

Estimating nitrate- nitrogen leaching rates under rural land uses in Canterbury

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Linda Lilburne
Trevor Webb
Raymond Ford
Vince Bidwell

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58 Kilmore Street
PO Box 345
Christchurch 8140
Phone (03) 365 3828
Fax (03) 365 3194

75 Church Street
PO Box 550
Timaru 7940
Phone (03) 687 7800
Fax (03) 687 7808

Website: www.ecan.govt.nz
Customer Services Phone 0800 324 636

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1 Introduction

Over the last two decades, agricultural production in the region has grown as a result of the increasing use of inputs, such as fertilisers, supplementary feeds and irrigation water, accompanied by the conversion of plantation forests and areas of extensive sheep and beef grazing into dairy farms.

At the same time, there is increasing evidence that Canterbury's freshwater resources are becoming degraded as a result of increasing inputs of nutrients, bacteria and sediment from these changing land uses (ECan 2008). If these land use changes continue under current management practices, modelling studies suggest that nitrate-N concentrations in shallow groundwater are likely to continue increasing in the future (Di & Cameron 2002; Bidwell *et al.* 2009). Faced with this pressure on the region's water resources, Environment Canterbury is reviewing its approach to managing the cumulative effects of land use, especially diffuse nutrient inputs, on water quality.

Initially, Environment Canterbury undertook a preliminary study to examine the effects of agricultural land uses on water quality between the Rakaia and Waimakariri rivers (Di & Cameron 2004). More recently, the Canterbury Mayoral Forum (2009) commissioned modelling at a regional scale to assess the potential changes to water quality as a result of concern over the consequences of intensifying agricultural land uses in the region (Bidwell *et al.* 2009).

The Proposed Natural Resources Regional Plan set measurable water quality objectives for surface waters and groundwaters addresses point source discharges and sets limits for nutrient losses from irrigated properties in inland areas of Canterbury. However, the plan did not include provisions to adequately address the cumulative effects of nutrient loads from intensifying land uses and multiple point-source discharges.

To remedy this problem, Bidwell (2008 & 2009) proposed an allocation approach, based on a "first in first served" basis to address the effects of nitrate-N discharges on shallow groundwater in relation to drinking water quality. A consent application to use water for irrigation would be assessed against existing land uses within a predetermined distance from the property where the proposed activity was going to take place. The discharge of nitrate-N from the proposed activity would be assessed in combination with the estimated nitrate-N leaching from land uses within the "area of interest."

The proposed approach required:

- A Geographical Information System (GIS) map of the principal land uses in the region (Hill *et al.* 2010).
- A long-term average nitrate-N leaching rate for each of the land uses under different soil types and rainfall zones in the region. The leaching rates would be attached to the GIS layer as a "lookup table".

Because of concern over the suitability of using the nitrate-N values for assessing resource consent applications, no further work was done to develop this tool (see Section 2).

Information on land uses and nitrate-N leaching rates was also required to model the cumulative effects of nitrate-N discharges from land uses on deeper ground water and spring-fed surface waters. An early version of the GIS land use map and nitrate-N discharge rates were used to model, at a regional scale, the potential changes to water quality of changing agricultural land uses for the Canterbury Water Management Strategy (Bidwell *et al.* 2009). Environment Canterbury will also use information in this report, as part of a case study, to model the effects of changing land uses on water quality in the middle and upper reaches of the Hurunui catchment, North Canterbury.

Environment Canterbury staff, with assistance from Landcare Research, began work on developing a regional GIS land use map, using data derived from the AgriBase™ data set, supplemented by information from the Land Cover Data Base2 (LCDB2), topographical maps, satellite imagery, and the Environment Canterbury consent database (Hill *et al.* 2010, Pairman & North 2010). Field work was carried out in the Culverden Basin to verify that the mapping data is of acceptable accuracy.

This report summarises the contributing work and the approach used to develop a set of nitrate-N leaching rates for a range of land uses in Canterbury, henceforth referred to in this report as the "lookup table".

2 Project history

At the outset, it was recognised that the key New Zealand researchers working on nitrate leaching and modelling would need to be brought together to pool their knowledge and to reach a consensus on nitrate-N leaching values. Environment Canterbury would use this information on the basis that these values represent the best scientific information that was available at the time.

It was not possible to derive the lookup table from measured values. The available and relevant experimental data is summarised in Webb (2009). There are only a very small number of long-term experimental studies of nitrate leaching, and these cover only one or two soil types and rainfall zones. Accurate measurements of leaching are also difficult to obtain (Webb 2009, Weihermuller *et al.* 2007). Modelling of nitrate-N leaching under various land uses is the only practical way of deriving a comprehensive lookup table suitable for the variety of conditions found on the alluvial plains of Canterbury. The experimental studies do, however, provide useful data for calibrating leaching models, which can be used to simulate leaching on a range of soil types and rainfall zones under various land management practices.

A series of workshops were held to define the modelling parameters, present and review the results, and to resolve inconsistencies in the modelling results.

2.1 Workshop 1 (May 2008)

The first science workshop was held at Environment Canterbury to discuss what were appropriate land use categories and values for long-term nitrate-N-nitrogen leaching rates for different land uses in the region. Participants (see Appendix 2) consisted of Environment Canterbury staff, and scientists with interest in nitrate leaching. The workshop concluded that existing information on nitrate-N leaching across a range of farm systems, climate and soil types was inadequate, and that modelling was required to develop a comprehensive and robust set of values. The parameters for this modelling were defined. This work would represent the “best science” available at the time, and would be updated as research became available and/or new models were developed. A follow-up workshop would be held to discuss the results.

HortResearch, Crop & Food Research and AgResearch were contracted by Environment Canterbury to model leaching under lifestyle blocks, turf grass – golf courses, outdoor pigs (Green & Clothier 2009); arable farming (Brown & Zyskowski 2009) and pastoral farming (Snow *et al.* 2008) respectively. An estimate of nitrate-N leaching under forestry in Canterbury was provided by Davis and Watt (2008). Table 2.1 summarises the principal features of the models.

Table 2.1: Description of the models used to estimate nitrate-N leaching

Model	Agency	Availability	Type	Scale		Inputs & processing	Outputs
Overseer [®] v5.2	AgResearch	Freely available	Empirical	Farm/ Farm Block	?	Inputs derived from farm systems. Internal databases & empirical relationships	Nutrient budget No drainage data
SPASMO	HortResearch now – Plant & Food)	Research model	Process	Paddock	Daily time step	Algorithms simulate physical & chemical processes	Nutrients and drainage
LUCI	Crop & Food Research now – Plant & Food)	Research model	Process	Paddock	Daily time step		Nutrients and drainage
SWatBal	SCION	Research model	Process	100 m cell	Daily time step	National scale climate and soil data	Drainage

To ensure a consistent set of inputs for the modelling, the Canterbury region was divided into four coastal rainfall zones (650mm/yr, 750mm/yr, 850mm/yr and 950mm/yr) and two inland rainfall zones (550mm/yr, 900mm/yr). The region's soils were grouped into seven categories, according to their profile available water storage and drainage characteristics, and the soil properties were summarised for each category (Webb 2008). The soil properties were subsequently amended as a result of further field work (Webb 2009, Appendix 3).

2.2 Workshop 2 (16 October 2008)

A follow up workshop with most of the participants from workshop 1 and representatives from the arable and dairy industry was held in mid October at Environment Canterbury to peer review and assess confidence in the results of the modelling (Brown & Zyskowski 2009; Green & Clothier 2008, Snow, *et al.* 2008). A number of issues were identified with the results, including discrepancies resulting from the use of different models (Webb & Lilburne 2008), the data sets used by the modellers, and the need to provide values for both standard and best land management practices so as to define a range of leaching rates.

In response to the matters raised at Workshop 2, Landcare Research and Lincoln Ventures critically reviewed the modelling results, and recommended that the SPASMO model be used to estimate nitrate-N leaching from pastoral farming (Bidwell & Webb 2009). Consequently, a contract was let to Plant & Food Research to model nitrate-N leaching from pastoral farm systems and to include the rainfall zones and soil types that had been omitted from the earlier work (Green & Clothier 2009). The arable modelling was also rerun to fix some internal errors and to cover the 950mm rainfall zone (Brown & Zyskowski 2009).

Landcare Research was asked to expand on their initial review (Bidwell & Webb 2009), and to critically review all the modelling work that had been carried out to date prior to the third science Workshop (Webb 2009).

2.3 Workshop 3 (5 November 2009)

A further workshop was held to discuss different results from the various models and to see if agreement could be reached on a set of nitrate-N discharge values.

Some outstanding issues were identified, including the different responses of the models to soil, climate and management, the use of different assumptions to define 'best' and typical management practices, and use of a single value to represent nitrate-N leaching rates (as opposed to a range). The primary sector expressed concern at the criticism of Overseer®, as various industry bodies have committed to supporting the future development of the model. It was agreed at the workshop that Environment Canterbury would work with primary sector representatives to finalise a set of nitrate-N leaching values.

2.4 Caucus meeting (9 February 2010)

Following the third science Workshop, a caucus meeting, facilitated by Bruce Thorrold, DairyNZ was held with Environment Canterbury staff, scientists, modellers and industry representatives to try and reach an agreement on a set of nitrate-N leaching values that could be used to complete the pastoral parts of the 'look-up table'. The approach taken was to use all available data, expert opinion, and modelling trends in a technical discussion aimed at consensus. It was agreed that the data from the Lincoln University Dairy Farm (LUDF) (unavailable before this date) fitted well with expert opinion based on past research, and these results were used as the starting point for assessing the modelling results. These results were extrapolated to dairy farms with higher and lower stocking rates on different soils and rainfall zones. These results were then extrapolated to sheep and beef systems by making some simple assumptions about the relative rates of nitrate-N leaching (Table 3.1).

At the meeting, there was insufficient time to complete the table or to do some internal consistency checking. Following the meeting, a smaller group of scientists¹ filled in some of the gaps and tidied up some inconsistencies. This involved obtaining and analysing additional leaching and drainage

¹ From LVL, Landcare Research & Ravensdown

information from the LUDF and ECan respectively. The main additions and changes done by this smaller group were to specify all the dryland drainage values (using Environment Canterbury's lysimeter data as a starting point), simplify the relationship between soil type (i.e. drainage) and nitrate-N leached (see section 3), add the relative ratios for 3 cows/ha and pigs, add border dyke irrigation, and finally add rates for high country leaching.

The key leaching rate assumptions relative to the LUDF data (4 cows/ha, winter-off) are as follows: increasing the stocking rate to 5 cows/ha increases the nitrate-N leaching rate (concentration & load) by 15%, reducing stocking rates to 3 cows/ha reduces the leaching rate by 25%. Wintering-on of dairy cows increases nitrate-N leaching rate by 25%. Beef are assumed to be the equivalent of 3 dairy cows/ha. Pigs are assumed to leach the same as 4 cows/ha, winter-off. Sheep are assumed to leach 50% less (than 4 cows/ha, winter-off)². Deer are assumed to leach 20% more than sheep. The stocking rate of the dryland land is assumed to be half that of the equivalent irrigated land.

In September the revised table and report was sent to the meeting participants for their comments and final agreement.

3 Final set of nitrate-N leaching values for the "look-up table"

The final results are based on the key assumptions and rules which were agreed at the February Caucus meeting (see previous section), in particular the relative leaching ratios between different land uses and climate zones. These relative rates are based on expert knowledge and modelling trends. Measured data and modelled trends were used to set the drainage under dry and irrigated conditions for the three main climate zones (coastal 650, 750 and 850 mm/yr). These drainage values were used for all the pastoral land use types.

3.1.1 Nitrate-N load for non-pastoral land uses

The results from the LUCI and Spasmo modelling were used for the non-pastoral land uses (i.e., arable, lifestyle blocks, berry and pip fruit, grapes) (Brown & Zyskowski 2009; Green & Clothier 2009). Golf values were taken from Green & Clothier (2008) since these were not listed in the Green & Clothier (2009) report. The best management arable values were used rather than the standard management values, since they will be compared with the pastoral values derived from the Lincoln University dairy farm which is considered to have best management. The SCION SWatbal results were used for exotic and native forestry, since forests drain less annual water compared to pasture because of foliage intercept of rainfall and plant uptake from their larger root area (Davis & Watt 2008). Denitrification is estimated to reduce the leachate by 50% on poorly drained soils (see Appendix 4).

3.1.2 Nitrate-N load for pastoral land uses

After a more detailed review of the literature, and results from the Lincoln University dairy farm, it was concluded that leaching under the same stocking rate for dairy farms can be modelled with a constant nitrate-N concentration, irrespective of drainage volume within the modelled range of drainage. This conclusion is based on

- i) Bidwell *et al.* (2003) who reviewed leaching data for a number of land uses and estimated nitrate-N concentration to increase with stocking rate and to have an annual average nitrate-N concentration of 13.9 mg N/L at 4 cows per hectare,
- ii) Di *et al.* (2005) who also reviewed leaching data for a range of land uses in Canterbury and estimated that 'Dairy grassland' has an average annual nitrate-N concentration of 13 mg N/L,
- iii) Analysis of the data from the Lincoln University Dairy Farm (a highly efficient farming enterprise) for 4 cows/ha winter off, showing that the best mathematical relationship

² Stu Ledgard's Taupo data compared sheep & cattle and about 50% - 60% difference in the leaching ratio. Overseer results are 60% less. – Betteridge *et al.* (2005) Monaghan *et al.* (2010)

between nitrate leached (kg N/ha) and amount of drainage (mm) collected in the lysimeters was a straight line. This dataset is the best available information on leaching under dairy farming in Canterbury and represents 7 years of lysimeter leaching data collected from a moderately deep and a stony soil under field conditions. Annual drainage varied from 50 to 600 mm/y (depending on winter rainfall). Values exclude any reductions due to an eco-n effect. The drainage-weighted average nitrate concentration from all the data is 12.5 mg N/L.

These results mean that the nitrate concentration in drainage from pastoral land use is assumed to be constant for all values of drainage, and that this constant value is 12.5 mg N/L for the base case of the best practice dairy farms with 4 cows/ha winter off). These nitrate-N load values then formed the 'base' data, from which nitrate-N loads for all the other land uses were then derived according to the assumptions from the Caucus Workshop (Table 3.1).

Table 3.1: Derivation of the nitrate-N leached values for different farm types

Land use/management	Relative ratio	Assumptions
Base = nitrate-N load (mass) of 4 cows/ha winter off		From Lincoln University Dairy Farm data and expected concentration trend
3 cows/ha winter off	75% of base	25% less leaching than 4 cows/ha winter off
3 cows/ha winter on	= base	25% less leaching than 4 cows/ha but with winter on approx = base
4 cows/ha winter on	= base + 25%	The winter on practice adds 25%
5 cows/ha winter off ³	= base + 15%	The additional stock adds 15%
Beef 100% (irrigated)	= base	Same as 3 dairy cows/ha winter on
Sheep 100% (irrigated)	50% of base	Half the leaching of 4 cows/ha winter off
Deer 100% (irrigated)	60% of base	Sheep + 20%
Dairy Support (irrigated)	= base + 25%	Stock is there only part of the year but are concentrated in a smaller area. Add 25%
Dairy support (dryland)	= base + 25%	Same as irrigated as it involves winter grazing
Pigs (dryland)	= base	Report by LEL (2001) equates an annual nitrogen load limit of 150 kg/ha (pig) to 200 kg/ha (dairy) in terms of permitted activity rules so this leads to pigs = base + 33% The Pork industry argues that pigs should have the same leaching threshold as cows in the regional rules. So it is assumed that pigs = base
Arable		LUCI modelling results (med values, best management practice) Brown & Zyskowski (2009)
Vegetables		Horticulture NZ are commissioning further modelling (C Keenan pers comm.) .
Fruit trees, Lifestyle & Golf		SPASMO modelling results for best management practice (Green & Clothier 2009)
Exotic and native forestry		SWatBal modelling results (Davis & Watts 2008)

³ Assumed that at 5 cows/ha, farms have to winter-off their cows.

Nitrate-N losses from farms with mixed proportions of sheep and beef are calculated as weighted averages based on the stock units specified in Hill *et al.* (2009) and sourced from MAF⁴. For example, in a 20% beef, 80% sheep operation, 20% of the head count is beef but they require 56.8% of the land so the nitrate-N load is calculated as $0.568 \times \text{beef mass NO}_3 \text{ load} + 0.432 \times \text{sheep mass NO}_3 \text{ load}$.

All dryland nitrate-N concentrations were assumed to be half that of the equivalent irrigated land use (assumes half the number of stock can be supported or half the amount of production). Nitrate-N losses under border dyke irrigation for the various land uses were assumed to follow the same ratios as described in Table 3.1 (irrigated), but estimated mass of N leached is higher due to the increased drainage.

The extrapolation approach used means that some of the more extreme values should be treated with caution. For example, a border dyke 4 cows/ha winter on system on a XL soil, if it exists or is used in a scenario, may need to also take into account other activities such as feed lot effluent capture.

3.1.3 Drainage for pastoral land uses

The irrigated drainage estimates came from the Caucus meeting and were a blend of modelling results and some LUDF data. Soil types are based on Webb (2009, Appendix 3). No limitations were placed on water availability. Dryland values came from an analysis of non-irrigated lysimeters located on four soil types run by Environment Canterbury, and expected trends between climate areas based on the LUCI and Spasmo modelling results. The Environment Canterbury lysimeter data could only be used to set the Lincoln drainage under VL and M soils. The lysimeter dataset was difficult to use as the drainage values are very variable over the ten or so years depending on the timing of the rainfall, and because of gaps and inconsistencies in the data. Modelling results are the only practical way to get estimates of long term average drainage for a range of soils. In this case, dryland drainage under other soils was extrapolated according to relative differences found in modelling results. Border dyke irrigation was interpolated from IRRICALC modelling results by Aqualinc (2008) where a 14-18 day return irrigation period was assumed.

Table 3.2: Estimated long term annual average drainage (in mm)

Climate	Soil type	Irrigated drainage	Dryland drainage	Border dyke
Lincoln (650mm)	XL	400 ⁵	160	1060
	VL	325	140 ⁶	690
	L	250	120 ⁷	610
	M	150	80 ⁸	610
	H	150	80	610
Darfield (750mm)	XL	450	180 ⁹	1150
	VL	350	160	760
	L	255	140	670
	M	180	100	660
	H	180	100	660
Hororata (850mm)	XL	500	200 ¹⁰	1200
	VL	375	180	820
	L	260	160	740
	M	210	120	710
	H	210	120	710

⁴ <http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/best-management-practices/reassessment-of-the-stock-management-system/re-assessment-of-stock-unit-system08.htm>

3.2 Derivation of nitrate-N leaching values for high country soils in Hurunui Catchment

Leaching of nitrate-nitrogen for the hill and steep-land soils in the Hurunui Catchment is based on the relationship between Land Use Capability classes and nitrate-N leaching (Table 2 in Carran *et al.* 2007). Stocking rates (SU) for the Land Use Capability classes are based on Fletcher *et al.* (1987). A relationship of $SU \times 1.2 = \text{kg N leached/ha/yr}$ was found by combining information from Carran *et al.* (2007) and Fletcher (1987). This relationship was then applied to the stocking rate derived from Agribase™ to estimate annual nitrate-N leaching for land areas in the Hurunui Catchment. The stocking rate per ha was calculated using the number of beef, sheep and deer, each multiplied by the relative stock units given in Hill *et al.* (2010).

3.3 Summary of pastoral lookup values

Figure 3-1 shows the drainage rates under irrigated and dryland conditions in the different areas and on the various soils.

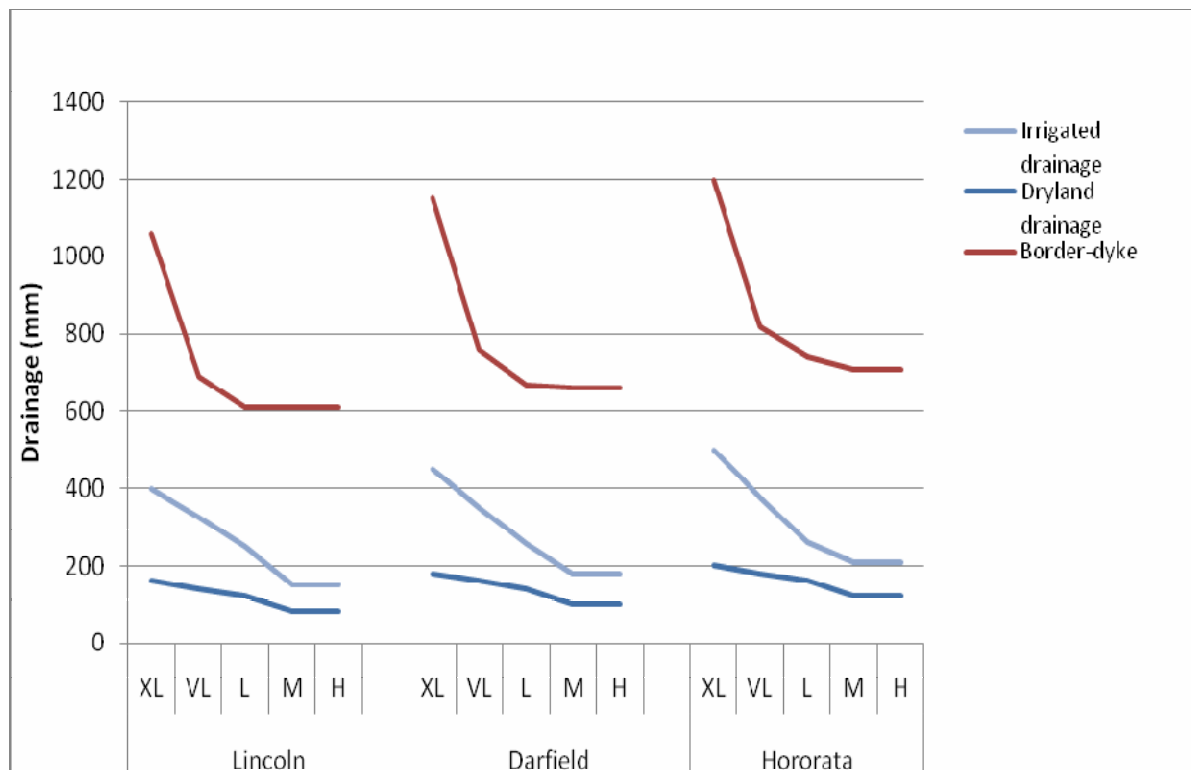


Figure 3-1: Drainage under irrigation (spray and border dyke) and dryland

⁵ All irrigated drainages estimates are from the caucus workshop

⁶ From ECan lysimeter data

⁷ Half way between SPASMO and Overseer® estimates

⁸ From ECan lysimeter data

⁹ Lincoln values + 20mm

¹⁰ Lincoln values + 40 mm

The following graph (Figure 3-2) show the nitrate-N mass and concentration lookup values by soil type and climate zone. 3 cows/ha winter on and 100% irrigated beef are not shown as they are the same as the base 4 cows/ha winter off land use. Figure 3-3 shows the nitrate-N mass leached under irrigated landuses including border dyke (concentration is not shown as it is the same under border dyke as it is under spray irrigation).

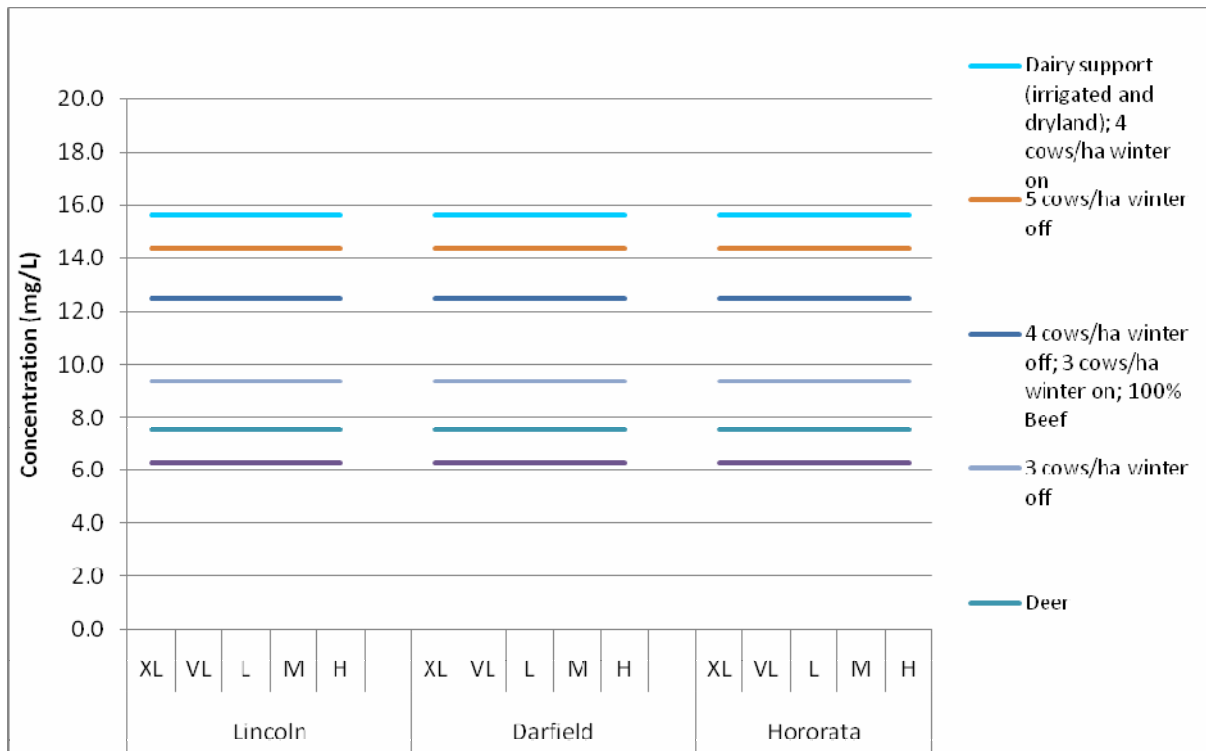
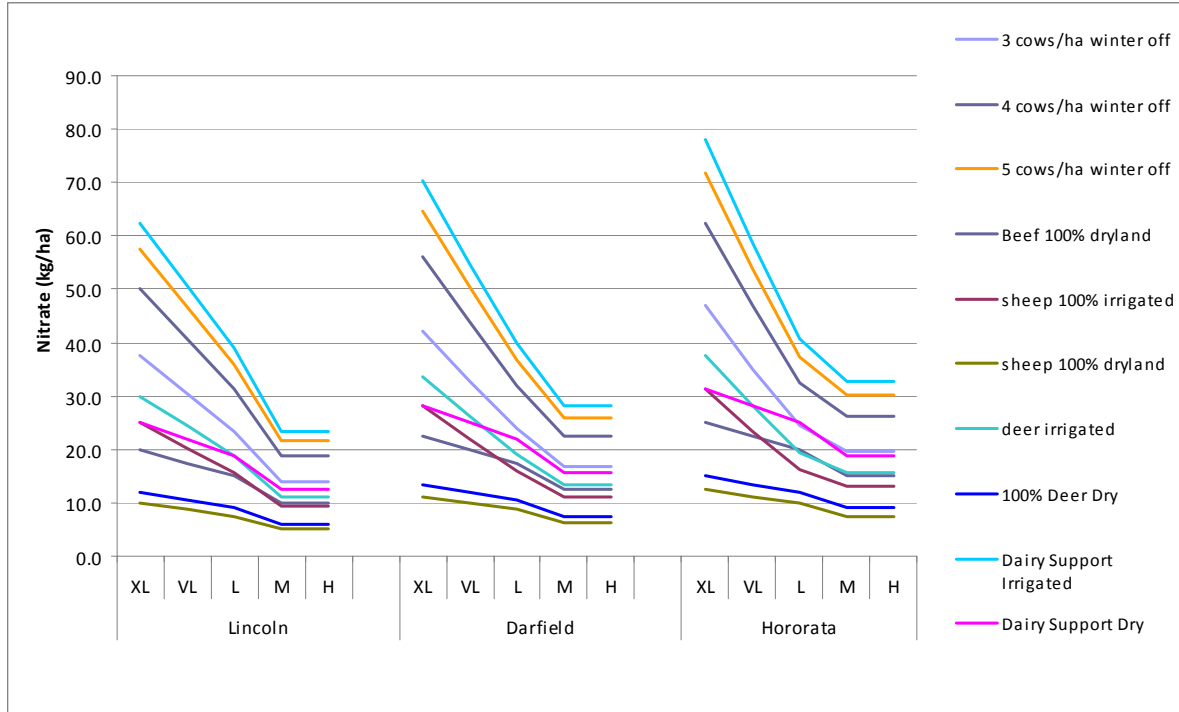


Figure 3-2: Graphs of nitrate-N concentration and nitrate-N mass leached according to soil and rainfall

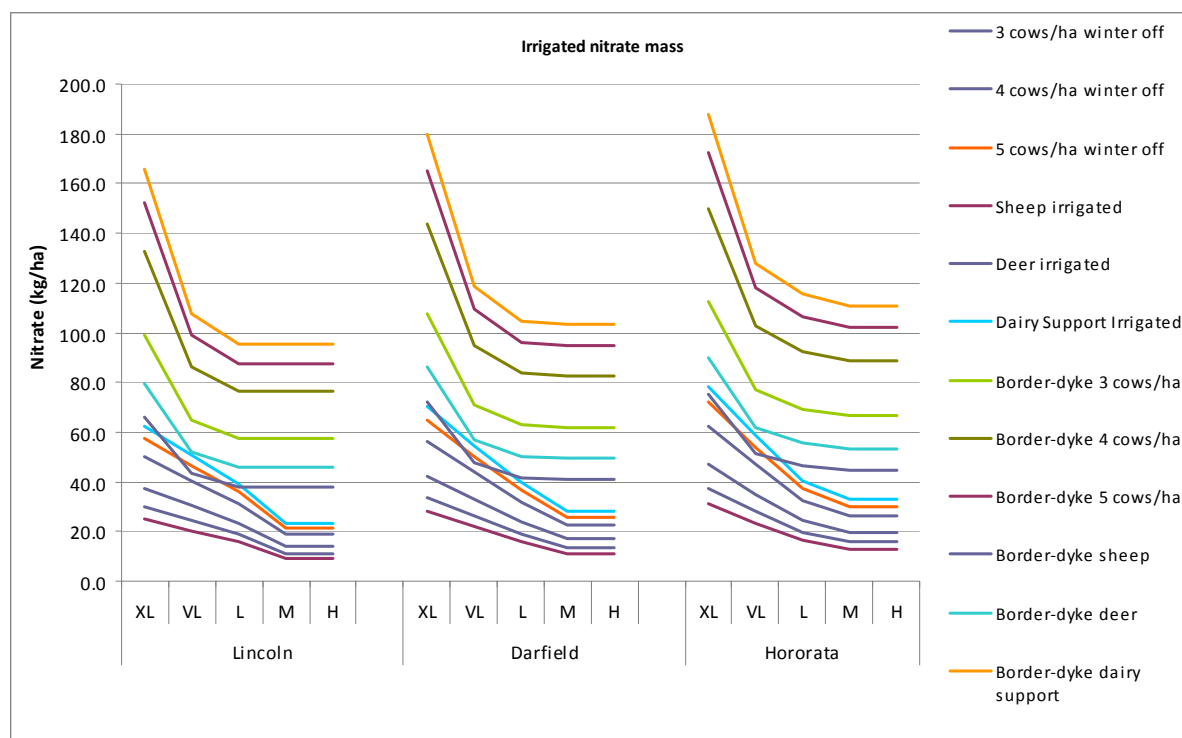


Figure 3-3: Mass nitrate-N leached under the irrigated land uses

4 Conclusions

There are many difficult issues in estimating nitrate-N leaching rates for the main land uses on different soils and rainfall zones, including the rarity of good long term measured data, which means that models cannot be reliability calibrated for Canterbury conditions. An expert approach was used to extend the Lincoln University Dairy Farm data to a range of soils, climates and other land uses. More data on both drainage and nitrate-N leaching rates is required, particularly on the shallow and stony soils. This will contribute to improvements in models such as Overseer® and Spasmo.

In the meantime, the values in this report are a reasonable starting point to gain an understanding of the regional implications of land use in relation to nitrate-N leaching. An important point that was raised and agreed by participants at the Caucus Workshop was that while these values are suitable for exploration of regional or large catchment scale land use scenarios and for screening the effects of proposed changes in land uses, they are not suitable for use at the farm scale (e.g in a consent process) as these values are simple long term annual estimates that do not take into account the many management practices that can minimise or add to the actual leaching. Also the extrapolation does not take into account the feasibility of some of the soil/climate/land use combinations.

5 Acknowledgements

The authors would like to acknowledge the useful reviews on this report by Shirley Hayward, Dairy NZ and Alistair Metherell, Ravensdown. Keith Cameron and Hong Di, Lincoln University are thanked for the use of their data. We would also like to thank Bruce Thorrold, Dairy NZ for his able leadership of the February caucus meeting, and all of the scientists and industry representatives for their input into the workshops and this report.

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Appendix 1: Final Table of leaching values

Table A.1 Look-up values for pastoral land uses

Farm type	Irrigation	Climate	Soil	Drainage mm/yr	Calc. conc. mg N/L	Trend mass kg N/ha/yr	Border dyke				
							Drainage mm/yr	Conc. mg N/L	Mass kg N/ha/yr		
3 cows/ha winter off	Irrigated	Lincoln	XL	400	9.4	37.5	1060.0	9.4	99.4		
			VL	325.0	9.4	30.5	690.0	9.4	64.7		
			L	250.0	9.4	23.4	610.0	9.4	57.2		
			M	150.0	9.4	14.1	610.0	9.4	57.2		
			H	150.0	9.4	14.1	610.0	9.4	57.2		
		Darfield	XL	450.0	9.4	42.2	1150.0	9.4	107.8		
			VL	350.0	9.4	32.8	760.0	9.4	71.3		
			L	255.0	9.4	23.9	670.0	9.4	62.8		
			M	180.0	9.4	16.9	660.0	9.4	61.9		
			H	180.0	9.4	16.9	660.0	9.4	61.9		
		Hororata	XL	500.0	9.4	46.9	1200.0	9.4	112.5		
			VL	375.0	9.4	35.2	820.0	9.4	76.9		
			L	260.0	9.4	24.4	740.0	9.4	69.4		
			M	210.0	9.4	19.7	710.0	9.4	66.6		
			H	210.0	9.4	19.7	710.0	9.4	66.6		
		3 cows/ha winter on	Irrigated	Lincoln	XL	400	12.5	50.0	1060.0	12.5	132.5
					VL	325.0	12.5	40.6	690.0	12.5	86.3
					L	250.0	12.5	31.3	610.0	12.5	76.3
					M	150.0	12.5	18.8	610.0	12.5	76.3
					H	150.0	12.5	18.8	610.0	12.5	76.3
Darfield	XL			450.0	12.5	56.3	1150.0	12.5	143.8		
	VL			350.0	12.5	43.8	760.0	12.5	95.0		
	L			255.0	12.5	31.9	670.0	12.5	83.8		
	M			180.0	12.5	22.5	660.0	12.5	82.5		
	H			180.0	12.5	22.5	660.0	12.5	82.5		
Hororata	XL			500.0	12.5	62.5	1200.0	12.5	150.0		
	VL			375.0	12.5	46.9	820.0	12.5	102.5		
	L			260.0	12.5	32.5	740.0	12.5	92.5		
	M			210.0	12.5	26.3	710.0	12.5	88.8		
	H			210.0	12.5	26.3	710.0	12.5	88.8		
4 cows/ha winter off	Irrigated			Lincoln	XL	400	12.5	50.0	1060.0	12.5	132.5
					VL	325.0	12.5	40.6	690.0	12.5	86.3
					L	250.0	12.5	31.3	610.0	12.5	76.3
					M	150.0	12.5	18.8	610.0	12.5	76.3
					H	150.0	12.5	18.8	610.0	12.5	76.3

Estimating nitrate-nitrogen leaching rates under rural land uses in Canterbury

Farm type	Irrigation	Climate	Soil	Drainage mm/yr	Calc. conc mg N/L	Trend mass kg N/ha/yr	Border dyke		
							Drainage mm/yr	Conc. mg N/L	Mass kg N/ha/yr
		Darfield	XL	450.0	12.5	56.3	1150.0	12.5	143.8
			VL	350.0	12.5	43.8	760.0	12.5	95.0
			L	255.0	12.5	31.9	670.0	12.5	83.8
			M	180.0	12.5	22.5	660.0	12.5	82.5
			H	180.0	12.5	22.5	660.0	12.5	82.5
		Hororata	XL	500.0	12.5	62.5	1200.0	12.5	150.0
			VL	375.0	12.5	46.9	820.0	12.5	102.5
			L	260.0	12.5	32.5	740.0	12.5	92.5
			M	210.0	12.5	26.3	710.0	12.5	88.8
			H	210.0	12.5	26.3	710.0	12.5	88.8
4 cows/ha winter on	Irrigated	Lincoln	XL	400	16.3	65.0	1060.0	16.3	172.3
			VL	325.0	16.3	52.8	690.0	16.3	112.1
			L	250.0	16.3	40.6	610.0	16.3	99.1
			M	150.0	16.3	24.4	610.0	16.3	99.1
			H	150.0	16.3	24.4	610.0	16.3	99.1
		Darfield	XL	450.0	16.3	73.1	1150.0	16.3	186.9
			VL	350.0	16.3	56.9	760.0	16.3	123.5
			L	255.0	16.3	41.4	670.0	16.3	108.9
			M	180.0	16.3	29.3	660.0	16.3	107.3
			H	180.0	16.3	29.3	660.0	16.3	107.3
		Hororata	XL	500.0	16.3	81.3	1200.0	16.3	195.0
			VL	375.0	16.3	60.9	820.0	16.3	133.3
			L	260.0	16.3	42.3	740.0	16.3	120.3
			M	210.0	16.3	34.1	710.0	16.3	115.4
			H	210.0	16.3	34.1	710.0	16.3	115.4
5 cows/ha winter off	Irrigated	Lincoln	XL	400	14.4	57.5	1060.0	14.4	152.4
			VL	325.0	14.4	46.7	690.0	14.4	99.2
			L	250.0	14.4	35.9	610.0	14.4	87.7
			M	150.0	14.4	21.6	610.0	14.4	87.7
			H	150.0	14.4	21.6	610.0	14.4	87.7
		Darfield	XL	450.0	14.4	64.7	1150.0	14.4	165.3
			VL	350.0	14.4	50.3	760.0	14.4	109.3
			L	255.0	14.4	36.7	670.0	14.4	96.3
			M	180.0	14.4	25.9	660.0	14.4	94.9
			H	180.0	14.4	25.9	660.0	14.4	94.9
		Hororata	XL	500.0	14.4	71.9	1200.0	14.4	172.5
			VL	375.0	14.4	53.9	820.0	14.4	117.9
			L	260.0	14.4	37.4	740.0	14.4	106.4

Estimating nitrate-nitrogen leaching rates under rural land uses in Canterbury

Farm type	Irrigation	Climate	Soil	Drainage mm/yr	Calc. conc. mg N/L	Trend mass kg N/ha/yr	Border dyke		
							Drainage mm/yr	Conc. mg N/L	Mass kg N/ha/yr
			M	210.0	14.4	30.2	710.0	14.4	102.1
			H	210.0	14.4	30.2	710.0	14.4	102.1
100% beef	dry	Lincoln	XL	160	12.5	20.0			
			VL	140.0	12.5	17.5			
			L	120.0	12.5	15.0			
			M	80.0	12.5	10.0			
			H	80.0	12.5	10.0			
		Darfield	XL	180.0	12.5	22.5			
			VL	160.0	12.5	20.0			
			L	140.0	12.5	17.5			
			M	100.0	12.5	12.5			
			H	100.0	12.5	12.5			
		Hororata	XL	200.0	12.5	25.0			
			VL	180.0	12.5	22.5			
			L	160.0	12.5	20.0			
			M	120.0	12.5	15.0			
			H	120.0	12.5	15.0			
100% beef	Irrigated	Lincoln	XL	400	12.5	50.0	1060.0	12.5	132.5
			VL	325.0	12.5	40.6	690.0	12.5	86.3
			L	250.0	12.5	31.3	610.0	12.5	76.3
			M	150.0	12.5	18.8	610.0	12.5	76.3
			H	150.0	12.5	18.8	610.0	12.5	76.3
		Darfield	XL	450.0	12.5	56.3	1150.0	12.5	143.8
			VL	350.0	12.5	43.8	760.0	12.5	95.0
			L	255.0	12.5	31.9	670.0	12.5	83.8
			M	180.0	12.5	22.5	660.0	12.5	82.5
			H	180.0	12.5	22.5	660.0	12.5	82.5
		Hororata	XL	500.0	12.5	62.5	1200.0	12.5	150.0
			VL	375.0	12.5	46.9	820.0	12.5	102.5
			L	260.0	12.5	32.5	740.0	12.5	92.5
			M	210.0	12.5	26.3	710.0	12.5	88.8
			H	210.0	12.5	26.3	710.0	12.5	88.8
100% sheep	Dry	Lincoln	XL	160	6.3	10.0			
			VL	140.0	6.3	8.8			
			L	120.0	6.3	7.5			
			M	80.0	6.3	5.0			
			H	80.0	6.3	5.0			
		Darfield	XL	180.0	6.3	11.3			

Estimating nitrate-nitrogen leaching rates under rural land uses in Canterbury

Farm type	Irrigation	Climate	Soil	Drainage mm/yr	Calc. conc mg N/L	Trend mass kg N/ha/yr	Border dyke		
							Drainage mm/yr	Conc. mg N/L	Mass kg N/ha/yr
			VL	160.0	6.3	10.0			
			L	140.0	6.3	8.8			
			M	100.0	6.3	6.3			
			H	100.0	6.3	6.3			
		Hororata	XL	200.0	6.3	12.5			
			VL	180.0	6.3	11.3			
			L	160.0	6.3	10.0			
			M	120.0	6.3	7.5			
			H	120.0	6.3	7.5			
100% sheep	Irrigated	Lincoln	XL	400	6.3	25.0	1060.0	6.3	66.3
			VL	325.0	6.3	20.3	690.0	6.3	43.1
			L	250.0	6.3	15.6	610.0	6.3	38.1
			M	150.0	6.3	9.4	610.0	6.3	38.1
			H	150.0	6.3	9.4	610.0	6.3	38.1
		Darfield	XL	450.0	6.3	28.1	1150.0	6.3	71.9
			VL	350.0	6.3	21.9	760.0	6.3	47.5
			L	255.0	6.3	15.9	670.0	6.3	41.9
			M	180.0	6.3	11.3	660.0	6.3	41.3
			H	180.0	6.3	11.3	660.0	6.3	41.3
		Hororata	XL	500.0	6.3	31.3	1200.0	6.3	75.0
			VL	375.0	6.3	23.4	820.0	6.3	51.3
			L	260.0	6.3	16.3	740.0	6.3	46.3
			M	210.0	6.3	13.1	710.0	6.3	44.4
			H	210.0	6.3	13.1	710.0	6.3	44.4
100% Deer	Dry	Lincoln	XL	160	7.5	12.0			
			VL	140.0	7.5	10.5			
			L	120.0	7.5	9.0			
			M	80.0	7.5	6.0			
			H	80.0	7.5	6.0			
		Darfield	XL	180.0	7.5	13.5			
			VL	160.0	7.5	12.0			
			L	140.0	7.5	10.5			
			M	100.0	7.5	7.5			
			H	100.0	7.5	7.5			
		Hororata	XL	200.0	7.5	15.0			
			VL	180.0	7.5	13.5			
			L	160.0	7.5	12.0			
			M	120.0	7.5	9.0			
			H	120.0	7.5	9.0			

Estimating nitrate-nitrogen leaching rates under rural land uses in Canterbury

Farm type	Irrigation	Climate	Soil	Drainage mm/yr	Calc. conc mg N/L	Trend mass kg N/ha/yr	Border dyke		
							Drainage mm/yr	Conc. mg N/L	Mass kg N/ha/yr
100% Deer	Irrigated	Lincoln	XL	400	7.5	30.0	1060.0	7.5	79.5
			VL	325.0	7.5	24.4	690.0	7.5	51.8
			L	250.0	7.5	18.8	610.0	7.5	45.8
			M	150.0	7.5	11.3	610.0	7.5	45.8
			H	150.0	7.5	11.3	610.0	7.5	45.8
		Darfield	XL	450.0	7.5	33.8	1150.0	7.5	86.3
			VL	350.0	7.5	26.3	760.0	7.5	57.0
			L	255.0	7.5	19.1	670.0	7.5	50.3
			M	180.0	7.5	13.5	660.0	7.5	49.5
			H	180.0	7.5	13.5	660.0	7.5	49.5
		Hororata	XL	500.0	7.5	37.5	1200.0	7.5	90.0
			VL	375.0	7.5	28.1	820.0	7.5	61.5
			L	260.0	7.5	19.5	740.0	7.5	55.5
			M	210.0	7.5	15.8	710.0	7.5	53.3
			H	210.0	7.5	15.8	710.0	7.5	53.3
Dairy Support	Dry	Lincoln	XL	160	15.6	25.0			
			VL	140.0	15.6	21.9			
			L	120.0	15.6	18.8			
			M	80.0	15.6	12.5			
			H	80.0	15.6	12.5			
		Darfield	XL	180.0	15.6	28.1			
			VL	160.0	15.6	25.0			
			L	140.0	15.6	21.9			
			M	100.0	15.6	15.6			
			H	100.0	15.6	15.6			
		Hororata	XL	200.0	15.6	31.3			
			VL	180.0	15.6	28.1			
			L	160.0	15.6	25.0			
			M	120.0	15.6	18.8			
			H	120.0	15.6	18.8			
Dairy Support	Irrigated	Lincoln	XL	400	15.6	62.5	1060.0	15.6	165.6
			VL	325.0	15.6	50.8	690.0	15.6	107.8
			L	250.0	15.6	39.1	610.0	15.6	95.3
			M	150.0	15.6	23.4	610.0	15.6	95.3
			H	150.0	15.6	23.4	610.0	15.6	95.3
		Darfield	XL	450.0	15.6	70.3	1150.0	15.6	179.7
			VL	350.0	15.6	54.7	760.0	15.6	118.8
			L	255.0	15.6	39.8	670.0	15.6	104.7

Estimating nitrate-nitrogen leaching rates under rural land uses in Canterbury

Farm type	Irrigation	Climate	Soil	Drainage mm/yr	Calc. conc. mg N/L	Trend mass kg N/ha/yr	Border dyke		
							Drainage mm/yr	Conc. mg N/L	Mass kg N/ha/yr
			M	180.0	15.6	28.1	660.0	15.6	103.1
			H	180.0	15.6	28.1	660.0	15.6	103.1
		Hororata	XL	500.0	15.6	78.1	1200.0	15.6	187.5
			VL	375.0	15.6	58.6	820.0	15.6	128.1
			L	260.0	15.6	40.6	740.0	15.6	115.6
			M	210.0	15.6	32.8	710.0	15.6	110.9
			H	210.0	15.6	32.8	710.0	15.6	110.9
50% beef; 50% sheep	dry	Lincoln	XL	160	11.5	18.4			
			VL	140.0	11.5	16.1			
			L	120.0	11.5	13.8			
			M	80.0	11.5	9.2			
			H	80.0	11.5	9.2			
		Darfield	XL	180.0	11.5	20.7			
			VL	160.0	11.5	18.4			
			L	140.0	11.5	16.1			
			M	100.0	11.5	11.5			
			H	100.0	11.5	11.5			
		Hororata	XL	200.0	11.5	23.0			
			VL	180.0	11.5	20.7			
			L	160.0	11.5	18.4			
			M	120.0	11.5	13.8			
			H	120.0	11.5	13.8			
50% beef; 50% sheep	Irrigated	Lincoln	XL	400	11.5	46.0	1060.0	11.5	121.9
			VL	325.0	11.5	37.4	690.0	11.5	79.4
			L	250.0	11.5	28.8	610.0	11.5	70.2
			M	150.0	11.5	17.3	610.0	11.5	70.2
			H	150.0	11.5	17.3	610.0	11.5	70.2
		Darfield	XL	450.0	11.5	51.8	1150.0	11.5	132.3
			VL	350.0	11.5	40.3	760.0	11.5	87.4
			L	255.0	11.5	29.3	670.0	11.5	77.1
			M	180.0	11.5	20.7	660.0	11.5	75.9
			H	180.0	11.5	20.7	660.0	11.5	75.9
		Hororata	XL	500.0	11.5	57.5	1200.0	11.5	138.0
			VL	375.0	11.5	43.1	820.0	11.5	94.3
			L	260.0	11.5	29.9	740.0	11.5	85.1
			M	210.0	11.5	24.2	710.0	11.5	81.7
			H	210.0	11.5	24.2	710.0	11.5	81.7
20% Beef;	Dry	Lincoln	XL	160	9.8	15.7			

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Farm type	Irrigation	Climate	Soil	Drainage mm/yr	Calc. conc. mg N/L	Trend mass kg N/ha/yr	Border dyke		
							Drainage mm/yr	Conc. mg N/L	Mass kg N/ha/yr
80% Sheep									
			VL	140.0	9.8	13.7			
			L	120.0	9.8	11.8			
			M	80.0	9.8	7.8			
			H	80.0	9.8	7.8			
				0.0					
		Darfield	XL	180.0	9.8	17.6			
			VL	160.0	9.8	15.7			
			L	140.0	9.8	13.7			
			M	100.0	9.8	9.8			
			H	100.0	9.8	9.8			
				0.0					
		Hororata	XL	200.0	9.8	19.6			
			VL	180.0	9.8	17.6			
			L	160.0	9.8	15.7			
			M	120.0	9.8	11.8			
			H	120.0	9.8	11.8			
20% Beef; 80% Sheep	Irrigated	Lincoln	XL	400	9.8	39.2	1060.0	9.8	103.9
			VL	325.0	9.8	31.9	690.0	9.8	67.6
			L	250.0	9.8	24.5	610.0	9.8	59.8
			M	150.0	9.8	14.7	610.0	9.8	59.8
			H	150.0	9.8	14.7	610.0	9.8	59.8
		Darfield	XL	450.0	9.8	44.1	1150.0	9.8	112.7
			VL	350.0	9.8	34.3	760.0	9.8	74.5
			L	255.0	9.8	25.0	670.0	9.8	65.7
			M	180.0	9.8	17.6	660.0	9.8	64.7
			H	180.0	9.8	17.6	660.0	9.8	64.7
		Hororata	XL	500.0	9.8	49.0	1200.0	9.8	117.6
			VL	375.0	9.8	36.8	820.0	9.8	80.4
			L	260.0	9.8	25.5	740.0	9.8	72.5
			M	210.0	9.8	20.6	710.0	9.8	69.6
			H	210.0	9.8	20.6	710.0	9.8	69.6
10% Beef; 90% Sheep	Dry	Lincoln	XL	160	8.6	13.7			
			VL	140.0	8.6	12.0			
			L	120.0	8.6	10.3			
			M	80.0	8.6	6.8			
			H	80.0	8.6	6.8			
		Darfield	XL	180.0	8.6	15.4			

Estimating nitrate-nitrogen leaching rates under rural land uses in Canterbury

Farm type	Irrigation	Climate	Soil	Drainage mm/yr	Calc. conc. mg N/L	Trend mass kg N/ha/yr	Border dyke		
							Drainage mm/yr	Conc. mg N/L	Mass kg N/ha/yr
			VL	160.0	8.6	13.7			
			L	140.0	8.6	12.0			
			M	100.0	8.6	8.6			
			H	100.0	8.6	8.6			
		Hororata	XL	200.0	8.6	17.1			
			VL	180.0	8.6	15.4			
			L	160.0	8.6	13.7			
			M	120.0	8.6	10.3			
			H	120.0	8.6	10.3			
10% Beef; 90% Sheep	Irrigated	Lincoln	XL	400	8.6	34.2	1060.0	8.6	90.7
			VL	325.0	8.6	27.8	690.0	8.6	59.0
			L	250.0	8.6	21.4	610.0	8.6	52.2
			M	150.0	8.6	12.8	610.0	8.6	52.2
			H	150.0	8.6	12.8	610.0	8.6	52.2
		Darfield	XL	450.0	8.6	38.5	1150.0	8.6	98.4
			VL	350.0	8.6	29.9	760.0	8.6	65.0
			L	255.0	8.6	21.8	670.0	8.6	57.3
			M	180.0	8.6	15.4	660.0	8.6	56.5
			H	180.0	8.6	15.4	660.0	8.6	56.5
		Hororata	XL	500.0	8.6	42.8	1200.0	8.6	102.7
			VL	375.0	8.6	32.1	820.0	8.6	70.2
			L	260.0	8.6	22.2	740.0	8.6	63.3
			M	210.0	8.6	18.0	710.0	8.6	60.7
			H	210.0	8.6	18.0	710.0	8.6	60.7
Pigs	Dry	Lincoln	XL	160	12.5	20.0			
			VL	140.0	12.5	17.5			
			L	120.0	12.5	15.0			
			M	80.0	12.5	10.0			
			H	80.0	12.5	10.0			
		Darfield	XL	180.0	12.5	22.5			
			VL	160.0	12.5	20.0			
			L	140.0	12.5	17.5			
			M	100.0	12.5	12.5			
			H	100.0	12.5	12.5			
		Hororata	XL	200.0	12.5	25.0			
			VL	180.0	12.5	22.5			
			L	160.0	12.5	20.0			
			M	120.0	12.5	15.0			
			H	120.0	12.5	15.0			

Table A.2 Lookup values for arable land uses

Farm type	Climate	Soil	Irrigated			Dry		
			Drainage mm/yr	Calc. conc. mg N/L	Trend mass kg N/ha/yr	Drainage mm/yr	Calc conc. mg N/L	Trend mass kg N/ha/yr
Arable - mixed	Lincoln	XL	214	13	27.82	187	15	28.05
		VL	304	6	18.24	160	12	19.2
		L	263	8	21.04	124	19	23.56
		M	254	5	12.7	97	15	14.55
		H	238	4	9.52	82	8	6.56
	Darfield	XL	238	12	28.56	149	17	25.33
		VL	313	7	21.91	126	13	16.38
		L	295	8	23.6	106	8	8.48
		M	275	6	16.5	214	12	25.68
		H	258	4	10.32	174	12	20.88
	Hororata	XL	294	10	29.4	270	11	29.7
		VL	374	6	22.44	231	9	20.79
		L	341	7	23.87	195	12	23.4
		M	321	5	16.05	175	10	17.5
		H	316	4	12.64	160	7	11.2
Arable - seasonal	Lincoln	XL	233	10	23.3	171	17	29.07
		VL	242	7	16.94	153	13	19.89
		L	210	8	16.8	124	16	19.84
		M	197	4	7.88	87	10	8.7
		H	192	1	1.92	47	3	1.41
	Darfield	XL	262	10	26.2	198	15	29.7
		VL	274	7	19.18	172	11	18.92
		L	247	8	19.76	148	13	19.24
		M	231	5	11.55	115	8	9.2
		H	223	1	2.23	78	4	3.12
	Hororata	XL	316	9	28.44	257	12	30.84
		VL	329	7	23.03	230	9	20.7
		L	311	8	24.88	202	11	22.22
		M	283	5	14.15	167	7	11.69
		H	278	2	5.56	134	3	4.02

Table A.3 Lookup values for the other land uses

Farm type	Climate	Soil	Drainage mm/yr	Calc conc. mg N/L	Trend mass kg N/h/yr
Forestry – exotic on developed land	Lincoln	XL	49	1.10	0.54
		VL	31.5	3.41	1.07
		L	14	5.71	0.80
		M	12	7.86	0.94
		H	10	10.00	1.00
	Darfield	XL	84	1.22	1.02
		VL	61.5	2.82	1.73
		L	39	4.42	1.72
		M	29.75	6.08	1.81
		H	20.5	7.74	1.59
	Hororata	XL	119	1.34	1.59
		VL	91.5	2.23	2.04
		L	64	3.13	2.00
		M	47.5	4.30	2.04
		H	31	5.48	1.70
	Forestry – exotic on undeveloped land	Lincoln	XL	49	1.10
VL			31.5	1.09	0.34
L			14	1.07	0.15
M			12	1.09	0.13
H			10	1.10	0.11
Darfield		XL	82	1.10	0.90
		VL	57.5	1.10	0.63
		L	33	1.09	0.36
		M	23	1.08	0.25
		H	13	1.08	0.14
Hororata		XL	119	1.10	1.31
		VL	119	1.10	1.31
		L	64	1.09	0.70
		M	47.5	1.10	0.52
		H	31	1.10	0.34
Forestry - native		Lincoln	XL	0.003	0.011
	VL		0.000	0.000	0.000
	L		0.000	0.000	0.000
	M		0.000	0.000	0.000
	H		0.001	0.001	0.001
	Darfield	XL	0.008	0.020	0.008
		VL	0.010	0.017	0.010
		L	0.010	0.010	0.010
		M	0.010	0.007	0.010
		H	0.002	0.001	0.002
	Hororata	XL	0.020	0.029	0.020
		VL	0.020	0.019	0.020
		L	0.023	0.010	0.023
		M	0.030	0.011	0.030
		H	0.030	0.009	0.030

Estimating nitrate-nitrogen leaching rates under rural land uses in Canterbury

Farm type	Climate	Soil	Drainage mm/yr	Calc conc. mg N/L	Trend mass kg N/h/yr
Viticulture	Lincoln	XL	206	2.4	5
		VL	171	3.5	6
		L	144	6.3	9
		M	119	10.1	12
		H	96	18.8	18
	Darfield	XL	236	2.1	5
		VL	198	3.0	6
		L	170	5.3	9
		M	145	9.0	13
		H	122	14.8	18
	Hororata	XL	261	1.9	5
		VL	222	2.7	6
		L	193	5.2	10
		M	174	8.6	15
		H	147	12.9	19
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Apple	Lincoln	XL	176	4.5	8
		VL	150	5.3	8
		L	124	6.5	8
		M	108	5.6	6
		H	55	10.9	6
	Darfield	XL	202	4.5	9
		VL	171	5.3	9
		L	145	6.2	9
		M	123	5.7	7
		H	71	7.0	5
	Hororata	XL	218	4.1	9
		VL	189	4.8	9
		L	159	5.7	9
		M	138	5.1	7
		H	80	7.5	6
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Berryfruit	Lincoln	XL	197	6.1	12
		VL	167	7.2	12
		L	135	8.9	12
		M	113	7.1	8
		H	77	15.6	12
	Darfield	XL	225	5.8	13
		VL	192	6.8	13
		L	158	8.2	13
		M	131	6.9	9
		H	97	11.3	11
	Hororata	XL	250	5.6	14
		VL	213	6.6	14
		L	176	8.0	14
		M	147	6.8	10
		H	113	10.6	12
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Summer fruit	Lincoln	XL	174	4.6	8
		VL	145	5.5	8
		L	121	5.8	7

Estimating nitrate-nitrogen leaching rates under rural land uses in Canterbury

Farm type	Climate	Soil	Drainage mm/yr	Calc conc. mg N/L	Trend mass kg N/h/yr
		M	106	4.7	5
		H	51	11.8	6
	Darfield	XL	197	4.6	9
		VL	167	4.8	8
		L	140	5.7	8
		M	120	4.2	5
		H	66	7.6	5
	Hororata	XL	213	4.2	9
		VL	184	4.9	9
		L	153	5.2	8
		M	131	4.6	6
		H	74	8.1	6
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Lifestyle	Lincoln	XL	192	10.9	21
		VL	154	10.4	16
		L	107	14.0	15
		M	90	17.8	16
		H	67	26.9	18
	Darfield	XL	216	8.3	18
		VL	179	8.4	15
		L	129	12.4	16
		M	110	15.5	17
		H	87	20.7	18
	Hororata	XL	241	7.9	19
		VL	202	6.9	14
		L	147	11.6	17
		M	128	14.1	18
		H	101	19.8	20
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Golf	Lincoln	XL	213.4	6.9	14.8
		VL	161.1	8.8	14.2
		L	103.3	18.1	18.7
		M	75.7	5.0	3.8
		H	45.1	20.3	9.1
	Darfield	XL	292.2	5.0	14.5
		VL	233.5	6.1	14.3
		L	160.5	14.2	22.9
		M	125	4.2	5.2
		H	85.4	19.2	16.4
	Hororata	XL	341.3	4.3	14.5
		VL	277.3	5.2	14.5
		L	200.2	12.7	25.4
		M	157.6	3.7	5.8
		H	113.2	16.5	18.7

The next two tables contain the same data (pastoral only) in a different layout.

Land use	Concentration (mg N/L)	Irrigation	Drainage (mm/y)												
			Area	Lincoln				Darfield				Hororata			
			Soil	XL	VL	L	M & H	XL	VL	L	M & H	XL	VL	L	M & H
3 cows/ha winter off	9.4	Spray irrigation	400	325	250	150	450	350	255	180	500	375	260	210	
			1060	690	610	610	1150	760	670	660	1200	820	740	710	
3 cows/ha winter on	12.5	Spray irrigation		325	250	150	450	350	255	180	500	375	260	210	
			1060	690	610	610	1150	760	670	660	1200	820	740	710	
4 cows/ha winter off	12.5	Spray irrigation	400	325	250	150	450	350	255	180	500	375	260	210	
			1060	690	610	610	1150	760	670	660	1200	820	740	710	
4 cows/ha winter on	16.3	Spray irrigation	400	325	250	150	450	350	255	180	500	375	260	210	
			1060	690	610	610	1150	760	670	660	1200	820	740	710	
5 cows/ha winter off	14.4	Spray irrigation	400	325	250	150	450	350	255	180	500	375	260	210	
			1060	690	610	610	1150	760	670	660	1200	820	740	710	
100% beef	12.5	Dryland		140	120	80	180	160	140	100	200	180	160	120	
			400	325	250	150	450	350	255	180	500	375	260	210	
			1060	690	610	610	1150	760	670	660	1200	820	740	710	
100% sheep	6.3	Dryland	160	140	120	80	180	160	140	100	200	180	160	120	
			400	325	250	150	450	350	255	180	500	375	260	210	
			1060	690	610	610	1150	760	670	660	1200	820	740	710	
100% Deer	7.5	Dryland		140	120	80	180	160	140	100	200	180	160	120	
			400	325	250	150	450	350	255	180	500	375	260	210	
			1060	690	610	610	1150	760	670	660	1200	820	740	710	
Dairy Support	15.6	Dryland	160	140	120	80	180	160	140	100	200	180	160	120	
			400	325	250	150	450	350	255	180	500	375	260	210	
			1060	690	610	610	1150	760	670	660	1200	820	740	710	
50% beef; 50% sheep	11.5	Dryland		140	120	80	180	160	140	100	200	180	160	120	
			400	325	250	150	450	350	255	180	500	375	260	210	
			1060	690	610	610	1150	760	670	660	1200	820	740	710	
20% Beef; 80% Sheep	9.8	Dryland	160	140	120	80	180	160	140	100	200	180	160	120	
			400	325	250	150	450	350	255	180	500	375	260	210	
			1060	690	610	610	1150	760	670	660	1200	820	740	710	
10% Beef; 90% Sheep	8.6	Dryland		140	120	80	180	160	140	100	200	180	160	120	
			400	325	250	150	450	350	255	180	500	375	260	210	
			1060	690	610	610	1150	760	670	660	1200	820	740	710	
Pigs	12.5	Dryland	160	140	120	80	180	160	140	100	200	180	160	120	

160
400

Land use	Concentration (mg N/L)	Irrigation	Nitrate mass (kg N/ha/y)												
			Area Soil	Lincoln				Darfield				Hororata			
				XL	VL	L	M & H	XL	VL	L	M & H	XL	VL	L	M & H
3 cows/ha winter off	9.4	Spray irrigation	133	38	30	23	14	42	33	24	17	47	35	24	20
				99	65	57	57	108	71	63	62	113	77	69	67
3 cows/ha winter on	12.5	Spray irrigation	133	50	41	31	19	56	44	32	23	63	47	33	26
					86	76	76	144	95	84	83	150	103	93	89
4 cows/ha winter off	12.5	Spray irrigation	133	50	41	31	19	56	44	32	23	63	47	33	26
				133	86	76	76	144	95	84	83	150	103	93	89
4 cows/ha winter on	16.3	Spray irrigation	133	65	53	41	24	73	57	41	29	81	61	42	34
				172	112	99	99	187	124	109	107	195	133	120	115
5 cows/ha winter off	14.4	Spray irrigation	133	58	47	36	22	65	50	37	26	72	54	37	30
				152	99	88	88	165	109	96	95	173	118	106	102
100% beef	12.5	Dryland	133	20	18	15	10	23	20	18	13	25	23	20	15
				50	41	31	19	56	44	32	23	63	47	33	26
100% sheep	6.3	Spray irrigation	133	86	76	76	76	144	95	84	83	150	103	93	89
				10	9	8	5	11	10	9	6	13	11	10	8
100% Deer	7.5	Dryland	133	25	20	16	9	28	22	16	11	31	23	16	13
				66	43	38	38	72	48	42	41	75	51	46	44
Dairy Support	15.6	Spray irrigation	133	12	11	9	6	14	12	11	8	15	14	12	9
				30	24	19	11	34	26	19	14	38	28	20	16
50% beef; 50% sheep	11.5	Border Dyke	133	80	52	46	46	86	57	50	50	90	62	56	53
				25	22	19	13	28	25	22	16	31	28	25	19
20% Beef; 80% Sheep	9.8	Spray irrigation	133	63	51	39	23	70	55	40	28	78	59	41	33
				166	108	95	95	180	119	105	103	188	128	116	111
10% Beef; 90% Sheep	8.6	Dryland	133	18	16	14	9	21	18	16	12	23	21	18	14
				46	37	29	17	52	40	29	21	58	43	30	24
Pigs	12.5	Spray irrigation	133	122	79	70	70	132	87	77	76	138	94	85	82
				16	14	12	8	18	16	14	10	20	18	16	12
10% Beef; 90% Sheep	8.6	Border Dyke	133	39	32	25	15	44	34	25	18	49	37	25	21
				104	68	60	60	113	74	66	65	118	80	73	70
Pigs	12.5	Dryland	133	14	12	10	7	15	14	12	9	17	15	14	10
				34	28	21	13	39	30	22	15	43	32	22	18
Pigs	12.5	Border Dyke	133	91	59	52	52	98	65	57	56	103	70	63	61
				20	18	15	10	23	20	18	13	25	23	20	15

Appendix 2: Science Workshop participants

Workshop One: 15 May 2008 held at Environment Canterbury Christchurch

Participants:

Ross Monaghan (AgResearch), Phil Abraham (ECan), Jan Hania (Environment Waikato), Reece Hill (Environment Waikato), Nick Pyke (Foundation for Arable Research), Brent Clothier (HortResearch), Steve Greene (HortResearch), Val Snow (AgResearch), Pam Guest (Consultant – ECan), Trevor Webb (Landcare Research), Steve Thomas (Crop and Food), Raymond Ford (ECan), Christina Robb (ECan), Keith Cameron (Lincoln University), Hong Di (Lincoln University), Hamish Brown (Crop and Food), Linda Lilburne (Landcare Research), Vince Bidwell (Lincoln Ventures), Barry Loe (Consultant ECan) Ian Whitehouse (Facilitator), Tina von Pein (Project Manager).

Workshop Two: 16 October 2008 held at Environment Canterbury, Christchurch

Participants:

Carl Hanson (ECan), Shirley Hayward (ECan), Keith Cameron (Lincoln University), Rachel Millar (Environment Southland), Ross Monaghan (AgResearch), Linda Lilburne (Landcare Research), Steve Green/Brent Clothier (Hort Research), Nick Pyke (Foundation for Arable Research), Ken Robertson (Horticulture New Zealand), John Glennie (ECan), Hamish Brown (Crop and Food), Raymond Ford (ECan), Viv Smith (ECan), Barry Loe (Consultant, ECan), Val Snow (AgResearch), Jeremy Bryant (AgResearch), Miriam Eagle (Ministry for the Environment), Steve Thomas (Crop and Food), Vince Bidwell (LVL), Trevor Webb (Landcare Research), Reece Hill (Environment Waikato), Pam Guest (ECan), Dawn Dalley (Dairy NZ), Ken T (ECan – for the introduction), Ian Whitehouse (Facilitator), Tina von Pein (Project Manager).

Workshop Three: 5 November 2009 held at Netball Centre Christchurch

Participants:

Vince Bidwell (Lincoln Environmental), Val Snow (AgResearch), Ross Monaghan (AgResearch), Steve Thomas (Plant & Food), Hamish Brown (Plant & Food), Steve Green (HortResearch), Brent Clothier (HortResearch), Sonia Whiteman (Horticulture New Zealand), Nick Pyke, (Foundation for Arable Research), Linda Lilburne (Landcare Research), Trevor Webb (Landcare Research), Rachael Millar (Environment Southland), Michael Bennett (Environment Southland), Viv Smith (ESR), Shirley Hayward (DairyNZ), Murray Davis (Scion), Penny Nelson (DairyNZ), Piotre Swierczynski (Ministry for the Environment), Lionel Hulme (Federated Farmers), Pam Guest (Consultant ECan), , Raymond Ford (ECan), Christina Robb (ECan), Barry Loe (Consultant, ECan), Ken Taylor (ECan), Carl Hanson (ECan), Ian Whitehouse (Facilitator), Tina von Pein (Project Manager).

Caucus: February 2010 held at Environment Canterbury, Christchurch

Participants:

Bruce Thorrold (DairyNZ), Vince Bidwell (Lincoln Environmental), Val Snow (AgResearch), Ross Monaghan (AgResearch), Mark Shepherd (AgResearch), David Wheeler (AgResearch), Alister Metherell (Ravensdown), Hamish Brown (Plant & Food), Steve Green (Plant & Food), Linda Lilburne (Landcare Research, ECan), Trevor Webb (Landcare Research), Shirley Hayward (DairyNZ), Penny Nelson (DairyNZ), Raymond Ford (ECan), Christina Robb (ECan), Ken Taylor (ECan), Tim Mallet (ECan), Carl Hanson (ECan), Tina von Pein (Project Manager).

Appendix 3: Webb (2009) Soil data for land overlying alluvial aquifers in Canterbury

February 2009

These notes are to accompany soil physical data for typifying profiles for land overlying alluvial aquifers.

Objective

‘To identify a core set of soil groups for the irrigable parts of the Canterbury Region to be used as a basis for developing a GIS map of nitrate leaching predictions.’

Reason for new soil data set

The data provided in July 2008 has been amended. Since that time I have sampled 12 stony to very stony profiles in Canterbury to determine available water content. This work indicates that stony horizons have significantly greater field capacity than previously estimated. This means that I underestimated profile available water for stony soils in my July report.

The previous data was limited to the upper 100 cm soil depth because this is an adequate depth to consider under irrigated conditions. There is a possibility of needing to analyse for deeper soils under dryland conditions, so I have added a deep profile that extends to 150 cm. I have also increased the depth of deep poorly drained soils to 150 cm as these soils are almost always very deep.

I have also added a further column in Table 3 to provide Ksat values. Initially I only sent under request to HortResearch because they needed them for their model. The Ksat values will be needed if analysis is undertaken to estimate denitrification. The Ksat values are median values to overcome the skew in lognormal data. Ksat was measured from 100 mm diameter cores, derived from the same soil dataset as the other data. Most of my sites were from long term pasture or short term pasture after cropping and do not represent what may be found under dairy to long term arable so I have added in a guesstimate of Ksat for topsoils under moderate compaction.

NB the estimate of denitrification in poorly drained soils is more related to a rising water table than to soil permeability. In Canterbury water tables tend to rise in poorly drained soils over the late winter/spring period. I would be very pleased if someone had monitoring data on this!!

Method

1. Define soil groups on the basis of significant difference in profile available water storage and the separation of soils with poor drainage. The target soil groups are shown in Table 1.
2. Find soils in Landcare Research databases that have water holding characteristics.
3. Classify profiles into soil groups.
4. Create typifying profiles by grouping similar horizons
5. Average required soil attributes for horizons for typifying horizons.

Attributes for soil groups L, M, H, D and Pd were derived from a dataset of eight soil series from the Canterbury Plains, held at Lincoln, containing 9 profiles for each of the soil series.

Attributes for soil groups XL, VL, PdL were derived from profiles on the National Soil Database and from sampling and analysis of a range of stony soils in 2008 (field capacity for stony horizons was derived from field moisture content in spring).

Separate data for chemical analyses was provided for soils under cropping for soils suited to arable use. This data illustrates the large differences in carbon and nitrogen evident between long term pasture and long-term cropping.

Results

Data for Canterbury Plains soils are recorded in Table 3. Table 4 contains a description of headings for Table 3.

Table 1 Target characteristics of typifying profiles

Soil group	Code	PAW (mm)
<i>Well drained profiles</i>		
Extremely light	XL	45 (<50)
Very Light	VL	70 (50-80)
Light	L	95 (80-110)
Medium	M	125 (110-150)
Heavy	H	170 (150-200)
Deep	D	235 (>200)
<i>Poorly drained profiles</i>		
Poorly drained	Pd	270 (>110)
Poorly drained, light	PdL	100 (<110)

Table 2 List of main soil series

Class	Soil series	Upland series
XL	Waimakariri very stony sand	Tasman very stony sand
VL	Waimakariri and Eyre stony silt loam, Lismore and Balmoral very stony silt loam	Mackenzie, Acheron stony loamy sand
L	Chertsey, Lismore shallow and stony silt loam	Mackenzie shallow sandy loam
M	Hatfield, Templeton, Wakanui mod deep silt loam	Pukaki mod deep sandy loam
H	Hatfield, Templeton, Wakanui (100 cm deep)	Dobson, Braemar, Curroughmore
D	Barrhill, Templeton, Wakanui (150 cm deep)	Uncommon
Pd	Temuka deep clay loam (150 cm)	Uncommon
PdL	Waterton, Taitapu shallow/stony silt loam	Uncommon

Estimating nitrate-nitrogen leaching rates under rural land uses in Canterbury

Table 3 Typifying profiles for Canterbury Plains. Numbers in parenthesis in the final column are guesstimates of Ksat under moderately compacted conditions.

Soil	Horizon attributes									Pasture		Cropping		Ksat mm/h
	Top (cm)	Base (cm)	Thick (cm)	BD (g/cc)	TP (%)	FC (%)	WP (%)	TAW (%)	Stones (%)	C (%)	N (%)	C (%)	N (%)	
Extremely light														
XL	0	10	10	1.25	52	35	8	27	40	2.3	0.21			100 (40)
XL	10	20	10	1.37	43	20	5	15	60	0.9	0.1			100
XL	20	100	80	1.6	43	12	2	10	70	0.4	0.04			100
Very Light														
VL	0	15	15	1.25	52	37	11	27	30	2.6	0.22			100 (40)
VL	15	35	20	1.37	45	32	8	24	50	1.2	0.1			60
VL	35	100	65	1.6	43	12	2	10	65	0.4	0.04			100
Light														
L	0	18	18	1.28	50	37	15	22	0	2.72	0.22	2.2	0.21	60 (20)
L	18	33	15	1.45	45	32	15	17	0	1.38	0.12	1.1	0.09	15
L	33	45	12	1.5	45	15	3	12	50	0.85	0.8	0.64	0.06	30
L	45	100	55	1.6	43	12	2	10	60	0.67	0.05	0.48	0.03	100
Medium														
M	0	20	20	1.34	49	38	16	22	0	2.9	0.24	2.09	0.17	60(10)
M	20	50	30	1.6	39	32	15	17	0	1.38	0.11	1.02	0.09	6
M	50	60	10	1.7	38	32	17	15	0	0.51	0.05	0.47	0.05	3
M	60	100	40	1.6	43	12	2	10	60		0.02		0.02	100
Heavy														
H	0	20	20	1.34	49	38	16	22	0	2.9	0.24	2.09	0.17	30 (10)
H	20	50	30	1.6	39	32	15	17	0	1.38	0.11	1.02	0.09	6
H	50	100	50	1.7	38	35	20	15	0	0.51	0.05	0.47	0.05	1
Deep														
D	0	20	20	1.34	49	38	16	22	0	2.9	0.24	2.09	0.17	30 (10)
D	20	50	30	1.6	39	32	15	17	0	1.38	0.11	1.02	0.09	6
D	50	100	50	1.7	38	35	20	15	0	0.51	0.05	0.47	0.05	1
D	100	150	50	1.6	40	35	22	13	0	0.35	0.04	0.35	0.04	3
Poorly drained														
Pd	0	20	20	1.25	50	47	27	20	0	4.96	0.45	2.85	0.23	100 (10)
Pd	20	50	30	1.5	46	42	27	15	0	1.92	0.17	1.36	0.11	3
Pd	50	100	50	1.45	44	43	23	20	0	1.03	0.08	0.6	0.04	3
Pd	100	150	50	1.45	44	43	26	17	0	0.6	0.05	0.6	0.04	6
Poorly drained, light														
PdL	0	20	20	1.25	50	42	16	26	0	4	0.38	2.55	0.21	100 (10)
PdL	20	50	30	1.45	46	35	15	20	30	1.6	0.14	1.25	0.1	10
PdL	50	100	50	1.6	44	14	3	11	60	0.67	0.05	0.07	0.05	100

Table 4 Description of Table headings in Table 3.

Heading	Description
Top	Depth to top of horizon
Base	Depth to base of horizon
Thick	Thickness of horizon
BD	Bulk density of fines
TP	Total porosity
FC	Field Capacity of fines (water at 10kPa)
WP	Wilting Point of fines (water at 1500kPa)
TAW	Total available water of fines (FC-WP)
Stones	Percentage of particles > 2mm diameter
C	Total Carbon
N	Total Nitrogen
Ksat	Saturated hydraulic conductivity

Appendix 4: Effect of poor drainage on leaching of nitrates

Trevor Webb
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There is limited research data available to compare nitrate leaching under poorly drained and well drained sites. It is, after all, rather difficult to measure leaching under a water table.

Measurements

Roland Stenger et al (2008) found very low N concentrations under poorly drained soils at Toenepi in the Waikato. Denitrification largely removed all nitrogen from these sites. Water tables rose into the upper 1m of soil earlier in the year and remained there for longer than would occur in most areas in Canterbury. There is also a confounding effect of abiotic denitrification related to reduction via presence of Fe²⁺ minerals – but this will largely occur below the root zone. Toenepi has deep fine texture materials extending into the aquifer and denitrification occurs within the vadose zone and within the aquifer.

Work on denitrification rates (as in de Klein et al. (2003) and Rappoldt and Corre (1997)) also indicate significant effects of poor drainage.

Application to Canterbury

The effect of poor drainage is very difficult to model due to the seasonal fluctuation of water tables. In Canterbury, there is likely to be some leaching of nitrates in the summer-autumn-early winter period – but late-winter and spring will have high denitrification rates in the root zone. Poorly drained soils in the lower plains will also have significant denitrification in the vadose and aquifer zones because these are fine-textured.

Recommendation

In the absence of a water table, poorly drained soils are very similar in profile features to heavy soils. The additional effect of a fluctuating water table could be accounted for by reducing this value from heavy soils. It is my recommendation that nitrate leaching for poorly drained soils be calculated as 0.5 x the value from heavy soils and for 'light poorly drained' be calculated as 0.5 x the value from light soils. I think that this will be a conservative estimate of the reduction in leaching due to poor drainage.

References

Roland Stenger, Greg Barkle, Craig Burgess, Aaron Wall and Juliet Clague 2008. Low nitrate contamination of shallow groundwater in spite of intensive dairying: the effect of reducing conditions in the vadose zone–aquifer continuum. *Journal of Hydrology (NZ)* 47 : 1-24

Seven well transects were established in this rolling downlands catchment. (The catchment has artificial drainage). The monitoring wells were typically only 2.5 to 3.0 m deep. The 34 wells were sampled monthly for two years. Relative to the land-use intensity on the dairy farms (avg. 3.1 cows/ha, 99 kg/ha/yr Nfertiliser), NO₃-N concentrations in the shallow groundwater were generally very low. Eighty percent of the 843 samples had concentrations below the ANZECC trigger value for eutrophication of surface water (0.44 mg NO₃-N L⁻¹). The results indicated that nitrate reduction through heterotrophic and/or autotrophic denitrification is widespread in this catchment in the vadose zone and/or in the shallow

aquifer. The overall mean of all samples analysed from the 34 wells was only 0.53 mg NO₃-N/L. Consistently very low concentrations came from sites underlying poorly drained soils. Average NO₃-N concentrations in 30 cm and 60 cm depth were predominantly substantially lower at the poorly drained sites compared to the well drained sites.

DeKlein et al (2003) (*Aust J of Soil Res.* 41:381-399). studied emission of N₂O from urine patches on four soil types and found that poorly drained soils had the largest emission of nitrous oxides caused by denitrification, even though this soil had lowest rainfall and temperature. Rappoldt and Corre (1997) found emission of N₂O were 10 times greater at 6 m from drains than at 1 m distance.

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Environment Canterbury offices

Christchurch
58 Kilmore Street
PO Box 345
Christchurch 8013

P: 03 365 3828
F: 03 365 3194

Timaru
75 Church Street
PO Box 550
Timaru 7940

P: 03 687 7800
F: 03 687 7808