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

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STATEMENT OF VALERIE OLGA SNOW

EXPERIENCE AND QUALIFICATIONS

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 Nitrogen ("**N**") leaching), “Rural Futures” (dynamic simulation model development), and “Land Use Change and Intensification” (developing tools for environmental policy development and monitoring).

3. Through this experience I have developed a strong understanding of:

    i. the biological and farm management processes important in determining the loss of nutrients, particularly nitrogen, from pastoral systems;

ii. the strengths and weaknesses of several different types of models used to estimate nutrient losses from pastoral systems; and

iii. the very significant challenges to representing the biological processes and farm management decisions that control nutrient loss from pastoral systems in dynamic simulation models.

4. 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.

INVOLVEMENT WITH THE APPLICATIONS / SCOPE OF EVIDENCE

5. I have been involved in assessing the potential impacts of the irrigation applications on water quality in the Upper Waitaki since December 2007. I was contracted by GHD in March 2008 to supervise work on modelling the losses of N and Phosphate ("**P**") from farms in the Upper Waitaki Basin in both the current (“dryland”) state and likely state should irrigation consents be obtained (“irrigated”) for the MWRL Cumulative Effects Study ("**Cumulative Effects Study**"). That work was carried out between April and August 2008 and included inputs from myself, Warren King, David Houlbrooke and Jeremy Bryant (AgResearch) as well as Duncan Smeaton (Smeaton Agricultural Consultancy) and Stephen Trolove (Crop and Food Research). I have reviewed the technical reports on irrigation and drainage (Aqualinc Research Limited 2008), groundwater modelling (GHD 2009b; sections 3 and 5.2.1 only) and rivers and lakes (GHD 2009a; sections 4.2, 4.3.1 and 4.3.2 only).

6. This evidence will:

i. describe the objectives of Farm Systems Modelling and its role in the Cumulative Effects Study;

ii. describe the challenges faced in representing the biophysical processes and farm management decisions that control nutrient loss from pastoral systems in models;

iii. describe the strengths and weaknesses of the different modelling approaches that were considered and why the ‘three-tier’ approach was selected;

iv. describe three-tier modelling approach, the assumptions used, and input data used;

v. describe the characteristics, modelled nutrient outputs and usage of the model results in the Cumulative Effects Study; and

vi. evaluate the results and potential errors or biases in the modelling and compare the results to previous studies of potential nitrogen and phosphorus losses from farms in the region.

7. It is useful at this stage to provide a brief overview of the three-tier methodology used to determine the likely nutrient losses from potential farming activities in the Upper Waitaki Basin. This three tier model is explained in more detail at paragraph 20 of my evidence.

8. The first step is to quantify the current pasture and forage crop growth and the likely future crop growth should the area be irrigated. This information is then used as the main input for farm systems models which (in the second tier) determine the realistic stocking rates that could be supported by the land. The final step is for this stocking rate information, plus information about the fertiliser crop production, soil data and weather data to be supplied to a programme called OVERSEER®. This programme produces data about whole farm nutrient losses.

9. The characteristics of the likely future farms, in terms of stock class and stocking rate and percentage of land irrigated, can be changed to provide data about nutrient losses from various types of farm. These results are set out in paragraph 37 and Appendix 3. The nutrient losses are then used by GHD in the Cumulative Effects Study.

FARM SYSTEMS MODELLING WITHIN THE CUMULATIVE EFFECTS STUDY

10. Farm systems modelling are programmes and systems which model the theoretical size, characteristics and performance of certain types of farms based on certain inputs.

11. A conceptual sketch of the Cumulative Effects Study is set out in **Figure 1** showing the sequence of steps (grey boxes) and the studies that contributed to each set (white boxes). The role of the future case Farm Systems Modelling in the Cumulative Effects Study is twofold:

i. to assist with validation of the surface water and ground water modelling by providing the source information about nutrient losses from the farmed areas of the catchment; and

ii. to assist with the disaggregation of the nutrient loads that each water body can tolerate into Nutrient Discharge Allowances (NDA) for each applicant.

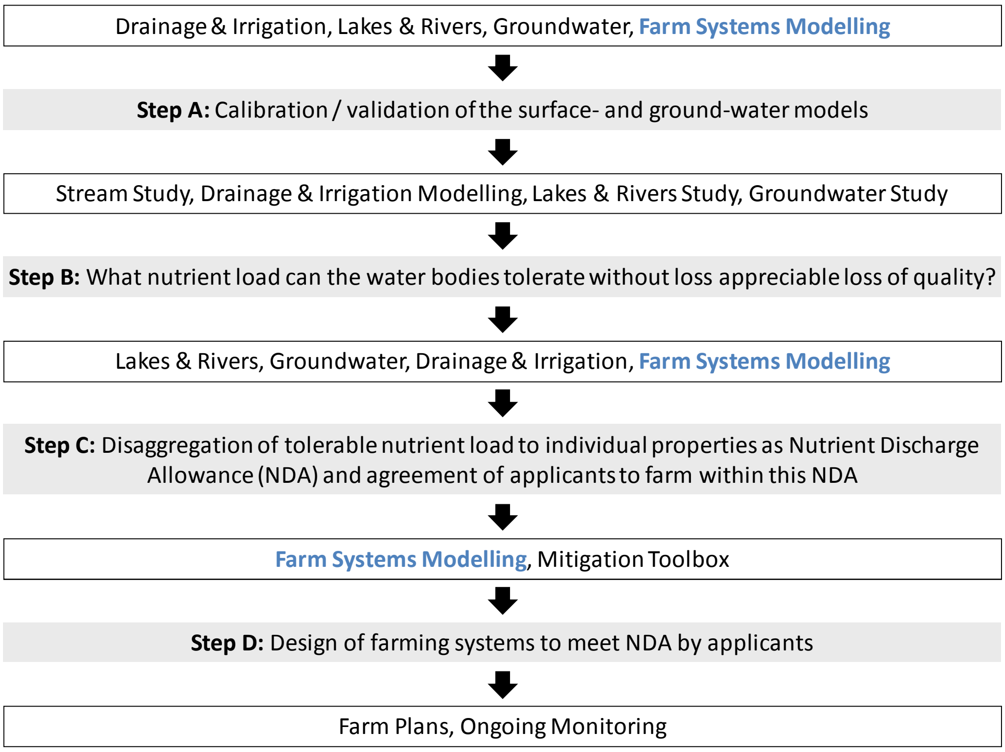

Figure 1. Simplified schematic of the Cumulative Effects Study and the role of the Farm Systems Modelling in the larger study showing the sequence of steps (grey boxes) and the studies that contributed to each set (white boxes).

MODELLING NUTRIENT LOSSES FROM PASTORAL SYSTEMS

Nutrient losses from pastoral systems

12. The dynamics of nutrient losses from pastoral farms is a complex result of biological processes (e.g. soil carbon and nitrogen, plant, animal) that are strongly influenced by abiotic inputs (e.g. weather) and human factors (farm management decisions) operating at the paddock and farm levels (Figure 2). Modelling of nutrient processes

in pastoral farms requires consideration of the generation or transfer of nutrients[1] as well as management and resource factors such as:

i. climate and climate variability,

ii. irrigation;

iii. soil type;

iv. animal stocking rate, types and pattern during the year;

v. supplement conservation and feeding strategies;

vi. nitrogen and other fertiliser usage; and

vii. forage crop integration into the system.

13. Pastoral farms operate as complex systems and – particularly when concerned with nutrient losses – it is not valid to model a single paddock without considering its relationship within the rest of the farm. The complex systems nature of pastoral farms emerges largely from two factors of relevance here:

i. Farmers have limited practicable means with which to match animal demand for feed against the ability of the farm to supply feed. The result is a mismatch between feed supply and demand that results in farmers running sub-optimal stocking rates in an attempt to even out discrepancies between feed supply and demand. Despite this, farms still experience periodic shortages of feed that farmers manage using a large variety of techniques that all affect the average stocking rate of the farm and the seasonality of that stocking rate. Without knowledge of the management options used it is not generally possible to know the realistic stocking rate of the farm. Importantly, the nutrient dynamics are highly dependent on the stocking rate.

viii. Pasture eaten by ruminants supplies considerably more nitrogen than can be used by the animals and converted into meat, wool or milk. Some 60-90% of the N ingested by animals is deposited back onto the pasture in the form of dung and

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[1] Fertilisers, animal excretion, N fixation, mineralisation and immobilisation from the fast and slow Carbon ("**Carbon**") and N pools in the soil, volatilisation, denitrification, leaching, runoff, transfers to parts of the farm such as laneways.

urine (Haynes and Williams 1993). However, dung and urine is only deposited on about 30% of the pasture area annually. This excretion results in very high N concentrations within the dung and urine patch areas - about 150 to 1000 kg N/ha depending on factors such as animal type, excretion type, feed supplied and grazing management. These amounts of N are in excess of the ability of the pasture plants to take up N into new plant tissue or for soils to adsorb. This is particularly true for the urine patch areas in which the N is both more concentrated and more mobile than in dung patches. The result is that most of the leaching from pastoral farms originates from urine patches the quantification of leaching the important factors are the concentration of N in the urine patches and their pattern in time and space over the farm.

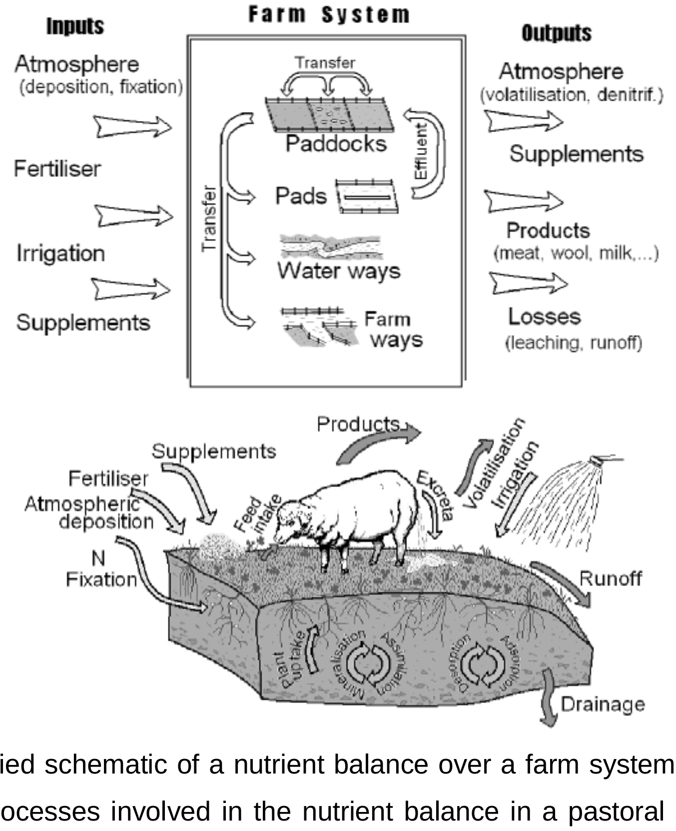

Figure 2. Simplified schematic of a nutrient balance over a farm system (upper) and the cycle and processes involved in the nutrient balance in a pastoral field (lower). From (Cichota and Snow 2009).

Potential modelling approaches

14. The estimation of nutrient losses from pastoral farms is complex. Nutrient losses result from a combination of:

ii. climate and climate variability;

iii. soil type;

iv. animal stocking rate, types and pattern during the year;

v. supplement conservation and feeding strategies;

vi. nitrogen and other fertiliser usage;

vii. forage crop integration into the system; and

viii. other factors.

15. There are several dynamic daily-timestep simulation models available that are capable of calculating pasture growth and the flow of nutrients through or over the soil system to ground and surface-water at the paddock or farm-scale (Cichota and Snow 2009). The dynamic daily-timestep models simulate farm production as well as nutrient losses but require a robust description of farm management and the ability to simulate the effects of urine patches to be useful in studies such as this. Those models particularly appropriate for consideration here because of availability, development or usage in New Zealand include (refer Figure 3):

i. APSIM (Moore *et al.* 2007),

ii. EcoMod (Johnson *et al.* 2008), and

iii. SPASMO (Rosen *et al.* 2004).

Other models are too detailed to be used for this work and require too much data that is not readily available, are not sufficiently developed (e.g. FarmSim) or are not being maintained (e.g. LUCI).

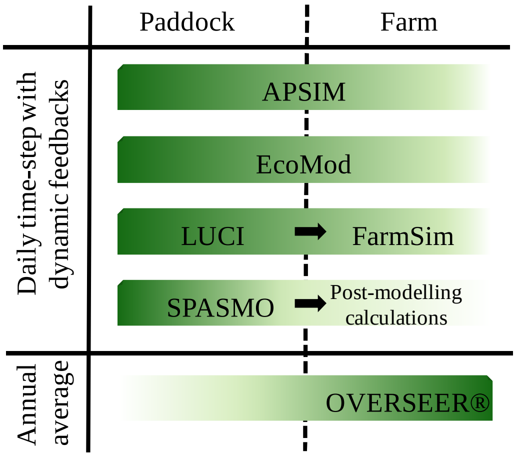

Figure 3. Simplified diagram of nutrient loss models indicating time and space scale of operation. The daily time-step models have dynamic feedback from production to nutrient losses lacking in the annual average models but have a poor representation of whole-farm systems. OVERSEER® has a strong representation of the whole-farm but lacks dynamic feedbacks.

16. While a single dynamic daily-timestep model would have advantages in that there would be a single modelling step between input information (soil, climate and management information) and the desired nutrient loss estimates, at present there are two important aspects of these models that are not sufficiently robust for use in a study such as this.

i. The first issue is the representation of urine patches. It is well known (Monaghan 2009) that the characteristics of urine patches (number, area, and time of deposition) are critical in controlling nitrogen losses from pastoral farms (Haynes and Williams 1993) and although there is active work in developing models that take specific account of urine patches (Snow *et al.* 2007; Hutchings *et al.* 2007; Snow *et al.* 2009a) these models are currently only suitable for research purposes and are not sufficiently tested or robust for use here.

ii. There are also significant challenges associated with dynamically modelling the management of pastoral farms (Snow and Lovatt 2008) in a manner that will provide a robust and realistic representation of the changes in stocking rate during the year – and the pattern of stocking rate is important in the generation of urine patches. It is relatively easy to simulate the grazing of a single paddock but when this is done the whole farm system constraints are ignored. Pasture utilisation and therefore stocking rate becomes unrealistically high, and this leads to unrealistically high nutrient loss estimates. While techniques to give a robust representation of whole-farm management are in development they are not sufficiently tested.

17. In contrast to the dynamic models, OVERSEER® is a nutrient budget model that:

    i. works on an annual-average time step representing a typical year;

    ii. models the whole farm, not individual paddocks, but does sub-divide the farm into blocks that are differentiated by pasture type, soil or management characteristics; and

    iii. unlike dynamic models has a robust representation of the whole-farm system and of the effect of urine patches on leaching.

18. However, OVERSEER® does not simulate farm production (production is an input to the model) and so does not have a feedback from, for example, higher than expected nutrient losses to:

    i. decreased nutrients available for pasture production to either decreased stocking rates and animal production; or to

    ii. increased fertiliser/supplement inputs and maintained animal production.

19. OVERSEER® also represents a farm near an equilibrium rather than in a transitional state. Therefore, if OVERSEER® is used to model a hypothetical/future/proposed farm, it must be teamed up with other models to supply reasonable and achievable production information and a multi-step modelling process is needed. Thus, the three tier system set out below was used for the analysis.

20. The rational for selection of the three-tier approach over the single-model (dynamic) approach was the distinct strength of OVERSEER® in including the effects of farm management and urine patches in its nutrient loss calculations. Previous work (Ledgard 2001; Ledgard and Menneer 2005; Monaghan 2009; Snow *et al.* 2009a) showing the importance of the amount and timing of the deposition of urine patches in controlling nutrient losses was considered to outweigh the limitations imposed by not having a dynamic feedback from production to leaching. The feedback limitation

was overcome in large part by only considering the before irrigation case against the steady-state post-irrigation state – the transition from one state to the other was not modelled with this approach. Further comment on the strengths and limitations is presented below in paragraphs 46-55.

DESCRIPTION OF THE MODELS USED

The three-tier approach

21. A methodology involving a three-tier modelling approach was developed to quantify the nutrient losses from the farm systems (Figure 4):

    i. The first tier was quantification of the dryland and irrigated pasture and forage crop growth using information from existing farms, EcoMod and review data.

    ii. The growth data was then used in the second tier farm system models (UDDER or Farmax depending on farm business type) to ensure that farm systems that were feasible over the long term were constructed. These ‘feasible’ farms have realistic stocking rates that are robust against the within and between-year variations in pasture growth.

    iii. The production, fertiliser and stocking information from those models, supplemented by other data, was then put into OVERSEER® to calculate the farm nutrient losses. GHD used that farm nutrient loss information to aid the calculation of likely effects on groundwater (GHD 2009b) and surface water (GHD 2009a).

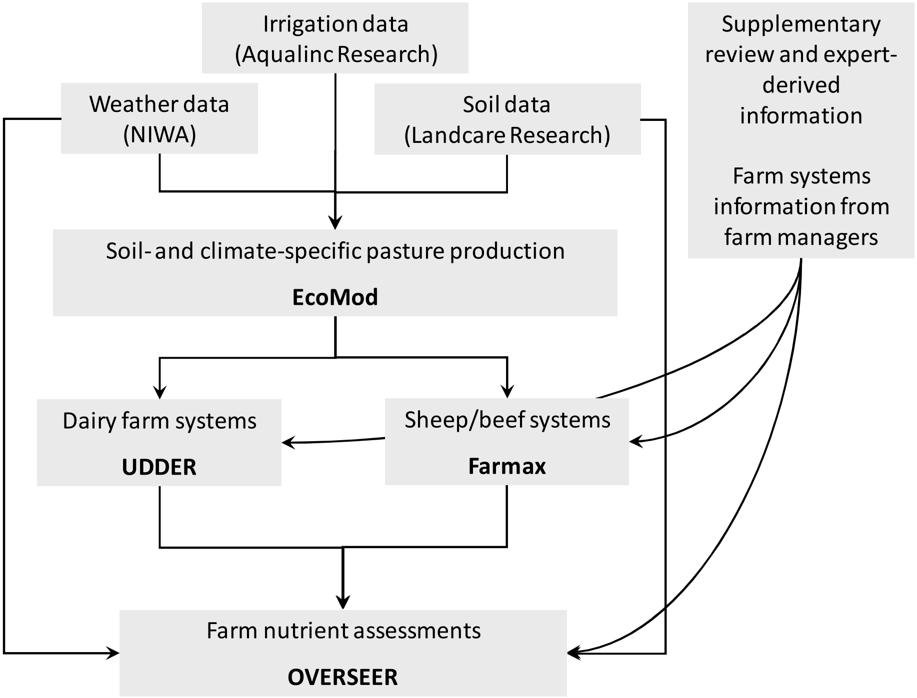

Figure 4. Diagram of the usage of the models in the three-tier approach to nutrient assessments.

Approach

22. The steps involved in the three-tier approach here were to:

i. Gather base weather, soil and irrigation information;

ii. Collate existing information on local pasture and forage growth rates and management (Trolove 2008; King 2008);

iii. Supplement the growth information with paddock-level modelling using EcoMod to extrapolate the information to a combination of soils and climates in the region;

iv. Gather information on existing production and management practices from farms in the Mackenzie Basin as well as generic information about planned farm policies should an irrigation consent be obtained;

v. Model the existing farm systems in collaboration with local farm managers to ensure that biologically feasible long-term average farm systems information was generated that also accurately reflected local farm management policies;

vi. Model future, irrigated and partially-irrigated, generic farm systems in Farmax (sheep/beef systems) and UDDER (dairy systems) to ensure that biologically feasible long-term average farm systems information was collated;

vii. Model the nutrient losses from those farm systems with the nutrient budget model OVERSEER® (see below) to calculate a long-term average nutrient loss.

EcoMod

23. EcoMod (version v4.2.2) is a dynamic biophysical simulation model designed to simulate pastoral farm systems of Australia and New Zealand (Johnson *et al.* 2008; see Johnson 2008 for full documentation). This model includes, with a high level of detail, the processes that take place in soil-water-plant-animal system of pastoral farms. It includes a management module, which allows the simulation of basic farm systems, as well as research setups, such as cutting trials. Essential elements of EcoMod that were used in this study include:

i. A multi-layered soil water storage and transport module that calculates infiltration, runoff, changes in soil water content, water uptake by plants, soil water evaporation, drainage and nutrient transport with the drainage from 2 - 10 cm thick soil layers on a sub-daily timestep;

ii. A carbon and nitrogen (organic and mineral) cycling module that includes inert, stabilised ('slow'), and fresh ('fast') pools of organic matter with transformation rates affected by temperature and water limitations; and

iii. A module for simulating the growth of several different pasture and forage plant species.

24. Very good comparisons of EcoMod simulated growth rates against measured data can be found in the published literature (e.g. Johnson *et al.* 2008; Cullen *et al.* 2008; White *et al.* 2008). The simulations results of White *et al.* (2008) from field pasture growth data from Winchmore are shown in Figure 5. EcoMod also has the ability to simulate the effect of urine patches on nitrogen leaching (Snow *et al.* 2009a) but does not have the necessary level of detail of farm management decisions needed to substitute for Farmax and OVERSEER® in this study.

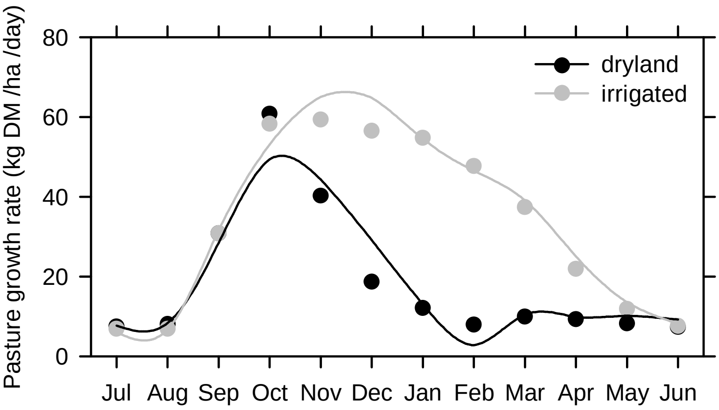

Figure 5. Comparison of median pasture growth rates (points) measured at Winchmore between 1996 and 2003 against that simulated (White *et al.* 2008) using EcoMod (lines) for dryland and irrigated conditions.

25. The primary inputs required by EcoMod include daily weather records, irrigation and fertiliser information, soil properties, pasture parameters, management settings. Further detailed information regarding the EcoMod inputs is set out in Appendix 1.

FARMAX Pro

26. FARMAX Pro (version 6.3.25.3)[2] was used to model the sheep and beef farm systems. With this whole-farm management software, the user can explore the consequences of changes to farm stocking policy to ensure that the future or planned farm systems are feasible. Here ‘feasible’ means that the planned stocking policy (the amount and pattern in time of animal production and purchases/sales of animals) can be biologically supported by the amount of pasture, forages, supplements and N fertiliser planned for the farm. Robust values of these quantities are essential to ensure that OVERSEER® receives viable farm-level information for the calculation of nutrient losses.

27. FARMAX Pro determines biological feasibility by calculating the minimum whole farm pasture cover required to meet animal requirements and comparing it to the farm cover predicted from the whole-farm feed supply and demand data (e.g. animal types, numbers, live weight, live weight gain, starting pasture cover, pasture quality,

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[2] FARMAX Pro evolved from StockPol, Marshall et al, (1991). Refer also www.farmax.co.nz.

pasture growth rates, forage crops and supplements fed including those brought into the farm system). If predicted pasture cover is below or excessively above the minimum required then the farm is declared not feasible and the farm management must be adjusted to attain a feasible farm. Webby *et al.* (1995) presented a favourable comparison of Farmax against farm production data and the model has been under continual improvement since that publication. Farmax is used by a number of farm consultants in New Zealand to support farm management decisions, particularly associated with substantial changes in farm policy.

UDDER

28. UDDER[3] was used for all dairy farm system simulations and fulfilled the same role as Farmax Pro did for sheep/beef farms. UDDER involves four main simulation stages:

    i. setting out the number of cows of each type (milking cows, calves, yearlings and dry cows),

    ii. determining the available pasture,

    iii. calculating the amount of energy consumed from pasture and other supplementary feeds, and

    iv. determining resulting milk production and changes to cows' body condition score.

29. Supplements can be conserved and fed when needed. Nitrogen can be applied at any time, with the pasture growth and duration of response specified by the user. Farm grazing land is subdivided into 50 equal virtual paddocks, with the growth in each virtual paddock based on a predicted rate of growth obtained experimentally, or in the present case by simulation. The amount of pasture offered to cows is calculated based on area available, excluding conservation areas and crops, rotation length and herbage mass. UDDER compared favourably against farm data (Larcombe 1989) and is used with dairy farm consulting businesses in Australia and New Zealand.

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[3] Hart et al. (1998); Larcombe (1990)

30. Both Farmax Pro and UDDER require information about dryland and irrigated farm systems policies and potential pasture and forage crop information. These were obtained from review of existing published information, discussion with local land managers. More information on the inputs is provided in Appendix 1.

OVERSEER®

31. The role of OVERSEER® (version 5.2.6.0) in this study was to provide effective whole-farm nutrient losses given feasible farm management, production and input data. The OVERSEER® model (Ledgard *et al.* 1999; Wheeler *et al.* 2003; Wheeler *et al.* 2006) uses empirical relationships, internal databases, and readily available data from a "feasible" farm to estimate the nutrient inputs and outputs at farm or paddock scale, and presents them as a nutrient budget. Here "feasible" refers to the fact that OVERSEER® does not simulate production but instead requires farm production and fertiliser use that are matched to the farm's ability to supply forage as inputs to the model. These quantities are usually known for existing farms or can be estimated for hypothetical farms using models such as Farmax Pro or UDDER.

32. In the calculations of nutrient rate, OVERSEER® assumes that best management practices have been followed such as following the fertiliser code of practice and preventing stock from accessing streams. More information on the range of practices assumed is presented below. It is also assumed that the system is in quasi-equilibrium and so OVERSEER® is not suited for examining the dynamics of a farm in rapid transition – but it can reasonably be used to assess the before and after transition states.

33. Because of the quasi-equilibrium assumption, OVERSEER is not suitable for estimating nutrient losses from particular years. Recent evidence tabled during the hearings in relation to Waikato Regional Council's Regional Plan Variation 5 (Ledgard 2007; Clothier 2008) have found OVERSEER® to be the most suitable model for assessing the long-term average nutrient losses from pastoral farms. A review by Monaghan (2009) found that the usage of OVERSEER® for the purpose here, estimating nutrient losses from current and planned farm systems, was justified.

34. OVERSEER® requires input information about local climate, irrigation water, soils, pasture types, farm production. The sources used for this information are given in Appendix 1. Initially all OVERSEER® runs were done with the recommended development setting, or “Developed”. Analysis of the OVERSEER® outputs for some irrigated blocks showed very large amounts of immobilisation of nitrogen in the soil organic matter. While it is normal for there to be substantial increases in soil organic nitrogen after a dryland is irrigated (Gillabel *et al.* 2007) these rates of immobilisation cannot be sustained indefinitely. As the irrigated pasture develops, soil organic N will increase until it attains a new equilibrium value. During that transition the immobilisation of N reduces the amount of N likely to leach. However, once that new equilibrium has been reached leaching will usually increase as immobilisation decreases. To obtain more conservative estimates of long-term leaching under irrigated conditions, the OVERSEER® simulations were run again with the development status of the irrigated blocks set to “Highly Developed”. This option in the model prevents any immobilisation and so gives an upper bound on the leaching from the irrigated blocks providing a highly conservative estimate, or worst case estimate, of N leaching from these blocks.

MODELLING OF CURRENT (DRYLAND) SYSTEMS

Dryland farm descriptions

35. Seven stations in the Upper Waitaki region were modelled to provide information on farm systems for a range of stocking rate, climate, and soil conditions. The modelled stations were chosen to span a range of key farm characteristics including stocking rate, stock type, existing irrigation systems, and area of winter forage cropping.

Dryland farm results

36. The results from the dryland status are shown below in Table 1 and in Figure 6

37. Figure 6 shows linear regressions of N or P loss against stocking rate[4] and in summary, the results were as follows:

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[4] Note that Killermont Station was not used in the regression analysis because the results arrived after the regression equation was needed by GHD for catchment scale modelling.

i. There was a strong relationship between effective stocking rate and N loss when two stations were removed from the analysis. The outlier stations were Ohau Downs and Simons Pass. The likely reasons for the outliers were a high percentage of area in forage cropping in the Ohau Downs Station and the large area of light soils on Simons Pass Station.

ii. Estimated P losses were low, less than 0.15 kg P /ha with the exception of Haldon Station. The higher P losses on Haldon Station (and Killermont) were a result of deer stock. There was a moderate relationship between P loss and stocking rate once Haldon and Ribbonwood Stations were removed from the analysis. The P losses from Ribbonwood were influenced by the effects of the Hill Country soil.

Station	N loss (kg/ha) "Developed"	N loss (kg/ha) "Highly Developed"	P loss (kg/ha)
Gray's Hill	3.6	4.1	0.09
Haldon	2.8	3.1	0.43
Killermont	2.7	2.9	0.17
Ohau Downs	5.1	-	0.06
Ribbonwood	3.3	-	0.14
Simon's Hill	5.3	7.6	0.10
Simon's Pass	4.0	4.3	0.02

Table 1. Station N and P loss by leaching and runoff. Where stations have existing irrigated blocks an estimate of effective whole-farm N loss assuming a "Highly Developed" status on the irrigated blocks is also given.

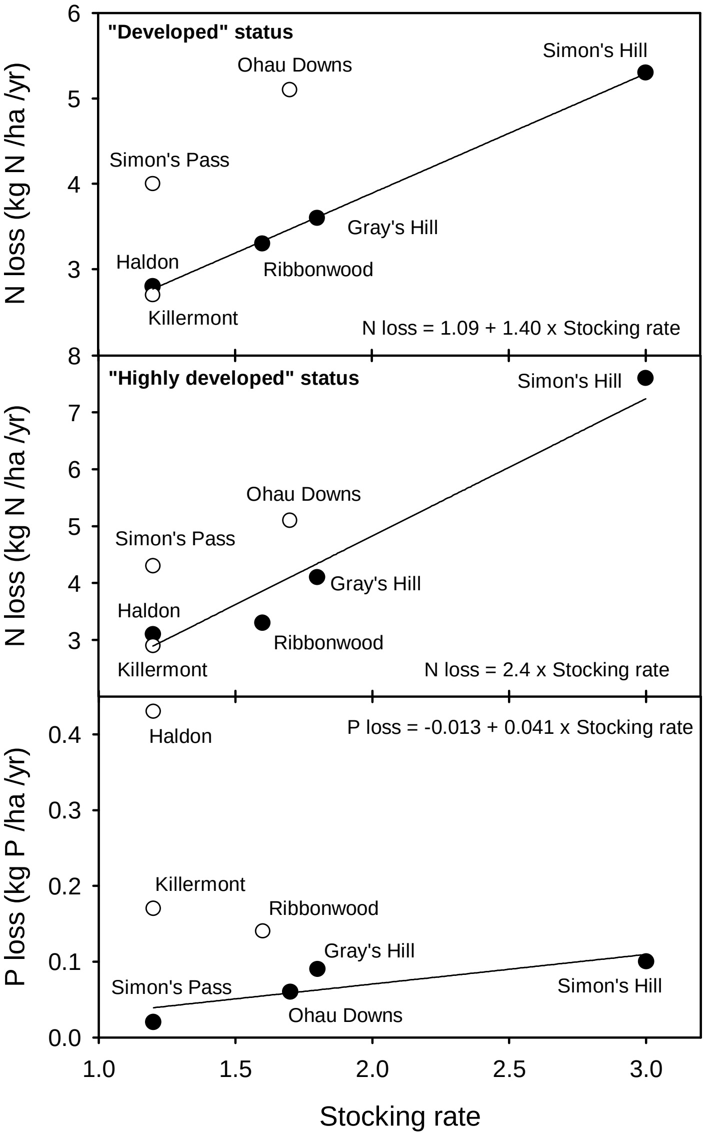

Figure 6. N loss (developed and highly developed cases) and P loss as affected by stocking rate in the current 'dryland' state.

MODELLING OF FUTURE (FULLY- AND PARTIALLY-IRRIGATED) SYSTEMS

Irrigated farm descriptions

38. In contrast to the dryland farm modelling, all the farm systems modelled were hypothetical systems designed, within certain constraints, to make effective use of

the forage that is likely to be grown under irrigated conditions in the Upper Waitaki region. The general farm descriptions were based on farmer's aspirations and were deliberately constructed to ensure that they spanned the likely range in irrigated farm systems.

i. Nine 'generic' dryland farm systems were modelled. The farms varied in the percentage of beef stock units on the farm (1, 10, and 21% of the total stock units) and the area of winter forage crop on the farm (0, 3, and 6% of the whole farm area). Typical nitrogen applications, 70 kg N /ha, were made to the forage crop area but no other nitrogen fertiliser was used on the farm.

ii. The series of irrigated sheep and beef systems modelled had 25, 35, or 100% of the farm area irrigated and included a range of beef stock units or dairy support stock units. Scenarios with and without nitrogen fertiliser used on the irrigated blocks were modelled. These, and all other irrigated farm systems, did not include any winter forage crop area because sufficient summer-grown forage was conserved to fill the winter feed gaps. These scenarios are labelled Farm10 to Farm24 and are +N or –N (30 scenarios in total). More detailed farm system description information is given in Table A1 (Appendix 3) including the stocking rate and animal ratios, and fertiliser N applications. Where N was applied the application was split between September and February.

iii. Five irrigated dairy farms were modelled with various stocking rates. It was assumed that the whole farm was irrigated. All farms used 120 to 140 kg N fertiliser /ha /yr. All farm systems were assumed to have an effluent reuse area of at least 8 ha /100 cows. The area was made larger, if necessary, to ensure a maximum N loading on the effluent area of 150 kg N /ha /yr. Details of the dairy farm systems are given in Table A2 (Appendix 3) including cow numbers, production information, supplements and N fertiliser applications.

Irrigated farm results

39. Table A3 (Appendix 3) gives the nutrient loss estimates for the farm systems described above and the results are shown graphically in Figure 7. The key findings are set out below:

i. **Sheep and beef farms:**

  a. Nitrogen losses were low, generally less than 5 kg N /ha, for farm systems with 0, 25, or 35% of the area irrigated and a “Developed” status. Although irrigating 25 or 35% of the area resulted in substantially higher stocking rates, about 5 times the dryland case, the losses from the irrigated farms were generally about the same as the losses from the dryland farms with the higher area of forage cropping.

  b. Phosphorous losses from the 20 and 35% irrigated systems increased, but again were only marginally higher than the dryland farm systems with the larger areas of forage cropping.

  c. Once the area of irrigation was increased to 100% of the farm the N and P losses were greater than the dryland scenarios with losses of 7 – 10 kg N /ha and 0.1 kg P /ha.

  d. There was no effect on nutrient losses when the beef stock units were replaced with dairy support stock units.

ii. **Dairy Farms:**

  a. As expected, the losses from dairy farms were higher than the other scenarios, ranging from 15 to 27 kg N /ha and 0.13 to 0.2 kg P /ha. There are however several options to mitigate these losses as demonstrated by the inclusion of a feed pad (Farm29 compared to Farm28; Table A3, Appendix 3).

iii. **Development Status:**

  a. The choice of development status (closed v's open symbols, Figure 7) had an effect of increasingly large magnitude as the area of irrigation in the sheep and beef farms increased but had less effect in the dairy farms that export more N in animal products than do sheep and beef farms. There is considerable uncertainty in the duration of the phase in which the pastures will continue to immobilise significant amounts of N and therefore of the time likely for the transition from the Developed to the Highly Developed state. As such, usage of the “Highly Developed” values is recommended as it represents a conservative upper bound on the nutrient losses.

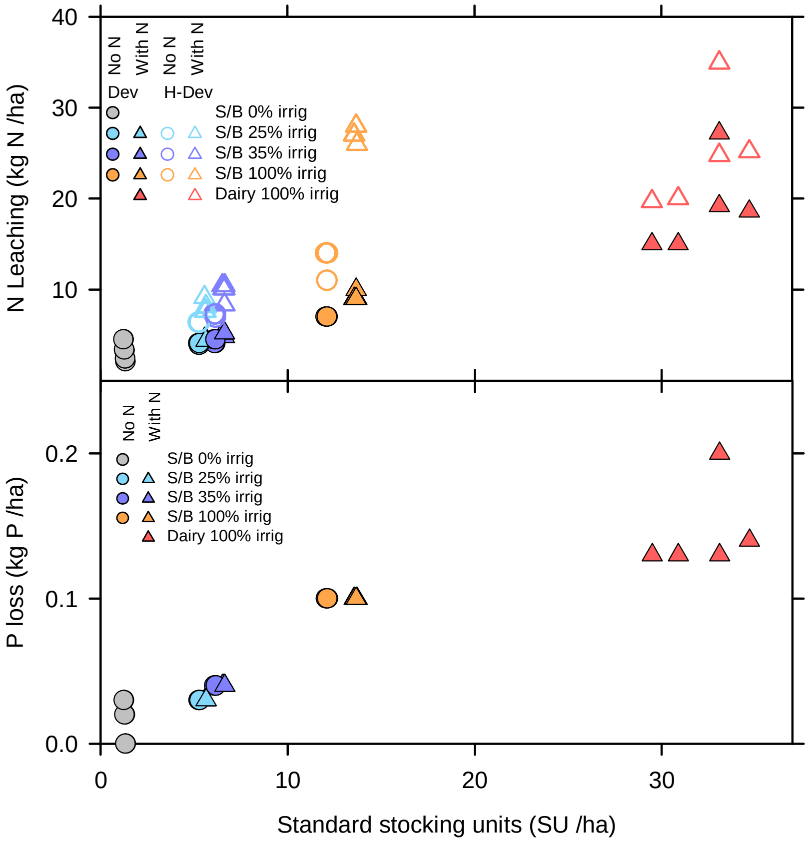

Figure 7. N loss (developed and highly developed cases) and P loss as affected by stocking rate in the potential future partially- and fully-irrigated state for sheep and beef ("S/B") and dairy farms. "Developed" status has been indicated by a solid fill and "Highly Developed" by an open symbol, triangles have been used for no N and circles for the usage of N fertiliser, symbol colour indicates farm system.

USAGE OF THE DATA BY GHD

40. GHD used the nutrient losses modelled from the existing stations and the generic farms in their modelling of ground and surface-water quality. The purpose of the modelling is described above. Following discussions with Melissa Robson (GHD) and review of selected sections of the GHD reports (GHD 2009a; b) it is my understanding that the information described above was used in the following ways.

i. The land cover database was the basis for the extrapolation of nutrient losses from farms across the catchment using a generation rate based approach. The land cover database was used to extract areas of unimproved/tussock, developed pasture, forage cropping, and irrigated pasture. Additional land cover groupings were created for hill country blocks (600 – 900 m) to reflect the increase in P losses associated with those areas. The average losses from different land uses across the seven modelled stations (Snow *et al.* 2008b; Table 2) were used to provide values for the land cover groupings for each farm. Nutrient losses from farms with existing irrigation associated with highly developed state were generated in the same way.

ii. As a check value for the current case, Agribase stocking rate information was obtained and applied at a property level using the regression equations in Snow *et al.* (2008b).

iii. For the future case, information about the proposed irrigated areas and systems were obtained from land managers and nutrient losses for each property were estimated as in (i) above using the generation rate based approach. As a check for the future values, Table 1 in Snow et al. (Snow et al. 2009b) was consulted by looking up the best match for each property and interpolating between farm descriptions were necessary. The "highly developed" N losses were assumed.

iv. As a check value for the future case the stocking rates proposed by the land managers were used with the regression equation (Snow *et al.* 2008b) using the "highly developed" assumption to provide a second estimate of property-level nutrient loss.

v. As a further check value for the future case, the proposed irrigated areas were geo-located and typical average nutrient losses applied using categories for dryland sheep/beef, irrigated sheep/beef and irrigated dairy. Those values were obtained from Snow *et al.* (2008b; 2009b).

vi. The N modelled as leaching from the stations was assumed to enter the groundwater system. A proportion of the N that entered the groundwater system was further transported to local streams as determined by local hydrogeology. Some of the N transported to the streams through gley soils was assumed to denitrify. That proportion was determined from published attenuation factors in Woods *et al* (2006).

vii. Originally all the P modelled as lost from the stations was assumed to enter the surface systems. However, the water quality information suggested that other pathways of P loss are relevant in the Upper Waitaki. Therefore to estimate future P concentrations in watercourses, not all the P lost from the farm was estimated to be captured in surface water but was split between ground- and surface-water as determined by local hydrogeology.

COMPARISON TO PREVIOUS WORK

McDowell (2004) Study

41. Likely phosphorous losses from the region under dryland and potential irrigated scenarios have been estimated by McDowell (2004). McDowell (2004) used the same model[5] as the current study but used zones typifying combinations of soil type and land use rather than modelling land management units as was done in the current study. The previous study assumed that all of the current dryland managed land uses were extensive sheep farming. The general comparisons to the Cumulative Water Study are as follows:

    i. P loss from the dryland state in the McDowell (2004) study ranged from 0.02 to 0.08 kg P /ha /yr where as in the current study it generally ranged from 0.02 to 0.1 kg P /ha /yr for the ‘typical’ stations but increased up to 0.43 kg P /ha /yr for Haldon Station which has a large area of deer farming.

    ii. P loss from the fully irrigated state in the McDowell (2004) study ranged from 0.25 to 0.85 kg P /ha /yr but was generally less than 0.3 kg P /ha /yr while in the current study ranged from 0.1 to 0.2 kg P /ha /yr when 100% of the area was irrigated.

42. Due to the differing methodologies used in the two studies it is not possible to make a direct comparison between the two sets of values but it clear that there are no substantial conflicts in recommended P losses from the two studies. This is to be expected, despite the difference in approach, given that the same model was used in the two studies.

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[5] The P loss model used by McDowell (2004) was subsequently incorporated into OVERSEER® as described by McDowell *et al* (2005).

Green (2005) Study

43. Likely nitrogen losses from farms in this region have previously been modelled by Green (2005) using a model called SPASMO. SPASMO is similar in concept to EcoMod. The Green (2005) study gave nitrogen losses that were substantially higher than those modelled in the current study. There are several differences in both the input assumptions and the results from the previous work and the modelling:

i. Green (2005) gave significantly greater soil-to-soil variation than reported here. In that modelling the assumed irrigation was 18 mm per application regardless of soil type. Here the irrigation was tailored to soil type and on the lighter soils was 10 mm per application – this would result in less drainage and leaching.

ii. Green (2005) assumed the use of substantially more N fertiliser, 200 compared to 70 or 120 kg N /ha /yr, than in the present study. This fertiliser included late winter and early spring applications that here were excluded under best practice requirements as likely to cause too high a risk of N leaching.

iii. The previous study assumed that no silage was made on the milking platform whereas we found this essential to control pasture growth in summer – this also agrees with local practice on an existing dairy farm. Making silage rather than buying in supplements will reduce leaching.

iv. The SPASMO modelling assumed that 80% of the pasture grown was utilised. Particularly in the dryland systems this level of utilisation is unrealistically high and would lead to high estimates of leaching.

v. The model used in the previous study (SPASMO) did not include any effect of urine patches on N leaching (Green 2005). It is not clear how the previous modelling managed to find so much leaching without the urine patch effect as several other measurement (Haynes and Williams 1993) and modelling studies have clearly shown that most of the leaching in pastoral systems is attributable to urine patches (e.g. Snow *et al.* 2009a; Hutchings and Kristensen 1995; Hutchings *et al.* 2007; McGechan and Topp 2004).

44. Direct comparison of the Green (2005) results and those here is not possible because of the differing input assumptions and the way that the Green (2005) results were presented, but it is clear that the Green (2005) study gave nitrogen losses that

are substantially higher than in the current study. However it is my belief that the representation of realistic farm systems in the current study has resulted in nutrient loss results that are more robust than the earlier study. This conclusion is somewhat supported by the water quality modelling in both the earlier (Snelder *et al.* 2005) and current (Norton *et al.* 2009) NIWA studies that gave nitrogen concentrations in the rivers that were too high compared to measurements (N. Norton and B. Spigel, personal communication, August 2009). The discrepancy between the nutrient concentrations modelled by Green (2005) and the measured river concentration may be because the river concentrations were not yet in equilibrium with the modelled land use however there has not been a statistically significant increase in river nutrient concentrations from 2004/05 to 2008/09. Also supporting this conclusion is that in the current study (GHD 2009a; b) that used the modelled dryland nutrient losses there is a good comparison between modelled water concentrations and those measured. It must be acknowledged however that that the effects of transport time lags and uptake by aquatic plants makes the comparison of nutrient loads leaving the farm boundary to those measured in ground and surface water problematic and it may be that the good agreement between the two data sets is coincidental.

EVALUATION OF MODEL AND ALTERNATIVES OF THE MODEL

Effects of Potential Errors in the Farm Systems Modelling

45. Given the role of the Farm Systems Modelling in the Cumulative Effects Study (Figure 1) the potential errors and possible implications in the Farm Systems Modelling include:

    i. Step A: Validation of the catchment water models

        a. Under- or over-estimates of the current case farm nutrient losses would lessen the quality of the, currently good, calibration/validation of the catchment water modelling.

        b. Over- or insufficient-sensitivity of the current case farm nutrient losses to soil, climate or farming intensity factors would lessen the quality of the validation and might affect the value of the calibrated factor for denitrification in the shallow groundwater that recharges streams with saturated margins.

ii. Step B: Calculation of tolerable nutrient loads

    a. The Farm Systems Modelling, apart from its role in validating the catchment water models, had no role in the calculation of the tolerable nutrient loads to the water bodies.

iii. Step C: Disaggregation of the nutrient loads to NDAs

    a. Under- or over-estimates of the future case farm nutrient losses would have no effect on the calculation of the NDAs.

    b. Over- or insufficient-sensitivity of the future case farm nutrient losses to soil, climate or farming intensity factors would alter the relativity in NDAs between individual properties but would have no effect on the tolerable nutrient load to the water bodies.

iv. Step D: Design of future farming systems

    a. Under-estimates of the future case farm nutrient losses has the potential to lead to future farming systems that exceed their NDA and result in intolerable decreases in water quality. For this reason, irrigation consents should be accompanied by farm plans detailing compliance to the mandatory best practice measures and required mitigations. The monitoring of water quality in the streams and lakes should be accompanied, where possible, by additional measurement and modelling on-farm at a more specific level than was possible in the generic farms.

    b. Over-estimates of the future case farm nutrient losses would result in farms that lose nutrients at rates less than the assigned NDA and would results in higher water quality in the water bodies. It would also mean that farmers were farming less intensively than they could while still meeting their NDA and might mean that they are not fully utilising the economic benefits of their irrigation consent.

    c. Over- or insufficient-sensitivity of the farm nutrient losses to soil, climate or farming intensity factors might result in imbalances in water quality at the nodes with some nodes having lower nutrient concentrations than calculated as tolerable in Step B while others would have higher concentrations than calculated as tolerable. The result would be a patchy distribution of poor water quality in the region. As above this potential implication can be lessened by high quality farm plans and monitoring.

Evaluation of the Model

46. The primary strength of the modelling approach used is that the system ensures that the farms are biologically feasible – that the proposed production can be supported by likely pasture growth along with the proposed imports of fertiliser and supplements. This assurance controls one of the largest sources of uncertainty in the modelled nutrient losses from the farm systems.

Multi-stage approach & unlinked models

47. A potential weakness of the multi-stage modelling approach is that it lacks dynamic feedbacks between the models. For example, if a farm were managed in such a way that it had unusually high leaching caused by poor irrigation, fertiliser or animal management, then higher nitrogen inputs would be required to maintain the modelled production. Because there is no dynamic feedback between the models this effect is not represented. The potential effect of this on the quality of the modelled nutrient losses is controlled because of the requirement that the farms are managed to best practice standards.

48. All the OVERSEER® modelling assumes that best practice is followed. This includes but is not limited to:

    i. Low-intensity instantaneous irrigation rates to prevent bypass flow of water and damage to the soil surface.

    ii. Design of irrigation systems to match the soil properties and low application amounts on shallower soil to prevent summer drainage.

    iii. Robust irrigation scheduling to prevent summer drainage.

iv. Fertiliser Code of Practise, with fertiliser applications justified by removal from the property in product.

v. No stock in streams or wetlands,

vi. Prevention of overland flow, pugging, soil erosion,

vii. Proper storage of supplements and responsible methods of feeding out that do not result in accumulations of excreta on small proportions of the farm

viii. Winter management of stock to prevent pugging and high densities of stock in one area for long times, and

ix. Feeding pads where large amounts of supplements are fed out

49. Should irrigation consents be obtained, it is recommended that land management plans to achieve best practice standards are required and that compliance with those plans is actively monitored.

Transition from dryland to irrigated state

50. It is expected that there will be an initial significant release of C and N in the first few seasons once the irrigation systems are commissioned (Polglase *et al.* 1995). After the initial disturbance to the pasture-soil system there will likely be a significant amount of immobilisation of C and N into the soil organic matter. This effect may last for some time but cannot continue indefinitely as the soils will eventually reach a new equilibrium. The initial loss of C and N is not captured by the models here. The medium term immobilisation of C and N is captured in the modelling using the "developed" state but the duration of this stage is unknown. The long-term equilibrium state is captured by the "highly-developed" assumption and should also substantially compensate for the expected short-term initial loss of C and N.

Soil type effect and shallow soils

51. There was relatively little specific soil type effect on modelled leaching from irrigated soils in this study. While this partly arises from use of soil-specific best management practice, this is also likely to be partly due to using a steady-state modelling system

that may not capture all the effects arising with irrigation in shallow soils (Monaghan 2009). Provided the soils are managed appropriately to type and best management practices are used and that inputs of fertiliser and imported supplements do not increase above that modelled here, the soil type effect on nutrient loss may not be great.

52. To control nutrient loss on shallow soils, well-designed and managed irrigation systems (low total and instantaneous irrigation intensity systems) are essential. If there is initially more leaching from the shallower soils but there is no additional N inputs (fertiliser and supplements) applied then pasture production and stocking will decline and so will leaching. Using a dynamic model (Snow *et al.* 2009a) to represent a single paddock, Bryant *et al.* (2008) showed that two differing soil types with differing soil storage properties in the Taupo region resulted in a relatively low soil-specific effect after the feedbacks into production, N fixation, immobilisation etc were taken into account.

Farm data

53. The farm system data obtained to represent the current case from the farm managers was important to ensuring that the Farmax and UDDER models were biologically feasible farms and the data going into OVERSEER® was robust. This data was initially obtained by interview with the relevant land managers. The Farmax/UDDER modelling setup and results were iterated between the modeller (Duncan Smeaton) and the land managers several times until the manager approved that the modelling was an accurate representation of the farms. Criticism of the farm systems modelling has included that:

    i. Modelled irrigated growth rates are too high compared to literature values;

    ii. Modelled growth rates in late summer are too high; and

    iii. The modelled N response rates in September are too high.

54. In response to these points I note the following points.

    i. Most of the pasture growth rates in the literature are from border dyke systems but some are for spray irrigation with fortnightly irrigations. Both these systems are irrigated infrequently and the pastures can spend a good deal of time under water stress. When typical border dyke conditions are mimicked in EcoMod the modelled pasture growth rates are comparable to those in the literature. I conclude that the growth rates used are defensible and that the differences between the values used and the literature values arise from the differences in the irrigation systems.

ii. The original EcoMod modelling showed the depressed late summer growth rates but this depression was removed after consultation with Dennis Fastier and Doug McIntyre. It is possible that the frequent irrigation with centre pivots will reduce the temperatures experienced by the pasture through evaporative cooling. Particularly on the properties intended to irrigate large areas it is conceivable that this could happen. Further quantitative assessment of this is beyond the scope possible here.

iii. Most, 80%, of the September N response rate occurred in the second month after application, in October when temperatures were warmer. The September-only N response rates were 3-5 kg DM /kg N compared to the two-month response rates of 18 kg DM /kg N.

55. A full discussion of all these points is given in Appendix 5.

Calibration of OVERSEER® for Upper Waitaki

56. OVERSEER® does not contain calibration data from the Upper Waitaki area, nor from other areas with a similar climate. This may be one of the reasons for the very high immobilisation in the "Developed" status. The OVERSEER® simulations with very high immobilisation would be regarded with caution and use the "Highly Developed" values (no immobilisation) should be used as a safety measure.

Forage cropping

57. Estimated leaching from forage cropping in this area was very high. The high leaching arises from fallow periods, cultivation of the soils, mineralisation of accumulated soil organic matter, fertiliser applications, and intensive grazing during winter. Forage cropping has been a necessary part of dryland farming systems but is not essential in irrigated systems as supplements made in summer can be fed

instead. Substitution of well-managed (best practice) irrigation for forage cropping is likely to be environmentally neutral provided best practice is followed in the feeding and storage of supplements.

CONCLUSION

58. There are limitations to the three-tier modelling approach used but in my opinion this approach incurs less uncertainty than not being able to properly represent farm management in dynamic models. The model results are highly dependent on the quality of the current farm systems information supplied by farm managers and used in the modelling of the current state. Best efforts were used to ensure that this was robust by iterating the model representation of the farms until the farm managers agreed that it mimicked their farm. OVERSEER® results would be more certain if local calibration data was available. In lieu of this, usage of the "Highly Developed" nutrient estimates, rigorous application of audited best practice, and monitoring should be required.

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APPENDIX 1: INPUT DATA SOURCES

1. **EcoMod.** The primary inputs required by EcoMod include daily weather records, irrigation information, soil properties, pasture parameters, management settings. A summary is provided below. See Snow and King (2008) for more detail.
   1. **Weather.** There are few weather stations in the study area that can supply the necessary information to run EcoMod so daily weather data from 1972 to 2007 was obtained from NIWA's Virtual Climate Station (VCS) network. This VCS data is calculated from measured weather data using spline interpolation (Tait *et al.* 2006; Tait and Turner 2005) over a 0.05° grid over New Zealand. Provided the VCS data gives, or is scaled to give, the correct long-term average rainfall for a particular site there is little difference in model estimates produced using measured data and VCS data (Cichota *et al.* 2008). VCS weather data was obtained for four locations (specified by P. Brown, Aqualinc Research) in the area to span the 500-800 mm rainfall range and the rainfall values were linearly scaled to obtain the intended average rainfall.
   2. **Soil properties.** The soil types in the region were categorised, by Aqualinc Research, into four principle soil types based on the capacity of the soil to hold plant-available water (PAW). The four soil categories used in the irrigation design were PAW values of 30, 60, 90, and 130 mm (P. Brown, Aqualinc Research, pers. comm. 2008) so these soils were also used for the pasture modelling. However the simulation modelling required soil properties in addition to the PAW. These values were summarised from data provided by T. Webb (Landcare Research) for modelling done in the initial nutrient assessment (Green 2005; page 10). For all the modelling a maximum rooting depth of 0.8 m was assumed.
   3. **Irrigation inputs.** Irrigation inputs were calculated by Aqualinc Research using the climate and soil information above with irrigation amounts scheduled on a daily basis subject to irrigation system design constraints (P. Brown, Aqualinc Research, pers. comm. 2008). Although the simulation model used in the growth modelling can calculate irrigation demand dynamically, the irrigation inputs calculated by Aqualinc Research were used in this modelling to ensure consistency with the drainage estimates used elsewhere in the nutrient assessment work.
   4. **Pasture parameters.** Most of the pasture module parameters were left at their default values (Johnson *et al.* 2008) but the cold and heat stress parameters,

previously shown to need local adjustment (White *et al.* 2008), were adjusted to provide reasonable agreement between literature and simulated dryland growth rates.

   v. **Management settings.** Farmax and UDDER require "potential" (unconstrained by overly high or low cover) growth rates and traditionally such data is found in research trials conducted under cage-cutting regime (Radcliffe 1974). There was not sufficient literature data on pasture and forage growth rates for the farm-scale modelling so the data was supplemented with simulation results. The modelling results here are from a cut-trial regime with return of the nutrients harvested in the cut pasture or forage to the soil as dung and urine and the pasture cut to 1.5 t DM /ha every 21 days. Although this regime is a little different to the cage-cut regime, previous testing with EcoMod (I.R. Johnson, pers. comm. 2008) has shown little difference in growth rates between these two simulation set ups.

2. **Farmax Pro and UDDER.** The farm system models require information about dryland and irrigated farm systems policies and potential pasture and forage crop information. These were obtained from several sources.
   i. **Farm climate and soil.** Station soil type by plant-available water category and annual rainfall was supplied by Aqualinc Research and GHD.
   ii. **Forage production.** Forage and pasture growth, likely fertiliser response rate, supplementary soil information was obtained through existing reports (DSIR 1964; Trolove 2008; King 2008; Snow and King 2008; Webb 1992)
   iii. **Dryland farm systems.** Dryland, or current state, farm system information including stocking rate; pattern of stock classes during the year; animal trading; production; supplements bought, made, and sold; fertiliser N used were obtained through personal interview with the relevant farm managers and/or advisors. The constructed farm system models were checked back with the farm managers to ensure that they were a good representation of the existing farms. This was achieved by sending modelled farm production outputs back to the farm managers, discussing the results by phone and/or email, and where needed making modifications to the farm system in the model. This process was iterated until each farm manager confirmed that the model was a good representation of the farm.
   iv. **Irrigated farm systems.** Irrigated state farm systems were designed using base pasture growth information from the earlier studies (Trolove 2008; King 2008; Snow and King 2008) but with modifications based on discussions with farmers and consultants (Dennis Fastier, Doug MacIntyre and Graeme Ogle) who have

accumulated experience with irrigated pastures and crops in the area. Two modifications were made. The predicted dip in modelled growth rates in February was removed and growth rates in spring were increased. As a result the modelled growth rates were increased by about 15%. Several possible farm systems were designed and quantified in the farm system models with the types of systems based on discussions with local farmers and consultants as to their aspirations should an irrigation consent be obtained.

3. **OVERSEER®.** OVERSEER® required input information from several sources. These included:
   - i. Site specific rainfall and average temperature were obtained from Webb (1992);
   - ii. Irrigation water nutrient concentrations were taken from Webb (1992) as mean concentration of the water in Lake Tekapo;
   - iii. The soil types for each block taken from soil maps in Webb (1992) with (DSIR 1964) as a secondary reference for stations beyond the extent of the Webb (1992) map
   - iv. Plant-available water was supplied by Aqualinc Research from GIS data derived from Webb (1992);
   - v. Annual drainage was supplied by Aqualinc Research modelling based on PAW and water inputs;
   - vi. Animal and farm productivity was derived from the Farmax Pro and UDDER modelling;
   - vii. Soil test information and fertiliser inputs were supplied by each station manager;
   - viii. Pasture types were assumed to be a ryegrass/white clover mix except for the hill country blocks which were assumed to be unimproved tussock land;
   - ix. Following local observations very low clover content was assumed for dryland areas and medium clover content on irrigated pasture.

APPENDIX 2: DESCRIPTION OF CURRENT FARM SYSTEMS

Dryland farm descriptions. Seven stations in the Upper Waitaki region were modelled to provide information on farm systems for a range of stocking rate, climate, and soil conditions. The modelled stations were chosen to span a range of key farm characteristics including stocking rate, stock type, existing and planned irrigation systems, and area of winter forage cropping. These stations, with brief details, were:

i. **Grays Hill Station.** The northern boundary of Grays Hill is 10km south of Lake Tekapo. Grays Hill Station is nearly 22000 ha in size of which 13000 ha is flat, unproductive and grazed only rarely. The rest of the farm comprises 150 ha of centre pivot irrigation, 2200 ha of flat to rolling slightly wetter country that is a lot more productive than the large (13000 ha) flat area. Finally, there are 6000 ha of hill country (Grays Hills). Because of this the effective farm area is considered to be only 8400 ha and it is this area that has been modelled. The effective farm area is stocked at 1.82 SU /ha. Enterprises include 11200 SU of Merinos, 1100 SU of Merino x Border Leicester and 3000 SU of cattle centred on breeding cows.

ii. **Haldon Station** is about 50 km from Lake Tekapo and comprises Haldon farm (6200 ha) on the north-east shore of Lake Benmore and Kirkliston farm (8200 ha) approximately 15 km to the north-east. The combined area of both properties is 14400 ha. The farms combined consist of approximately 900 ha of flat rolling country, 680 ha of irrigated land (mostly border dyke with some centre pivot) and 12400 ha of rolling to very steep hill country. Approximately 500 ha of land is currently unused due to rabbit predation. The overall nominal stocking rate is 1.2 stocking units /ha consisting of 8000 SU of Merino sheep, 1800 SU of Merino x Border Leicester sheep, 9500 SU of deer and 6050 SU of Hereford breeding cows.

iii. **Killermont Station** comprises 3688 ha about half of which is relatively flat and the other half is steep hills. There is a small block (~100 ha) of spray irrigation and a larger block that is cultivated and includes forage cropping. The property is stocked at 1.2 SU /ha with 3730 SU of Merino sheep and 390 SU deer based on a hind breeding system. There are 270 SU of steers traded within the year. Note that Killermont Station (Snow *et al.* 2008a) was modelled later in the study and the data was not included in the regression equation used by GHD to extrapolate the results to other farms (see below). The stocking mix and rate and

N loss are very similar to Haldon Station and so would not affect the regression equation for N.

iv. **Ohau Downs Station** is located at the southern end of Lake Ohau, 20km north of Omarama. The Station consists of a mix of rolling and flat country, with the flats in several terraces. This farm is undergoing a development programme and contains approximately a quarter undeveloped “native” pasture, a quarter rarely grazed QE II reserve land with the rest in developed dryland pasture and ryecorn. The farm is 5100 ha in size and carries 8300 SU sheep (Merino and some Merino x Suffolk) and 400 SU young cattle. The effective farm stocking rate is 1.71 SU /ha.

v. **Ribbonwood Station.** Ribbonwood Station and Shelton Downs adjoin and are run as one entity. Here they are modelled as one unit under the Ribbonwood Station name. Shelton Downs is rolling to flat and is 2700 ha in size and comprises mostly oversown topdressed semi-developed pastures. Ribbonwood is 7300 ha and contains 1200 ha of productive flats at its eastern end and 600 ha of much less productive flats at its western or Ahuriri River end. In the middle, there are 5500 ha of hills. The entire property, (both farms) is stocked at 1.6 SU /ha with 12200 SU of Merino sheep and 3800 SU of cattle based on a breeding cow system. The farm is 15 km north-west of Omarama and experiences a colder climate than some of the other stations modelled.

vi. **Simons Hill Station** is adjacent to the eastern side of Simons Pass and is 20km north east of Twizel. The Station is 6000 ha but only half of this is considered to be effective farm area because there are 3000 ha of unproductive flats that are currently ungrazed. Of the remaining 3000 ha there are 150 ha of irrigated by centre pivot when flow rates from the Maryburn permit, nearly 900 ha of developed flat to rolling country and 1900 ha of oversown, topdressed hills. The effective farm carries 3 SU /ha (excluding the unproductive flats) of Merino sheep, 9600 SU in total excluding the area. In the last year some cattle have been introduced to the system.

vii. **Simons Pass Station** is located at the south end of Lake Pukaki and is mostly flat to rolling. Large areas of the flats are essentially unproductive. The farm has 70 ha of border dyke irrigation which operates between 1 and 5 months of the year depending on the flow rate of the contributing Maryburn Stream. The farm has about 3500 ha of variously developed pasture and 2900 ha of much less productive land. The farm stocking rate is 1.2 SU /ha comprising 7000 SU of Merino sheep and 600 SU of 2 and 3 year steers.

APPENDIX 3: FUTURE FARM SCENARIOS

Table A1. Summary of the sheep/beef farm scenarios

Scenario	%Area Irrigated	%Area Easy Dry Pasture	%Area Easy Dry Forage Crop	%Area Steep	N irrig block (kgN /ha)	# Trading Lambs	% Sheep SU	% Cattle SU	% Dairy Support SU	Farm SU /ha
Farm01	0%	39%	0%	61%	0	0	99%	1%	0%	1.3
Farm02	0%	36%	3%	61%	0	0	99%	1%	0%	1.3
Farm03	0%	33%	6%	61%	0	0	99%	1%	0%	1.3
Farm04	0%	39%	0%	61%	0	0	90%	10%	0%	1.3
Farm05	0%	36%	3%	61%	0	0	89%	10%	0%	1.3
Farm06	0%	33%	6%	61%	0	0	89%	10%	0%	1.2
Farm07	0%	39%	0%	61%	0	0	79%	21%	0%	1.3
Farm08	0%	36%	3%	61%	0	0	79%	21%	0%	1.3
Farm09	0%	33%	6%	61%	0	0	79%	21%	0%	1.2
Farm10+N	25%	14%	0%	61%	70	0	100%	0%	0%	5.6
Farm10-N	25%	14%	0%	61%	0	0	100%	0%	0%	5.3
Farm11+N	25%	14%	0%	61%	70	0	90%	10%	0%	5.6
Farm11-N	25%	14%	0%	61%	0	0	90%	10%	0%	5.3
Farm12+N	25%	14%	0%	61%	70	0	79%	21%	0%	5.6
Farm12-N	25%	14%	0%	61%	0	0	79%	21%	0%	5.2
Farm13+N	35%	4%	0%	61%	70	0	100%	0%	0%	6.6
Farm13-N	35%	4%	0%	61%	0	0	100%	0%	0%	6.2
Farm14+N	35%	4%	0%	61%	70	0	90%	10%	0%	6.6
Farm14-N	35%	4%	0%	61%	0	0	90%	10%	0%	6.1
Farm15+N	35%	4%	0%	61%	70	0	79%	21%	0%	6.5
Farm15-N	35%	4%	0%	61%	0	0	79%	21%	0%	6.1
Farm16+N	100%	0%	0%	0%	70	11540	100%	0%	0%	13.7
Farm16-N	100%	0%	0%	0%	0	10193	100%	0%	0%	12.1
Farm17+N	100%	0%	0%	0%	70	10373	90%	9%	0%	13.6
Farm17-N	100%	0%	0%	0%	0	9245	90%	9%	0%	12.1
Farm18+N	100%	0%	0%	0%	70	20242	82%	18%	0%	13.7
Farm18-N	100%	0%	0%	0%	0	17993	82%	18%	0%	12.2

Scenario	%Area Irrigated	%Area Easy Dry Pasture	%Area Easy Dry Forage Crop	%Area Steep	N irrig block (kgN /ha)	# Trading Lambs	% Sheep SU	% Cattle SU	% Dairy Support SU	Farm SU /ha
Farm19+N	25%	14%	0%	61%	70	0	89%	0%	11%	5.6
Farm19-N	25%	14%	0%	61%	0	0	89%	0%	10%	5.3
Farm20+N	25%	14%	0%	61%	70	0	74%	0%	21%	5.6
Farm20-N	25%	14%	0%	61%	0	0	78%	0%	21%	5.3
Farm21+N	35%	4%	0%	61%	70	0	89%	0%	11%	6.6
Farm21-N	35%	4%	0%	61%	0	0	89%	0%	11%	6.2
Farm22+N	35%	4%	0%	61%	70	0	79%	0%	21%	6.6
Farm22-N	35%	4%	0%	61%	0	0	79%	0%	21%	6.2
Farm23+N	100%	0%	0%	0%	70	10373	90%	0%	10%	13.6
Farm23-N	100%	0%	0%	0%	0	9245	91%	0%	9%	12.1
Farm24+N	100%	0%	0%	0%	70	20242	82%	0%	18%	13.7
Farm24-N	100%	0%	0%	0%	0	17993	82%	0%	18%	12.1

Table A2. Summary of the dairy farm scenarios.

Scenario	**Farm25**	**Farm26**	**Farm27**	**Farm28**	**Farm29**
Description	Dairy 4/ha Crossbreed WinterOff	Dairy 5.3 /ha Crossbreed WinterOff	Dairy 3.7 /ha Friesian WinterOff	Dairy 3.3 /ha Friesian WinterOn	Dairy 3.3 /ha Friesian WinterOn+Pad
Farm area (ha)	300	300	300	300	300
Winter herd (cows /ha)	4	5.3	3.7	3.3	3.3
November herd (cows /ha)	3.9	5.2	3.6	3.3	3.3
Replacement Stock	Off	Off	Off	Off	Off
Stocking rate (SU /ha)(1)	29.5	34.7	30.9	33.1	33.1
Sep fertiliser N (kg N /ha)	40	40	40	60	60
Oct fertiliser N (kg N /ha)	40	40	40	40	40
Nov fertiliser N (kg N /ha)	40	40	40	40	40
Total fert. N used (kg N /ha)	120	120	120	140	140
Cows wintered off (%)	100	100	100	0	0
Feedpad	No	No	No	No	Yes
Pasture eaten (t DM /ha)	11.4	14.3	11.3	11.5	11.5
Silage fed (t DM /ha)	4.1	2.7	4.6	5.4	5.4
PKE/concentrates (t DM /ha)	0.7	2.1	1.1	1.3	1.3
Production (kg MS /ha)	1409	1617	1379	1279	1279
Effluent area (ha)	96	125	88	80	177

(1) – calculated based on 550 kg DM consumption per SU

APPENDIX 4: NUTRIENT LOSSES FROM THE FUTURE FARM SYSTEMS

Table A3. Estimated nutrient loss from the modelled farm scenarios. N losses are given with both “Developed” and “Highly developed” options.

Scenario	Description	N loss (kg N /ha) Developed	N loss (kg N /ha) Highly dev.	P Loss (kg P /ha)
Farm01	0% irrig - 0% forage, ~0% beef SU	2.1	n/a	<0.01
Farm02	0% irrig - 3% forage, ~0% beef SU	3.3	n/a	0.02
Farm03	0% irrig - 6% forage, ~0% beef SU	4.5	n/a	0.03
Farm04	0% irrig - 0% forage, ~10% beef SU	2.4	n/a	<0.01
Farm05	0% irrig - 3% forage, ~10% beef SU	3.3	n/a	0.02
Farm06	0% irrig - 6% forage, ~10% beef SU	4.5	n/a	0.03
Farm07	0% irrig - 0% forage, ~20% beef SU	2.4	n/a	<0.01
Farm08	0% irrig - 3% forage, ~20% beef SU	3.4	n/a	0.02
Farm09	0% irrig - 6% forage, ~20% beef SU	4.5	n/a	0.03
Farm10-N	25% irrig - ~0% beef SU	3.9	6.4	0.03
Farm10+N	25% irrig - ~0% beef SU	4.4	7.6	0.03
Farm11-N	25% irrig - ~10% beef SU	3.9	6.4	0.03
Farm11+N	25% irrig - ~10% beef SU	4.4	7.6	0.03
Farm12-N	25% irrig - ~20% beef SU	4.1	6.4	0.03
Farm12+N	25% irrig - ~20% beef SU	4.6	9.1	0.03
Farm13-N	35% irrig - ~0% beef SU	4.1	7.0	0.04
Farm13+N	35% irrig - ~0% beef SU	4.8	8.3	0.04
Farm14-N	35% irrig - ~10% beef SU	4.1	7.3	0.04
Farm14+N	35% irrig - ~10% beef SU	5.2	10.1	0.04
Farm15-N	35% irrig - ~20% beef SU	4.5	7.3	0.04
Farm15+N	35% irrig - ~20% beef SU	5.2	10.4	0.04
Farm16-N	100% irrig - ~0% beef SU	7.0	11.0	0.10
Farm16+N	100% irrig - ~0% beef SU	9.0	26.0	0.10
Farm17-N	100% irrig - ~10% beef SU	7.0	14.0	0.10
Farm17+N	100% irrig - ~10% beef SU	9.0	27.0	0.10
Farm18-N	100% irrig - ~20% beef SU	7.0	14.0	0.10
Farm18+N	100% irrig - ~20% beef SU	10.0	28.0	0.10
Farm19-N	25% irrig - ~10% dairy support SU	3.9	6.4	0.03
Farm19+N	25% irrig - ~10% dairy support SU	4.6	7.6	0.03
Farm20-N	25% irrig - ~20% dairy support SU	4.1	6.4	0.03
Farm20+N	25% irrig - ~20% dairy support SU	4.4	8.1	0.03
Farm21-N	35% irrig - ~10% dairy support SU	4.5	7.3	0.04
Farm21+N	35% irrig - ~10% dairy support SU	5.2	10.1	0.04
Farm22-N	35% irrig - ~20% dairy support SU	4.5	7.3	0.04
Farm22+N	35% irrig - ~20% dairy support SU	5.2	10.4	0.04
Farm23-N	100% irrig - ~10% dairy support SU	7.0	14.0	0.10
Farm23+N	100% irrig - ~10% dairy support SU	9.0	27.0	0.10
Farm24-N	100% irrig - ~20% dairy support SU	7.0	14.0	0.10
Farm24+N	100% irrig - ~20% dairy support SU	9.0	28.0	0.10
Farm25	Dairy 4/ha Crossbreed WinterOff	15.0	19.7	0.13
Farm26	Dairy 5.3 /ha Crossbreed WinterOff	18.6	25.2	0.14
Farm27	Dairy 3.7 /ha Friesian WinterOff	15.0	20.0	0.13
Farm28	Dairy 3.3 /ha Friesian WinterOn	27.2	34.9	0.13
Farm29	Dairy 3.3 /ha Friesian WinterOn+Pad	19.2	24.8	0.20

APPENDIX 5: PASTURE GROWTH RATES IN THE UPPER WAITAKI

Summary

- The farm systems modelling has been criticised stating:
    - Modelled irrigated growth rates are too high compared to literature values;
    - Modelled growth rates in late summer are too high; and
    - The modelled N response rates in September are too high.

  This document is a response to these criticisms.
- Most of the pasture growth rates in the literature are from border dyke systems but some are for spray irrigation with fortnightly irrigations. Both these systems are irrigated infrequently and the pastures can spend a good deal of time under water stress. When typical border dyke conditions are mimicked in EcoMod the modelled pasture growth rates are comparable to those in the literature.
- I conclude that the growth rates used are defensible and that the differences between the values used and the literature values arise from the differences in the irrigation systems.
- The original EcoMod modelling showed the depressed late summer growth rates expected from the literature but this depression was removed after consultation with Dennis Fastier and Doug McIntyre. It is possible that the frequent irrigation with centre pivots will reduce the temperatures experienced by the pasture through evaporative cooling. Particularly on the properties intended to irrigate large areas it is conceivable that this could happen. Further quantitative assessment of this is beyond the scope possible here.
- Most, 80%, of the September N response rate occurred in the second month after application, in October when temperatures were warmer. The September-only N response rates were 3-5 kg DM /kg N compared to the two-month response rates of 18 kg DM /kg N.
- Should the modelling have overestimated the growth and response rates, it will have affected the assumed future farm systems. There would be some flow on effect to the calculation of the individual discharge allowances but not to the allowable total nutrient discharges to each node.
- If the growth and response rates that occur in the actual future farm systems differ from those modelled then the actual future farm systems will be different from those modelled. However the future systems will be evaluated against their discharge allowances using actual farm performance and any error in the modelling will be irrelevant in that process even if OVERSEER® is used in the monitoring.

1. Introduction

There has been some criticism that the modelled pasture growth rates used in the farm system modelling are too high and cannot be justified given data in the literature. In the overall scheme the values are reasonably important. In assessment of the discharge allowances the values have a minor importance but when farm plans are compared against discharge allowances the anticipated pasture growth rates are reasonably important:

depending on how the monitoring against plan is done farmers may have to unduly de-intensify or may emit too high a nutrient load

There were three main points of criticism: that the modelled irrigated growth rates without N fertiliser were too high, that the growth rates in late summer are too high because in reality there will be temperature stress, and that the N response rate in September was too high given the temperatures in the region. These two points are addressed below.

2. Irrigated Pasture Growth Rates

Recommended annual pasture growth using the EcoMod simulation model for irrigated soils for irrigated soils was 11.2 t DM /ha /yr (Snow and King 2008) but those values were increased to 13.6 in UDDER and 14.3 t DM /ha /yr in Farmax Pro during the process of describing the farms with some existing irrigation with the respective models. Information supplied by Doug McIntyre was also used. The changes were that the early spring growth rates were increased and the modelled drop in growth rate in February was removed. The increased growth rates have been criticised as being too high for the region based on published data.

Literature values for irrigated growth rates in the Upper Waitaki region range from 4.5 to 11.9 t DM /ha /yr (Greenwood 1982) for irrigated fertilised (P and S, not N) pastures when summarising the irrigation research from Tara Hills Research Station. Irrigation at Tara Hills was border dyke irrigation with a large variety of management rules on relatively shallow soils (primarily Mackenzie soils, 30-60 mm plant-available water) and in the climate best typified by the 500 mm annual rainfall. Typical of flood irrigation on shallow soils, irrigation efficiencies were low and ranged from 26-70%, more usually at the lower end of the range. Irrigation applications ranged from 70-180 mm /application with often well over 1000 mm of irrigation applied per year. Irrigation return times varied from 6 to 50 days with a typical value of 15 days.

Scott (1992) reports pasture growth values in excess of 18 t DM /ha /yr for “under irrigation with high fertiliser rates” and supplies a mean values for the Streamland soils (probably best matched by the 60-90 mm PAW soils in the current study) of 15 t DM /ha /yr under irrigation and fertiliser. Here fertiliser appears to refer to P and S rather than N fertilisers. Scott (1992) also provides a contour plot indicating that irrigated growth rates of 12-15 t DM /ha /yr are only possible on the deeper soils. The text does not elaborate on irrigation type but does give annual average irrigation amounts ranging from 200 to 1400 mm /yr with the amount of irrigation needed inverse to annual rainfall and soil water storage.

Scott and Maunsell (1981) report a irrigation x fertiliser x species trial conducted on Haldon Station in the 1970s. There were both grasses and legumes in the trial but no grass-legume mixtures. Legumes and grasses received various amounts of P and S and the grasses received 345 kg fertiliser N /ha spread over three dressings in this cut-and-carry trial. Irrigation was applied fortnightly, mostly by spray irrigation, in the amount of about 75 mm per irrigation. Given the lack of a grass-legume mix in this trial it is difficult to use the information in the context of the current work but Scott and Maunsell (1981) reported that all legume species exceeded 15 t DM /ha /yr. None of the grass treatments exceeded 11.7 t

DM /ha /yr but the shape of the growth curves (Scott and Maunsell 1981; Fig. 2) suggests water and/or N stress in the grasses after November.

All the proposed irrigation will be using pressurised systems with designs for 10 mm every two days on the very light (30 mm PAW) soils and 20 mm every four days on the deeper soils. The annual total is also limited to 600 mm /yr. These modern irrigation designs differ considerably from the older systems used at Tara Hills and it is likely that the growth rates under the pressurised systems will be considerably higher than under the border dyke systems. Additional modelling was done to see if the differences could be explained by the irrigation system design.

A subset of the EcoMod pasture simulations reported by Snow and King (2008) were re-run with varying assumptions about the irrigation applications. Only simulations in the “500 mm” climate, most appropriate for comparison to Tara Hills, were used and only the 30 mm and 130 mm PAW soils. These soils span the range in the Upper Waitaki region and the 30 mm soils are more typical of those at Tara Hills.

The following irrigation types were run:
- no irrigation on both soils, “dryland”;
- 100 mm applied every 21 days from 1 October to 31 March on both soils, “21 day”;
- 100 mm applied every 14 days from 1 October to 31 March on both soils, “14 day”;
- 100 mm applied every 7 days from 1 October to 31 March on both soils, “7 day”;
- 10 mm applied every 2 days for the 30 mm soil or 20 mm applied every 4 days for the 130 mm soil with irrigation from 1 October to 31 March, “2-4 days”; and
- the soil- and climate-specific irrigation designs (Aqualinc Research Limited 2008) that were used in the original modelling that are similar to the 10 mm and 20 mm designs above but with additional irrigation scheduling to take account of summer rainfall and capped to 600 mm /yr as required by MIC, “Pivot”.

The results are shown in Figure 1 with the box and whisker plots showing the variation of annual pasture growth rates between 1972 and 2007. The 14-day irrigations on the 30 mm soil are the simulations with the irrigation design most typical of those at Tara Hills. For that set of simulations annual modelled growth ranged between 3.1 and 11.7 t DM /ha /yr with a median value of 6.1 t DM /ha /yr. This is lower than reported from Tara Hills but is also for the lightest of soils found at the Research Station. Figure 1 reveals a strong sensitivity to soil type with a median growth on the 130 mm soil being 13.2 t DM /ha /yr (ranging between 10.5 and 17.8 t DM /ha /yr)

For the shallow soils, such as those found at Tara Hills, although the infrequent irrigation supplied by border dyke systems substantially increases growth rates the soil’s store of plant-available water is exhausted soon after the irrigation application and so the pasture spends a period of time in a state of water stress between irrigations. This results in decreased growth rates compared to the more frequent irrigation supplied by centre pivot irrigation systems. The effect of the more frequent irrigation for the shallow soils is clearly demonstrated in Figure 1. The effect is muted considerably in the deeper soils with a larger store of plant-available water.

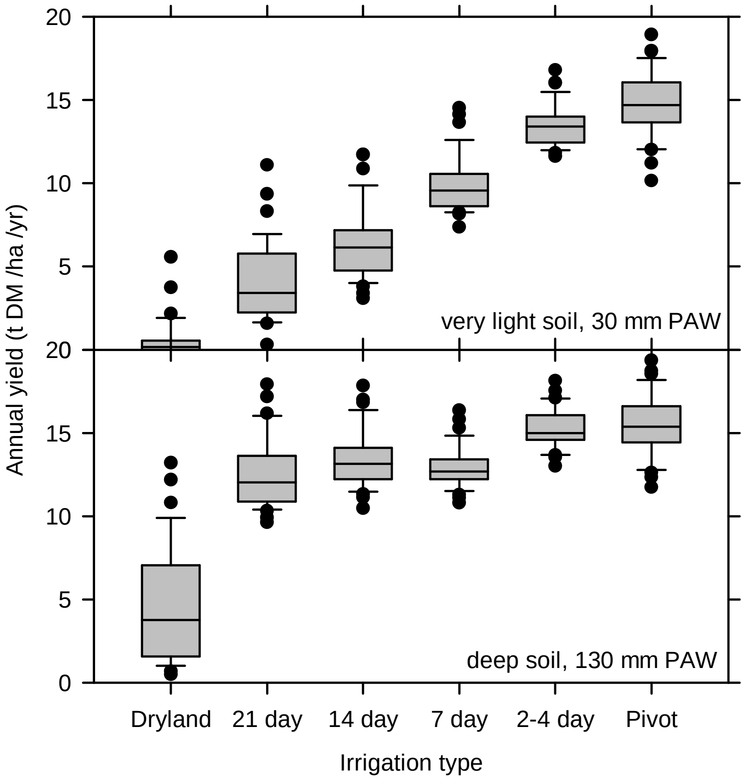

Figure 1. Annual growth rate in the "500 mm" rainfall climate and the "30 mm" and "130 mm" soils for a range of irrigation assumptions. In the labelling "14 day", for example, refers to the return interval between 100 mm irrigations. The "Pivot" irrigations were as designed by Aqualinc (Aqualinc Research Limited 2008). The box-whiskers show the spread of likely growth rates across the simulation years.

Greenwood (1982) reported pasture growth rates varying between from 4.5 to 11.9 t DM /ha /yr at Tara Hills. Replication of the soil, climate and irrigation applied as near as possible in EcoMod resulted in a range of 3.1 to 11.7 t DM /ha /yr – values very close to those measured at Tara Hills. The values used in the farms systems modelling were higher than this but this is attributable to the irrigation system designs as shown above in Figure 1. Comparison against the Scott (1992) and Scott and Maunsell (1981) is more difficult because of the monocultures used in their research. These irrigation in the Scott and Maunsell (1981) trial was also at a 14-day interval so the general observations above apply but the only conclusion I can make is that the 14-day EcoMod values above are not inconsistent with the Scott and Maunsell (1981) values given the differences in growing conditions between the trial and the simulations.

I conclude that the growth rates used are defensible and that the differences between the values used and the literature values arise from the differences in the irrigation systems. A qualification to this is that the modelled growth rates assume that the legume content of the pasture is maintained in a healthy state and this may require attention to the micronutrient status of the soil as well as good grazing management.

3. Late Summer Growth Rates

It was also stated that the modelled late summer growth rates would be achievable because the air temperatures were too high and would cause heat stress in the pastures. This is indeed plausible and in the EcoMod modelling (Snow and King 2008), particularly evident in the deeper soils (see Figure A4 in Snow and King 2008) where the February growth rates are lower than those in January or March. Duncan Smeaton used those values, including the February growth rate depression, in the initial Farmax Pro modelling of Dennis Fastier's property. Dennis, and later Doug McIntyre, indicated that with centre pivot irrigation they did not observe the February depression so Duncan smoothed the pasture growth rate curve across the months.

It is possible that the frequent irrigation with centre pivots on the Fastier and McIntyre properties has reduced the temperatures experienced by the pasture through evaporative cooling. Particularly on the properties intended to irrigate large areas it is conceivable that this could happen. Quantitative assessment of this possible effect is beyond the scope possible here,

Should the modelling have overestimated the late summer growth rates it will have had little flow on effect to the calculation of the discharge allowances. Any late summer growth reduction will affect the future farm systems but the systems will be evaluated against their discharge allowances and using actual farm performance and any error in the modelling will be irrelevant in that process even if OVERSEER® is used in the monitoring.

4. September N Response Rate

The assume response rate to N fertiliser in September was has been criticised by Stuart Ford as being too low with the rationale that temperatures in September are too low to support the assumed response rate. He did not indicate what response rate he would consider believable.

To address this comment, I have looked at the modelling (Snow and King 2008) that was used to estimate the response rate. The response rates reported are 2-month values, that is the additional amount of pasture growth over the two months post N application expressed per unit of N applied. On examining the simulation results, the pattern of the response (first month to total over two months) varied depending on month of application in a predictable pattern. The values are shown in Table 1. For September only 20% of the total response occurred during September. Some of the N that was not used by the pasture, volatilised, immobilised or leached during September was used by the pasture in October and boosted growth rates, and the modelled N response rate, once temperatures rose and growth conditions improved. Assessed alone, the September-only response rate was only 3-5 kg DM /kg N, values that arise from the low temperatures at the time.

Without more data, or more precise expression of his expectations, it is not possible to address Stuart's concerns further than the analysis below. If Stuart's statements were based on the expectation that all the growth from the September application occurred during September then this may alleviate his worries.

Should the modelling have overestimated the September N response rate it will have had little flow on effect to the calculation of the discharge allowances. If the response rates that occur in the actual future farm systems differ from those modelling in the assessment study that will affect the future farm systems but the systems will be evaluated against their discharge allowances and using actual farm performance and any error in the modelling will be irrelevant in that process even if OVERSEER® is used in the monitoring.

Table 1. Modelled N response rates giving the range and average across years, the rate recommended for modelling that accounts for unavoidable inefficiencies of application, and the proportion of the total (2-month) response that occurred in the first month after application.

	N Response Rate (kg DM /kg N)			Proportion of response in first month
Month	Range	Average	Recommended	
Jan	4-26	17	11	0.6
Feb	0-22	11	7	0.5
Mar	0-18	8		0.5
Apr	0-17	6		0.4
May	0-7	2		0.6
Jun	0-2	0		0.2
Jul	0-2	0		0.0
Aug	0-16	5		0.0
Sep	0-27	18	15	0.2
Oct	19-30	25	18	0.5
Nov	22-34	27	18	0.5
Dec	16-32	25	18	0.6

5. References

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