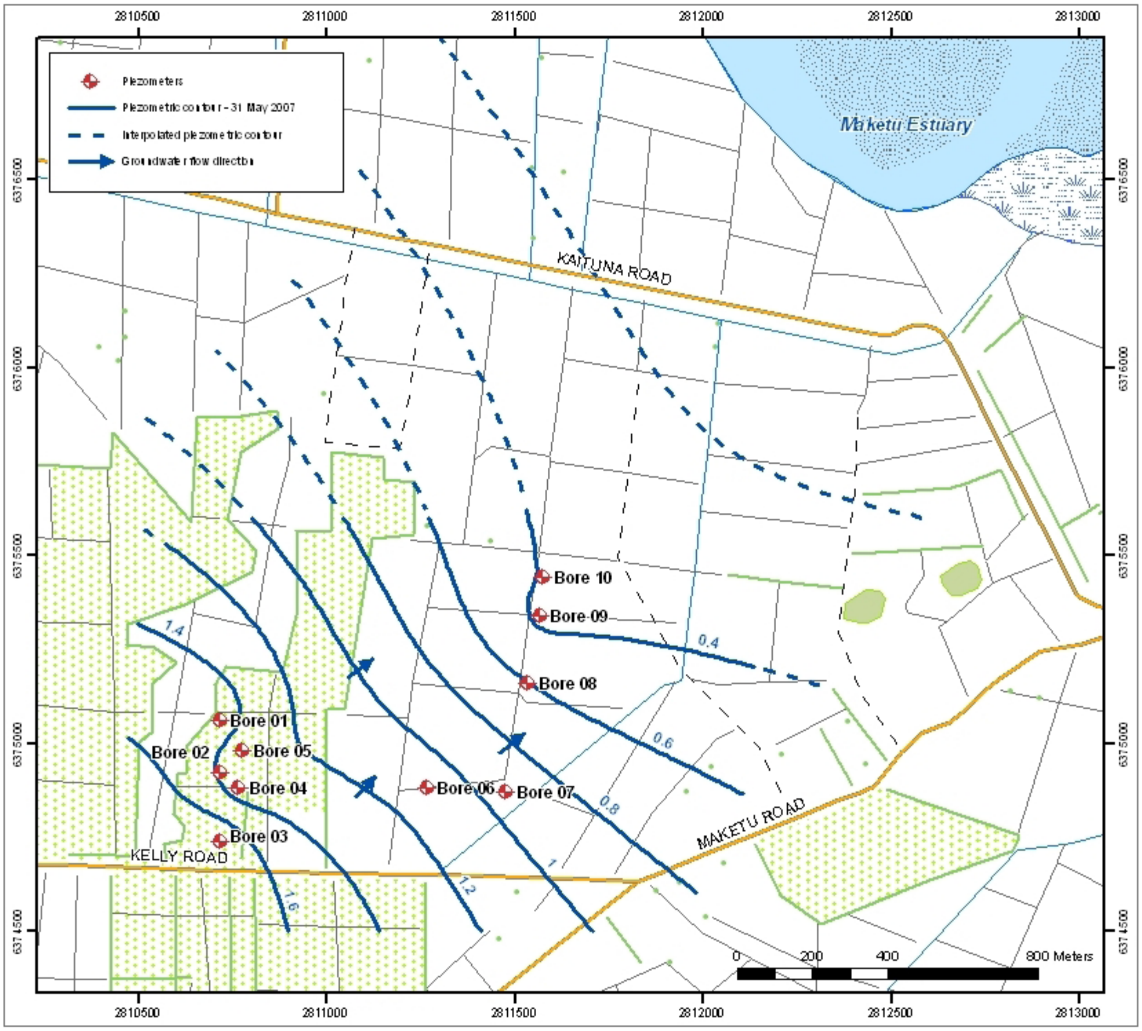


Figure 2 Piezometric surface contours showing the direction of groundwater flow in the shallow aquifer at Kelly Road, Maketu.

Chapter 3: Results

The average conductivity and nutrient concentrations for each bore over the three year period are presented in Figure 3. Time series plots of nutrient concentrations from selected bores are presented in Figures 4, 5 and 6.

3.1 Conductivity

Conductivity measures the quantity of dissolved salts in water. It can also be used as a coarse method of typing water. Bores 1 to 5 have very similar conductivity. Bores 6 and 7 have higher conductivity and Bores 8 to 10 have lower conductivity. Assuming the same water type was flowing under the whole study area it is apparent that different influences are affecting the groundwater chemistry.

3.2 Phosphorus

Phosphorus levels are uniform across the kiwifruit orchard at about 0.05 g/m^3. On the dairy property the phosphorus levels are generally between 0.1 to 0.2 g/m^3. Bore 6 on the dairy farm remained uniform at 0.1 g/m^3 although this area was later converted to kiwifruit. Bore 7 showed a decline in phosphorus concentration to low levels probably related to the change in land use to kiwifruit.

3.3 Nitrogen

Ammonium nitrogen levels were high in Bore 7, and 8 to a lesser extent, while the other bores had insignificant levels. The difference between the Kjeldahl and ammonium nitrogen is the organic and particulate nitrogen levels. Bore 7 may have a higher organic and particulate nitrogen load but generally there is little difference across all the bores. Almost all the nitrogen is present in the dissolved form as nitrate nitrogen. The exception is Bore 7 which had the elevated ammonium nitrogen level. The level of nitrate nitrogen in the kiwifruit orchard was about 1 g/m^3. The dairy property had nitrate levels ranging from 0.3 to 4.5 g/m^3.

Figures 4 to 6 show time series plots for two bores from each property. Bore 1 showed a strong seasonal component in nitrate nitrogen level which did not occur in Bore 2. Ammonium nitrogen levels were low in each of Bores 1 and 2. In Bore 6 the nitrate levels rose to a peak of 12 g/m^3 in the mid part of the study. In the latter part of the study this part of the farm was converted to kiwifruit. Nitrate levels were generally low in Bore 7 but ammonium nitrogen levels were high and decreased over the period of the study.

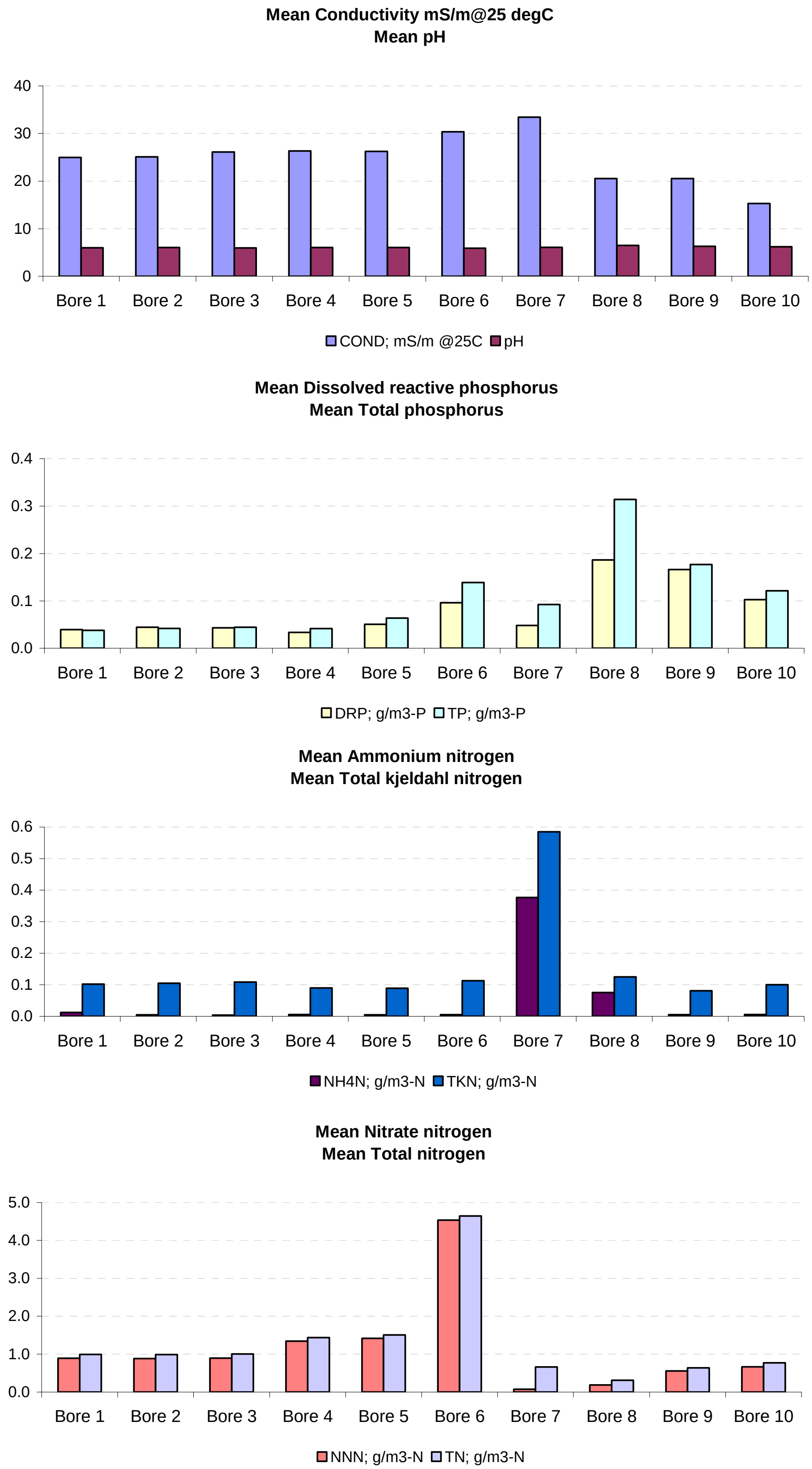


Figure 3 *Average conductivity, pH and nutrient data for the 10 bores. Bores 1 to 5 were on the kiwifruit property and 6 to 10 on the dairy farm.*

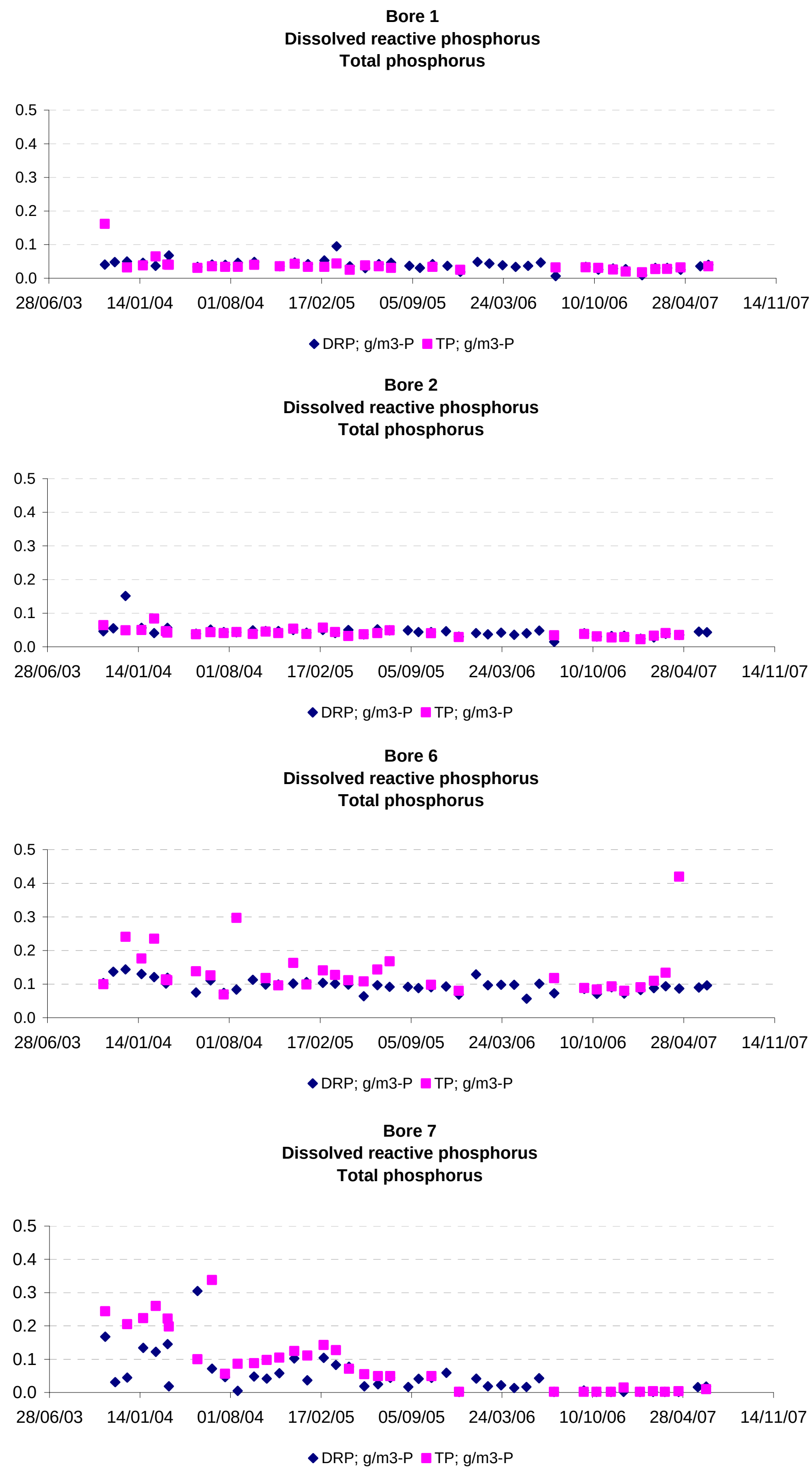


Figure 4 Time series plots for selected bores showing dissolved reactive phosphorus and total phosphorus (g/m^3).

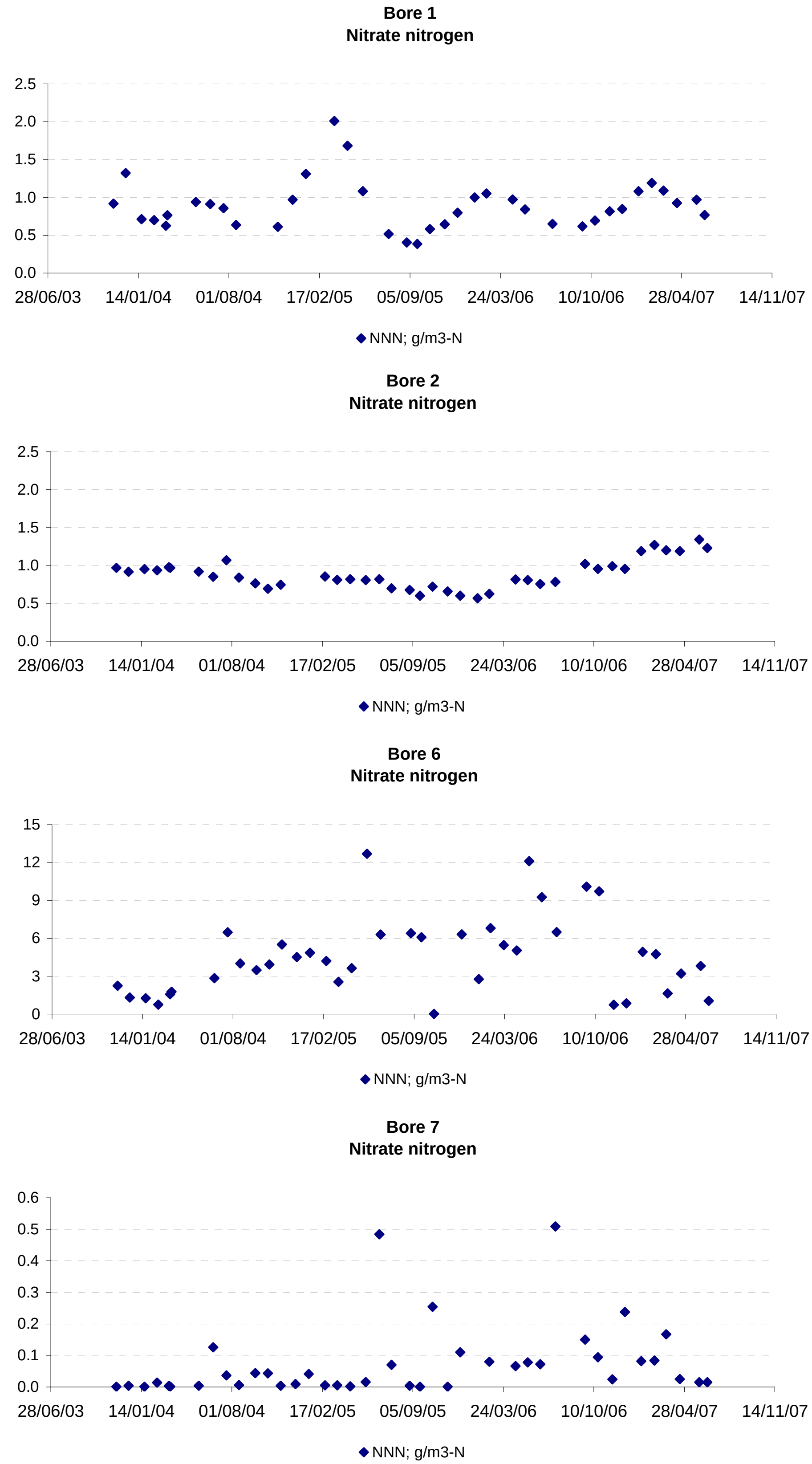


Figure 5 Time series plots for selected bores showing nitrate nitrogen concentrations (g/m^3).

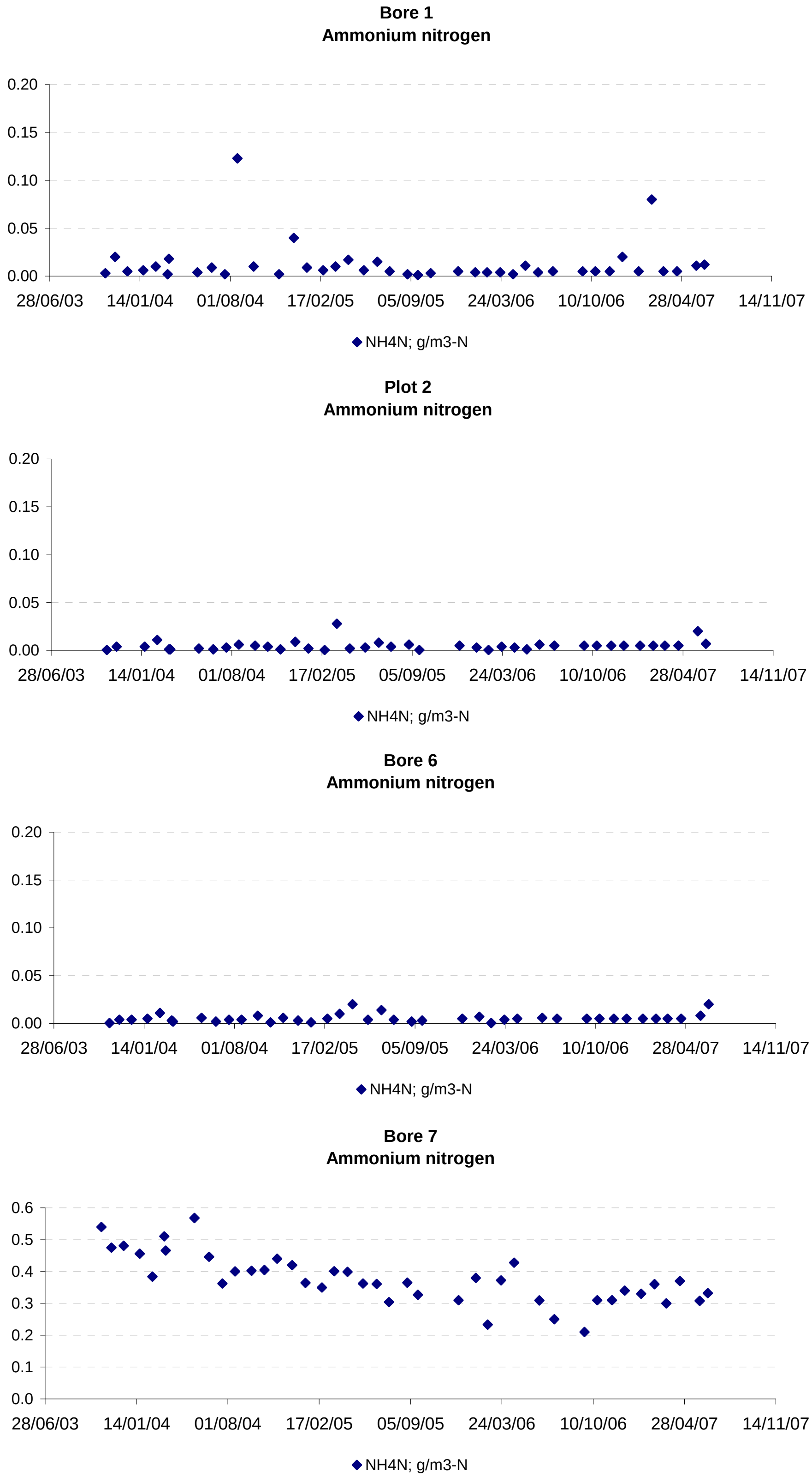


Figure 6 Time series plots for selected bores showing ammonium nitrogen concentrations (g/m^3).

Chapter 4: Discussion

4.1 Study results

The groundwater map in Figure 2 indicates a flow path under the whole study area. The same chemical type of water would be expected in all bores except for the fact that there is a step down from the ash soil to the peat soil which is at a lower level. The conductivity shows that there is a discontinuity in the water type. One explanation is that the aquifer at the lower level is a separate aquifer and that the upper aquifer emerges in the drainage system. Alternatively, the aquifer at the lower level could be the same water body but contains lesser dissolved nitrogen due to de-nitrification in the peat layer.

Phosphorus leaching appears to be occurring with higher phosphorus levels under the dairy land use. If phosphorus leaching is occurring it would be expected that nitrate would also be leaching. Nitrate being at very low concentration in this water tends to suggest that de-nitrification is occurring in the peat soil and the same aquifer is being measured across the whole study area.

4.2 Sustainable Farming Fund (SFF) project (03/092)

The SSF project examined beneficial production outcomes and the fate of a range of fertiliser minerals in the plant tissue. It also assessed the potential for environmental impacts of leached nitrogen. A summary report is attached as Appendix 1. The findings indicate that leaching of nitrogen from kiwifruit orchards could be excessive. In one season of the trial the high fertiliser application site (250 kg nitrogen/ha) was estimated to have leached 80 kg nitrogen/ha. With the completion of the trial HortResearch are in a position to recommend environmentally responsible and sustainable fertiliser application rates that maintain high production levels.

4.3 Nutrient export

Nitrogen and phosphorus export coefficients have been calculated for the kiwifruit block using all the data from the five bores. Coefficients have also been calculated for the dairy farm using Bore 6. This information is presented Table 1.

A hydrological budget is calculated using average rainfall for the Kaituna, Te Matai site (1,313 mm/yr) minus a theoretical annual evapotranspiration rate and a range is obtained by using the average rainfall (1,623 mm/yr) for the district from the HortResearch modelling. Evapotranspiration (780 mm/yr) is taken from HortResearch modelling. This may be low for pastoral land.

Table 1 Calculated nutrient export from a kiwifruit orchard and a dairy farm in Kelly Road, Maketu.

	Phosphorus kg/ha/yr	Nitrogen kg/ha/yr
Kiwifruit	0.27 – 0.42	5.8 – 9.2
Dairy	0.8 – 1.26	24 - 38

The nitrogen calculation (kiwifruit) can be compared to Steve Green's SPASMO modelled outcome scenarios for typical Bay of Plenty soil types in Appendix 2.

4.3.1 **HortResearch modelled outcomes**

In the HortResearch model outputs (Appendix 2), the soil groups are referred to as 'Te Puke' or 'Rotorua'. The soils in both of these groups are in fact from widespread locations in coastal and central Bay of Plenty. However, the properties available to HortResearch, at the time of the modelling, did not have the soil groups of the Lake Rotorua catchment.

Soil properties are detailed below.

Te Puke soils

Scenario number	PAW	TAW	rhob	stones	tot C	tot N	Drainage class
1 KATIKATI SANDY LOAM	103.9	195.2	0.77	0	6.80	0.59	Well
2 KUKUMOA FINE SANDY LOAM	139.1	259.6	1.02	0	2.40	0.24	Imperfect
3 PAENGAROA SANDY LOAM	114.5	205.8	1.05	0	5.53	0.43	Somewhat excessive
4 RANGITAIKI SANDY LOAM	130.5	229.1	1.15	0	2.03	0.17	Well
5 TE PUKE SANDY LOAM	134.6	240.4	0.88	0	3.97	0.31	Well

Rotorua soils

Scenario number	PAW	TAW	rhob	stones	tot C	tot N	Drainage class
1 KAINGAROA SAND	147.8	212.2	0.67	22.0	3.13	0.12	Somewhat excessive
2 MAROA FINE SANDY LOAM	107.9	213.6	0.74	13.7	7.43	0.42	Well
3 NGAKURU SANDY LOAM	122.8	219.5	0.77	2.0	5.67	0.43	Well
4 ROTOMAHANA SANDY LOAM	113.7	190.1	1.01	7.0	2.93	0.23	Well
5 TIHOI LOAMY SAND	90.8	155.8	0.83	9.0	3.83	0.26	Well

PAW = plant available water [mm/m] from -0.1 bar (field capacity) to -1.0 bar (refill point)
TAW = total available water [mm/m] from -0.1 bar (field capacity to -15.0 bar (wilting point)
rhob = the soils bulk density [kg/L]
stones = total stone content in top 0.3 m of soil
tot C = total carbon content in top 0.3 m of soil
tot N = total nitrogen content in to 0.3 m of soil

Key to model outputs (SPASMO model run):

- Water balance [mm/year]
  - ⇨ Site number = soil type
  - ⇨ ET crop = vine water use
  - ⇨ E soil = soil evaporation
  - ⇨ Rainfall (RF) = mean annual rainfall
  - ⇨ RF intercept = interception losses of RF in the canopy
  - ⇨ Irrigation = annual irrigation need
  - ⇨ Drainage = mean annual drainage
  - ⇨ Runoff = mean annual runoff

- Ammonium [kg N/ha]

  - ⇨ Added = fertiliser ammonium added
  - ⇨ NH_4 uptake = plant uptake
  - ⇨ Runoff = surface runoff (not calculated)
  - ⇨ Volatilised = volatilisation losses and the amount leached (all other factors are internal transformations).
  - ⇨ Mineralised = organic nitrogen (soil, plant tissue and DON) being transformed into mineral nitrogen.

- DON [kg N/ha] = dissolved organic nitrogen. Basically plant material that breaks down and enters the soil system e.g. leaf litter and material from winter pruning. This should all be mineralised at the end of year.

- Plant removal = the amount of dry matter (DM) and nitrogen allocated to some parts of the plant e.g. shoots, leaves and fruit.

The significant part of the model outcomes for environmental impact is the nitrate that is leached. It is typically less than 15 kg/ha with the concentration mostly around 1-4 g/m^3. Table 2 shows a summary of the nitrate leached from the two groups of soils for irrigated and non-irrigated orchards with low fertiliser use (67 kg N/ha) and high fertiliser use (134 kg N/ha).

Table 2 Modelled nitrogen leaching (kg/ha) from kiwifruit land use on five Te Puke area and five Rotorua area soils.

	Non-irrigated	**Irrigated**
Low fertiliser	Median (range)	Median (range)
Te Puke soils (coastal)	8.7 (5.5 – 12.4)	9.7 (5.6 – 12.5)
Rotorua soils (central)	2 (1.4 – 17.3)	3.5 (1.6 – 17.4)
High fertiliser		
Te Puke soils (coastal)	9.1 (7.2 – 12.6)	9.1 (7.2 – 12.6)
Rotorua soils (central)	3.5 (1.6 – 17.4)	3.7 (1.9 – 18)

Chapter 5: Conclusion

5.1 Study outcomes

In the time since the study was carried out, modelling has become more sophisticated and is the preferred method of assessing land use effects. More aspects of all types of land use are becoming characterised by numerical parameters. Leaching losses to the environment are one of these parameters and mitigation methods to reduce leaching are being developed and also incorporated into the models.

The Sustainable Farming Fund Project and SPASMO model outcomes have shed light on the nitrogen leaching from kiwifruit. It is possible that some high nitrate contamination of groundwater found in the earlier Environment Bay of Plenty study (Environment Bay of Plenty, 2002) was a result of excessive nitrogen fertilisation of kiwifruit.

The dairy study site at Kelly Rd was unusual in that it was converted to kiwifruit during the study and was partially on a soil with underlying peat layers, which may have resulted in de-nitrification rather than leaching of excess nitrate nitrogen. Dairying can produce high levels of nitrate in groundwater, but the study has shown that the peat soils may mitigate the effects of nitrate leaching.

The original study found that for most of the Bay of Plenty, nitrate levels were less than the New Zealand drinking water standard of 11.3 g/m^3 nitrate nitrogen. In the Rotorua lakes district water quality targets require much lower nitrogen leaching than this. The average nitrogen target for catchment inputs to Lake Rotorua is about 1 g/m^3.

Excessive nitrogen leaching from kiwifruit can be controlled by fertiliser management and the SPASMO model is now available to assist growers.

5.2 Implications for the Rotorua lakes

The Rotorua lakes are the most sensitive area of the Bay of Plenty to nitrogen and phosphorus enrichment. Typical nutrient losses from dairy farms cannot be accommodated in the catchment of Lake Rotorua while at the same achieving the remediation targets for the lake. Innovations in dairy farm management are reducing nutrient loss e.g. winter grazing management alternatives. However, reductions of up to 50% in nutrient export are needed and this will be difficult for farmers to achieve.

Changing land use to a horticultural activity (like kiwifruit) promises to reduce nutrient leaching to within a range to meet the catchment nitrogen leaching target, but the climate in Rotorua has been too harsh for kiwifruit.

There has been considerable investigation by climate scientists into the preferred climate range for kiwifruit (Salinger & Kenny, 1995). A report to Environment Bay of Plenty in March 2006, “Biotic Effects of Climate Change in the Bay of Plenty” (Kenny 2006) referred to the regional shift in kiwifruit growing area with climate change. Inland areas such as the Rotorua catchment become more suitable for kiwifruit as temperature warms and the coastal zone becomes unsuitable, at least for the Hayward variety.

Some kiwifruit orchards were established in the Rotorua area in the 1980’s but no large scale industry has established. Avocados currently extend up Maniatutu Road just to the north of Lake Rotoiti. An assessment could be undertaken to examine the feasibility of establishing a kiwifruit/avocado or other horticultural activities around Rotorua in the future. If feasible the economics of land use change could follow. This may provide an alternative to dairying if significant nutrient loss reduction is not possible for the dairy industry.

5.3 Nitrate contamination of groundwater in the Bay of Plenty

Nitrate contamination was not found to be a widespread problem in the Bay of Plenty (Environment Bay of Plenty, 2002). The risk factors were found to be over-use of nitrogen fertiliser on kiwifruit orchards, oxidation ponds discharging to soakage or discharging to surface drains where the water could soak to the shallow groundwater. Theoretically, very high winter stocking numbers can result in high nitrate leaching from pasture. At Rerewhakaaitu there is an area to the east on Tarawera Ash soils used for wintering of cows. Elevated nitrate levels, though still in compliance with the drinking water standard, are found in the assumed groundwater flow pathway towards the Rangitaiki River.

As a result of the shallow groundwater survey and regional groundwater sampling, changes in nitrate levels can be monitored in the future.

5.4 Phosphorus leaching

Monitoring of the 10 bores at Kelly Road, Maketu, suggested that phosphorus leaching was occurring on the dairy farm. Phosphorus levels were about double in groundwater under the dairy unit compared to the kiwifruit orchard. This is not significant in the Kelly Road area but could be significant if related to land use change in the Rotorua lake catchments. The groundwater is shallow at Kelly Road but in the lake catchments varies from shallow to very deep. If dairying on 5,000 ha was changed to horticulture and the same phosphorus leaching reduction was found at Rotorua, this would amount to about 1 tonne/year phosphorus reduction to the lake. This is a low proportion of the phosphorus target. However, with horticulture surface runoff would also be significantly reduced.

Phosphorus levels have not increased over the past forty years in inflows to Lake Rotorua. This is possibly related to improvements in effluent management from farms and the dairy industry despite intensification of cow numbers in the catchment.

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Appendices

Appendix 1 Final report SFF (03/092)

Appendix 2 HortResearch modelling output

Appendix 1 – Final SFF Report Template

Sustainable Farming Fund
Ministry of Agriculture and Forestry
Te Manatū Ahuwhenua, Ngāherehere

http://www.maf.govt.nz/sff/about-projects/search/03-092/index.htm (for all reports and Final report)

Project Title:	Sustainable management of water and nitrogen in 'Hort16A' kiwifruit
Project Number:	03/092
Date of Report:	February 2008

Executive Summary

- Levels of nitrogen (N) applied to kiwifruit are high compared with those applied to other perennial fruit crops.
- Kiwifruit are grown in humid areas with high rainfall and while irrigation use is becoming more common through the Bay of Plenty, it is more commonly applied in Northland, Nelson and Hawke's Bay, where soil water content is compromised.
- With high levels of N application and high soil moisture contents, leaching of N is common. Even under a conventional application rate of 150 kg N/ha/y, leaching losses of up to 40 kg N are likely.
- During the three years of the trial, vegetative growth was limited on vines with no additional N fertiliser added, but average fruit sizes were reduced by about 10 g in the second year of the trial.
- Calculations of plant-available mineral N in some key kiwifruit soils illustrate that soils used to produce kiwifruit are typically fertile and deliver significant amounts of mineral N for uptake during the growing season. These data have been used to parameterise the Soil Plant Atmosphere Model (SPASMO) developed by HortResearch. They allow more accurate estimates of N application, based on delivery of N from the soil.
- A rate of between 80 to 120 kg N/ha/y should be sufficient to retain kiwifruit vine productivity, whilst also reducing the environmental risk of N leaching.

1 Omitted

2 Project objectives

To ensure the economic and environmental sustainability of the ZESPRI™ GOLD kiwifruit (‘Hort16A’), industry New Zealand growers must comply with the global trend for increased environmental accountability through mechanisms such as EUREP-GAP (now renamed GlobalGAP). These protocols require that orchard inputs, such as irrigation and nitrogen (N) fertilisers, are applied based on demonstrated need and are demonstrably safe for the environment. Specific information about the water and nitrogen balances in kiwifruit orchards is essential for fulfilment of these protocols. This project aimed to give specific information for kiwifruit grown in the Bay of Plenty region. The modelling component of this project allows findings from this field site to be applied to other growing regions.

Overall the aim for this project was to develop robust management guidelines that both growers and regional authorities could use to demonstrate environmental responsibility and achieve economic gain for ‘Hort16A’. The project aimed to recommend appropriate water and nitrogen inputs to maintain production levels while maximising water and nitrogen uptake efficiencies, in order to minimise losses of both nitrogen and water beyond the grasp of plant roots. In order to complete this, we parameterise existing models with specific kiwifruit data. These data were gathered from a customised trial conducted on a high-performing commercial ‘Hort16A’ property over the three years of the project.

The irrigation components of the objectives were not addressed in this project. The site selected for trial work did not require irrigation during the three years of the trial, so no data on the water use efficiency (as related to irrigation) of ‘Hort16A’ were collected.

3 Approach

A trial site selected in June 2004 was specifically chosen because of its consistently high yield of top quality fruit, which typically show high dry matter and good fruit size.

The experimental vines were given different levels of N fertiliser over the three years of the trial. Nitrogen application rates were Zero (where no N fertiliser was applied to the vines), Control (normal commercial application rates) and High (approximately twice the commercial application rate). The Control N application rate was between 110 and 140 kg N/ha/y and the High N rate was between 240 and 295 kg N/ha/y. Applications of all other nutrients during the three years of the trial were at commercial application rates. For a full list of nutrients applied during the course of the trial, please refer to the article Appendix 5.

The vines were periodically instrumented with heat pulse equipment (Figure 1) to give measurement of total vine water use on an hourly basis during the growing season. These data are a key component of the water balance model developed for kiwifruit and contribute to leaching estimates via model predictions. This water use data, along with local meteorological data, allow us to predict water use for kiwifruit in any region. In this trial water was never limiting at the experimental site as recorded using Time Domain Reflectometry (TDR) equipment which measures volumetric water content of the soil.

Figure 1 Heat pulse equipment installed in a kiwifruit vine.

The trial site was instrumented with drainage meters, which capture drainage at 1.2 m depth, along with TDR (Time Domain Reflectometry) which measured soil moisture content to 1.2 m (Figure 2). Analysis of these data define the site water balance, and allows parameterisation of the SPASMO Model to estimate drainage beyond the root zone. By evaluating N content in the drainage water from the site, we were able to evaluate N losses under the contrasting N application rates at the site.

Figure 2 Installation of drainage meters (left), and Time Domain Reflectometry (TDR) probes awaiting installation (right).

The N content of the above-ground vine portions was also evaluated (Figure 3). Through fruit and shoot sampling at 2 to 4 week intervals throughout the three growing seasons, total N taken up (given total biomass and total N being removed by the fruit) was calculated. These data contribute to model parameterisation, including loss of N due to leaching, and allow predictions of N utilisation at other sites, if local meteorological data are also available.

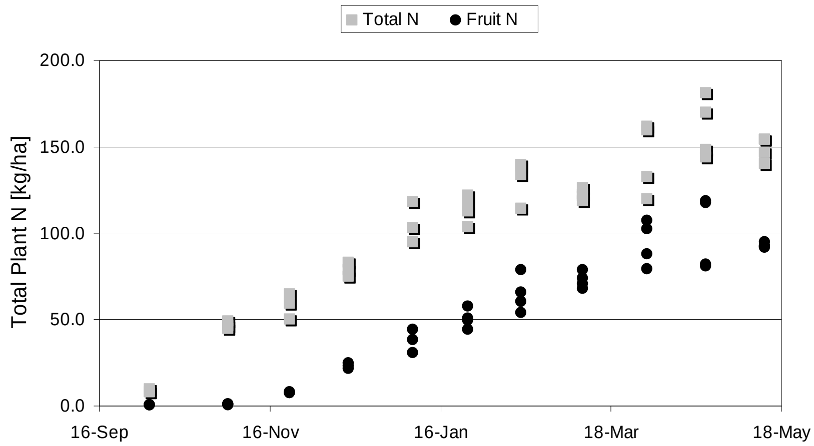

Figure 3 Total ZESPRI™GOLD plant nitrogen (N) in fruit in the total above-ground vine biomass during the season.

4 What were the main findings from this project?

Data from this project show that on this soil, significant levels of plant-available (mineralised) N are present in the soil and that even under conditions where no additional N fertilisers are applied, vines continue to perform well, and yield and fruit quality are retained (see Appendix 5).

In summary, under a conservative application rate of 140 kg/ha/y, we may expect leaching of up to 40 kg/ha/y i.e. approximately 30% of the N added is in excess of what the plants require. Nitrogen application above this level, and which are common in the kiwifruit industry, will result in even higher leaching losses. As requirements for demonstrated need for inputs, including water and fertilisers, these data give growers a better benchmark for calculating an N balance for their site, and assist in reducing the risk of nutrients leaching beyond the grasp of roots.

5 What difference has this project made to your group / community of interest / industry?

We are now better positioned to recommend reduced N inputs. We also have an improved understanding of N mineralisation processes within typical soils used for kiwifruit production. These data can now be utilised when decisions on N application rates are being made by growers and consultants, at which time an account of the N status of the soil and its likely plant availability can be incorporated.

Key to the uptake of this information is now making use of existing linkages between growers and industry support services, including fertiliser representatives and consultants, to give growers sound advice on the reduction of N application to ‘Hort16A’.

6 Is there anything that you have learnt that would be useful for new project teams?

Within this project we struggled to make the best use of in-kind support offered by regional councils and other stakeholders. We also struggled to deliver the workshops planned throughout the project. Perhaps stakeholder involvement would have been more effective if a key grower contact person, such as a consultant, were directly involved in the project management. This would have improved our delivery of information to growers and strengthened the project.

7 Where to from here – what are the next steps?

A ZESPRI-HortResearch funded PhD student is continuing to use the trial site for an ongoing assessment of the impact of N and pruning intensity on vine performance including fruit quality and canopy growth. This study further extends the initial investigations undertaken under this SFF project.

The work conducted under this SFF has highlighted that more N than required is typically applied to kiwifruit vines in the Te Puke area and that improvements in both the amount of N added and the timing of these additions can be made. Balance Agri-nutrients Ltd are keen to develop further the existing N calculator for kiwifruit. They would like to focus on a better evaluation of the seasonal starting point of N status in the vines and the surrounding soil. The N start point can be taken into consideration when N balances are being calculated for the season. We are currently preparing a proposal around this and will submit this to Balance Agri-nutrients Ltd for funding approval within the next couple of months.

Appendix 2 – HortResearch modelling output

MODEL RUN ON 20080829 AT 05:31:52
SPASMO-2D-Model Inputs-TePuke-Kiwifruit.par
TePukeClimateData(1972-2007).csv
Crop-Kiwifruit.csv

Low fertiliser
No Irrigation

Water balance [mm/year]					
Site number	1	2	3	4	5
ET crop	698.9	708.2	703	706.6	706.3
E soil	146.1	144.8	137.1	144.4	158.5
Rainfall	1623.2	1623.2	1623.2	1623.2	1623.2
RF intercept	38.4	38.4	38.4	38.4	38.4
Irrigation	0	0	0	0	0
Drainage	590.5	411.6	688.4	594.8	571.3
Runoff	151.2	322	57.8	140.2	150.5
Ammonium [kg N/ha]					
Added	22.4	22.4	22.4	22.4	22.4
NH4 uptake	67.8	65.6	59	52	55
Runoff	0	0	0	0	0
Volatilzed	3.7	3.2	3	2.2	3.1
Hydrolized	0	0	0	0	0
Mineralized	101.2	103.2	81.9	74.4	77.2
Nitrified	-49.9	-53.2	-40.5	-40.3	-39.3
Resident	1.2	1.7	1.4	1.6	1.1
Leached	1.6	2.4	1.1	2.8	1.4
Conc [mg/L]	0.302	0.631	0.173	0.494	0.267
Nitrate [kg N/ha]					
Added	44.8	44.8	44.8	44.8	44.8
NO3 uptake	86.1	83.1	79.7	75	75.9
Runoff	0	0	0	0	0
Nitrified	49.9	53.2	40.5	40.3	39.3
Denitrified	0.9	3.7	1	1.3	1.1
Resident	0.2	0.3	0.2	0.2	0.2
Leached	7.1	10	4.4	7.8	6.5
Conc [mg/L]	1.634	3.344	0.915	1.972	1.505
DOC[kg C/ha]					
Added	1907.4	1859.3	1756.6	1611.5	1651.3
Runoff	0	0	0	0	0
Resident	20.4	20.1	18.9	18.3	18
Leached	0	0	0.1	0	17.2
Conc [mg/L]	0	0	0.002	0.001	1.917
DON[kg N/ha]					
Added	64.7	63.8	59.8	54	54.9
Runoff	0	0	0	0	0
Resident	0.6	0.6	0.6	0.6	0.6
Leached	0	0	0	0	0.5
Conc [mg/L]	0	0	0	0	0.057
Plant removal [kg/ha]					
DM removed	0	0	0	0	0
DM pruned	2412	2326.2	2207.6	2034	2096.2
N in prunings	20.3	19.5	18.4	16.8	17.3
Crop DM	4089.4	3919.5	3734.3	3463.5	3573.8
Crop N	77.4	73.9	70.2	64.7	66.8
N fixed	0	0	0	0	0
N removed	0	0	0	0	0
N topped	0	0	0	0	0
P removed	0	0	0	0	0
P topped	0	0	0	0	0

MODEL RUN ON 20080828 AT 11:54:54
SPASMO-2D-Model Inputs-TePuke-Kiwifruit.par
TePukeClimateData(1972-2007).csv
Crop-Kiwifruit.csv

High fertiliser
No Irrigation

Water balance [mm/year]					
Site number	1	2	3	4	5
ET crop	698.9	708.2	703	706.6	706.3
E soil	146.1	144.8	137.1	144.4	158.5
Rainfall	1623.2	1623.2	1623.2	1623.2	1623.2
RF intercept	38.4	38.4	38.4	38.4	38.4
Irrigation	0	0	0	0	0
Drainage	590.5	411.6	688.4	594.8	571.3
Runoff	151.2	322	57.8	140.2	150.5
Ammonium [kg N/ha]					
Added	44.8	44.8	44.8	44.8	44.8
NH4 uptake	90.1	88.2	82.3	75	77
Runoff	0	0	0	0	0
Volatilzed	5.6	5.3	4.6	4	5.1
Hydrolized	0	0	0	0	0
Mineralized	116.4	118.6	97.6	90.7	91.3
Nitrified	-63	-65.7	-53.3	-54.7	-51.2
Resident	1.7	2.4	2.1	2.4	1.7
Leached	1.7	2.5	1.1	2.8	1.5
Conc [mg/L]	0.306	0.633	0.18	0.501	0.283
Nitrate [kg N/ha]					
Added	89.6	89.6	89.6	89.6	89.6
NO3 uptake	143.2	139.7	135.1	132.4	131.2
Runoff	0	0	0	0	0
Nitrified	63	65.7	53.3	54.7	51.2
Denitrified	1.3	4.1	1.5	2.1	1.6
Resident	0.4	0.5	0.3	0.3	0.4
Leached	7.4	10.1	6.1	8.6	7.2
Conc [mg/L]	1.685	3.369	1.147	2.117	1.642
DOC[kg C/ha]					
Added	2754.5	2702.5	2603.6	2497.5	2484.4
Runoff	0	0	0	0	0
Resident	30.1	29.7	28.9	29.2	27.5
Leached	0	0	0.8	0.5	27.7
Conc [mg/L]	0	0	0.028	0.022	3.1
DON[kg N/ha]					
Added	94.8	94	90.3	85.9	83.7
Runoff	0	0	0	0	0
Resident	1	1	0.9	1	0.9
Leached	0	0	0	0	0.8
Conc [mg/L]	0	0	0	0	0.092
Plant removal [kg/ha]					
DM removed	0	0	0	0	0
DM pruned	3511.6	3416.6	3294.8	3166.9	3180.5
N in prunings	30.6	29.8	28.6	27.3	27.3
Crop DM	5962.8	5772.1	5575.9	5378.1	5423
Crop N	117.1	112.8	108.7	104.3	105.2
N fixed	0	0	0	0	0
N removed	0	0	0	0	0
N topped	0	0	0	0	0
P removed	0	0	0	0	0
P topped	0	0	0	0	0

MODEL RUN ON 20080828 AT 11:35:31
SPASMO-2D-Model Inputs-Rotorua-Kiwifruit.par
RotoruaClimateData(1972-2007).csv
Crop-Kiwifruit.csv

Low fertiliser
Irrigation

Water balance [mm/year]					
Site number	1	2	3	4	5
ET crop	816.2	816	816	816.2	812.1
E soil	168.5	179.2	173.8	167.2	171.2
Rainfall	1354.7	1354.7	1354.7	1354.7	1354.7
RF intercept	32.5	32.5	32.5	32.5	32.5
Irrigation	94.2	112.1	122.5	136.7	132.9
Drainage	403.1	363	374.8	393.5	388.5
Runoff	30.3	79	83	84.2	85.7
Ammonium [kg N/ha]					
Added	22.4	22.4	22.4	22.4	22.4
NH4 uptake	23.8	81	48.4	40.1	41.8
Runoff	0	0	0	0	0
Volatilzed	3.7	5.7	5.7	5.1	5.1
Hydrolized	0	0	0	0	0
Mineralized	18.5	138.2	60	46.8	54.1
Nitrified	-12.5	-71.2	-27.8	-22.9	-27.5
Resident	0.5	1.1	0.8	0.9	1.2
Leached	0.5	3	0.2	0.4	1.3
Conc [mg/L]	0.12	0.873	0.068	0.114	0.346
Nitrate [kg N/ha]					
Added	44.7	44.7	44.7	44.8	44.8
NO3 uptake	55.3	90.1	70.8	65.6	66.2
Runoff	0	0	0	0	0
Nitrified	12.5	71.2	27.8	22.9	27.5
Denitrified	0.1	9.7	0.6	0.3	0.3
Resident	0.1	0.4	0.1	0.2	0.2
Leached	1.6	14.9	1.3	1.8	5.1
Conc [mg/L]	0.616	5.095	0.437	0.644	1.837
DOC[kg C/ha]					
Added	1031	2104.4	1502.3	1347.2	1373.7
Runoff	0	0	0	0	0
Resident	12.1	24.5	17.4	15.9	16.6
Leached	44.8	0	5.3	17.4	0.4
Conc [mg/L]	7.891	0	0.896	3.104	0.042
DON[kg N/ha]					
Added	30.3	74.3	48.5	42.7	44.2
Runoff	0	0	0	0	0
Resident	0.3	0.8	0.5	0.5	0.5
Leached	1.2	0	0.1	0.4	0
Conc [mg/L]	0.219	0	0.021	0.063	0.001
Plant removal [kg/ha]					
DM removed	0	0	0	0	0
DM pruned	1394.4	2620.5	1948	1760.2	1783.5
N in prunings	10.8	22.5	15.9	14.2	14.4
Crop DM	2497.4	4380.8	3368.3	3067.2	3095.8
Crop N	45.4	83.7	62.7	56.7	57.3
N fixed	0	0	0	0	0
N removed	0	0	0	0	0
N topped	0	0	0	0	0
P removed	0	0	0	0	0
P topped	0	0	0	0	0

MODEL RUN ON 20080828 AT 11:50:36
SPASMO-2D-Model Inputs-TePuke-Kiwifruit.par
TePukeClimateData(1972-2007).csv
Crop-Kiwifruit.csv

High fertiliser
Irrigation

Water balance [mm/year]					
Site number	1	2	3	4	5
ET crop	710.2	709.7	710.1	710.2	710.2
E soil	146.1	144.8	137.1	144.4	158.5
Rainfall	1623.2	1623.2	1623.2	1623.2	1623.2
RF intercept	38.4	38.4	38.4	38.4	38.4
Irrigation	68.8	22.5	52.5	44.6	45
Drainage	642.2	429	731.6	632.2	608.4
Runoff	156.9	325.5	60.1	143.8	154.5
Ammonium [kg N/ha]					
Added	44.8	44.8	44.8	44.8	44.8
NH4 uptake	93.3	88.8	83.5	75.8	78.2
Runoff	0	0	0	0	0
Volatilzed	5.7	5.4	4.7	4.1	5.2
Hydrolized	0	0	0	0	0
Mineralized	121	119.2	100.4	91.6	93
Nitrified	-64.3	-65.7	-54.5	-54.4	-51.6
Resident	1.6	2.4	2.1	2.3	1.6
Leached	1.7	2.5	1.2	2.8	1.6
Conc [mg/L]	0.29	0.612	0.176	0.48	0.272
Nitrate [kg N/ha]					
Added	89.6	89.6	89.6	89.6	89.6
NO3 uptake	144.5	139.8	136.8	132.3	131.6
Runoff	0	0	0	0	0
Nitrified	64.3	65.7	54.5	54.4	51.6
Denitrified	1.3	4.1	1.5	2.1	1.6
Resident	0.4	0.5	0.3	0.3	0.4
Leached	7.4	10.1	5.6	8.5	7.2
Conc [mg/L]	1.525	3.174	1.028	1.931	1.521
DOC[kg C/ha]					
Added	2814.9	2713	2640.8	2501.8	2508.4
Runoff	0	0	0	0	0
Resident	30.7	29.7	29.1	28.6	27.6
Leached	0	0	0.8	0.5	29.2
Conc [mg/L]	0	0	0.029	0.023	3.161
DON[kg N/ha]					
Added	97.6	94.5	92	85.9	84.7
Runoff	0	0	0	0	0
Resident	1	1	0.9	0.9	0.9
Leached	0	0	0	0	0.9
Conc [mg/L]	0	0	0	0	0.095
Plant removal [kg/ha]					
DM removed	0	0	0	0	0
DM pruned	3565.9	3424.4	3327.8	3168	3202.3
N in prunings	31.2	29.9	29	27.3	27.5
Crop DM	6026.1	5776.6	5610.1	5368.4	5446.6
Crop N	118.3	112.9	109.4	104.1	105.6
N fixed	0	0	0	0	0
N removed	0	0	0	0	0
N topped	0	0	0	0	0
P removed	0	0	0	0	0
P topped	0	0	0	0	0

MODEL RUN ON 20080829 AT 05:33:56
SPASMO-2D-Model Inputs-Rotorua-Kiwifruit.par
RotoruaClimateData(1972-2007).csv
Crop-Kiwifruit.csv

Low fertiliser
Irrigation

Water balance [mm/year]					
Site number	1	2	3	4	5
ET crop	796.9	787.8	780.6	767.5	761
E soil	168.5	179.1	173.7	167.2	171.2
Rainfall	1354.7	1354.7	1354.7	1354.7	1354.7
RF intercept	32.5	32.5	32.5	32.5	32.5
Irrigation	0	0	0	0	0
Drainage	330.9	285.9	294.4	312.3	312.6
Runoff	27.7	72.2	76.4	77.8	80.1
Ammonium [kg N/ha]					
Added	22.4	22.4	22.4	22.4	22.4
NH4 uptake	23.4	76.1	45.2	37.8	39.8
Runoff	0	0	0	0	0
Volatilzed	3.6	5.5	5.6	5	5
Hydrolized	0	0	0	0	0
Mineralized	17.9	131.2	55	42.9	51
Nitrified	-12.4	-69.5	-26	-21.5	-26.5
Resident	0.6	1.2	0.8	1	1.2
Leached	0.4	2.7	0.2	0.4	1.1
Conc [mg/L]	0.133	1.025	0.076	0.122	0.391
Nitrate [kg N/ha]					
Added	44.7	44.7	44.7	44.7	44.7
NO3 uptake	55.3	88.6	69.1	64.4	65.4
Runoff	0	0	0	0	0
Nitrified	12.4	69.5	26	21.5	26.5
Denitrified	0.1	9.5	0.6	0.3	0.3
Resident	0.1	0.6	0.1	0.1	0.2
Leached	1.5	14.6	1.2	1.6	4.9
Conc [mg/L]	0.755	6.689	0.535	0.752	2.299
DOC[kg C/ha]					
Added	1021.3	2007.4	1435.3	1296.7	1330.2
Runoff	0	0	0	0	0
Resident	12	23.4	16.6	14.9	15.7
Leached	40.3	0	4	13.8	0.3
Conc [mg/L]	7.601	0	0.727	2.713	0.031
DON[kg N/ha]					
Added	29.9	69.2	45.5	40.6	42.5
Runoff	0	0	0	0	0
Resident	0.3	0.8	0.5	0.4	0.5
Leached	1.1	0	0.1	0.3	0
Conc [mg/L]	0.21	0	0.016	0.053	0
Plant removal [kg/ha]					
DM removed	0	0	0	0	0
DM pruned	1386.2	2543.9	1882.2	1705.6	1737.1
N in prunings	10.8	21.7	15.3	13.7	14.1
Crop DM	2489.7	4312.2	3283.5	2989.9	3030.9
Crop N	45.4	82.5	61.3	55.6	56.5
N fixed	0	0	0	0	0
N removed	0	0	0	0	0
N topped	0	0	0	0	0
P removed	0	0	0	0	0
P topped	0	0	0	0	0

MODEL RUN ON 20080828 AT 11:16:05
SPASMO-2D-Model Inputs.par
Rotorua Climate Data (1972-2007).csv
Crop-Kiwifruit.csv

High fertiliser
No Irrigation

Water balance [mm/year]					
Site number	1	2	3	4	5
ET crop	796.9	787.8	780.6	767.5	761
E soil	168.5	179.1	173.7	167.2	171.2
Rainfall	1354.7	1354.7	1354.7	1354.7	1354.7
RF intercept	32.5	32.5	32.5	32.5	32.5
Irrigation	0	0	0	0	0
Drainage	330.9	285.9	294.4	312.3	312.6
Runoff	27.7	72.2	76.4	77.8	80.1
Ammonium [kg N/ha]					
Added	44.7	44.7	44.7	44.7	44.7
NH4 uptake	43.4	96.4	65.7	58.4	60.8
Runoff	0	0	0	0	0
Volatilzed	6.8	9.3	9.4	8.7	8.9
Hydrolized	0	0	0	0	0
Mineralized	29.7	144.8	67.7	55.9	64.6
Nitrified	-22.5	-81.3	-36.4	-32.2	-36.9
Resident	1.1	1.7	1.3	1.6	1.9
Leached	0.7	2.7	0.2	0.5	1.2
Conc [mg/L]	0.212	1.027	0.087	0.157	0.407
Nitrate [kg N/ha]					
Added	89.5	89.5	89.5	89.5	89.5
NO3 uptake	108.6	143.6	123.5	118.7	119.7
Runoff	0	0	0	0	0
Nitrified	22.5	81.3	36.4	32.2	36.9
Denitrified	0.2	10.9	0.9	0.5	0.5
Resident	0.2	0.7	0.2	0.2	0.3
Leached	2.8	14.7	1.4	2.4	5.6
Conc [mg/L]	1.337	6.713	0.645	1.071	2.524
DOC[kg C/ha]					
Added	1833.2	2792	2243.4	2113.1	2147.3
Runoff	0	0	0	0	0
Resident	21.7	33	26.3	24.6	25.6
Leached	81.3	0	7.4	29	1.3
Conc [mg/L]	15.477	0	1.344	5.708	0.137
DON[kg N/ha]					
Added	56.3	96.7	72.4	68.1	70.5
Runoff	0	0	0	0	0
Resident	0.6	1.1	0.8	0.7	0.8
Leached	2.3	0	0.2	0.6	0
Conc [mg/L]	0.44	0	0.033	0.126	0.001
Plant removal [kg/ha]					
DM removed	0	0	0	0	0
DM pruned	2456.5	3578.4	2948.1	2772.6	2799.4
N in prunings	20.2	31.4	25	23.4	23.8
Crop DM	4328.1	6088.2	5114.1	4812.8	4840.2
Crop N	82.1	120.5	99.1	93	93.8
N fixed	0	0	0	0	0
N removed	0	0	0	0	0
N topped	0	0	0	0	0
P removed	0	0	0	0	0
P topped	0	0	0	0	0

MODEL RUN ON 20080828 AT 11:35:31
SPASMO-2D-Model Inputs-Rotorua-Kiwifruit.par
RotoruaClimateData(1972-2007).csv
Crop-Kiwifruit.csv

Low fertiliser
Irrigation

Water balance [mm/year]					
Site number	1	2	3	4	5
ET crop	816.2	816	816	816.2	812.1
E soil	168.5	179.2	173.8	167.2	171.2
Rainfall	1354.7	1354.7	1354.7	1354.7	1354.7
RF intercept	32.5	32.5	32.5	32.5	32.5
Irrigation	94.2	112.1	122.5	136.7	132.9
Drainage	403.1	363	374.8	393.5	388.5
Runoff	30.3	79	83	84.2	85.7
Ammonium [kg N/ha]					
Added	22.4	22.4	22.4	22.4	22.4
NH4 uptake	23.8	81	48.4	40.1	41.8
Runoff	0	0	0	0	0
Volatilzed	3.7	5.7	5.7	5.1	5.1
Hydrolized	0	0	0	0	0
Mineralized	18.5	138.2	60	46.8	54.1
Nitrified	-12.5	-71.2	-27.8	-22.9	-27.5
Resident	0.5	1.1	0.8	0.9	1.2
Leached	0.5	3	0.2	0.4	1.3
Conc [mg/L]	0.12	0.873	0.068	0.114	0.346
Nitrate [kg N/ha]					
Added	44.7	44.7	44.7	44.8	44.8
NO3 uptake	55.3	90.1	70.8	65.6	66.2
Runoff	0	0	0	0	0
Nitrified	12.5	71.2	27.8	22.9	27.5
Denitrified	0.1	9.7	0.6	0.3	0.3
Resident	0.1	0.4	0.1	0.2	0.2
Leached	1.6	14.9	1.3	1.8	5.1
Conc [mg/L]	0.616	5.095	0.437	0.644	1.837
DOC[kg C/ha]					
Added	1031	2104.4	1502.3	1347.2	1373.7
Runoff	0	0	0	0	0
Resident	12.1	24.5	17.4	15.9	16.6
Leached	44.8	0	5.3	17.4	0.4
Conc [mg/L]	7.891	0	0.896	3.104	0.042
DON[kg N/ha]					
Added	30.3	74.3	48.5	42.7	44.2
Runoff	0	0	0	0	0
Resident	0.3	0.8	0.5	0.5	0.5
Leached	1.2	0	0.1	0.4	0
Conc [mg/L]	0.219	0	0.021	0.063	0.001
Plant removal [kg/ha]					
DM removed	0	0	0	0	0
DM pruned	1394.4	2620.5	1948	1760.2	1783.5
N in prunings	10.8	22.5	15.9	14.2	14.4
Crop DM	2497.4	4380.8	3368.3	3067.2	3095.8
Crop N	45.4	83.7	62.7	56.7	57.3
N fixed	0	0	0	0	0
N removed	0	0	0	0	0
N topped	0	0	0	0	0
P removed	0	0	0	0	0
P topped	0	0	0	0	0

MODEL RUN ON 20080828 AT 11:07:37
SPASMO-2D-Model Inputs.par
RotoruaClimateData(1972-2007).csv
Crop-Kiwifruit.csv

High fertiliser
Irrigation

Water balance [mm/year]					
Site number	1	2	3	4	5
ET crop	816.2	816	816	816.2	812.1
E soil	168.5	179.2	173.8	167.2	171.2
Rainfall	1354.7	1354.7	1354.7	1354.7	1354.7
RF intercept	32.5	32.5	32.5	32.5	32.5
Irrigation	94.2	112.1	122.5	136.7	132.9
Drainage	403.1	363	374.8	393.5	388.5
Runoff	30.3	79	83	84.2	85.7
Ammonium [kg N/ha]					
Added	44.7	44.7	44.7	44.8	44.8
NH4 uptake	43.8	101.7	69	60.6	62.7
Runoff	0	0	0	0	0
Volatilzed	6.9	9.5	9.5	8.8	9
Hydrolized	0	0	0	0	0
Mineralized	30.2	152.1	72.8	59.7	67.6
Nitrified	-22.5	-83	-38.1	-33.5	-37.8
Resident	1.1	1.5	1.2	1.6	1.9
Leached	0.8	3	0.3	0.6	1.3
Conc [mg/L]	0.189	0.874	0.078	0.146	0.359
Nitrate [kg N/ha]					
Added	89.5	89.5	89.5	89.5	89.5
NO3 uptake	108.6	145	125.1	119.8	120.3
Runoff	0	0	0	0	0
Nitrified	22.5	83	38.1	33.5	37.8
Denitrified	0.1	11.1	0.9	0.5	0.5
Resident	0.2	0.5	0.2	0.3	0.4
Leached	2.9	15	1.6	2.6	5.7
Conc [mg/L]	1.092	5.115	0.534	0.919	2.026
DOC[kg C/ha]					
Added	1844.8	2892.1	2311.8	2162.6	2192.7
Runoff	0	0	0	0	0
Resident	21.9	34.3	27.3	25.9	26.9
Leached	89.3	0	9.6	35.2	1.8
Conc [mg/L]	15.911	0	1.604	6.28	0.174
DON[kg N/ha]					
Added	56.7	102.2	75.5	70	72.1
Runoff	0	0	0	0	0
Resident	0.6	1.1	0.8	0.8	0.8
Leached	2.5	0	0.2	0.8	0
Conc [mg/L]	0.453	0	0.04	0.141	0.001
Plant removal [kg/ha]					
DM removed	0	0	0	0	0
DM pruned	2467	3659.7	3018.8	2831.4	2853.4
N in prunings	20.2	32.3	25.6	23.8	24.1
Crop DM	4338.8	6165.2	5209.9	4902.8	4922.9
Crop N	82	121.7	100.5	94	94.5
N fixed	0	0	0	0	0
N removed	0	0	0	0	0
N topped	0	0	0	0	0
P removed	0	0	0	0	0
P topped	0	0	0	0	0