ACHIEVING THE REQUIRED N LEACHING REDUCTIONS – REDUCING N LEACHING IN REAL LIFE

Ina Pinxterhuis[1], Tony Coltman[2], Paul Edwards[1], Leighton Parker[3]
[1] DairyNZ, Lincoln
[2] Canlac Holdings, Dunsandel
[3] Perrin Ag Consultants Ltd, Rotorua

Key messages

- Several New Zealand catchments will need to reduce agricultural nutrient loss to improve water quality. For dairy milking platforms in the Selwyn/Te Waihora catchment, this means a 30% reduction in nitrogen (N) loss to water from their baseline good management practice N loss rate (2009-2013).
- Options to reduce N leaching include: more efficient use of water, fertiliser and effluent; using low-N supplements; and reducing cow numbers in autumn. These reduce the amount of surplus N in the farm system and N deposited on pasture when plant N uptake is low and risk of drainage is increasing.
- Each farm has constraints and requires its own reduction strategies to achieve nutrient obligations. This paper shows that options are available to improve the efficiency of N use while retaining a highly profitable system.

Responding to water quality policy in Canterbury

Many farms in Canterbury are facing the challenge of reducing their nitrogen (N) loss to well below their current level. N loss to water is mostly N leaching from urine patches in grazed dairy systems, but also includes N leached from areas between urine patches, N loss from run-off and direct deposit of dung or urine into waterways, if these are accessible by animals. N leaching is defined as all N drained to below 60 cm soil depth, assumed to be the root zone. Poor irrigation management contributes to drainage and over-application of N from fertiliser and effluent (e.g. when not adjusting fertiliser applications to compensate for the N applied in effluent) increases the risk of N leaching.

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Environment Canterbury, and regional zone committees, have developed policies in response to the National Policy Statement for Freshwater Management (updated in 2014; Ministry for Environment 2014), with the policy for the Selwyn/Te Waihora catchment (Environment Canterbury 2014) made operative from February 2016. This policy requires all farms to be implementing good management practices (GMP) by June 2017, as defined by six industries (dairy, sheep and beef, deer, arable, horticulture and outdoor pork) in the Matrix of Good Management Project (2015). Dairy farms that have an estimated N loss of more than 15 kg N/ha/yr must reduce losses by 2022, by 30% (dairy milking platform) and 22% (dairy support) of the Good Management Practice Nitrogen and Phosphorus Loss Rates for the property's baseline land use (i.e. 2009-2013). From 2037 no farm will be permitted to leach more than 80 kg N/ha/yr.

To enable dairy farmers achieve these requirements, farmers will need to know their baseline Good Management Practice Nitrogen Loss Rate, as estimated with a nutrient budgeting tool (usually OVERSEER®; Wheeler et al. 2011; www.overseer.co.nz; Overseer hereafter). Next, they need to know options that reduce N loss to meet their target, and decide which are appropriate for their farm. Finally, they must implement the chosen options successfully. This requires a strong commitment from the farmers. A strong industry effort is also essential, to make information available, to develop new practical and cost-effective options, and to help build suitable support for farmers.

Options to reduce N leaching

Two large research programmes are investigating options to reduce N leaching from agricultural farming systems: Pastoral 21 (P21) and Forages for Reduced Nitrate Leaching (FRNL). See https://www.dairynz.co.nz/publications/technical-series/technical-series-october-2014/ for summaries. P21 has conducted four dairy farmlet studies across New Zealand: Waikato, Manawatu, Canterbury and Otago (Shepherd et al. 2017). Regionally applicable farm systems were compared, one reflecting current practice and others that implemented practices predicted to reduce N leaching significantly: reduced fertiliser and supplement N input, reduced stocking rate, and standing cows off pasture from several hours per day to all day during wet conditions or in autumn/winter.

FRNL aims to find pasture plants and forage crops that reduce the surplus N intake of animals, reduce or alter urinary N excretion, and increase plant N uptake from the soil, e.g. through deeper rooting or cool season growth (Pinxterhuis et al. 2015). New Zealand's standard perennial ryegrass-white clover pastures contain more protein than grazing animals require, and the surplus N is excreted, mainly via urine. The urine patch, in turn, contains levels of N which are higher than pasture plants can take up. The remainder is at risk of draining below the root zone and ending up in ground and surface water.

While some novel options to reduce N leaching are not yet considered by Overseer (e.g. combinations of pasture species), key water and nutrient management principles confirmed in P21 farmlet trials and FRNL experiments are well researched and reflected in Overseer:

- Apply irrigation efficiently by monitoring soil moisture and taking account of the weather forecast and soil water holding capacity. This increases herbage production and plant N uptake, while managing the risk of N leaching, i.e. loss of water containing dissolved nutrients below the root zone
- Reduce N inputs by applying fertiliser and effluent only when plants are able to utilise the applied nutrients well (e.g. not during drought, high rainfall or low temperatures). This reduces the amount of N cycling in the farm system and the surplus N in the soil that is at risk of leaching
- Use supplements with relatively low N content. This reduces the animals' N intake and hence N excreted in urine
- Stand cows off pasture in wet or cold periods when pasture growth is low. This avoids depositing urine on the soil when risk of drainage is high or plant N uptake is less, and gives the opportunity to spread effluent on crop or pasture at times of the year when plants are growing and utilising the nutrients applied.

Commercial farms collaborating with research

FRNL includes a network of monitor farms in Canterbury: four dairy farms, two mixed livestock farms, two arable farms and one mixed arable-dairy farm. The farmers monitor their management in detail. Daily activities are recorded in a purpose-built spreadsheet and data are summarised to support management, e.g. a feed wedge to optimise pasture utilisation, and monthly reports of inputs and production to keep track of input efficiency. The monitor farmers work with researchers and consultants to develop nutrient budgets and farm system models for their farm, and to develop modelling scenarios which are tested for their potential to reduce N leaching and improve profitability. Ultimately, promising scenarios are tested in practice.

This paper reports on one modelling exercise where an FRNL dairy monitor farm in the Selwyn catchment was modelled with Overseer and Farmax (a physical and financial farm

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system model; www.farmax.co.nz). Scenarios to achieve the future N loss requirements were developed using the principles outlined above, and tested in the models for impact on N leaching, production and profitability.

Canlac Holdings – farm performance in 2015-2016 season

Canlac Holdings is located 5 km west of Dunsandel in the Selwyn catchment. Since 2013 the dairy farm has been operated by Tony Coltman and Dana Carver, 50:50 sharemilkers with an equity interest. Canlac Holdings is a top-performing business through maximising production and utilisation of pasture, effectively converting imported feed into milk and keeping a tight control of costs. The farm's vision is:

"To be a leader in the dairy industry in all areas by excelling with top 5% production, top 5% financial returns, and aesthetically well-presented farm, all environmental standards exceeded and happy, healthy staff".

The farm comprises a 348.5 ha milking platform (335 ha effective) and a 155 ha leased support block. The water quality regulation is the land owners' responsibility, so we will focus on the milking platform in this paper.

Most of the miking platform comprises a well-draining Lismore soil (Lism_1a.1; S-map https://smap.landcareresearch.co.nz) and 43 ha is a moderately well-draining Mayfield soil (Mayf_2a.1).

In 2013 some rotorainers were replaced by a second pivot, resulting in 82% of the farm being irrigated by two large pivots. The remainder is irrigated by two rotorainers (9% of the area) and sprinklers (the remaining 9% of the area). In 2013 the effluent irrigation area was increased from 21% to 41% of the milking platform (effective hectares).

In the 2015-2016 season, stocking rate was 4.2 cows per effective ha, milking 1390 cows at peak. Average liveweight per cow was 491 kg. Milk solids (MS) production was 502 kg MS/cow or 2,087 kg MS/ha. The spring-calving Friesian-cross herd had a BW of 141/47 and PW of 178/64.

The comparative stocking rate was 84 kg liveweight/t DM feed and the feed conversion efficiency was 85 g MS/kg DM. Pasture management was optimised for high production and utilisation. Weekly farm walks, the use of a feed wedge, a rotation length to maximise pasture growth and quality, timely irrigation and effective use of a relatively high level of N fertiliser increased pasture eaten from 15.7 t DM/ha in 2013-2014 to 18.5 t DM/ha in 2015-2016. In the 2015-2016 season a feed pad was built to optimise utilisation of purchased feeds, 3.0 t DM/ha supplements. External grazing supplied another 3.2 t DM/ha.

Total farm working expenses were $3.50/kg MS, including feed costs of $1.52. Due to the low milk price, more emphasis was put on increasing livestock income in the past two seasons. Beef bulls were used for late calvers, and this increased the return from calves from

$20-30 per bobby calf to $100-200 per four-day old dairy/beef cross calf. Also, the price for cull cows was higher in the last years. This resulted in an increase of livestock income from $0.34/kg MS in 2013-2014 to $0.55/kg MS in 2015-2016.

Modelling good management practice

Overseer (version 6.2.3) nutrient budgets were prepared for the 2009-2010 to 2015-2016 seasons. The first four years, i.e. 2009-2010 to 2012-2013, are considered the farm's nitrogen baseline (Environment Canterbury 2014). The average N leaching for these years was 76 kg N/ha/yr (Figure 1).

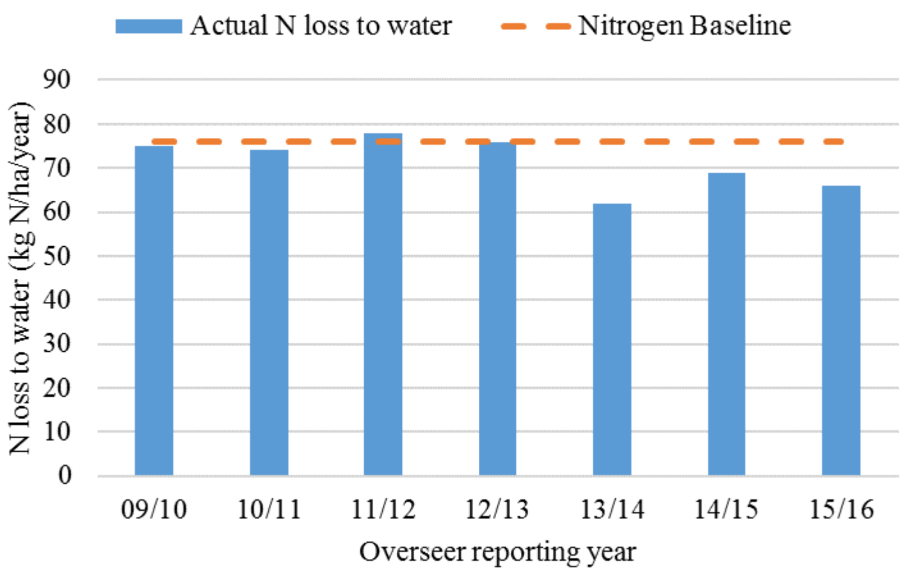

Figure 1. Overseer estimated N leaching for the milking platform of Canlac Holdings. Nitrogen baseline is the average of the 2009-2010 to 2012-2013 years.

Improvements in irrigation and enlargement of the effluent area in 2013 reduced N leaching to 62 kg N/ha. However, the N surplus increased due to intensification (more N fertiliser used and more supplements imported, and consequently more cows/ha), from an average of 157 kg N/ha/yr in the baseline period to 220 kg N/ha in 2015-2016. The N surplus is the amount of N input that is not converted to products. In this paper we use a simple

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calculation: [N in fertiliser and supplements] minus [N in products as milk, meat and crop sold off farm]. This surplus N is at risk of loss through leaching, ammonia volatilisation and gaseous loss, e.g. nitrous oxide, a potent greenhouse gas. It should be noted that Overseer's N surplus calculation includes an estimate of clover N fixation in pasture as input and will, therefore, be higher than our simplified calculation. We exclude N fixation because it is difficult to measure at farm scale and several assumptions need to be made to calculate this. Information on N input from fertiliser and supplements, however, is normally available for each farm.

The Selwyn/Te Waihora Zone sub-regional regulation requires farms to operate at or below their baseline N loss at GMP from 2017-2018. We translated GMP into modelling rules for Overseer:

- No N fertiliser applications in the months of May, June and July
- No more than 50 kg N/ha applied per month on pasture blocks
- No more than 400 kg N/ha applied per annum from fertiliser and effluent on pasture blocks
- Total N/ha applied on effluent block does not exceed the average N applied on non-effluent blocks
- Less water applied in shoulders of the season (September, October and March) than in summer (November to February). Overseer adjusts the amount of water applied to rainfall when irrigation scheduling is based on soil water budget or soil moisture sensors. But if a fixed depth and return rate is used, these should be altered in the shoulders of the season to avoid over-application of water
- Have less than three months fallow after cropping. If not, use a catch crop in between the main crops, e.g. an annual grass or (winter) cereal crop.

Applying these rules to the nitrogen baseline Overseer files reduced the average N loss from76 kg N/ha to 71 kg N/ha. The milking platform is currently operating below this baseline GMP N loss (Figure 1).

Farm system and management changes to reduce N leaching

From 2022, milking platforms need to be operated at 30% below their GMP baseline. This means Canlac has to reduce N loss to 50 kg N/ha for the milking platform.

Two scenarios were modelled:

1. Reduce the number of cows in autumn by culling 90% of the non-pregnant cows and cull cows early (1 April)
2. Reduce the overall number of cows by 50 and maintain the current culling strategy.

Both scenarios reduced N fertiliser use from 290 kg N/ha to 215 kg N/ha on average (235 kg N/ha on the non-effluent areas and 205 kg N/ha on the effluent areas) and reduced the amount of N fertiliser in April. Through re-nozzling, water application by the rotorainers was reduced from 35 to 30mm every 6 days (5 mm/day) and a bucket test carried out to confirm this target. The amount of imported N in feed was reduced by buying maize silage and using some fodder beet on the feed-pad instead of some of the pasture silage and PKE. The proportion of low-N imported feed was increased from 8% to 52%. In all cases a feed pad was in use.

Table 1 summarises the modelling results. The scenario with early culling achieved an N loss below the target of 50 kg N/ha. The scenario with reduced stock numbers by 50 cows throughout the year did not. This illustrates that Overseer responds strongly to cow numbers and feed eaten in autumn, reflecting the relatively high risk of N leaching from urine patches deposited in autumn, when plant growth and associated N uptake is slowing down and risk of drainage is increasing in the months ahead.

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Table 1. Summary of results of modelling scenarios to reduce N leaching for Canlac. Current = modelled current system (2015-2016); Scenario 1 = early cull; Scenario 2 = 50 fewer cows at peak. See text for full explanation of scenarios.

Physical Indicators	**Current**	**Scenario 1**	**Scenario 2**
Dairy farm total area (ha)	346	346	346
Effective area (ha)	335	335	335
Cows wintered	1,484	1,474	1,432
Peak cows milked	1,410	1,400	1,360
Stocking rate (cows/ha)	4.21	4.18	4.06
Production (kg MS)	698,031	671,083	671,455
– per hectare (kg MS/ha)	2,084	2,003	2,004
– per cow (kg MS/cow)	495	479	494
Pasture Eaten (t DM/ha)	18.5	18.0	18.0
N Fertiliser applied (kg N/ha)	290	215	215
Purchased feed (t DM)	1,032	976	898
Grass silage	148	0	0
Maize silage	41	532	401
PKE	801	381	442
Fodder beet bulb	42	63	55
– per hectare (t DM/ha)	3.1	2.9	2.7
– per cow (t DM/cow)	0.7	0.7	0.7
Winter crop (t DM/ha)	3.2	3.2	3.1
Financial Indicators			
Total income ($)	4,600,051	4,435,479	4,425,725
Total operating expenses	2,731,438	2,668,188	2,654,003
– $/kg MS	3.91	3.98	3.95
Total operating profit	1,868,613	1,767,291	1,771,722
– $/ha	5,578	5,275	5,289
Change in profit ($)		-101,322	-96,890
Environmental Indicators			
Total N leached (kg N/yr)	21,076	16,995	18,368
N leached (kg N/ha/yr)	61	49	53
N surplus (kg N/ha/yr)[1]	215	126	122
N conversion efficiency (%)[1]	39	52	53
kg MS/kg N surplus	9.7	15.9	16.4
Operating profit $/kg N surplus	25.94	41.87	43.35

[1] Excludes N fixation as input; see text for explanation.

Both Scenario 1 and Scenario 2 reduced farm profit by 5% from Current, using a milk price of $6.00. This was due to 4% lower milk production from less pasture eaten (due to less N fertiliser applied), less PKE, and a 1-2% increase in costs (mostly feed).

Nitrogen efficiency parameters for the scenarios reflected the reduced amount of N brought onto the farm: the N surplus was reduced by 11-13% and the N conversion efficiency was improved by 3%.

Eco-efficiency is a measure of how much is produced per unit of environmental impact, e.g. kg MS produced per kg N surplus. Eco-efficiency can also be monetary, e.g. operating profit $ per kg surplus. Both measures were improved considerably in the scenarios: kg MS/kg N surplus increased by 64-69% and operating profit $/kg N surplus increased by 61-67%.

Benchmarking environmental performance

Actual and modelled N leaching for the current Canlac system are similar to the 64 kg N/ha estimated average for Canterbury dairy milking platforms (DCANZ and DairyNZ 2017). However, N leaching varies widely in Canterbury due to differences in soil type and climate. Therefore, to assess nutrient management it is more useful to compare N surplus and N conversion efficiency (NCE) with relevant published data.

For the Matrix of Good Management project in Canterbury, a large dairy dataset derived from Ravensdown's 2013/14 nutrient budgets was used. The average N surplus (excluding N fixation) for this dataset was 146 kg N/ha and NCE was 48% (Pinxterhuis et al. 2015b). The relatively high input Canlac system resulted in a higher N surplus and lower NCE than the averages of this dataset. The two scenarios resulted in better N surplus and NCE than the averages of the dataset.

Table 2 provides the key environmental results of two dairy systems implemented in the Pastoral 21 farmlet study in Canterbury (Chapman et al. 2017). These systems can be considered very well-managed with maximum pasture production and utilisation, and efficient use of fertiliser and supplements. The stocking rate, MS production/ha, fertiliser use and supplement imported ('intensity') of Canlac's current system was closer to the P21 Higher-Input system than the Lower-Input system. The N surplus was lower and the NCE higher than the P21 Higher-Input system; N leaching was higher for Canlac due to the more freely draining soil type than the Templeton sandy loam of the P21 farmlets.

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The two scenarios for Canlac show a significant improvement in N surplus, NCE and eco-efficiency (kg MS or operating profit per kg N surplus), but they do not achieve the efficiency of the P21 Lower-Input system. The P21 Lower-Input system operated at a considerably lower N input than Canlac's current and potential systems and the P21 Higher-Input system, resulting in a much lower N surplus and higher NCE, higher eco-efficiency and lower N leaching. While profitability of the P21 Lower-Input system was still high, production at the farm level was lower. However, at catchment or regional level, production may not be reduced if the high input systems source their supplements locally and all hectares are counted, i.e. including the hectares where the supplements and replacement stock are grown and non-lactating cows are wintered (Chapman et al. 2017).

Table 2. N surplus and NCE (excluding N fixation) from well-managed dairy milking platforms of Canterbury Pastoral 21 farmlets (calculated from data in Chapman et al. 2017). Lower-Input = 3.5 cows/ha, 509 kg MS/cow and 1,782 kg MS/ha, 154 kg N fertiliser/ha, 70 kg DM cereal grain/cow and $4,302 operating profit/ha[1]; Higher-Input = 5.0 cows/ha, 476 kg MS/cow and 2,378 kg MS/ha, 309 kg N fertiliser/ha, 680 kg cereal grain/cow and $4,205 operating profit/ha[1].

	Lower-Input	Higher-Input
N leaching (kg N/ha)	32	46
N surplus (kg N/ha) [1]	57	286
N conversion efficiency (%) [1]	68	36
kg MS/kg N surplus	31.3	8.3
Operating profit $/kg N surplus [2]	75.47	14.70

[1] Excludes N fixation as input; see text for explanation.

[2] Operating profit was calculated with a milk price of $6.10/kg MS.

Conclusion

The scenario modelling showed that a high-performing dairy farm such as Canlac Holdings has options available to reduce N leaching to the limits set in the catchment's regulations, i.e. a reduction of 30% from its baseline at good management practice. Major investments by Canlac, in the irrigation system and a feed pad, have already reduced N leaching and improved N efficiency since the baseline years, and, therefore, already contributed to achieving the 30% reduction. Nonetheless, a high profit was still achieved.

The Canterbury Pastoral 21 farmlet study showed that further reductions in N leaching are possible by reducing N inputs and N surplus even further.

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References

Canterbury Matrix of Good Management Project 2015. Industry-agreed Good Management Practices relating to water quality. Version 2, 18 September 2015. 24 pp. http://files.ecan.govt.nz/public/pc5/MGM_Technical_Reports/Industry_Agreed_Good_Management_Practices_MGM_2015.pdf

Chapman D F, Edwards G, Dalley D, Cameron K, Di H, Bryant R, Romera A, Clement A, Malcolm B and Curtis J. 2017. Nitrogen leaching, productivity and profit of irrigated dairy systems using either low or high inputs of fertiliser and feed: The Pastoral 21 experience in Canterbury. In: Science and policy: nutrient management challenges for the next generation. (Eds. L. D. Currie and M. J. Hedley). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 30. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 12 pages.

DCANZ and DairyNZ. 2017. Sustainable Dairying: Water Accord. Three years on… Progress report for the 2015/16 season. 40 pages. https://www.dairynz.co.nz/media/5787310/water_accord_summary_3-years_on_web_v2.pdf

Edwards G R, de Ruiter J M, Dalley D E, Pinxterhuis J B, Cameron K C, Bryant R H, Di H J, Malcolm B J and Chapman D F. 2014. Urinary nitrogen concentration of cows grazing fodder beet, kale and kale-oat forage systems in winter. Proceeding of the 6th Australasian Dairy Science Symposium, 144-147. http://www.adssymposium.com.au/inewsfiles/2014proceedings/21EdwardsADSS2014.pdf

Environment Canterbury. 2014. Proposed Variation 1 to the Proposed Canterbury Land and Water Regional Plan, 68pp. Environment Canterbury, Christchurch.

Notes:

Ministry for Environment. 2014. National Policy Statement for Freshwater management 2014. Ministry for the Environment, Wellington. http://www.mfe.govt.nz/fresh-water/freshwater-management-nps.

Pinxterhuis J B, Beare M and Edwards G. 2014. Forage systems to reduce nitrate leaching. DairyNZ Technical Series 24: 12-13. https://www.dairynz.co.nz/publications/technical-series/technical-series-october-2014/

Pinxterhuis, J B, Beare M H, Edwards G R, Collins R P, Dillon P and Oenema J. 2015a. Eco-efficient pasture based dairy farm systems: a comparison of New Zealand, The Netherlands and Ireland. Grasslands Science in Europe 20: 349-366. http://www.europeangrassland.org/printed-matter/proceedings.html

Pinxterhuis I., Kuhn-Sherlock B and Dennis S. 2015b. Matrix of Good Management: Estimating nutrient loss of Canterbury Dairy farm systems operating at Good Management Practice. DairyNZ Report, Lincoln, Canterbury New Zealand. 191 pp. http://previous.ecan.govt.nz/publications/General/MGM_Dairy_Technical_report_final.pdf

Shepherd M, Hedley M, Macdonald K, Chapman D, Monaghan R, Dalley D, Cosgrove G, Houlbrooke D and Beukes P. 2017. A summary of key messages arising from the Pastoral 21 Research Programme. In: Science and policy: nutrient management challenges for the next generation. (Eds. L. D. Currie and M. J. Hedley). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 30. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 10 pages.

Wheeler D, Cichota R, Snow V and Shepherd M. 2011. A revised leaching model for OVERSEER® nutrient budgets. In: Adding to the knowledge base for the nutrient manager. (Eds. L.D. Currie and C L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 24. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 6 pages.