

BEFORE THE CANTERBURY REGIONAL COUNCIL

IN THE MATTER OF the Resource Management Act 1991

A N D

IN THE MATTER OF Water permit applications by Simons Pass Station Limited and
Simons Hill Station Limited, Rosehip Orchards New Zealand
Limited and High Country Rosehip Orchards Limited

**STATEMENT OF EVIDENCE OF VALERIE OLGA SNOW
DATED 17 NOVEMBER 2009**

STATEMENT OF EVIDENCE OF VALERIE OLGA SNOW

1. My name is Valerie Olga Snow. I hold a Bachelor of Agricultural Science (1983) and a Ph.D. in soil physics (1992) from Massey University. I have 18 years of research experience having been employed as a soil physicist and systems modeller at Michigan State University, USA (1992-1993), CSIRO, Australia (1994-2001), HortResearch (2001-2003), and AgResearch (2003 onwards). My research has focussed on the measurement and modelling of water, nitrogen and other solutes through several types of managed ecosystems including plantation forestry, cropping systems, and pastoral systems.
2. I currently lead the Systems Modelling Team within the Agricultural Systems Section in AgResearch. The team develops and applies several different types of simulation models to various issues, mostly environmental in focus, facing pastoral systems. My current research includes contributions to the “Pastoral 21 Environment Programme” (forecasting the risk of N leaching), “Rural Futures” (dynamic simulation model development), and “Land Use Change and Intensification” (developing tools for environmental policy development and monitoring). Through this experience I have developed a strong understanding of:
 - a. the biological and farm management processes important in determining the loss of nutrients, particularly nitrogen, from pastoral systems;
 - b. the strengths and weaknesses of several different types of models used to estimate nutrient losses from pastoral systems; and
 - c. and the very significant challenges to representing the biological processes and farm management decisions that control nutrient loss from pastoral systems in dynamic simulation models.
3. I have been involved in discussions relating to the potential impacts of the irrigation applications on water quality in the Upper Waitaki since December 2007. From April to August 2008 I contributed to the modelling and supervised the team from AgResearch and Crop & Food Research (now Plant and Food Research) for the completed farm systems and modelling that became part of the “Cumulative Effects Study” conducted by GHD.
4. I have been involved in discussions related to the estimation of nutrient losses from Simons Hill (“Simons Hill”) and Simons Pass (“Simons Pass”) Stations since June 2009 and from Rosehip Orchards New Zealand (“Rosehip Orchards”) and High

Country Rosehip Orchards (“High Country”) since September 2009. Four people have contributed to the nutrient modelling.

- a. Miss Linda Yates (AgResearch) has performed the bulk of the OVERSEER® modelling. Miss Yates has considerable experience with OVERSEER® including contributions to the teaching of the Sustainable Nutrient Management Course when was employed by Massey University. Miss Yates has successfully completed the Advanced Sustainable Nutrient Management Course.
 - b. Mr Ian Power (AgResearch) performed some OVERSEER® modelling and contributed to quality-control checks of the modelling. Mr Power manages AgResearch’s Nutrient Emissions Unit and has successfully completed the Advanced Sustainable Nutrient Management Course.
 - c. Professor Derrick Moot (Lincoln University) provided advice on the management of the lucerne crops used in the APSIM modelling and checked the results of the lucerne modelling for credibility against industry-achievable yields.
 - d. My contribution was collation of inputs, some OVERSEER® modelling, the APSIM modelling and collation of outputs. I have over 15 years of experience in modelling nutrient losses from many types of land use systems using APSIM.
5. This evidence discusses: the approach used to model the total nutrient losses from the proposed irrigated areas and their associated dryland areas; the models used for the nutrient estimation along with their strengths and weaknesses for the current purpose; the modelled nutrient losses from the irrigated areas; and finally discusses the environmentally-conservative nature of the modelling.
6. I confirm that I have read and am familiar with the “Code of Conduct for Expert Witnesses” in the Environment Court Practice Note (31 July 2006). I agree to comply with the Code.

Modelling Approach

7. This evidence presents information on the likely nutrient losses from several proposed land uses for seven irrigated areas that contribute towards the nutrient thresholds for six ground- and surface-water nodes. The derivation of these thresholds and the comparison of the modelled nutrient losses against the thresholds will be covered by Dr Robson in her evidence.

8. The area contributing to each of the six nutrient thresholds was sub-divided into several categories by Mr Peter Glasson and the areas, slopes, soil information, and intended uses supplied to me in spreadsheet form. These areas are described in the Appendices on Page 12 with additional, more detailed, information presented on the proposed irrigated areas on Page 13.
9. Nutrient losses from the dryland areas were calculated from the intended land use utilising information from the previous AgResearch¹ and GHD² modelling. Full information on these, including the information sources, is given in the Appendices on Page 12.
10. Nutrient losses from the irrigated areas were modelled using OVERSEER® or a combination of OVERSEER® with APSIM for a range of potential land uses as shown in the Appendices on Page 14. The farm systems were based on Farmax modelling performed by Mr Graeme Ogle and presented in his evidence³. Because of the similarity of climate, soil types and proposed farm systems between the irrigated areas it was not necessary to explicitly model all the combinations of irrigated area and farm systems. Instead, sufficient combinations were modelled that the nutrient losses could be robustly extrapolated to the other areas on a “per hectare” basis. System descriptions are given in the Appendices on Page 14 while the table on Page 18 gives proposed combinations of irrigated area and land use and also indicates which combinations were formally modelled and the source of the information used for those systems that were not formally modelled.
11. Most of the farm systems were modelled in OVERSEER®. The exceptions were the lucerne-based systems which, at present, OVERSEER® cannot model. These systems were modelled in a combination of APSIM and OVERSEER®. All of those systems are operated on a 10-year rotation with lengths of break between lucerne crops varying from 0 to 3 years. The detailed management of the lucerne, as described in APSIM, including the grazing management is given in the Appendices on Page 19. The approach taken was to model the years that were lucerne only or lucerne being renewed with a forage crop in APSIM and the years with cash crops in OVERSEER®. The APSIM and OVERSEER® results were then combined in the

¹ Snow VO, Smeaton DC, Houlbrooke DJ (2008) Upper Waitaki Farm Systems and Nutrient Assessment. Stage 3: Base case nutrient assessments. Addendum - Killermont Station. Report prepared for GHD. September 2008. AgResearch, Palmerston North.

² GHD (2009) Cumulative Water Quality Effects of Nutrients from Agricultural Intensification in the Upper Waitaki Basin. Rivers and Lakes Report. Prepared for Russell McVeagh on behalf of Mackenzie Water Research Limited. April 2009. GHD.

³ Statement of evidence of Graeme Ian Ogle. In the matter of The Resource Management Act 1991 and in the matter of water permit applications by Simons Pass Station Limited, Simon Hill Station Limited, Rosehip Orchards NZ, and High Country Rosehips.

correct proportions to obtain the systems described in the Appendices. The OVERSEER® and APSIM input files are available on request.

12. There is no equivalent of OVERSEER®'s HD⁴ setting in either the OVERSEER® cropping module or in APSIM. One of the purposes of the HD setting is to add a safety margin as OVERSEER® might underestimate leaching in shallow soils. The HD effect for the OVERSEER® cropping models was calculated by adding the amount of mineral N remaining in the soil at the end of the year to the calculated leaching losses. Net immobilisation of nitrogen in the APSIM model of the lucerne system was first high⁵ and then tapered off⁶, as would be expected for a system under change. However, because there was no discernable trend of increased leaching with time⁷, it was assumed that the HD leaching values were the same as the Developed setting.
13. APSIM could not be used to assess the P losses from the lucerne system and the OVERSEER® cropping modelled P losses were less than 0.1 kg P /ha /yr. In light of the P losses estimated from the pastoral model of OVERSEER® these values did not seem reasonable. Therefore, as an environmentally-conservative approach, the losses from these systems were assumed to be 0.6 kg P /ha /yr which was the highest value modelled from any of the pastoral blocks.

OVERSEER® for Estimating Farm Nutrient Losses

14. In the existing evidence^{8,9} and in a Section 42A report¹⁰ OVERSEER® has been confirmed as the most appropriate tool to assess likely nutrient losses from proposed farming systems in the Mackenzie Basin. OVERSEER® is a nutrient budget model that works on an annual-average time step representing a typical year, models the whole farm, but takes into account within-farm variation of pasture type, soil and

⁴ HD – “Highly Developed” setting in overseer OVERSEER®'s pastoral model that prevents any further immobilisation of nitrogen into the soil organic matter.

⁵ About 80 kg N /ha /yr for the first 10 years including a net mineralization of 12 kg N /ha in the first year of irrigation.

⁶ Averaged about 25 kg N/ha /yr after the first 10 years

⁷ There was of course a strong pattern in time related to the renewal of the lucerne. About 75% of the leaching occurred in the year of renewal and the subsequent year.

⁸ Monaghan RM (2009) Statement of evidence of Ross Monaghan. In the matter of the Resource Management Act 1991 and in the matter of a resource consent applications to take and use water for irrigation in the Mackenzie Basin.

⁹ Snow VO (2009) Statement of evidence of Valerie Olga Snow. In the matter of the Resource Management Act 1991 and in the matter of a resource consent applications to take and use water for irrigation in the Mackenzie Basin.

¹⁰ Clothier BC (2009) Report of Brent Euan Clothier. Before the Commissioners appointed by Canterbury Regional Council in the matter of The Resource Management Act 1991 and in the matter of 60 water permit applications to take and use water, 30 land use consent applications and 20 discharge permit applications, for agricultural and horticultural activities. Section 42A Officer's Report. Date of Hearing: 21 September 2009.

management characteristics. OVERSEER® has a robust representation of the whole-farm system and of the effect of urine patches on leaching. OVERSEER® does not simulate farm production but requires farm production and management as an input to the model. In the modelling presented in this evidence, the farm production was estimated by Farmax Modelling. That modelling methodology and the anticipated farm production has been reported by Mr Graeme Ogle³.

15. The primary strength of the OVERSEER® modelling approach is that, in development of the model, due attention is paid to the aspects of farm management that have the strongest influences on nutrient losses. Because most of the nitrogen leached from pastoral farms originates from urine patches, it is not possible to adequately estimate nitrogen loss from these farms without robustly including the number, stock class, and pattern in time of animal intake on the farm. Other factors, such as fertiliser inputs and imported animal supplements, are also important but their effect is primarily mediated through animal excretion into urine patches. In order to accurately model the deposition in time of urine patches it is necessary to model the details of farm management as this controls the number of animals on the property. Dynamic simulation models, such as APSIM, are not yet adequately able to mimic future¹¹ management at the whole farm level and so are not currently robust for use to anticipate nutrient losses from pastoral farms.

16. A potential weakness of OVERSEER® for modelling nutrient losses from these farms in the Mackenzie Basin includes that Dr Ross Monaghan and I are of the opinion that OVERSEER® is underestimating losses from some of the particularly shallow soils in the Basin **Error! Bookmark not defined.** This weakness can be mitigated by using the “Highly Developed” option in OVERSEER®¹². Another potential weakness of OVERSEER® is that it requires that best management practices are used for several aspects of farm management. These best management practices include code of practise fertiliser applications¹³ and best practice in the design and operation of the irrigation systems. All the OVERSEER® model results presented in this evidence assumed that stock would be fenced from waterways. These best management practices are therefore required of the farm managers and are built into the farm environmental management plans.

¹¹ Past, and therefore known, farm management can be modelled. Future management at the paddock level can also be modelled.

¹² Snow VO (2009) Statement of Valerie Olga Snow. Rebuttal of Evidence. In the matter of the Resource Management Act 1991 and in the matter of a resource consent applications to take and use water for irrigation in the Mackenzie Basin.

¹³ Code of Practice for Nutrient Management (With Emphasis on Fertiliser Use). NZFMRA, 2007 (www.fertresearch.org.nz/code-of-practice)

Another weakness of OVERSEER® is that not all of the proposed farm management systems can currently be modelled in OVERSEER®. This includes the planned lucerne systems for Rosehip Orchards and High Country. These weaknesses are addressed by taking environmentally-conservative assumptions that are known to over-estimate likely nutrient losses the lucerne systems in another model, APSIM.

Robustness of APSIM for Estimating Nutrient Losses from Lucerne

17. APSIM^{14,15} is a dynamic simulation model of the soil-plant system. It contains modules for capturing the processes occurring in the soil water and carbon/nitrogen cycle¹⁶ as well as the growth of many crops, including lucerne¹⁷. Much of the early development of APSIM was within a setting of investigating the limitations to crop growth in the Australian environment. Over the years the scope of the modelling capability in APSIM has expanded and it has been used to investigate drainage under cropping¹⁸ systems and in mole-tile drained paddocks¹⁹, water²⁰ and nitrogen²¹ management in effluent-irrigated systems, and currently is being expanded to include modules to simulate pasture species growth and to represent the management of pastoral farms. The model source code is openly available from the APSIM web site¹⁵ and the software licences are readily available.
18. The particular strength of APSIM is that it captures the impact of soil, climate and management on nitrate leaching and that it expresses the feedbacks from leaching into changes in production. Depending on the system it is possible that the changes

¹⁴ Keating BA, Carberry PS, Hammer GL, Probert ME, Robertson MJ, Holzworth DP, Huth NI, Hargreaves JNG, Meinke H, Hochman Z, McLean G, Verburg K, Snow VO, Dimes JP, Silburn DM, Wang E, Brown SD, Bristow KL, Asseng S, Chapman SC, McCown RL, Freebairn DM, Smith CJ (2003) An overview of APSIM, a model designed for farming systems simulation. *European Journal of Agronomy* **18**, 267-288.

¹⁵ <http://www.apsim.info/apsim/>

¹⁶ Probert ME, Dimes JP, Keating BA, Dalal RC, Strong WM (1998) APSIM's water and nitrogen modules and simulation of the dynamics of water and nitrogen in fallow systems. *Agricultural Systems* **56**, 1-18.; and Ranatunga K, Hill MJ, Probert ME, Dalal RC (2001) Comparative application of APSIM, RothC and Century to predict soil carbon dynamics. In 'MODSIM 2001'. Canberra pp. 733-738.; and Thorburn PJ, Probert ME, Robertson FA (2001) Modelling decomposition of sugar cane surface residues with APSIM-Residue. *Field Crops Research* **70**, 223-232.

¹⁷ Robertson, M.J., Carberry, P.S., Huth, N.I., Turpin, J.E., Probert, M.E., Poulton, P.L., Bell, M., Wright, G.C., Yeates, S.J., and Brinsmead, R.B. (2002). Simulation of growth and development of diverse legume species in APSIM, *Australian Journal of Agricultural Research* 53:429-446.; and Robertson M, Gaydon D, Latta R, Peoples M and Swan A (2004) Simulating lucerne/crop companion farming systems in Australia. In: "New directions for a diverse planet". Proc. 4th International Crop Science Congress, Brisbane, CDROM ISBN 1 920842 217. Web site www.cropscience.org.au

¹⁸ Verburg K, Bond WJ (2003) Use of APSIM to simulate water balances of dryland farming systems in south eastern Australia. CSIRO Land and Water Technical Report 50/03, Canberra.

¹⁹ Snow VO, Houlbrooke DJ, Huth NI (2007) Predicting soil water, tile drainage, and runoff in a mole-tile drained soil. *New Zealand Journal of Agricultural Research* **50**, 13-24.

²⁰ Snow VO, Bond WJ, Myers BJ, Theiveyanathan S, Smith CJ, Benyon RG (1999) Modelling the water balance of effluent-irrigated trees. *Agricultural Water Management* **39**, 47-67.

²¹ Snow VO, Smith CJ, Polglase PJ, Probert ME (1999) Nitrogen dynamics in a eucalypt plantation irrigated with sewage effluent or bore water. *Australian Journal of Soil Research* **37**, 527-544.; and Snow VO, Dillon PJ, Bond WJ, Smith CJ, Myers BJ (1999) Groundwater contamination from effluent irrigation. *Journal Australian Water and Wastewater Association* **26**, 26-29.

in production might, within the model, lead to additional feedbacks of increased fertiliser usage and in turn would increase crop growth that might further increase leaching. In this respect it operates more as a complete system than does OVERSEER®. Another strength of APSIM is that it models the crop production rather than relying on sensible input values for the soil and climate being modelled. There are some farming systems that can be modelled in APSIM, such as lucerne, which cannot currently be modelled in OVERSEER®.

19. Potential weaknesses of APSIM for the work described here include the existing mechanisms for dealing with patchy urine returns to the soil and subsequent leaching are limited and so the simulation management rules to control the urine return must be considered with care. APSIM is more sensitive to input data, particularly weather and soil properties, than is OVERSEER®. Mechanisms for modelling whole farm management in APSIM are under development and this can be a limitation for some applications. The usage here was in a single-paddock context so this weakness does not apply.

Dryland Nutrient Losses

20. The land uses of the dryland areas of the properties do not change between land use scenarios and were not formally modelled. Values from previous work in the Water Quality Study were instead used to estimate the losses from these areas. Those values are given in the Appendices on Page 12. Nitrogen losses ranged from 1.8 to 5.3 kg N /ha /yr and P losses ranged from 0.01 to 0.2 kg P /ha /yr. Note that, consistent with the Water Quality Study, there is no usage of the HD setting for dryland blocks as the modelled immobilisation was consistently low. The per hectare values were multiplied by the respective areas to obtain the total dryland nutrient losses for each property and node. Those node values are given in Table 1.

Table 1: Total N and P loss for the dryland areas for each of the properties and nodes.

Irrigation Area	Area (ha)	Total N loss (kg N /yr)	Total P loss (kg P /yr)
High Country	632	1220	7
Rosehip Orchards	163	292	1
Simons Hill - Maryburn	1299	4308	229
Simons Hill - Pukaki Flats	2776	6951	259
Simons Pass - Maryburn	393	2079	43
Simons Pass - Pukaki Flats	3472	12761	218

Per Hectare Irrigated Nutrient Losses

21. Nutrient losses were modelled from a range of farming systems and soil types and the per hectare nutrient losses from those combinations are given in Table 2. Note that the last two lines of the table represent the particular cropping years in the lucerne-cropping cycle rather than the whole 10-year rotation average. They are included for reference only as it is the rotation average that is required for the calculation of the irrigated area nutrient losses and for in comparison against the nutrient discharge allowances.

Table 2: Modelled N and P loss for the systems and soils modelled. The farming systems are described in the Appendices on Page 14. “Winter Wheat” and “Forage & Barley” give the values for those particular years in the cropping system. All the other values are long-term averages for the whole system.

System	Soil	N loss, Dev	N loss, HD	P loss
		(kg N /ha /yr)	(kg N /ha /yr)	(kg P /ha /yr)
Bull	PAW30/60	9	16	0.5
Crop10	PAW30/60	20	24	0.6
Crop15	PAW30/60	20	27	0.6
DOFF	PAW30/60	16	18	0.5
	PAW90/130	17	20	0.6
Luc	PAW30/60	9	9	0.6
LucLamb	PAW30/60	20	20	0.6
SBFIN	PAW30/60	8	12	0.4
	PAW90/130	10	13	0.5
SBHC	PAW30-130	9	13	0.3
SBIFIN	PAW30/60	9	13	0.2
	PAW90/130	11	14	0.2
Winter Wheat	PAW30/60	20	56	0.6
Forage & Barley	PAW30/60	16	48	0.6

22. At the HD condition the nitrogen losses ranged from a low of 8 kg /ha /yr for one of the sheep and beef systems to a high of 27 kg N /ha /yr for the most intensive cropping system considered. Phosphorus losses ranged from 0.2 to 0.6 kg P /ha /yr. Many of the proposed systems show lower nutrient losses for the lighter soil types (PAW30/60) than the heavier soils (PAW90/130). This is because less intensive farming systems have been proposed for those soil types.

Total Area Nutrient Losses

23. The nitrogen and phosphorus losses from the various irrigated scenarios were aggregated up by multiplying the loss values for the irrigated areas for each proposed land use. The dryland nutrient losses were added to the losses from the irrigated area to calculate the total losses for each area. These values are given in Table 3 and were supplied to Dr Robson. Dr Robson's evidence will include comparison of the estimated total area nutrient losses against the allocated nutrient discharge allowances.

Table 3: Modelled N and P loss for the irrigated areas and associated dryland areas modelled for all farming systems.

Farming System	Irrigated block nutrient losses (kg /yr)			Total area nutrient losses (kg /yr)		
	N (Dev)	N (HD)	P	N (Dev)	N (HD)	P
High Country						
Luc	4500	4500	300	5720	5720	307
SBFIN	4000	6000	200	5220	7220	207
SBIFIN	4500	6500	100	5720	7720	107
Rosehip Orchards						
Bull	7290	12960	405	7582	13252	406
Crop10	16200	19440	486	16492	19732	487
Crop15	16200	21870	486	16492	22162	487
Luc	7290	7290	486	7582	7582	487
LucLamb	16200	16200	486	16492	16492	487
SBFIN	6480	9720	324	6772	10012	325
SBIFIN	7290	10530	162	7582	10822	391
Simons Hill - Maryburn						
SBHC	4248	6136	142	8556	10444	371
Simons Hill - Pukaki Flats						
DOFF	27760	31230	868	34711	38181	1127
SBFIN	13880	20820	694	20831	27771	953
SBIFIN	15615	22555	347	22566	29506	606
Simons Pass - Maryburn						
SBFIN	2870	3731	144	4949	5810	187
SBIFIN	3157	4018	57	5236	6097	100
Simons Pass - Pukaki Flats - Area 1A (deeper soils)						
DOFF	22219	26140	784			
SBFIN	13070	16991	654			
SBIFIN	14377	18298	261			
Simons Pass - Pukaki Flats - Area 1B (lighter soils)						
DOFF	15680	17640	490			
SBFIN	7840	11760	392			
SBIFIN	8820	12740	196			
Simons Pass - Pukaki Flats - both soils						
DOFF	37899	43780	1274	50660	56541	1492
SBFIN	20910	28751	1046	33671	41512	1264
SBIFIN	23197	31038	457	35958	43799	675

Environmentally-Conservative Nature of the Modelling Methodology

24. The modelling methodology used was environmentally conservative. Where the models used did not permit an exact replica of the proposed farming systems then conservative assumptions were made. For example the mineral nitrogen remaining in the soil at the end of the cropping cycles was assumed to leach under the HD scenario. Given that the cropping cycles ended in February with a forage crop direct drilled while there was still a reasonably good growing period, it is unlikely that the entire remaining nitrogen will leach and so this is a conservative assumption. On the irrigated pastoral blocks high Olsen P values, 25 for sheep and beef and 30 for dairy, were assumed so as to ensure that P losses were not underestimated.
25. The environmental conservatism does not however lessen the need for best management practice on the properties. Given the large area of irrigation proposed and the light soils in the Pukaki Flats areas of Simons Pass and Simons Hill Stations, I recommend that a high standard of monitoring be maintained. This would include soil sampling for development status and, if technically possible, the use of large lysimeters to monitor losses on an on-going basis.

Conclusions

26. Several combinations of farming systems have been modelled, primarily in OVERSEER® but some systems with the assistance of APSIM, for the proposed irrigated areas on the land owned by Simons Pass Station Limited, Simons Hill Station Limited, Rosehip Orchards New Zealand Limited, and High Country Rosehip Orchards Limited.

Val Snow

17 November 2009

Appendix 1: Sub-areas within the Nutrient Discharge Allowance Nodes with calculation method (see “Notes”) and estimated nutrient losses for the dryland areas.

Irrigation ID	AreaID	Notes	Area (ha)	Status	Slope	Soil	StockRate (SU/ha)	N loss (kg/ha/yr)	P loss (kg/ha/yr)
High Country	HC_Dry	2, 6	632	dryland	Flat	PAW60	0.6	1.93	0.01
High Country	HC_Irr	7	500	irrigated	Flat	PAW60	several		
Rosehip Orchards	RO_Dry	5	163	dryland	Flat	PAW60	0.5	1.79	0.01
Rosehip Orchards	RO_Irr	7	810	irrigated	Flat	PAW60	several		
Simons Hill, Maryburn	SHS4_Dry	2, 5	157	dryland	Flat	PAW60/130	1.5	3.19	0.05
Simons Hill, Maryburn	SHS_6	1, 2	148	dryland	Hills	PAW60	1.5	3.19	0.2
Simons Hill, Maryburn	SHS_8	2	143	dryland	Slopes	PAW60	1.5	3.19	0.2
Simons Hill, Maryburn	SHS_9	2	657	dryland	Hills	PAW60	1.5	3.19	0.2
Simons Hill, Maryburn	SHS_10	3	116	dryland	Slopes	PAW60	1.5	3.19	0.2
Simons Hill, Maryburn	SHS_7	2	78	dryland	Flat	PAW90	3	5.29	0.11
Simons Hill, Maryburn	SHS4_Irr	7	472	irrigated	Flat	PAW60/130	several		
Simons Hill, Pukaki Flats	SHS3_Dry	4, 5	518	unfarmed	Flat	PAW30/60	0	2	0.02
Simons Hill, Pukaki Flats	SHS_1	4	429	unfarmed	Flat	PAW30	0	2	0.02
Simons Hill, Pukaki Flats	SHS_2	4	14	unfarmed	Flat	Wetland	0	2	0.02
Simons Hill, Pukaki Flats	SHS_3	4	556	unfarmed	Flat	PAW30	0	2	0.02
Simons Hill, Pukaki Flats	SHS_4	4	83	unfarmed	Flat	PAW30	0	2	0.02
Simons Hill, Pukaki Flats	SHS_5	3	1176	dryland	Hills	PAW60	1.5	3.19	0.2
Simons Hill, Pukaki Flats	SHS3_Irr	7	1735	irrigated	Flat	PAW30/60	several		
Simons Pass, Maryburn	SPS2_Dry	2, 5	225	dryland	Flat	PAW130	3	5.29	0.11
Simons Pass, Maryburn	SPS_5	2	168	dryland	Flat	PAW90/130	3	5.29	0.11
Simons Pass, Maryburn	SPS2_Irr	7	287	irrigated	Flat	PAW130	several		
Simons Pass, Pukaki Flats	SPS_1	4	292	unfarmed	Flat	PAW30/60	0	2	0.02
Simons Pass, Pukaki Flats	SPS1B_Dry	2, 5	612	dryland	Flat	PAW30/60	1.5	3.19	0.05
Simons Pass, Pukaki Flats	SPS_2	2	1313	dryland	Flat	PAW90/130	1.5	3.19	0.05
Simons Pass, Pukaki Flats	SPS_3&7	2	182	dryland	Flat	PAW60	1.5	3.19	0.05
Simons Pass, Pukaki Flats	SPS_4	2	105	dryland	Flat	PAW30/60	1.5	3.19	0.05
Simons Pass, Pukaki Flats	SPS1A_Dry	2, 5	817	dryland	Flat	PAW90/130	3	5.29	0.11
Simons Pass, Pukaki Flats	SPS_6	2	151	dryland	Flat	PAW130	3	5.29	0.11
Simons Pass, Pukaki Flats	SPS1A_Irr	7	1307	irrigated	Flat	PAW90/130	several		
Simons Pass, Pukaki Flats	SPS1B_Irr	7	980	irrigated	Flat	PAW30/60	several		

Notes: 1 - 409 ha of DoC estate excluded from this area; 2 - From Snow etal (2008) Stage 3 report; 3 - N loss from Snow etal (2008) Stage 3 report, P loss from p89 App B GHD (2009) Rivers & Lakes for hill country; 4 - From p89 App B GHD (2009) Rivers & Lakes for general unfarmed but vegetated areas; 5 - dryland area within the irrigation command area; 6 - 377 ha of Upper Terrace, remainder dryland area within the irrigation command area; 7 - N and P load modelled for this study and reported in this evidence. “Several” in the stocking rate column refers to the many scenarios that were considered for the irrigated areas. These stocking rates are described elsewhere in the report.

Appendix 2: Irrigated Area Descriptions and Systems Modelled

27. The modelling presented in this evidence relates to seven irrigated areas contributing to six nutrient thresholds. There are two irrigated areas within the area labelled as “Simons Pass Pukaki Flats”. Descriptions of the farm systems modelled are given in the evidence of Mr Graeme Ogle. A summary of the areas and farm systems considered are:
- a. **Simons Pass – Pukaki Flats Area 1 (SPS1A)**: irrigated area of 1307 ha of deeper, 90 and 130 mm PAW¹ soils, within Simons Pass Station at the northern end of the Pukaki Flats. The average annual rainfall is 589 mm. The proposed farming systems include dairying with wintering off, dairying wintering on with a feed pad, sheep and beef finishing, and intensive sheep and beef finishing.
 - b. **Simons Pass – Pukaki Flats Area 2 (SPS1B)**: irrigated area of 980 ha of shallower, 30 and 60 mm PAW soils, within Simons Pass Station at the northern end of the Pukaki Flats. The average annual rainfall is 589 mm. The proposed farming systems include dairying with wintering off, dairying wintering on with a feed pad, sheep and beef finishing, and intensive sheep and beef finishing.
 - c. **Simons Pass – Maryburn (SPS2)**: irrigated area of 287 ha of deeper soils west of the Mary Range within Simons Pass Station. The average annual rainfall is 589 mm. The proposed farming systems are sheep and beef finishing, and intensive sheep and beef finishing.
 - d. **Simons Hill – Pukaki Flats (SHS3)**: irrigated area of 1735 ha of shallower, 30 and 60 mm PAW soils, within Simons Hill Station at the southern end of the Pukaki Flats. The average annual rainfall is 510 mm. The proposed farming systems are dairying with wintering off, dairying wintering on with a feed pad, sheep and beef finishing, and intensive sheep and beef finishing.
 - e. **Simons Hill – Maryburn (SHS4)**: irrigated area of 472 ha of all four soil types within Simons Hill Station. The average annual rainfall is 510 mm. The land use is an integrated high country sheep and beef system.
 - f. **High Country (HC)**: irrigated area of 500 ha of the lighter soil types within High Country Rosehip Ltd. The average annual rainfall is 589 mm. The proposed farming systems are sheep and beef finishing, intensive sheep and beef finishing, and lucerne hay..

¹ PAW – plant-available water – the amount of water accessible by a pasture type plant species with a rooting depth of 0.8 m. Deeper rooting plants will be able to access a greater amount of water.

- g. **Rosehip Orchards (RO)**: irrigated area of 810 ha of the lighter soil types within Rosehip Orchards Ltd. The average annual rainfall is 589 mm. The proposed farming systems are summer-only bull beef, sheep and beef finishing, and intensive sheep and beef finishing, lucerne hay, lucerne hay with lamb grazing, lucerne hay with light grazing and about 10% cropping, and lucerne hay with light grazing and about 15% cropping.

Appendix 3: Farm System Descriptions

- 28. Dairying with wintering off. **DOFF**.
 - a. Heavier soil: 2.9 Friesian cows /ha at peak milking producing about 1100 kg milk solids /ha. Effluent is captured and stored until conditions are suitable for irrigation when the effluent is irrigated at low application depths and rates. The effluent area is 23% of the total farm area. All stock replacements are grazed away after weaning. All stock are wintered off the milking platform. No forage crops are planted and no supplements are imported. Nitrogen fertiliser is used of 126 kg N /ha /yr on the non-effluent area. Superphosphate is applied to maintain an Olsen P of 30. The area SPS1A_DOFF was formally modelled.
 - b. Lighter soil: 2.5 Friesian cows /ha at peak milking producing about 1000 kg milk solids /ha. Effluent is captured and stored until conditions are suitable for irrigation when it is irrigated with a low-rate irrigated. The effluent area is 20% of the total farm area. All stock replacements are grazed away after weaning. All stock are wintered off the milking platform. No forage crops are planted and no supplements are imported. Nitrogen fertiliser is used of 138 kg N /ha /yr on the non-effluent area. Superphosphate is applied to maintain an Olsen P of 30. The area SPS1B_DOFF was formally modelled and SHS3_DOFF was assumed to have the same per hectare nutrient losses.
- 29. Integrated High Country System. **SBHC**.
 - a. No stock in winter but supporting 16.5 SU /ha overall 17% of which are beef animals. 8% of the irrigated area is planted to ryecorn forage. N fertiliser of 40 kg N /ha /yr is used on the pasture and 66 kg N /ha /yr on the forage block. Superphosphate is applied to maintain an Olsen P of 25.
- 30. Lamb finishing, bull finishing and dairy grazing. **SBFIN**.

- a. Heavier soil: 18.1 total SU /ha of which 71% are from beef animals. 7% of the irrigated area is planted to ryecorn forage. N fertiliser of 40 kg N /ha /yr is used on the pasture and 66 kg N /ha /yr on the forage block. Superphosphate is applied to maintain an Olsen P of 25. Irrigated area SPS1A_SBFIN was formally modelled and the per hectare nutrient loss was applied to SPS2_SBFIN.
 - b. Lighter soil: 16.6 total SU /ha of which 71% are from beef animals. 7% of the irrigated area is planted to ryecorn forage. N fertiliser of 40 kg N /ha /yr is used on the pasture and 66 kg N /ha /yr on the forage block. Superphosphate is applied to maintain an Olsen P of 25. Irrigated area SPS1B_SBFIN was formally modelled and the per hectare nutrient losses were applied to SHS3_SBFIN, RO_SBFIN, and HC_SBFIN.
31. Intensive lamb finishing, bull finishing and dairy grazing. **SBIFIN**.
- a. Heavier soil: 19.9 total SU /ha of which 68% are from beef animals. 15% of the irrigated area is planted to forage crops of turnips, kale and swede. N fertiliser of 40 kg N /ha /yr is used on the pasture and between 40 and 60 kg N /ha /yr on the forage blocks. Superphosphate is applied to maintain an Olsen P of 25. Irrigated area SPS2_SBFIN was formally modelled and the per hectare nutrient losses were applied to SPS1A_SBFIN
 - b. Lighter soil: SPS1B_SBFIN, SHS3_SBFIN, RO_SBFIN, and HC_SBFIN were estimated from the same system for the heavier soil (SPS2_SBFIN) using the ratio between SPS1B_SBFIN and SPS1A_SBFIN to scale the nitrogen losses down by 20% and 8% for the N losses at Dev and HD and by 20% for the P losses to account for less intensive system run on the lighter soil.
32. Summer-only bull beef finishing. **Bul**.
- a. Light soil: 21.1 total SU /ha of which 100% are from beef animals. No forage crops are planted. N fertiliser of 76 kg N /ha /yr is used on the pasture. Superphosphate is applied to maintain an Olsen P of 25. Irrigated area RO_Bul was formally modelled.
33. Lucerne hay, no grazing. **Luc**.²

² Note that the systems "Luc", "Crop10", and "Crop15" are additional to those described by Mr. Ogle. They do not significantly alter the feasibility of the livestock enterprises, as such they did not need additional remodeling in Farmax

- a. Light soil: On average 17.9 t DM /ha /yr lucerne hay was removed in 3 to 5 cuts (usually 4) per year with cutting triggered when the above-ground biomass reaches 4.5 t DM /ha. Lucerne is renewed every 10 years by spraying in October and direct drilling in the new crop in December. No N fertiliser is applied. RO_Luc was formally modelled and the values applied to HC_Luc.

- 34. Lucerne hay, light grazing with lambs. **LucLamb**.
 - a. Light soil: On average 13.9 t DM /ha /yr lucerne hay removed by 3 cuts per year until the end of January with cutting triggered when the above-ground biomass reaches 4.5 t DM /ha. The lucerne is grazed by lambs at a stocking rate of 35 lambs /ha between from February through to April eating on average 1.2 kg DM /lamb /day. There is no grazing in the year in which the lucerne is renewed. Lucerne is renewed every 10 years by spraying in February and direct drilling oats (no ryecorn crop model was available) in early March. The oats were grazed on 15 August and sprayed out in October. Lucerne was direct drilled in December. No N fertiliser is applied. RO_LucLamb was formally modelled.

- 35. Lucerne hay, with winter wheat. **LucCrop10**.
 - a. Light soil: This is a 10-year rotation primarily of lucerne hay with autumn lamb grazing as above but with a longer break including some cropping. Eight years of lucerne hay with lamb grazing as above. In mid-February spray out the lucerne and direct drill winter wheat. Light grazing of the wheat with lambs in May. Apply N fertiliser of 150 kg N over 3 applications in April, June and September. Harvest in January at 8 t /ha. In February direct drill with ryecorn or triticale and continue as in the renewal year for the LucLamb option ending in the drilling of lucerne in December and continuing with the hay and grazing management for 8 years before the next winter wheat crop. RO_LucCrop10 was formally modelled.

36. Lucerne hay, with specialist cropping. **LucCrop15**.
- a. Light soil: This is a 10-year rotation primarily lucerne hay with autumn lamb grazing as above but with an even longer break including more cropping. Seven years of lucerne hay with lamb grazing as above. In mid-February spray out the lucerne and direct drill winter wheat. Light grazing of the wheat with lambs in May. Apply N fertiliser of 150 kg N over 3 applications in April, June and September. Harvest in January at 8 t /ha. In February direct drill with ryecorn or triticale and apply 25 kg N /ha each in March, June, August and September. Graze the crop in June and September. Plant barley in November and apply 50 kg N /ha each in November and December. Harvest in February and plant another forage crop to begin the lucerne part of the rotation so that it ends with the drilling of lucerne in December and continuing with the hay and grazing management for 7 years before the next winter wheat crop. Note that there was considerably more N fertiliser applied to this rotation than might be usual in the Mackenzie Basin. OVERSEER® indicated a significant N deficit and fertiliser was strategically applied to avoid this as an environmentally-conservative assumption. RO_LucCrop15 was formally modelled.

Appendix 4: Farming systems considered in this application, those formally modelled or source of estimation, and estimated N and P losses

System ID	SPS1A	SPS1B	SPS2	SHS3	SHS4	HC	RO
Farming systems considered in this application							
DOFF	SPS1A_DOFF (modelled)	SPS1B_DOFF (modelled)		SHS3_DOFF (Est. SPS1B)			
SBFIN	SPS1A_SBFIN (modelled)	SPS1B_SBFIN (modelled)	SPS2_SBFIN (Est. SPS1A)	SHS3_SBFIN (Est. SPS1B)		HC_SBFIN (Est. SPS1B)	RO_SBFIN (Est. SPS1B)
SBIFIN	SPS1A_SBIFIN (Est. SPS2)	SPS1B_SBIFIN (Est. SPS2)	SPS2_SBIFIN (modelled)	SHS3_SBIFIN (Est. SPS2)		HC_SBIFIN (Est. SPS2)	RO_SBIFIN (Est. SPS2)
HC					SHS4_HC (modelled)		
BUL							RO_BUL (modelled)
Luc						HC_Luc (Est. RO_Luc)	RO_Luc (modelled)
LucLamb							RO_LucLamb (modelled)
LucCrop10							RO_Crop10 (modelled)
LucCrop15							RO_Crop15 (modelled)

System ID: DOFF - Dairying, wintered off; DPAD - Dairying, with feed pad; SBFIN - Sheep/beef finishing; SBIFIN - Intensive sheep/beef finishing; HC - Integrated High Country; BUL - Bull beef, summer only; Luc - Lucerne hay, no grazing; LucLamb - Lucerne hay, light grazing; LucCrop10 - Lucerne80%:Forage10%:Cropping10%; LucCrop15 - Lucerne70%:Forage15%:Cropping15%

Appendix 5: Management and Simulation of Lucerne in APSIM

37. The lucerne rotations could not be modelled in OVERSEER® and so APSIM was used instead. The ability of APSIM to model crop growth as well as the carbon and nitrogen balances in the soil and leaching as been described in the main body of this evidence.
38. **Weather and simulation duration.** Daily weather records for 1972 to mid-October 2009 were obtained for latitude of -44.175 and longitude of 170.225 from the NIWA Virtual Climate Station¹ database. This database has previously been shown to be provide a good weather record with a robust comparison in simulation outputs compared to measured weather data². Following recommended procedure², the rainfall was scaled to the known long-term average, 510 mm /yr, and wind speed before 1997 was presented to the model as a monthly average. The absolute value of the few negative wind speeds was taken. The proposed farming system is a 10-year rotation which would have allowed for only three full rotations within the data record. More critically, the existing data record would only have allowed for three realisations of the renewal year for the lucerne and it is that year that is expected to result in the greatest leaching. To overcome this, the data record was reused several times to construct a 100-year weather sequence. The ensured that the lucerne renewal year was simulated 10 times and occurred during the actual years of 1972 (initial establishment), 1974, 1976, 1982, 1984, 1986, 1992, 1994, 1996, 2002, and 2004.
39. **Soil properties.** The soil properties developed in the initial pasture growth and drainage modelling in EcoMod³ were used with soil organic matter levels as recommended by Mr Trevor Webb for the region. The soils modelled for the Rosehip Orchards and High Country properties were the 30 mm and 60 mm PAW soils. The PAW stated is that appropriate for pasture with a 0.8 m rooting depth. Lucerne has a significantly deeper rooting depth on these soils, some 2.0 to 2.5 m deep⁴ which allows it to access about 30 mm more water in these light soils than can pasture with

¹ Tait A, Henderson R, Turner R, Zheng Z (2006) Thin plate smoothing interpolation of daily rainfall for New Zealand using a climatological rainfall surface. *International Journal of Climatology* **26**, 2097-2115; Tait A, Turner R (2005) Generating multiyear gridded daily rainfall over New Zealand. *Journal of Applied Meteorology* **44**, 1315-1323.

² Cichota R, Snow VO, Tait AB (2008) A functional evaluation of the Virtual Climate Station rainfall data. *New Zealand Journal of Agricultural Research* **51**, 317–329.

³ Snow VO, King W (2008) Upper Waitaki Farm Systems and Nutrient Assessment Stage 2: Pasture and ryecorn growth modelling. Report prepared for GHD. May 2008. AgResearch, Palmerston North.

⁴ Professor Derrick Moot, Lincoln University, personal communication, November 2009.

its shallower root system. Following information from Mr Webb^{5,6} the soil organic matter was set at 2% organic carbon at the surface and 0.05% at depth.

40. **Irrigation management.** The irrigation designs by Aqualinc Research⁷ were used to set the irrigation rules. For the “30mm” soil 10 mm of irrigation was applied whenever the calculated soil water deficit reached 15 mm but with a maximum return interval of 2 days. For the “60mm” soil the depth of application was 20 mm, the critical deficit was 30 mm, and the return interval was 4 days.
41. **Crop management.** Professor Moot⁴ provided advice on the management of the lucerne crop and an existing report⁸ provided guidance for the forage cereal used in the renewal programme. The lucerne cultivar used was “Kaituna” and it was sown to achieve 500 plants /m² on 1 December following a two month fallow. No N fertiliser was used on the lucerne crop. Ryecorn is a popular winter forage cereal in the Mackenzie Basin⁸ but that species was not available as a crop module in APSIM. Instead an oat crop was used. The cultivar was “Wintaroo” and was sown on 1 March after a 10-day fallow to achieve a plant density of 40 plants /m². No N fertiliser was applied at sowing. This is typical of forage cereal crops sown into long-term pasture in the region⁸.
42. **Grazing lucerne.** The lucerne was to be cut for silage and hay until autumn when it was to be grazed by lambs⁹. This is significant because the urine patches caused by grazing animals are known to be a primary source of leaching¹⁰ and previous work¹¹ has shown that if, in a simulation model, the urine is uniformly returned to the soil then leaching will be underestimated. This is a known effect for the large urine patches caused by mature beef animals but is likely to be a smaller effect for lambs which have much smaller urine patches¹⁰. Nevertheless it was important that the effect be captured in the modelling. The following assumptions were made. Some

⁵ Webb TH (1992) Soils of the Upper Waitaki Basin, South Island, New Zealand. DSIR Land Resources Scientific Report No. 3. DSIR Land Resources, Lower Hutt, New Zealand.

⁶ Soil data for land overlying alluvial aquifers in Canterbury. Trevor Webb. June 2008. Personal communication.

⁷ Aqualinc Research Limited (2008) Irrigation and Drainage Modelling of the Upper Waitaki Basin. Prepared for GHD Limited. Report No C08054/1. August 2008. Aqualinc Research Limited.

⁸ Trolove S (2008) Yields of dryland and irrigated crops grown in the Upper Waitaki Catchment – literature review. Crop & Food Research Confidential Report No 2105. Report prepared for AgResearch. May 2008. Crop and Food Research, Palmerston North, New Zealand.

⁹ Statement of evidence of Graeme Ian Ogle. In the matter of The Resource Management Act 1991 and in the matter of water permit applications by Simons Pass Station Limited, Simon Hill Station Limited, Rosehip Orchards NZ, and High Country Rosehips.

¹⁰ Haynes RJ, Williams PH (1993) Nutrient cycling and soil fertility in the grazed pasture ecosystem. *Advances in Agronomy* **49**, 119-199.

¹¹ Snow VO, Johnson IR, Parsons AJ (2009) A Single Heterogeneous Paddock approach to modelling the effects of urine patches on production and leaching in grazed pastures. *Crop and Pasture Science* **60**, 691–696.

4000 kg DM /ha (determined by initial simulation runs) was removed by 35 lambs /ha eating 1.2 kg DM /lamb /day for 90 days. This resulted in 160 kg N eaten by the lambs each autumn. Of that 0.3 was assumed to be laid down as body mass, and using typical ratios¹⁰ 0.3 was assumed to be excreted as dung and the remaining 0.4 as urine.

43. It is important to capture the proportion of the crop that receives urine returns correctly – this is less of an issue for dung which is a slow-release form of N. Literature review¹⁰ shows that typically lambs urinate 20 times per day on a wetted area on 0.03 m². However because there are 500 lucerne plants /m², so that each plant nominally occupies an area of 0.01 m², with overlapping root systems. Given these area ratios the wetted urine patch must cover between 4 and 9 plants directly. If the lucerne plants within 0.3 m of the centre of the urine patch as assumed to have roots that reach into the urine patch then two 'layers' of surrounding plants can be taken to have access to the N in the urine. The amounts to between 16 and 47 plants, or 0.16 to 0.47 m² of soil surface area. In this modelling a conservative approach was taken and a value of 0.23 m² was used to represent the area affected by urine. The effective deposition then became 44 kg N /ha /yr to be applied on a single day during the grazing. This was taken to be the middle of the month with the actual month of deposition cycling through the grazing months. Previous work¹² has shown that temporal aggregation such as this is an effective method to represent urine deposition and when applied in the autumn results in an over estimate of leaching – this providing a conservative assumption in this instance. The dung was applied uniformly over the paddock in the month following the urine deposition.
44. The lucerne was cut for conservation whenever it reached a biomass of 4.5 t DM /ha until February when the lamb grazing began. It was assumed that 15% of the cut biomass was lost during harvest and drying and that dry matter, with the accompanying nitrogen, was returned to the soil surface as plant residues to be incorporated into the soil organic matter in the normal course of the simulation. No N fertiliser was applied.

¹² Snow VO, Zyskowski RF, Cichota R, Lilburne LR, Jamieson PD (2007) The effect of temporal aggregation on modelling pasture growth and nitrate leaching from urine patches. In 'MODSIM 2007 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2007. ISBN : 978-0-9758400-4-7. www.mssanz.org.au/MODSIM07/papers/25_s25/TheEffect_s25_Snow_.pdf. University of Canterbury. (Eds D Kulasiri, L Oxley) pp. 1646-1652. (Modelling and Simulation Society of Australia and New Zealand).

45. **Grazing forage cereal.** It was assumed that cereal crops were mob-stocked with a high density of animals to ration intake. This made the simulation of the excretal returns somewhat easier than the longer grazing of the lucerne as it could be assumed that the whole soil surface area was affected by excreta. The cereal crop was grazed every year on 15 August. This date was chosen as a conservative assumption. It was sufficiently late that there was a reasonable biomass on the crop, and therefore a reasonable return of excreta to the soil surface, yet it was sufficiently early that the N in the urine was likely to leach.
46. **Results – Immobilisation of nitrogen.** It is important to examine not just the leaching but also some of the other outputs to ensure that the results are reasonable. The changes in the soil carbon and nitrogen are important in this.

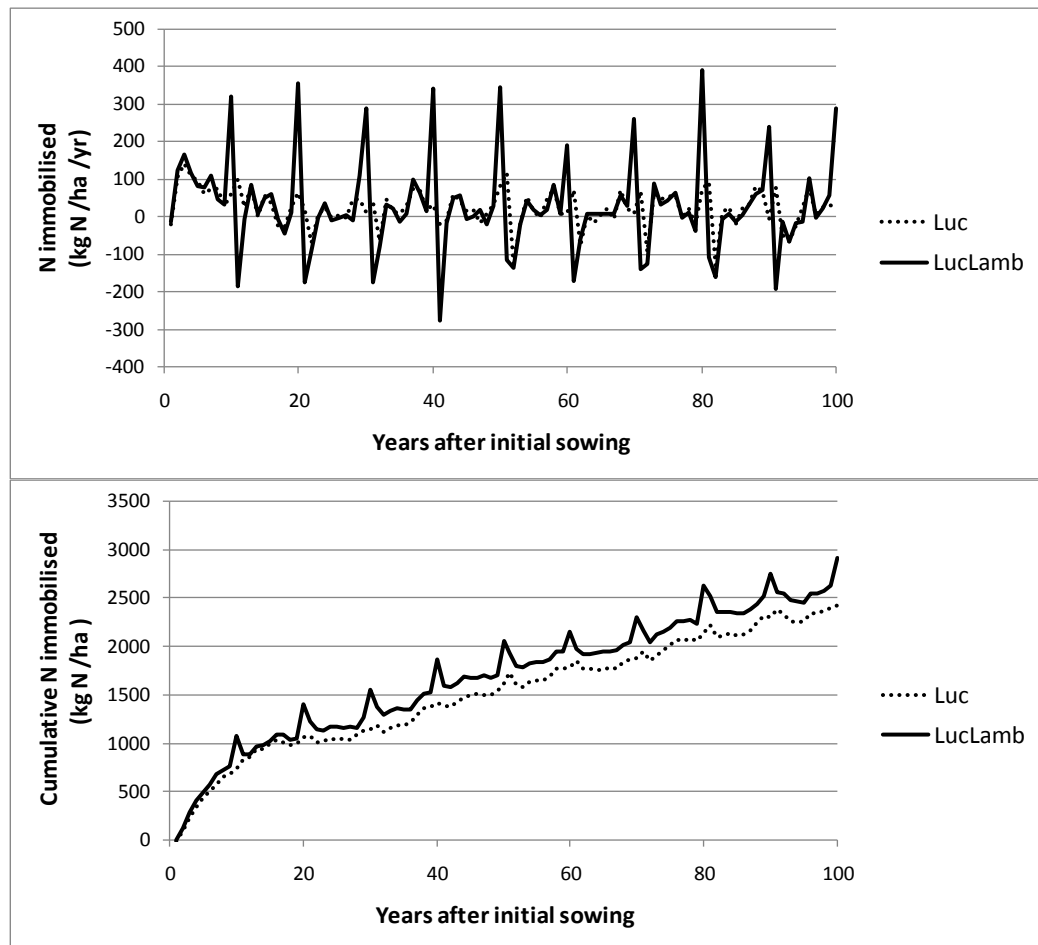


Figure A5.1. The annual (upper plot) and cumulative (lower plot) amount of nitrogen immobilised into the soil organic matter in the 30 mm soil for the “Luc” and “LucLamb” simulations.

47. Figure A5.1 gives shows the likely changes in organic nitrogen in the soil under the continuous lucerne (Luc) which is renewed every ten years with a short fallow and a more conventional system where the lucerne is grazed in autumn and the renewal stage includes a grazed forage cereal crop (LucLamb). Note that here the soil organic matter includes dead roots (live roots still attached to growing plants are not included in the soil organic N pool) as well as the organic matter that has been processed through the soil microbial system. After initial sowing, and conversion from a dryland state to irrigated, immobilisation of nitrogen peaked at over 100 kg N /ha /yr and averaged about 75 and 85 kg N /ha /yr in the first ten years in the Luc and LucLamb systems. After 35 years the average immobilisation reduced to 34 and 38 kg N /ha /yr and eventually settled down to about 25 kg N /ha /yr with a little more immobilisation in the LucLamb than Luc. This slightly higher average immobilisation in LucLamb is likely a result of the lower average C:N ratio of the organic matter returns in the all-legume Luc system and perhaps because of the larger bulk returns of organic matter into the LucLamb system in winter when mineralisation rates are very low. The much greater year-to-year fluctuation in LucLamb around the renewal dates is caused by the timing of the end of the cereal forage crop relative to the reporting time.
48. **Results – Drainage.** Figure A5.2 shows the annual drainage from the two systems. There is slightly higher annual average drainage from LucLamb, 262 mm /yr, than from Luc, 256 mm /yr. This probably results from the slightly longer time that the LucLamb system has with low leaf area index because of the greater complexity of the renewal method than does the Luc system. Both values are higher than the Aqualinc Research⁷ estimates for the 30 mm soil in the 500 mm rainfall zone which was 225 mm /yr. This might arise from the time that these systems have low leaf area index at some times of the cropping cycle or might arise from a relatively small difference in implementation of the irrigation rules.

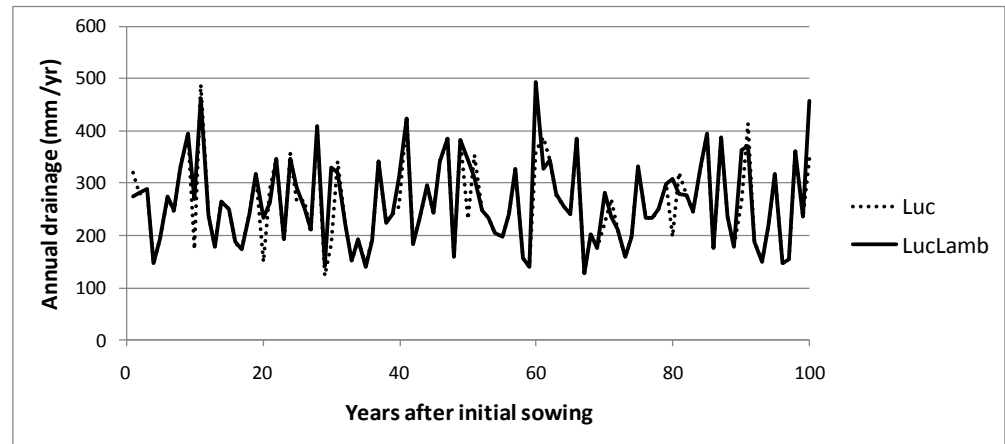


Figure A5.2. Annual drainage from the 30 mm soil for the “Luc” and “LucLamb” simulations.

49. **Results – Crop Growth.** The average annual total (lucerne and oat combined) dry matter harvested (by cutting or grazing) was 17.5 and 15.9 t DM /ha /yr in the Luc and LucLamb systems (Figure A5.3).

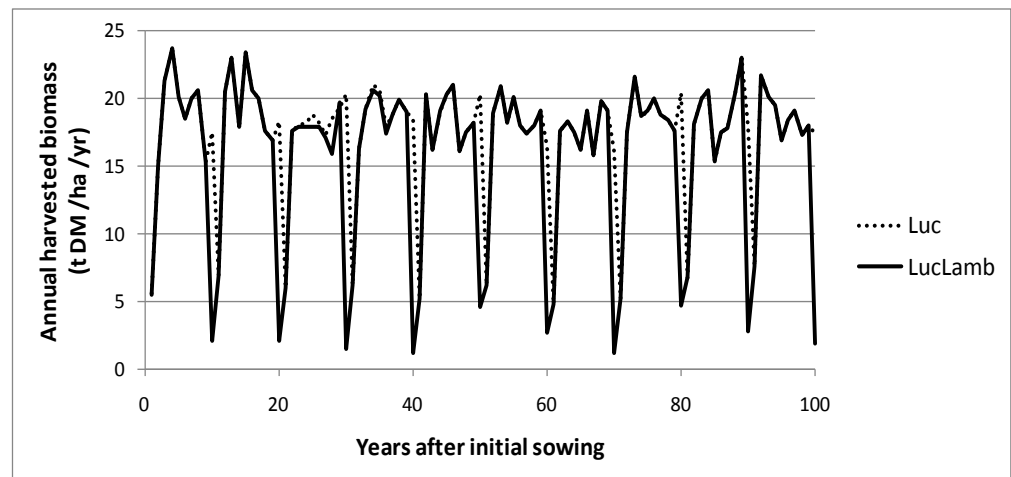


Figure A5.3. Annual biomass harvested (conserved lucerne, grazed lucerne and grazed forage cereal) from the 30 mm soil for the “Luc” and “LucLamb” simulations.

50. Substantially lower amounts of dry matter were harvested in the years in which the lucerne was renewed. The average lucerne outside the renewal years was 18.8 t DM /ha /yr. Although this compares well against the 18.8 t DM /ha /yr growth at high P fertiliser levels reported by Scott and Maunsell¹³ in a cutting trial run in the 1970s

¹³ Scott D, Maunsell LA (1981) Pasture irrigation in the Mackenzie Basin. 1. Species comparison. *New Zealand Journal of Experimental Agriculture* **9**, 279-290.

there are significant differences between the growth conditions. The Scott and Maunsell data was for Wairau lucerne grown on a substantially deeper soil with fortnightly irrigation. The cultivar effect cannot be quantified here but it might be argued that the frequent irrigation on the shallow soil for this deep rooted species might produce little difference in growth compared to rather less frequent irrigation on a deeper soil. Greenwood¹⁴, in reporting data from the Tara Hills Research Station, indicated irrigated lucerne yields of up to 7.5 - 12 t DM /ha /yr. The irrigation management is not explicitly stated but was likely to have been fortnightly flood irrigation. The crop management was also unclear but some stands were set-stocked which is well known in lucerne to substantially depress lucerne growth and survival. Given these limited examples there is the possibility that APSIM has overestimated the lucerne growth but the simulated growth is within the range expected by Professor Moot⁴ for these soils in this district. Lucerne yield in the renewal years of the Luc system averaged 6 t DM /ha /yr or about a third of that in the established lucerne. This is well within the range reported by Greenwood¹⁴ but is probably more consistent between years than might normally be expected in this environment.

51. The average yield of the oats was 2.4 t DM /ha /yr in the years that it was sown. This does not compare well against the 4.6 t DM /ha /yr reported for March-sown ryecorn in Rangiora¹⁵ but Rangiora has a winter climate better suited to higher yields than the Mackenzie Basin. The simulated yield is within the range cited by Trolove⁸ for March-sown ryecorn on dryland soils who reported that March was generally too late to expect a good cereal crop. There is little data available for autumn-sown irrigated cereals in the region⁸. The simulated growth may be low but did provide a reasonable amount of forage with which to graze in late winter for this renewal system. As such it provides a source of leachable N in the renewal cycle.
52. **Results – Leaching.** Figure A5.4 shows the annual pattern of leaching at 1.0 m deep for the 60 mm soil and at 3.0 m deep for the 30 mm and 60 mm soils. The average annual leaching is summarised in table A5.1. The leaching at 1.0 m deep is shown for reference as previous work in the Taupo catchment found relatively high leaching from cut-and-carry lucerne stands but that work has been criticised as measuring the leaching at too shallow a depth. If leaching is measured within the

¹⁴ Greenwood PB (1982) Irrigation research at Tara Hills High Country Research Station 1948 to 1982. Ministry of Agriculture and Fisheries, Mosgeil.

¹⁵ Stephen RC, Saville DJ 1993. Characteristics of cereal and ryegrass greenfeeds which contribute to superior herbage yield in late winter. Proceedings Annual Conference – Agronomy Society of New Zealand 23: 47–51.

toot zone, such as at 1.0 m deep, then substantial amounts of N can be assumed to leach whereas it was actually taken up by the crop below the depth of measurement. Table A5.1 shows that the leaching at 1.0 m deep is about half that at 3.0 m deep. The greatest effect of this is seen (Figure A5.4) in the years between the renewal cycles when leaching is relatively low. In the renewal years (which can clearly be seen in the figure below) the amount of N released is substantially in excess of the ability of the crop to take it up and the measurement depth effect is proportionately less important.

Table A5.1: Average annual N leaching for combinations of measurement depth, soil type and farming system.

Soil and depth	Average annual leaching (kg N /ha /yr)	
	Luc	LucLamb
60 mm soil at 1.0 m deep	16	35
30 mm soil at 3.0 m deep	10	21
60 mm soil at 3.0 m deep	8	19
Average at 3.0 m	9	20

53. Figure A5.4 shows the pattern of leaching in time. The renewal years are obviously important in the leaching and it might be possible to devise management practices that reduce that leaching. Average annual leaching from the combination of 30 mm and 60 mm soils was 9 and 20 kg N /ha /yr for the two systems and appear to be robust values to use in the farming systems nutrient analysis.

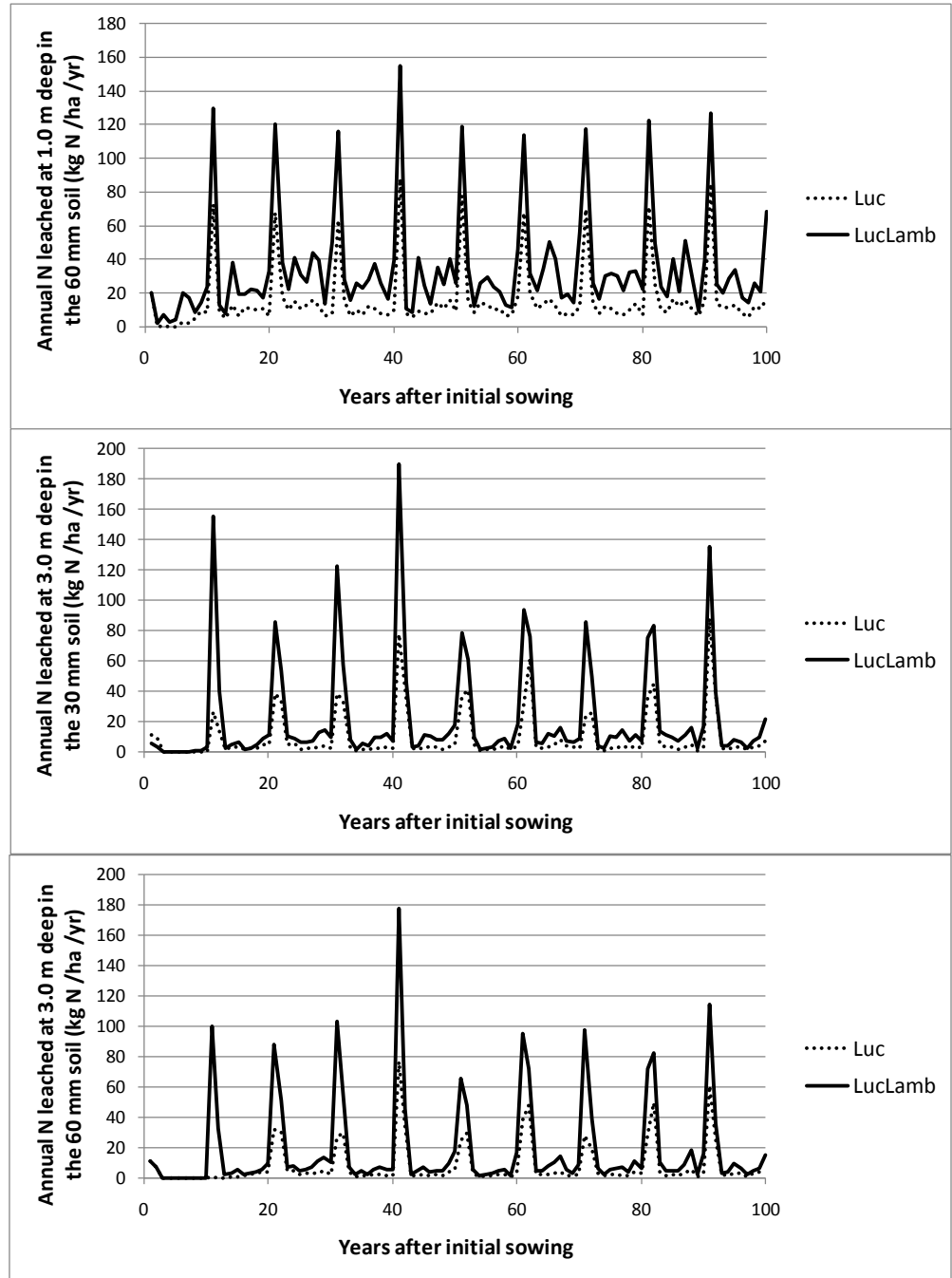


Figure A5.4. Annual N leaching at 1.0 m deep in the 60 mm soil and at 3.0 m deep from the 30 and 60 mm soils for the “Luc” and “LucLamb” systems.

Appendix 6: Irrigated area total N and P losses

Area and system	N loss (kg N /ha /yr)		P loss (kg P /ha /yr)	Irrig. Area (ha)	Block N loss (kg N/yr)		Block P loss (kg P /yr)
	Dev	HD			Dev	HD	
HC_SBFIN	8	12	0.4	500	4000	6000	200
HC_SBIFIN	9	13	0.2	500	4500	6500	100
HC_Luc	9	9	0.6	500	4500	4500	300
RO_Bull	9	16	0.5	810	7290	12960	405
RO_SBFIN	8	12	0.4	810	6480	9720	324
RO_SBIFIN	9	13	0.2	810	7290	10530	162
RO_Luc	9	9	0.6	810	7290	7290	486
RO_LucLamb	20	20	0.6	810	16200	16200	486
RO_Crop10	20	24	0.6	810	16200	19440	486
RO_Crop15	20	27	0.6	810	16200	21870	486
SHS3_DOFF	16	18	0.5	1735	27760	31230	868
SHS3_SBFIN	8	12	0.4	1735	13880	20820	694
SHS3_SBIFIN	9	13	0.2	1735	15615	22555	347
SHS4_SBHC	9	13	0.3	472	4248	6136	142
SPS1A_DOFF	17	20	0.6	1307	22219	26140	784
SPS1A_SBFIN	10	13	0.5	1307	13070	16991	654
SPS1A_SBIFIN	11	14	0.2	1307	14377	18298	261
SPS1B_DOFF	16	18	0.5	980	15680	17640	490
SPS1B_SBFIN	8	12	0.4	980	7840	11760	392
SPS1B_SBIFIN	9	13	0.2	980	8820	12740	196
SPS2_SBIFIN	11	14	0.2	287	3157	4018	57
SPS2_SBFIN	10	13	0.5	287	2870	3731	144