BEFORE THE	Canterbury Regional Council
IN THE MATTER OF	the Environment Canterbury (Temporary Commissioners and Improved Water Management) Act 2010
AND	
IN THE MATTER OF	Submission and Further Submission on Proposed Plan Change 3 to the Proposed Canterbury Land and Water Regional Plan

STATEMENT OF EVIDENCE OF DR ROGER HAYDN WILLIAMS ON BEHALF OF THE SOUTH CANTERBURY PROVINCE OF FEDERATED FARMERS OF NEW ZEALAND

Dated 24 September 2015

South Canterbury Federated Farmers Inc
Solicitor R Gardner
Counsel Acting D van Mierlo
Ph 03 7311070
Email deanvanmierlo@gmail.com

INTRODUCTION

1 My full name is Dr Roger Haydn Williams.

2 I am the General Manager of Science (Sustainable Production) for Plant & Food Research, a New Zealand government-owned Crown Research Institute. My role involves leading a group of 120 scientists and technical staff to undertake science focussed on delivering impact to New Zealand's horticultural and arable industries, with a particular focus on sustainable primary production.

3 Prior to joining Plant & Food Research in 2013, I worked as the Director of Research Development at the Foundation for Arable Research. While working at the Foundation for Arable Research, I was appointed one of the technical co-leads for the Matrix of Good Management project to provide technical leadership on behalf of the arable and horticultural sectors. This is a role that I have continued to carry out while employed at Plant & Food Research.

4 My previous experience includes working as the Head of Science for the Royal Horticultural Society in the United Kingdom, as well as a number of research roles for the primary sector in the United Kingdom.

5 I hold a Doctor of Philosophy Degree from the University of Sheffield, and a Postgraduate Diploma in Public Leadership and Management from University of Warwick.

6 I am a member of the Board of the Precision Agriculture Association of New Zealand (PAANZ).

7 I have authored numerous articles and peer reviewed publications related to arable and horticultural systems.

8 Although this is not a Court hearing, I have read the Environment Court's Code of Conduct for Expert Witnesses, and I agree to comply with it. My qualifications as an expert are set out above. I confirm that the issues addressed in this brief of evidence are within my area of expertise, except where I state I am relying on what I have been told by another person. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed.

9 I am familiar with the Proposed Variation 3 to the Proposed Canterbury Land and Water Regional Plan (the Variation) to which these proceedings relate.

SCOPE OF EVIDENCE

10 In my evidence I have been asked to provide a summary of the Matrix of Good Management project.

MATRIX OF GOOD MANAGEMENT

11 The Matrix of Good Management (MGM) project is a collaboration between six primary sector organisations: DairyNZ Ltd, Beef + Lamb New Zealand (B+LNZ), Deer Industry New Zealand (DINZ), NZPork, Horticulture New Zealand (HortNZ) and the Foundation for Arable Research (FAR), three Crown Research Institutes (AgResearch, Plant & Food Research and Landcare Research), and Environment Canterbury (ECan). It is overseen by a cross-sector governance stakeholder group.

12 The purpose of the project is to produce a suite of industry-agreed good management practice (GMP) definitions and the means to estimate the nitrogen (N) and phophorus (P) losses from Canterbury farms operating at GMP (Williams *et al.,* 2014 & 2015).

13 The project takes a co-design and co-production approach with active participation of all project partners.

Background

14 Although there is widespread support for the implementation of GMP across primary industries (Anon., 2012a & b), until recently there were no commonly agreed definitions of GMP nor a good understanding of the nutrient losses that occur from different farming enterprises operating at GMP. This information is needed to assess the nutrient losses from different land uses under GMP which can be used to support the development of effective resource management policy.

Funding & Governance

15 Cash funding for the MGM project is provided by ECan, other contributing Regional Councils (Hawkes Bay, Waikato, Horizons (Manawatu), Otago, Greater Wellington, Southland, Auckland and Bay of Plenty), Ministry for Primary Industries, Ministry for the Environment, Plant & Food Research, AgResearch, and primary industry bodies (FAR, DairyNZ Ltd, NZPork, HortNZ, B+LNZ, DINZ). In-kind contributors include AgResearch, B+LNZ, DairyNZ Ltd, DINZ, ECan, FAR, HortNZ, NZPork, Plant & Food Research (through the LUCI programme).

Key project components

16 The project commenced in 2013, is set to deliver phase 1 in late 2015, and has involved:

a) Defining GMP by each industry sector involved in the project consulting with farmers and other rural professionals and then taking a consensus approach to establishing consolidated GMP definitions relevant across industry sectors;

b) Deriving a set of modelling rules that enable translation of the narrative, industry-agreed GMP definitions into parameters that can be modelled;

c) Producing a matrix of N and P losses by grouping similar farm systems, soil and climate combinations together, and estimating N and P losses from these farm systems using the modelling rules derived from the GMP definitions (the 'catchment matrix');

d) Developing an online tool for applying the GMP modelling rules, derived from the definitions of GMP, to existing OVERSEER® nutrient budgets for individual farms to estimate N and P losses if these farms were operating at GMP (the 'on-farm matrix').

17 An important element of the MGM project design is the central role played by each of the primary sectors involved (FAR, DairyNZ Ltd, NZPork, HortNZ, B+LNZ, DINZ) in defining GMP, reviewing the GMP modelling rules, agreeing the clustering of farm types, climates and soils, and testing the catchment and on-farm matrices. Although each sector is represented within the project structure by appropriately experienced staff, a highly consultative approach involving farmers and other rural professionals has been taken by each sector.

18 The project has already delivered a suite of industry-agreed GMP definitions (Anon., 2015) and work is nearing completion to deliver the catchment matrix and the online tool for farm scale N and P loss estimates.

Defining good management practice

19 While existing conceptual definitions of GMP have provided a useful starting point for discussion, the aim within the MGM project was to describe the practical farming actions that are considered to constitute GMP. In other words, each sector aimed to

articulate the reasonable management actions that farmers could be expected to take when managing a tidy and efficient farm.

20 Each sector took an iterative approach to defining GMP, generally involving workshop sessions with groups of farmers and rural professionals. Draft lists of tangible GMP measures arising from these discussions were the subject of further discussion and refinement within industry sectors.

21 As draft GMP for each sector were compared for equivalency by the industry representatives on the Project Development Group (PDG), it became clear that there was considerable commonality in GMP across sectors. Through further consultation and revision a set of consolidated, industry-agreed GMP definitions and implementation guidance notes were produced.

Deriving of GMP modelling rules

22 Estimating N and P losses requires a modelling approach as no feasible systems exist to measure losses at the whole-farm scale (Vogeler & Snow, 2012; Lilburne *et al.*, 2012b).

23 OVERSEER® works at the whole-farm scale, is widely used in New Zealand, is freely available and was accepted by the industry representatives on the MGM project as the best tool available to estimate N and P losses for the purposes of the project (Williams *et al.*, 2012).

24 To estimate N and P losses from farms operating at GMP, it was also necessary, where possible, to translate the industry-agreed narrative definitions of GMP into parameters that could be modelled in OVERSEER®, i.e. to derive a set of GMP modelling rules.

25 These modelling rules were transparently co-developed and tested by the project's scientists working alongside the primary industry representatives. Workshops with farms and other rural professionals were used to test and improve the modelling rules. The project's cross-sector 'Reference Group', made up of farmers and industry representatives, played a significant role in reviewing and refining the modelling rules.

26 The two areas of greatest contention within this aspect of the project were deriving modelling rules for irrigation and nutrient management GMPs. Both can significantly influence estimates of N and P loss and both are technically challenging to model. Transparency regarding the assumptions behind these and the other modelling rules

will enable further improvements to be made over time should this be considered necessary.

27 The GMP modelling rules are intended to reflect the intent of the industry-agreed GMPs within the OVERSEER® model. They are not intended to be prescriptive actions that a farmer should do in order to be operating at GMP.

Producing the catchment matrix (of generalised farm systems by soil and climate)

28 The catchment matrix is intended to provide estimates of N and P loss from typical farm systems operating at GMP across the range of relevant soils and climates in Canterbury. The steps to creating the catchment matrix were:

a) Constructing a set of farm systems, described here as ‘base farms’, that represent the breadth of farming enterprises present in Canterbury;

b) Constructing a set of climate categories covering the range of climates in Canterbury;

c) Constructing a set of soil categories covering the range of soils in Canterbury;

d) Modelling N and P losses for the base farms operating within the relevant combinations of climate and soil clusters using the modelling rules derived from the industry-agreed definitions of GMP.

29 To establish what relevant farm systems should be included, each industry sector collected information on real farm systems and farm management from a sample of the farms in Canterbury.

30 For the smaller sectors (deer, outdoor pigs) this was by invitation. For others, a random sample of farms was selected and the owners/managers invited to participate (horticulture, arable, beef and sheep) or data from a large industry database of OVERSEER® files was used (dairy, courtesy of Ravensdown Fertiliser Co-operative).

31 Data collected from the farms were detailed enough to establish descriptions of farm systems in either Farmax Pro (Webby *et al.*, 1995), Farmax Dairy Pro (Bryant *et al.*, 2010) or APSIM (Keating *et al.*, 2003) models and to calculate their nutrient losses using the OVERSEER® model (Wheeler *et al.*, 2006; Cichota *et al.*, 2012). Farmax was not used to describe typical farm systems for the dairy industry, but a cluster

analysis was conducted using the Ravensdown database, including OVERSEER® output, to describe farm systems, management and accompanying nutrient losses.

32 These data were then ‘sense-checked’ in consultation with farmers and other relevant industry players to ensure that the farm systems and management were relevant to the industry in Canterbury, and to ensure that any outliers and gaps were identified. The data were then assessed to ensure that the relevant range of climates and soils for each land use in Canterbury were represent.

33 Within Canterbury there is considerable variation in the key environmental conditions that influence nutrient losses from farms. Annual rainfall on the agricultural land varies from 430 mm/yr in the eastern McKenzie Basin to 5500 mm/yr close to the Main Divide, elevation ranges from sea level to 2360 m above sea level, soils range from very poorly drained to well drained with estimates of Profile Available Water (to 1 m depth) that range from 45 to 235 mm.

34 The primary sources of information for climate and soil respectively are the NIWA Virtual Climate Station Network (Tait *et al.*, 2006) and S-map (Lilburne *et al.*, 2012a).

35 A clustering exercise was undertaken to group the climate stations and soil types into a manageable set for creating the catchment scale matrix. This was led by the project scientists but reviewed and agreed with the industry representatives following consultation with farmers and other rural professionals. The project’s Reference Group also helped in this regard.

36 The final step in developing the catchment matrix involves modelling N and P losses for the base farms operating within the relevant combinations of climate and soil clusters using the modelling rules derived from the industry-agreed definitions of GMP. This is being done using OVERSEER® and will be completed by late 2015.

37 Since the catchment matrix will be populated with N and P loss estimates for generalised ‘base farms’ operating within clustered climate and soil zones, the figure given for any particular combination of farm type, climate cluster and soil cluster may not necessarily represent the actual losses from a real-world farm as accurately as applying the GMP modelling rules to an actual OVERSEER® budget specific to that farm. Consequently, the catchment matrix is better suited, for example, to catchment-scale accounting for N and P losses than to estimating the N and P losses for a specific property at a particular point in time.

Producing the on-farm matrix (an online tool for applying GMP modelling rules to OVERSEER® nutrient budgets)

38 It was originally intended that the catchment matrix described above would be developed with sufficient resolution of farm types, climate clusters and soil clusters to be useful for estimating N and P losses for specific properties. However, as the clustering approaches were developed, concerns arose that the range of N and P losses represented within single clusters would be too large.

39 In parallel, it became apparent that it would be technically feasible to take the modelling rules derived from the industry-agreed definitions of GMP and apply these directly to OVERSEER® budgets to estimate N and P losses under GMP.

40 Accordingly, it was agreed that the project would develop the means for farmers to upload OVERSEER® nutrient budgets into an online 'portal', have the GMP modelling rules applied directly to these budgets, and have an estimate of N and P loss under GMP returned.

41 This is now in the latter stages of development and testing. The steps in this process are as follows:

a) A user uploads an OVERSEER® nutrient budget to the online portal hosted by ECan;

b) The portal checks that the OVERSEER® budget is in the latest version of OVERSEER® and, if not, the file is rejected and the user informed they need to upgrade their budget;

c) The portal checks that the appropriate soil data are present and, if not, the file is rejected and the user is directed to the S-map fact sheets for details of the soils on their farm;

d) After these initial checks, the portal applies the GMP modelling rules to the uploaded OVERSEER® budget, the N and P losses are estimated for this adjusted OVERSEER® budget using OVERSEER®, and the results reported to the user and to ECan;

e) The original and adjusted OVERSEER® nutrient budgets are deleted from the portal.

42 In this way, the user will be able to see the difference, if any, in N and P losses from their farm before and after the application of the GMP modelling rules. If they were already operating beyond GMP, the estimate of losses under GMP may be higher than the estimate under current practice. Conversely, if they are operating below GMP, the estimate of losses under GMP will be lower.

SUMMARY

43 The Matrix of Good Management has already delivered a set of consolidated, industry-agreed GMP definitions that set out the principles and practice of farm GMP in relation to water quality.

44 By the late 2015 the project is also set also deliver:

a) A matrix of N and P loss estimates for typical farms operating at GMP across a range of clustered climate and soil zones, which will be particularly suited to catchment scale applications;

b) An online tool for estimating N and P losses under GMP based on interrogating OVERSEER® nutrient budgets produced for specific farms.

45 The project has adopted a collaborative and transparent approach with extensive industry consultation and engagement throughout.

Dr Roger Williams

24 September 2015

REFERENCES

Anon, 2012a. Second Report of the Land and Water Forum: Setting limits for Water Quality and Quantity Freshwater Policy- and Plan-Making through Collaboration. http://www.landandwater.org.nz/. [Accessed 16 August 2015].

Anon, 2012b. Third Report of the Land and Water Forum: Managing Water Quality and Allocating Water. http://www.landandwater.org.nz/. [Accessed 16 August 2015].

Anon, 2015. Industry-agreed good management practices relating to water quality. http://ecan.govt.nz/publications/General/Industry_Agreed_GMPs_A5_Version2_Sept2015_FINAL.pdf. [Accessed 24 September 2015].

Bryant, JR, Ogle, G, Marshall, PR, Glassey, CB, Lancaster, JAS, Garcia, SC, Holmes and CW, 2010. *Description and evaluation of the Farmax Dairy Pro decision support model*. New Zealand Journal of Agricultural Research 53 13–28.

Cichota, R, Snow, VO, Vogeler, I, Wheeler, DM and Shepherd, MA, 2012. *Describing N leaching from urine patches deposited at different times of the year with a transfer function*. Soil Research 50 694-707.

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 and Smith, CJ, 2003. *An overview of APSIM, a model designed for farming systems simulation*. European Journal of Agronomy 18 267–288.

Lilburne, LR, Hewitt, A and Webb, T, 2012a. *Soil and informatics science combine to develop S-map: a new generation soil information system for New Zealand*. Geoderma 170 232-238.

Lilburne, L, Carrick, S, Webb, T and Moir, J, 2012b. *Computer-based evaluation of methods to sample nitrate leached from grazed pasture*. Soil Use and Management 28 19-26.

Tait, A, Henderson, R, Turner, R and 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.

Vogeler, I, Snow and VO, 2012. *Measure or (which) model to set limits and monitor achievement*. Invited presentation to "Smart Management" LandWISE 2012. Wednesday 23 May 2012, Havelock North.

Webby, RW, McCall, DW and Blanchard, VJ, 1995. *An evaluation of the Stockpol® model*. Proceedings of the New Zealand Animal Production Society 55 145–149.

Wheeler, DM, Ledgard, SF, Monaghan, RM, McDowell, RW and De Klein, CAM, 2006. *OVERSEER® Nutrient budget model - What it is, what it does*, In: Currie, LD, Hanly and JA (Eds.). Implementing sustainable nutrient management strategies in agriculture. Occasional Report No. 19. Fertilizer and Lime Research Centre, Massey University: Palmerston North, New Zealand, pp. 231–236.

Williams, R, Brown, H, Ford, R, Lilburne, L, Pinxterhuis, I, Robson, M, Snow, V, Taylor, K, von Pein, T, 2014. *The matrix of good management: defining good management practices and associated nutrient losses across primary industries.* In: Currie, LD and Christensen, CL (Eds.).

Nutrient management for the farm, catchment and community. http://flrc.massey.ac.nz/publications.html. Occasional Report No. 27. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

Williams, R, Brown, H, Brown, I, Ford, R, Lilburne, L, Pinxterhuis, I, Robson, M, Snow, V, Taylor, K, von Pein, T, 2015. *The matrix of good management: towards an understanding of farm systems, good management practice, and nutrient losses in Canterbury.* In: Currie, LD and Burkitt, LL (Eds.). Moving farm systems to improved attenuation. http://flrc.massey.ac.nz/publications.html. Occasional Report No. 28. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

A peer review of OVERSEER® in relation to modelling nutrient flows in arable crops

A report commissioned by
The Foundation for Arable Research

January 2013

Prepared by a working group chaired by Michael Dunbier[1] and including Hamish Brown[2], Doug Edmeades[3], Reece Hill[4], Alister Metherell[5], Clive Rahn[6], Peter Thorburn[7] and Roger Williams[8] with technical briefings provided by Mark Shepherd[9] and David Wheeler[9]

---

[1] Dunbier and Associates Ltd
[2] Plant and Food Research
[3] agKnowledge
[4] Waikato Regional Council
[5] Ravensdown Fertiliser Co-operative Ltd
[6] PlantNutrition Consulting
[7] CSIRO
[8] Foundation for Arable Research
[9] AgResearch

Contents

EXECUTIVE SUMMARY

Loss of nutrients, especially nitrate and phosphate, from farmland to surface and ground water can reduce farm productivity, harm the environment, and, in the case of nitrate, impact on drinking water quality. Effective nutrient management on farms is therefore a priority for both farmers and regional authorities.

Recognising this, and in response to the National Policy Statement for Freshwater Management, regional authorities across New Zealand are developing regional plans to improve water quality. In many cases, these plans refer to use of OVERSEER®, a computer model originally designed to assist farmers and their advisers to examine on-farm nutrient use and movements, in order to optimise production and environmental outcomes.

OVERSEER® already has an established role in guiding nutrient management in pastoral farming. This is due in part to its ability to capture the complexities of whole farm systems. This functionality has been optimised for pastoral production over many years of development and user testing. A relatively recent enhancement is the capability to model nutrient flows in arable crops.

This new capability has been developed using a number of simplifications. These are consistent with the approach taken in modelling pastoral systems within OVERSEER® but contrast with approaches taken in other crop-soil interaction models. Although the OVERSEER® crop model has already been tested to a limited extent, more comprehensive testing is needed to determine whether these simplifications impair the model's capability for predicting long-term average nitrate leaching in arable systems. Further testing would also help to build confidence amongst users.

The OVERSEER® user interface for crops is also relatively under-developed compared to the pastoral model and is in need of further attention before it will be able to deal effectively with complex crop rotations.

In addition to these crop model-specific considerations, the application of OVERSEER® in the context of regional authority water policy raises new technical and administrative considerations. In particular, deployment in a policy context requires greater transparency regarding the scientific basis of the model and in the software development and validation processes. Stakeholder participation in the model's strategic development would help to build trust.

Furthermore, as model predictions are inherently uncertain for a variety of reasons e.g. random error, inaccurate specification of parameters, and biases in process representation, models such as OVERSEER® are generally better able to predict relative changes than absolute values. Regulatory authorities, and all model users, need to recognise this aspect of model application.

In conclusion, OVERSEER® is the best tool currently available for estimating N leaching losses from the root zone across the diversity and complexity of farming systems in New Zealand. This review sets out a pathway for improving its fitness for this purpose in the arable sector (see recommendations). It also highlights that the new challenges facing OVERSEER® place demands on the development team and model owners that need to be acknowledged and resourced appropriately.

Summary of recommendations		
	Recommendation	**Notes**
Testing OVERSEER®		
1	Compare OVERSEER® estimates of N leaching to measured values	OVERSEER® crop model estimates of N leaching should be evaluated against measurements of N leaching to identify whether there are any systematic errors in predictions
2	Compare OVERSEER® estimates of N leaching to estimates from established research models	OVERSEER® crop model estimates of N leaching should be evaluated against predictions of long-term leaching produced by established, detailed research models e.g. APSIM
3	Continue to improve OVERSEER® based on findings from (1) and (2)	The testing outlined in recommendations (1) and (2) is likely to identify and justify areas for further development of OVERSEER® to improve N leaching predictions
Transparency in development of OVERSEER®		
4	Establish a process for peer review of OVERSEER®	An expert standing reference group should be constituted by the owners to monitor OVERSEER® performance and advise on the need for, and review changes to, operating parameters
5	Implement operational protocols	Robust operational protocols should be established for the development, maintenance and operation of OVERSEER® e.g. version control, validation and management of change process
6	Facilitate wider stakeholder engagement in strategic development	OVERSEER® stakeholder strategy workshops should be held at least annually to review and discuss strategic development of the tool
Usability issues		
7	Improve the user interface of the crop model	The structure and user interface of the OVERSEER® crop model should be redesigned to make it effective for complex arable rotations
Communication and training		
8	Inform and train OVERSEER® stakeholders	Training opportunities should be developed that focus on fostering common understanding around OVERSEER® and include policy implementation scenarios using and critiquing the use of OVERSEER® in terms of limits and strengths of use
Governance of OVERSEER®		
9	Review governance	The governance of OVERSEER® should be reviewed to establish processes appropriate for the demands likely to be placed on it including its emerging use as a regulatory tool
10	Review resources	Resourcing should be reviewed to enable OVERSEER® to meet demands that have increased in scope and complexity
11	Review risks	A formal risk management exercise should be undertaken, taking particular note of succession planning for key staff

GLOSSARY

Acronym	Explanation
APSIM (Agricultural Production Systems Simulator)	APSIM (an initiative between CSIRO, University of Queensland, and State of Queensland) is internationally recognised as a highly advanced simulator of agricultural systems. It contains a suite of modules which enable the simulation of systems that cover a range of plant, animal, soil, climate and management interactions. It is undergoing continual development, with new capability added to regular releases of official versions over time. Its development and maintenance is underpinned by rigorous science and software engineering standards.
CENTURY model	The CENTURY agro-ecosystem model (from Colorado State University) simulates C, N, P, and S dynamics through an annual cycle over time scales of centuries and millennia. The producer submodel may be a grassland/crop, forest or savanna system, with the flexibility of specifying potential primary production curves representing the site-specific plant community. CENTURY was especially developed to deal with a wide range of cropping system rotations and tillage practices for system analysis of the effects of management and global change on productivity and sustainability of agro-ecosystems.
CSIRO (Commonwealth Scientific and Industrial Research Organisation)	CSIRO is Australia's national science agency and one of the largest and most diverse research agencies in the world.
DAYCENT model	DAYCENT is the daily time-step version of the CENTURY model.
FAR (Foundation for Arable Research)	FAR is an applied research and information transfer organisation responsible primarily to New Zealand arable growers.
LUCI (Land Use Change & Intensification)	Plant & Food Research is the leading partner in the LUCI programme. The programme is designed to provide the integrated knowledge and tools required by land users and policy makers to assess and better manage the impacts associated with land use change and intensification on agricultural productivity and the environment. LUCI paddock-scale models predict the environmental impacts of land use and management change and are used to inform regional and central government policy development.

INTRODUCTION

Nutrient losses from agriculture

Worldwide there is increasing concern about nutrient losses from agriculture. Nitrate (N) leaching in particular is a problem in many agricultural areas. Examples include many parts of Europe (Oenema *et al.*, 2003), the Mississippi Basin in USA (Goolsby *et al.*, 2001), and even tropical agricultural areas such as the north eastern coast of Australia (Thorburn *et al.*, 2003). In these examples, considerable effort has been/is being put into reducing nitrate leaching in an effort to improve groundwater and associated surface water quality (see Appendix 1). Computer models of the dynamics of N leaching are playing a crucial role in both understanding and managing the nitrate leaching problem. In New Zealand, OVERSEER® is one such model for use at farm scale.

OVERSEER® and water quality policy in New Zealand

New Zealand's National Policy Statement for Freshwater Management, which came into effect on 1 July 2011, set the tone for a consistent approach to improving water quality and managing water use across the country. Accordingly, regional authorities are developing regional plans aimed at reducing agriculturally-derived nitrate and other nutrient levels in water. The favoured approach is regulation of nutrient losses from farmland rather than capping nutrient inputs *per se*. This output-based approach has the potential to offer more flexibility for farmers to use nutrients efficiently and maintain or improve productivity than input limits. However, determining nutrient losses is more difficult than monitoring inputs. As measurement of losses is impractical at present, a modelling approach is needed and OVERSEER® is set to be the model of choice. At present, Environment Canterbury, Otago Regional Council, Environment Southland, Waikato Regional Council, and Environment Bay of Plenty specify use of OVERSEER® for recording estimated nutrient discharges from individual properties. Other regional authorities are also looking at using OVERSEER® in this way.

Evolution of OVERSEER®

OVERSEER® began as a decision support system designed for farm consultants to assist them in giving on-farm nutrient management advice in pastoral systems. It has now evolved into a tool being used to implement regional policy and regulations in relation to nutrient losses from all types of agriculture (see Technical Supplement). This has involved development of new functionality, including the capacity to model cropping systems. It has also meant that among the diversity of stakeholders with an interest in OVERSEER®, there is a wide range of different perceptions and understandings of the role and utility of OVERSEER®. These stakeholders include:

- **Farmers** both individually and collectively;
- **Policy agencies** and in particular regional authorities and the Ministry for the Environment;
- **Nutrient management advisors,** primarily fertiliser company representatives and farm consultants;
- **The owners** (AgResearch Ltd, the Ministry of Primary Industries and the Fertiliser Association of New Zealand representing Ballance AgriNutrients Ltd and Ravensdown Fertiliser Co-operative Ltd);
- **Research community** because continued development of OVERSEER® requires nutrient management research and provides a useful knowledge transfer delivery tool for dissemination of new insights.

Nutrient advice in arable cropping

Nitrogen management in arable cropping in recent years has been focussed on within-season, real-time tailoring of fertiliser inputs according to soil fertility, crop needs, and weather. Tactical planning tools such as the ‘Wheat Calculator’ and ‘AmaizeN’ have been developed to assist with this. It is only relatively recently that a cropping model has been integrated into OVERSEER®. In contrast to informing ‘real-time’ crop management decisions, OVERSEER® predicts long term (multi-year), average nutrient flows and losses to the environment at the farm scale.
There has not, therefore, been demand from arable farmers for development of the cropping model of OVERSEER® and it has not been widely used in the arable context.

Rationale for a review of the OVERSEER® cropping model

Given the emerging role for OVERSEER® in influencing nutrient management across farming sectors and throughout New Zealand, the relatively recent addition of crop modelling to OVERSEER®, and the limited verification of the outputs of this functionality, the Board of FAR commissioned an expert peer review of the arable cropping model of OVERSEER® (see Appendix 2) with the following terms of reference.

With respect to estimating nutrient efflux in intensive arable cropping systems including vegetable production and dairy support:

1. *What are the strengths and weaknesses of OVERSEER® 6?*
2. *What, if any, further developments of OVERSEER® would significantly and cost-effectively increase its usefulness and usability?*

Whilst this review specifically addresses functionality of the cropping model of OVERSEER®, some generic issues were also identified and these are reported here. Additionally, due to time constraints, the review focussed primarily on nitrogen, although it is accepted that there are other components to water quality including phosphate, sediments and microbial contamination.

FINDINGS AND RECOMMENDATIONS

Testing OVERSEER®

OVERSEER® has been designed to predict long-term leaching losses on an annualised basis and this approach has been adopted in developing the cropping model. It uses long term, average annual climatic data, a monthly time step and a single soil layer. In contrast, other research-focussed crop models designed to predict the dynamics of N leaching use short-term (days to weeks) climatic data, daily time steps and multiple soil layers. Whilst the simplifications adopted in OVERSEER® appear to be consistent with the policy requirements for managing water quality, they may mean that the cropping model is unable to model the impacts of crop management interventions which occur on a scale of days, weeks and months e.g. precise timing of fertiliser applications to meet crop growth needs.

Relatively little information is available to evaluate the reliability of the current cropping model in OVERSEER® to predict long-term average N leaching in arable systems. The crop model now in OVERSEER® is a modified version of the model developed by Cichota *et al.* (2010). These authors evaluated their model as follows:

- Testing against field trials data, albeit limited to a small data set: one site (Lincoln) and two rotations with different fertiliser inputs.
- Inter-model testing against the more complex plant-soil dynamics model called LUCI (itself not well tested for predicting N leaching).

Finally, new versions of OVERSEER® have been released since the early testing, and these new versions have some substantial changes (e.g. a move to quasi-daily water balance calculations) that may affect predictions of N leaching.

For all these reasons it is essential that the OVERSEER® cropping model undergoes further testing to provide users with sound information on the accuracy or otherwise of the predicted N leaching losses.

Recommendation 1: Compare OVERSEER® estimates of leaching to measured values

OVERSEER® crop model estimates of N loss should be evaluated against measurements of N leaching, to identify whether there are any systematic (as opposed to random) errors in predictions[10]. Predictions should be assessed against deep drainage flux and nitrate concentration of the drainage water, as well as N leaching. This testing would help clarify whether there are any issues in the OVERSEER® water balance and/or N mineralisation approaches. However, these tests would not provide definitive evidence on the overall performance of OVERSEER® because it is not calibrated to predict N leaching over short periods. It is a long-term average model and must also be tested in this context.

Recommendation 2: Compare OVERSEER® estimates of leaching to estimates of established research models

OVERSEER® crop model estimates of N loss should be evaluated against predictions of long-term leaching produced by an established, detailed research model (or models). APSIM would be an appropriate detailed research model against which to compare OVERSEER®, given recent efforts put into APSIM's application in New Zealand and its track record elsewhere. This testing should be undertaken in two phases[11]:

a) At specific sites where N leaching has been measured and the detailed model has been calibrated and tested. The assumption in this recommendation is that a calibrated detailed model will provide the most relevant information of long-term N leaching in the absence of measured data.

---

[10] An assumption in this recommendation is that systematic errors (e.g. consistent over- or under-prediction) will translate to errors in long-term predictions, whereas random errors will tend to cancel out.

[11] In this testing, the detailed model could be deployed in two configurations. The first is that which is based on the default parameter values in the model and the model structure and calibration that has yielded good predictions of N leaching at experimental sites (i.e. as deployed in 2a). The second is a configuration where the detailed model has been set up to have its soil models/modules (e.g., number of layers, rooting depth) and/or N mineralisation parameters to mimic those in OVERSEER®. APSIM could be configured to mimic OVERSEER® with reasonable ease. Deploying the detailed model to mimic the structure/parameterisation OVERSEER® would help identify parts of OVERSEER® (e.g. soil v. crop) that are causing errors in prediction (if any). Estimated resources and timing for the model testing would be: a dedicated Post-Doctoral Fellow and time of the OVERSEER® development team for 1 year. We also suggest that there is an on-going role for this review panel in steering this validation work.

b) Over a wider range of conditions (such as soils, climates, management systems, etc). The purpose of this test is to determine whether the sensitivity of the detailed model to these conditions is also seen in OVERSEER®. It assumes that the responses in a calibrated detailed model are representative of the 'true' variations in N leaching across these conditions.

c) Sensitivity analysis. The degree to which within-year crop management operations such as timing of fertiliser applications affect long term average nitrogen leaching, and hence their importance in being included in the OVERSEER® modelling framework, is unclear. Therefore, activities (a) and (b) should include a sensitivity analysis of the impact of such management tactics on predicted long-term N leaching. This analysis would define the relative impact of the tactics compared with strategies, and hence signify whether further investment is required in adding tactical management capability to the OVERSEER® cropping module. A similar approach to evaluating OVERSEER® phosphate loss predictions would also be worthwhile.

Recommendation 3: Continue to improve OVERSEER® based on findings from recommendations (1) and (2)

The testing suggested above is likely to identify and justify if further development is needed in OVERSEER®, possibly including:

- Implementation of multiple layers into the soil model, and different rooting depths for different crops;
- Implementation of daily time step for the soil nitrogen balance;
- Improvements to the mineralisation routines. This will require the collection of data from a wide range of soil types and land use histories, and testing under different temperature conditions;
- Recalculation of the coefficients in the leaching models using a better validated detailed soil model to provide N leaching and Mineral N and Drainage values;
- Implementation of drainage calculations that appropriately account for the effects of variability;
- Technical refinement to enable modelling of subtle crop management mitigation measures e.g. timing of fertiliser applications. However, it is recognised that there is a trade-off here with simplicity of user interface and data input requirements.

The above comparisons would ideally form an integral part of ongoing cycles of model testing, development, and validation within OVERSEER®.

Transparency in the science underpinning OVERSEER®

It is likely that OVERSEER® is going to be used in a public policy context to facilitate the reduction of diffuse nitrate pollution in agriculture. Thus, the extent to which it is fit-for-purpose will be questioned by an increasingly wide range of stakeholders and the model will be under increasing scrutiny as it develops into this role. Therefore, open and independent review of the science underpinning OVERSEER®, the assumptions made in its application, and the operational aspects of the model will be essential to build confidence in its integrity and use.

This confidence will enable much faster and more effective delivery of OVERSEER®. Additionally while increased formality of process may increase cost, the significantly greater scrutiny that OVERSEER® will face demands transparency if risks are to be adequately managed. However, it is important to emphasise that this does not reflect on the integrity of either the model or those servicing it. It is simply that as the model is to be used more widely in the future more transparency will be required.

The interest of stakeholders in the development and current and future use of OVERSEER® has been amply demonstrated in the course of this review. Such engagement is positive for the future of the model and can be exploited to enhance the resourcing and implementation of the model and confidence in its use.

Recommendation 4: Establish a process for peer review of OVERSEER®

The owners of OVERSEER® should establish a standing committee comprising technical experts who are independent of the owners to provide the owners and users with an objective oversight and analysis of the performance of OVERSEER® and any further technical changes made to it. The standard required for this technical oversight must be such that it can withstand legal scrutiny.

Recommendation 5: Implement operational protocols

A set of protocols defining the operation and application of OVERSEER® should be prepared to a suitable standard to withstand legal scrutiny. This will include but not be limited to version control, validation and the management of change process.

Recommendation 6: Facilitate wider stakeholder engagement in strategic development

OVERSEER® stakeholder strategy workshops should be held at least annually.

Usability issues

A fundamental principle of the OVERSEER® model is that it is developed in a way that is easy to use and that it provides output that is relevant and useful. Rahn (2004) discussed several of the barriers to use for decision support models. It must be recognised that there are now a range of potential users and stakeholders, as noted earlier, whose needs should be carefully taken into account when using and applying the OVERSEER® model.

Significant software issues with the user interface of the current version of the cropping model of OVERSEER® result in slow and tedious performance. In particular, implementation of the “Crop Rotations” input screen is troublesome. This needs to be addressed as soon as possible.

The cropping model is currently structured such that there is a ‘lead-in’ year followed by an assessment year. This is satisfactory if only a few paddocks are to be modelled, but for a large arable farm with many paddocks at different stages in a 5 - 7 year rotation the current structure can result in a situation where every paddock has to be modelled independently. Hence data entry can become very onerous, with double entry of data for every rotation stage. Further, the complete rotation may not be represented in a single year, meaning that the result will not reflect a long term average for the whole rotation. It is essential that a software improvement to the cropping model is implemented so that it is a simple task to carry over data from one year to the next.

The primary aim of OVERSEER® is to calculate a long term average nutrient budget for a farm system. Therefore, an alternative structure where the user can enter typical crop rotations over a number of years and OVERSEER® models the nutrient loss for every year entered would potentially be a more efficient model. Because there may be a variety of soil types on the farm, a modelling structure where an area-weighted average over a combination of soils and rotations may be required. Both individual crop and long term average nutrient losses could be reported. While not precisely representing actual management in a particular year, this would achieve the major aim of identifying problem areas where mitigation strategies would have the greatest benefit. It would also allow the modification of crop rotations to be explored as a mitigation strategy. However, it is acknowledged that a trade-off exists between ease of use and flexibility to customise inputs to represent actual management. For example if a farm has a mix of light and heavy soils some of the details of the rotation (timing of sowing, fertiliser application, irrigation) may vary from paddock to paddock depending on the crop soil type. Moving to a ‘typical rotation’ structure would lose these subtleties of management which can be important in managing N loss. Therefore further consideration is needed to deliver a simple interface with sufficient flexibility to closely match OVERSEER® management with actual farm practice.

Users will also be more favourably disposed to OVERSEER® if the outputs of the model are in a form that is relevant and matched to the scale and complexity of the farming systems it is to be used for, and provide:

- An indication of compliance with any nutrient discharge allowances prevailing;
- A list of mitigation options so that alternative management practices can be evaluated.

Another source of frustration for users is software coding errors for which the processes for model verification need to be improved. This is not an easy task given the size and complexity of the model but it is extremely important for building confidence amongst users.

Recommendation 7: Improve the user interface of the crop model

Improvements could include:

- Addressing the current software issues that limit ability to input crop rotations in a reasonable timeframe (this is urgent).
- Implementing a crop rotation-based structure rather than a paddock-based structure. Note that this will have implications for the requirement of some regulatory bodies to use OVERSEER® as a retrospective compliance tool.
- Ensuring that data does not need to be entered more than once (both within an assessment year and between years).
- Linking to climate and soil databases to simplify the entry of technical data, but with the ability for users to modify this with site specific data.
- Implementing mechanisms for data import from (and export to) other commonly used farm management software.
- Developing schemes so that farm data can be collected on web or paper forms in a way that can be easily entered into the model by experienced users.
- Providing links by which records can be easily communicated to regulatory authorities.
- Developing the interface so that it provides some indication of compliance.
- Developing OVERSEER® capacity to be used in a predictive decision making way to improve both crop and environmental management rather than just as an historical compliance tool.

Communication and training

Knowledge of OVERSEER® is relevant at regional, catchment and farm scales, although it is specifically a farm-scale model. Consequently, the range of stakeholders is broad and includes central government, regional authorities, farmers, farm groups and industry groups. Stakeholders have different perceptions and understanding of how OVERSEER® works and how it can be used.

The review has identified benefits in creating common perceptions and knowledge of OVERSEER® across stakeholders so they share a common understanding of appropriate application of OVERSEER® for farm decision support and policy development and implementation.

Like any model, OVERSEER® predictions have associated uncertainty in both the farm management setting and the policy implementation setting. Enhanced training and communication is needed to improve the common understanding of the limits and strengths of OVERSEER® within these constructs.

Different approaches are likely to be required for the different stakeholder groups. However, fostering opportunities for shared learning between stakeholder groups will be advantageous. The review identifies two stakeholder groups, policy developers and farmers, which would benefit from policy related OVERSEER® training through a mix of courses and workshops.

The existing Massey University supported Fertilizer & Lime Research Centre short courses on Sustainable Nutrient Management in New Zealand Agriculture are seen as having potential for training in the application of OVERSEER® in a policy framework. The courses are accessible and used currently by regional authorities and industry for training and accreditation (Institute of Primary Industry Management and DairyNZ are currently developing an accreditation scheme). These courses could include a module on the use of OVERSEER® in relation to nutrient management policy with scenarios including a full range of policy implementation examples and possibly regional specificity.

Recommendation 8: Inform and train OVERSEER® stakeholders

This should include:

- Fostering common understanding around OVERSEER® capabilities;
- Policy implementation scenarios using and critiquing the use of OVERSEER® in terms of limits and strengths of use.

Governance of OVERSEER®

The evolution of OVERSEER® from a decision support system for research and advisory purposes to a primary tool for nutrient management, including setting regulatory limits by regional authorities, is remarkable. The obligations placed on the owners in terms of the strategic direction and resourcing of the model and of managing risks have, as a consequence, increased substantially and are likely to continue to increase.

Implementing the recommendations of this review without slowing development at this key stage in the model's history will require a significant expansion in the current OVERSEER® team. Such an expansion however will greatly improve the capability of the team to deliver a useful tool to meet the ever-increasing challenge of reducing diffuse pollution in agriculture.

Recommendation 9: Review governance

Review the governance of OVERSEER® to establish processes appropriate for the demands likely to be placed on the model in the foreseeable future including its use as a regulatory tool.

Recommendation 10: Review resources

Consider the resources necessary to enable OVERSEER® to meet these increasingly broad and complex demands and how additional resources can best be obtained.

Recommendation 11: Review risks

Undertake a formal risk management exercise, taking particular note of succession planning for key staff.

CONCLUDING REMARKS – IMPLICATIONS FOR STAKEHOLDERS

- OVERSEER® is a valuable tool for managing the impact of nutrient losses from the diversity of farming systems in New Zealand and it is appropriate to continue to invest in development of OVERSEER® rather than developing a new tool.
- The rapid extension of the role of OVERSEER® has substantially changed its risk profile and the owners and users need to be aware of this. Reducing the risks resulting from the use of OVERSEER® will require governance and process changes that increase trust in its use and enhance credibility of the results it produces.
- By allowing OVERSEER® to be used in a broader policy and regulatory space the owners have implicitly accepted a responsibility to ensure that it remains fit for purpose in these new uses. This review sets out a pathway to improve its fitness for purpose in the arable sector.
- The continued development of OVERSEER® to faithfully represent arable cropping situations will take time. Managing the expectations of all stakeholder groups is probably the biggest challenge facing OVERSEER®. Strong and consistent leadership from all the groups involved in intensive annual crops, along with policy stakeholders at both national and local levels, will be required.
- Models, such as OVERSEER®, are generally better able to predict relative changes than absolute values. Regulatory authorities, and other model users, need to recognise this aspect of model application and frame their use of OVERSEER® with this in mind.

TECHNICAL SUPPLEMENT

Context of modelling nitrate leaching

There are many different types of models, generally developed for different purposes. In the context of soil N management, models can fall into different categories (after Shaffer, 2002):

- *Screening models.* Semi-quantitative models primarily aimed at evaluating the effects of N management on crop yield and/or the environment.
- *Application process N models*. These are process-based N simulation models aiming to provide quantitative estimates of N lost to the environment and (to varying degrees) crop production as a function of N management.
- *Detailed research models*. These models include complex C/N processes and interactions in soils and plants, and allow close examination of N management effects on processes such as nitrate leaching, nitrous oxide emissions, and crop nutrient stress.

A widely used approach in screening models is nutrient budgeting (Oborn *et al.*, 2003). Nutrient budgeting allows estimation of nutrient surpluses, which are a primary driver of long-term N losses to the environment. Oenema *et al.* (2003) distinguish between the scales of nutrient budget: *soil surface, farm gate* and *soil system*. *Soil surface* budgets track the difference between nutrient inputs to (e.g., fertiliser), and removal from (e.g. in crop nutrient off-take) soils in one dimension. *Farm gate* budgets do the same at a whole farm scale, and so account for between-field nutrient transfers, as is common (and important) in pastoral production systems. Both of these approaches implicitly assume that soil nutrient reserves are in steady state. When this assumption is not valid, such as when there is substantial mineralisation of N from, or immobilisation of N by soil organic matter, soil nutrient dynamics need to be considered. These dynamics are included in *soil system* nutrient budgets.

Processes that impact on, and so could be included in, models for studying soil N dynamics are plant N uptake, nitrification, denitrification, mineralization, immobilisation, volatilization, symbiotic N_2 fixation and leaching. Generally, in models incorporating these processes, calculations are done on a daily (or more frequent) time step, at different depths within the soil profile, and represent a field (or point) scale (Cannavo *et al.*, 2008). Models operating at spatial scales larger than the field are more likely to be semi-qualitative; e.g. screening models (Shaffer, 2002) or "indicators" (Cannavo *et al.*, 2008), and may include farm nutrient budget models. Cichota and Snow (2009) provide a good illustration of different temporal and spatial scales of nutrient loss models (Fig 1).

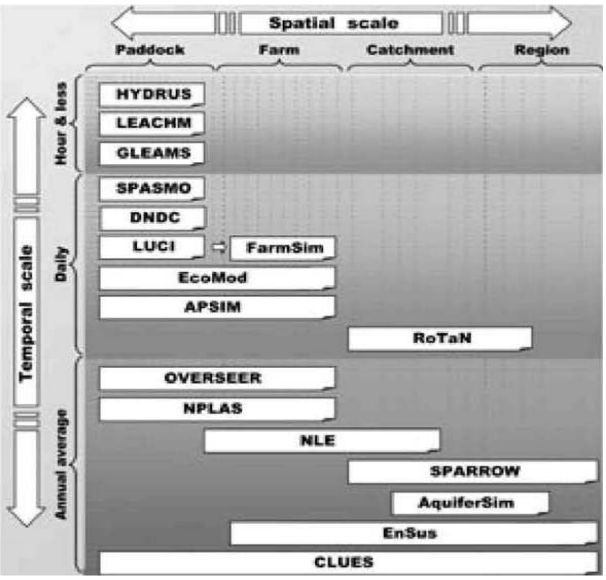

Fig. 1. Illustration of the different temporal and spatial scales of nutrient loss models (from Cichota and Snow, 2009.)

The processes needed to model N dynamics are more consistent with Shaffer's (2002) detailed research models than application process N models. While the term "Detailed research models" implies these models have a complexity that limits their application in a practical context, there are many examples of them being applied at broad (e.g., regional or national) scales for informing management of nitrate leaching (e.g. Thorpe *et al.*, 2008; Bouraoui and Grizzetti, 2008; Carroll *et al.*, 2012) and other N-related environmental issues (e.g. N_2O emissions; Del Grosso *et al.*, 2006). Similarly, models of this level of complexity can be 'delivered' to, and used by, farmers to guide management of their farms (Hochman *et al.*, 2009).

The 'evolution' of OVERSEER®

The OVERSEER® model was developed on farm-gate nutrient balance principles, to guide nutrient management in pastoral farms (Table 1). The model was (is) driven by input of actual farm production, so there was no need to include detailed, fully mechanistic plant and animal growth and yield modelling. For loss of nutrients to the environment, this strategy, in essence, means the nutrient surplus is set by the user (as the difference between the inputs of nutrient applications and removals), and the model's role is to partition the losses to the different possible pathways (gaseous losses, runoff or leaching plus net mineralisation/immobilisation, adsorption/slow release).

Initially, N leaching was estimated based on N surplus, site and climate factors, including rainfall (v2). The model evolved from a block scale to a farm with effluent (v4), then to a full farm model (v5) that accounted for nutrient transfers between paddocks, and between farm structures (pads, farm dairy effluent) and blocks in pastoral farms. The model's domain expanded to include arable crops in v5.0 and forage crops in v5.3. The cropping model was revised following the project on *Nitrogen management for environmental accountability* (Bromley and Catherwood, 2006) and released in v5.4, although a separate monthly drainage model was used to estimate N leaching. All the cropping models used a 2 year cycle, accounted for both the nutrient uptake and removal by these crops, and estimated the amount of N mineralisation following cultivation. They also focused on the N transformations with a year, not a crop rotation.

In summary, OVERSEER® has 'evolved' (in Shaffer's terminology) from a *screening model* towards an *application process N model*. N leaching predictions from OVERSEER® (v5.3 and v6.0) for dairy pastures have been tested, and the error is estimated to be +/- 20% (Ledgard *et al.*, 2006; Anon., 2012). Similarly, testing of N leaching in the development of an upgraded N balance module for cropping systems against outputs from a process model (the LUCI framework model) and results of a field experiment with two crop rotations have been good (Cichota *et al.*, 2010). Although these results are positive, the extent of OVERSEER®'s evaluation for predicting N leaching is relatively limited and the LUCI model is not in itself well validated for predicting N leaching. As well, there have been modifications to OVERSEER® since this original testing, and the effect of these modifications is unknown.

Table 1: OVERSEER® Development timeline

(www.OVERSEER®.org.nz/OVERSEER®Model/OVERSEER®History/OVERSEER®Developmenttimeline.aspx 26/9/12).

Year	Model	Scale	Drivers	Founder	Main Users	Outcomes
1982-84	CFAS	non-camp paddock	Consistent fertiliser recommendation systems	Public good	Consultants	Nationwide nutrient recommendation system for production Inputs + recycling by animals
1992-94	Database summary of P, K and S field trials	Mostly small plots, 3 yr+ data per trial	Data summary and funding cuts	Fert-Research	Science	Sharpened up recommendations Consensus Nutrients other than P
1996	Outlook	non-camp paddock	Utilise the P, K and S trials	Fert-Research Public good	Fertiliser reps	Productivity and economics Software + CFAS + database
1999	PKS Lime	non-camp paddock	Update to include lime	MAF Fert-Research	Fertiliser reps	Outlook + lime Need to change model name
2000	OVERSEER® 2	non-camp paddock	Environmental	MAF	AgResearch	Include N (environmental)
2000	OVERSEER® 3	non-camp paddock	Development of the Code of Practice for Fertiliser Use	Fert-Research	Fertiliser reps	Combined NPKS Lime (productivity and econometric) and nutrient budget (environmental) into a single model.
2002	OVERSEER® nutrient budgets (ovr 4)	Farm, block Camp/non-camp	Common practice for land application of effluent	MAF public good (effluent)	Ag and Fert consultants	Nutrient budget (including environmental effects) covering farm scale and farm dairy effluent use on land.
2003	OVERSEER® nutrient budgets (ovr 5)	Farm, block Camp/non-camp	Greenhouse gas emissions Sustainability Addition of minor nutrients (Ca, Mg, Na, acidity added)	MAF Public good	Fertiliser reps Farmers Private consultants Science	Educative tool Environmental focus (N leaching, greenhouse gas emissions, energy)
2005	OVERSEER® nutrient budgets (ovr 5.2)	Farm, block Camp/non-camp	Increased functionality and mitigation options P runoff module	MAF	Fertiliser reps Farmers Private consultants Science Policy	Increased use in evaluating farm management effects on nutrient flows and environmental emissions. Interest in possible regulatory role.
2008	OVERSEER® Nutrient Budgets (ovr 5.3)	Farm, block Camp/non-camp	Monthly stock calculator Forage crop Addition of DCD Addition of wetlands and riparian strips	MAF Fert-Research SFF	Fertiliser reps Farmers Private consultants Science Policy	Increased use in evaluating farm management effects on nutrient flows and environmental emissions. Increasing use in regulatory role.
2009	OVERSEER® Nutrient Budgets (ovr 5.4)	Farm, block Camp/non-camp	Input parameter reports added. Major changes to fruit, vegetable and arable cropping models.	MAF Fert-Research SFF	Fertiliser reps Farmers Private consultants Science Policy	Wider applicability of the model to other, non-pastoral, sectors
2012	OVERSEER® Nutrient Budgets (ovr 6.0)	Farm, block Camp/non-camp	Change to web browser model, major chnages in model, including Integration of all blocks types, upgrade of N model, ghg product reports	MPI, FANZ	Fertiliser reps Farmers Private consultants Science Policy	Wider applicability of the model to other, non-pastoral, sectors Improved predictions based on new science

The challenge confronting OVERSEER®

The OVERSEER® model has been given the ‘challenge’ of predicting long-term average N leaching to assess whether farming activities and/or management practices meet relevant water quality policies. This challenge requires a model to ‘straddle’ the gap between screening models generally used to assist farm management (which, thus, have an important requirement for user friendliness) and detailed models that include complex C/N processes that are needed for close examination of N management effects on processes such as nitrate leaching. However, OVERSEER®’s application as a farm management tool has, quite appropriately, resulted in assumptions to simplify the processes represented. These simplifications include:

1. Long-term average data for rainfall, and monthly figures for total irrigation applied, are used to estimate daily time-steps for rainfall and irrigation. These values in turn are used to estimate monthly aggregated drainage values.
2. Soil mineral nitrogen supply and crop N uptake is based on a monthly time step;
3. It uses a single, 1.5m deep soil layer, rather than a composite of several discrete horizons.

The OVERSEER® model also faces a second ‘challenge’: that is being applicable to the wide range of agricultural practices in New Zealand (i.e. dairy farming, forage cropping, arable cropping, etc.). The different systems have contrasting characteristics. Pastures are generally perennial, with ground cover year round (unless over grazed) and an established root system, making them amenable to a simplified modelling approach (i.e., those listed above). However, dairy farms are complex management systems, with animals grazing different fields, gathering near milking sheds, having stand-off pads, etc. These features make nutrient budgeting complex as the animals, in effect, transfer nutrients from field to field. Thus, a nutrient balance model for dairy farming needs quite sophisticated representation of the farm management system, in contrast to the potentially simple representation of the plant-soil system. The complexity of nutrient balances in pastoral systems is recognised by Oenema *et al.* (2003) in the need for *farm gate* nutrient budgeting. While these simplifications in OVERSEER®’s plant-soil modelling approach have been shown to be appropriate for pastoral systems, it is less clear whether they are appropriate for other agricultural systems.

In cropping systems, nutrients are predominantly applied to a given field through fertilisers, manures, etc., and there are minimal nutrient transfers within the farm. Nutrient exports in harvested product are relatively easily quantified. Thus, *soil surface* nutrient budgeting approaches are appropriate for cropping systems. However, there is much greater complexity in the plant-soil component of cropping systems. Crop management can result in a substantial variation in soil conditions on a daily basis such as N fertiliser application to soil which may/may not support an actively growing plant, or which may/may not be irrigated immediately afterward. Different crops can have different rooting depths, and the soil can be bare during fallows.

The management complexity in arable systems comes through crop rotations and the timing of management interventions. Capturing N dynamics in these situations has generally been achieved through daily (or sub-daily) time step models. Sometimes the aim of these models has been to capture daily N dynamics and N leaching from the system. For example, the EU Nitrate directive (that nitrate concentration in leaching waters never exceeds 50 mg/L) implies the need for daily information. Furthermore the spatial complexity of a cropping farm can be much greater than many pastoral farms, with each paddock potentially having a unique crop rotation and management history.

Thus, the challenge for the application OVERSEER® is how to balance the management complexity and soil-plant simplicity of pastoral systems with the comparative soil-plant complexity and management simplicity of arable systems. Further, the context of OVERSEER®'s application in all agricultural systems is in predicting long-term average, rather than daily N dynamics and leaching. Given that some of the complexity in modelling the soil-plant dynamics in cropping systems is driven by the requirement to provide short-term predictions, it is valid to ask: what simplification can be made in the model for predicting long-term average values in arable systems? The application of the current (v6) and earlier versions of OVERSEER® to arable systems can therefore be framed as a hypothesis about the simplifications that can be made, with the null hypothesis being that the simplifications appropriate for a pastoral system are also appropriate for arable systems.

Testing this hypothesis is complicated by the difficulty in obtaining data on long-term average N leaching. N leaching is difficult to measure due to spatial and temporal variation (as discussed by Cichota and Snow, 2009), and long-term data are scarce.

Sources of uncertainty in modelled outputs

OVERSEER® has evolved from a decision support system designed for on-farm fertiliser and nutrient management advice to a tool being used to implement regional policy and regulations in relation to nutrient losses from agriculture. Therefore, all users of OVERSEER® must appreciate its limitations and must have a good understanding of the uncertainties in OVERSEER® estimates. A report by Ledgard and Waller (2001) indicated that the variability in OVERSEER® estimates of the amount of N leaching from the root zone are associated with i) uncertainty around values for inputs and ii) comparison with measured values. In total this uncertainty is of the order of ± 20%.

1. **Input uncertainty.** The principle of 'garbage in equals garbage' out applies. Users must appreciate that a good understanding of the inputs that 'drive' OVERSEER® is essential and must develop knowledge of the effects of changing the input variables on the key outputs (viz. N leaching and P runoff).
2. **Measurements versus modelling uncertainty**. This is inherent in OVERSEER® and is an expression of the certainty/uncertainty arising from attempting to model complex biological processes with a minimum set of inputs. The estimated uncertainty in N leaching (from the root zone) in the pastoral model is ± 20%. There is currently no estimate of the error in N leaching in the cropping model and no estimate in the error in predicted P runoff in either model.

In addition, choice of weather data sets can have a profound effect on performance. If long term average data are used to determine the limits, these data should also be utilised for determining compliance.

OVERSEER® in a policy environment

The sources of uncertainty in OVERSEER® are particularly relevant in the policy environment. For example, in the Proposed Canterbury Land & Water Regional Plan, after 2017 a figure of 20 kg N/ha/yr has been set as the trigger point for reporting to the regional authority. If this figure is exceeded, a Farm Environmental Plan must be developed, implemented and reported. This trigger point should logically incorporate the limits of accuracy of OVERSEER® (i.e. whether the trigger point is 20 ± 4 kg N/ha/yr or whether the 20 kg N/ha/yr is the upper limit).

In other words, policy transparency about how the accuracy of OVERSEER® relates to the trigger point for reporting is important. This approach would make explicit the uncertainty around the OVERSEER® estimates of predicted N leaching.

Policy makers should consider the accuracy of OVERSEER® and the uncertainty associated with the inputs and outputs from the model. Placing OVERSEER® into a policy setting where the outputs are regarded as a fixed and absolute number may instigate legal challenges and experts could be drawn in to discussion over the appropriateness or otherwise of input variables used in any given farm situation. Nationally, there are examples of the use of OVERSEER® in a policy context that can be used to explore alternative uses of absolute and relative OVERSEER® outputs (e.g. Regional Plan Variation 5 – Lake Taupo Catchment, Proposed Canterbury Land & Water Regional Plan).

Although input errors may be a significant source of uncertainty in OVERSEER® N leaching estimates between farms, this is probably relatively minor within a farm where the user is examining the effects of changes in on-farm practices because many of the parameters (e.g. site factors such as area, soil, slope, rainfall) remain constant under any comparative scenario. Again, this emphasises that a good understanding of the model and training in its use are important for the use of OVERSEER® in a regulatory context.

In a regulatory context, the impact of OVERSEER®-related uncertainties are lessened when the model is used to examine "what-if-scenarios" (as it is in part of the Proposed Canterbury Land & Water Regional Plan) and when assessing relative N loss changes within a farm (as in the Regional Plan Variation 5 – Lake Taupo Catchment).

The generic issue of uncertainty in environmental models is covered in some detail in an article by Mike Freeman in the Resource Management Journal (August 2011): *'The resource consent process: Environmental models and uncertainty'*. In it, the author states:
'Similarly, but more specific to environmental models, the United States Environmental Protection Agency ("USEPA") guidance on the use of environmental models "Guidance on the Development, Evaluation, and Application of Environmental Models" Council for Regulatory Environmental Modeling, 2009, states that model developers and users should:

a) *subject their model to credible, objective peer review;*
b) *assess the quality of the data they use;*
c) *corroborate their model by evaluating the degree to which it corresponds to the system being modelled; and*
d) *perform sensitivity and uncertainty analyses.'*

Estimation of nitrate leaching

A number of shortcomings were identified in the OVERSEER® model's methods for predicting N leaching that are likely to justify improvement. N leaching is estimated in OVERSEER® as:

$$N\ Leached = Mineral\ N \times a \times (Drainage/PAWC)^{b}$$

Where PAWC is the plant available water capacity of the soil and a and b are empirical coefficients. Estimations of N leached are most dependent on the values of Mineral N, the 'a' coefficient, and Drainage and there are short comings in each of these elements in the OVERSEER® crop model.

Mineral N is calculated from the N balance which starts with the Mineral N left in the soil at the start of the month, adds N from fertiliser and mineralisation of residues and soil organic matter, removes N from crop uptake, denitrification and then finally leaching. N fertiliser is a user-specified value and should be correct provided the user enters the right values. Crop N uptake is closely linked to user specified yields using crop specific N concentrations of growth coefficients so the total N uptake should be accurate, although the monthly dynamics of this uptake are calculated within the model. However, the model uses a single 1.5m soil layer and assumes all of the nitrogen in this layer is available for crop uptake regardless of the depth that the nitrogen would be at and the depth of the crop’s roots at any point in time. For shallow rooted crops and early in the crop’s duration this could over-estimate the amount of N that the crop can take up and so give low estimates of Mineral N and subsequent leaching.

Predictions of mineralisation of N from residues and soil organic matter are estimated by the model, and these estimations are based on short (3 month) laboratory incubations from one trial. This has then been applied to a range of different soil types and climates across New Zealand without testing and with limited confidence that the predictions are correct. The model can predict very large values for N mineralisation (> 200 kg/ha annually). While such values have been recorded elsewhere (Webb *et al* 2001), errors in these predictions can translate to large errors in N leaching predictions.
Testing of the effects of recent land use history, temperature and soil water on the long term (1 year) mineralisation of soil organic matter from different key soil types is needed to test, enhance and provide confidence that the mineralisation aspects of the model are working correctly.

The ‘a’ coefficients were calculated from an exercise (described in detail by Cichota et.al., 2009) where monthly N leached, Drainage and Mineral N were taken from a detailed daily time step water and N balance model (The LUCI-framework model). While this provided a good method for setting parameters for the simplified N leaching model in OVERSEER®, the values of these parameters are dependent on the N leaching values that were predicted by the LUCI model. While the principles used to estimated N leaching in this model are well established, the actual predictions of N leaching from the LUCI framework model were not well validated and the model is no longer under development. To provide greater certainty in the values of the ‘a’ coefficient, the fitting exercise should be repeated with a better tested, detailed N leaching model.

The Drainage value is estimated daily and then summed to give monthly values for N leaching predictions. Because OVERSEER® is not intended to predict actual N leaching, rather long term averages, the long term average rainfall and potential evapotranspiration (ET) data are used to calculate drainage. However there is an inherent error in this approach as shown below.

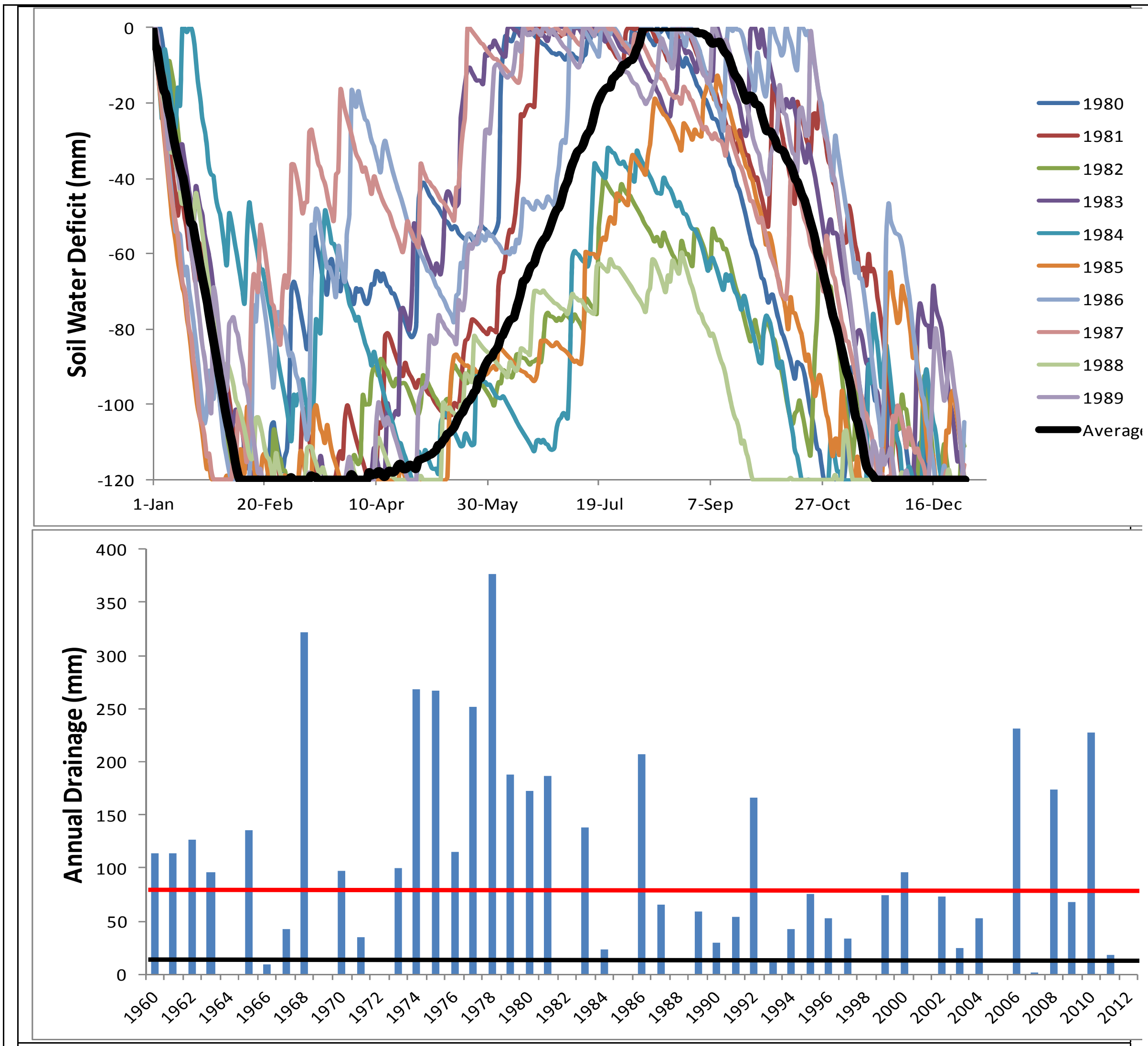

Figure 2a) Soil water deficit (SWD) throughout a number of years calculated daily using actual rainfall and EP data also calculated daily throughout a year using long term average rainfall and EP data for each day. Soil was assumed to have a maximum deficit of 120mm and SWD was set to zero on the 1 of January in each year.
Figure 2b) Annual drainage calculated for 51 years using daily water balance with actual rainfall and ET data. The red line is the annual drainage from these 51 years (70mm). The black line is the annual drainage calculated from the same daily water balance using the long term averages (averaged over the same 50 years) for rainfall and ET. Calculations for both figures used rainfall and EP data from the Lincoln meteorological station.

Issues related to choice of metadata sets

A simple daily water balance was run for 50 years using actual rainfall and ET data from Lincoln (dry) to predict soil water deficit (SWD) and drainage. The same daily water balance was run for a hypothetical year using the 50 year averages of rainfall and ET for each day. The water balance was set to zero on the 1st of January each year. The SWD calculated using the average data quickly drops to its minimum and stays there until April (Fig. 2a). It then increases and reaches 0 in early August and begins to decrease again in September. So there is only a short period in August when any drainage occurs and the total drainage for this long term average calculation was 16mm.

Figure 2a also shows the SWD for 10 actual years. The SWD in some years was below zero throughout the winter therefore no drainage would have occurred. In other years, for long periods, the SWD was zero and drainage events would have happened.

The annual drainage amounts calculated using actual rainfall and ET data in 51 years (Fig. 2b) ranged from zero to 377mm and the median of this long-term data was 70mm (see the red line in Fig. 2b). This is considerably more than the 16mm of drainage that was calculated using the long term average data (the black line on Fig. 2b). The reason for the difference is that long term averages fail to take proper account of the effects of variation in actual patterns of rainfall. In locations where rainfall is high and less variable, or where soils are shallow, the importance of this error is less. However, in lower rainfall situations and on soils with high available water capacity, the error in drainage and subsequent estimations of leaching is large and this is evident in the testing of the OVERSEER® crop model (See Fig. 8 in Cichota *et al.*, 2010). So when OVERSEER® is used for assessing compliance, the same meteorological dataset should be used as was used to set the limits or there is a risk that a verdict of non–compliance will be in error.

Implications of monthly time step and single soil profile for N leaching model

Processes in soil N dynamics have generally been quantified and parameterized in optimal (laboratory) or well specified field conditions, and then have "correction factors" (Cannavo *et al.*, 2008) applied to extrapolate the process dynamics to other soil or climatic conditions. Thus, moving between time steps in modelling these processes may, at 'face value', be a matter of deriving the appropriate correction factors. However, most of the processes are affected by the soil environment, particularly water content. Thus, while it might be practical to have rate coefficients for N mineralisation for both daily and monthly calculation time steps, it is less clear whether coupling monthly coefficient with, say, an average monthly water content would be valid. These issues are well illustrated in the 'evolution' of the monthly time step CENTURY model (Parton *et al.*, 1994) to a daily time step (DAYCENT; Del Grosso *et al.*, 2001) to improve the capability of the model for simulating environmental losses of N. The CENTURY model is still widely used but in applications less dependent on short-term variations in the soil environment (e.g., soil C accounting: http://www.cometvr.colostate.edu/).

Nitrate leaching is critically dependent on the downward movement of water through the soil profile. Clearly, water infiltrating into dry soil does not infiltrate to as great a depth as that infiltrating into wet soil. Soil tends to dry more at shallow depths, as plant water extraction tends to be greater at shallow depth (where there is a greater density of root) and water evaporates from the soil surface. Thus accurate water balance modelling generally requires some differentiation of soil depth, e.g. dividing the soil into layers. Temporal dynamics also affect soil water content (and so N leaching), through the interplay of infiltration and drying events. For example, 90 mm of rainfall occurring on one day followed by 29 dry days will result in a different pattern of soil water contents and movement than 30 days with 3 mm of rain each day. Yet both scenarios would be treated similarly in a monthly time step model. The magnitude of the difference between daily and monthly time step calculations would depend on the environment at the location in question – is it more like the former scenario, or the latter?

The water balance illustration shows that it is hard to judge *a priori*, whether or not complexity (or simplicity) in a model is appropriate. This fact is recognised in most reviews of models (e.g. Cichota and Snow, 2009). Simplicity makes the models easier to understand and can aid in interactions with stakeholders and undertaking scenario analyses. However, the consequences of simplification are not always clear (Cannavo *et al.*, 2008). Likewise, the assumptions made in the simplification are not always well documented.

APPENDIX 1: Overseas approaches diffuse pollution from agriculturally derived nutrients

To provide some context for the New Zealand approach to management of nutrient losses from agriculture, examples are given here of approaches used in Europe and Australia. In Europe, the regulatory approach to limiting N leaching caps fertiliser inputs, which constrains farmers' ability to optimise their farming enterprise while complying with N leaching limits. In contrast, the federal Government in Australia has taken an incentive approach to encourage farmers to develop and adopt management practices that reduce nutrient discharge towards pre-set targets. More detail on these two examples follows.

European approaches to reducing nitrate pollution

Post-World War II the main challenge was to increase agricultural production, and mineral fertilisers played a major role. In 1972 the UN hosted the first international meeting on how human activities were harming the environment and putting humans at risk. This heralded a major change of emphasis from maximum production to the protection of the environment.

In Europe, the European Parliament created a Standing Committee on the Environment and the European Community adopted its first Environmental Action Programme in 1973. In the 70s and 80s increasing numbers of initiatives were set up to protect the marine environment in the Baltic, North and Mediterranean Seas. A conference was held in London in 1987 where the countries bordering the North Sea established specific goals to substantially reduce the inputs of phosphorous and nitrogen to those parts of North Sea where such inputs were likely directly or indirectly to cause pollution.

Following on from many legislative changes in Europe, the Nitrates Directive was published in 1991. The main objective of this directive was "*to reduce water pollution caused or induced by nitrates from agricultural sources and prevent further such pollution*" This will be achieved by a number of measures:

- The designation of Nitrate Vulnerable Zones – known areas of land in a country which drain into waters which contribute to pollution;
- Action programmes and suitable monitoring programmes need to be established for these designated areas;
- Codes of Good Agricultural Practice.

Each country was responsible for setting up its own NVZs and Action programmes to meet the requirements of the directive. In England 70% of land was designated into NVZ areas. Rules regulating nitrogen use in Nitrate Vulnerable Zones to protect water from nitrate pollution have been in place since the late 90s The Action Programmes were set up and provided guidance for use of nitrogen in Nitrate Vulnerable Zones. The key measures in the NVZ rules in England include[12]:

- **Livestock manure N farm limit:** Farmers must ensure that the total loading of nitrogen from livestock manures to the farm does not exceed a loading limit of 170 kg of nitrogen per hectare per year unless derogation is in place.

---

[12] Adapted from http://archive.defra.gov.uk/environment/quality/water/waterquality/diffuse/nitrate/action-nvz.htm

- **Closed Periods**: These are times during the year when the spreading of organic manure with high available nitrogen content (e.g. slurry, poultry manure) is prohibited. Closed periods apply for both organic manures and manufactured nitrogen fertilisers and typically range from 3 – 5 months depending on the soil type and land use.
- **Manure Storage Capacity**: Farmers must provide by 1 January 2012, at least six months' storage capacity for poultry manures and pig slurry, and at least five months for slurry from other types of livestock.
- **Crop Requirement**: Farmers must plan all applications of nitrogen to a crop (whether the nitrogen be present within manufactured nitrogen fertiliser, organic manure, or any other nitrogen-containing material) so that they are compliant with an upper cap on nitrogen applications (termed an N Max limit).
- **Spreading Locations**: Farmers are required to undertake a written assessment to identify areas of land at risk of runoff and causing water pollution. Applications of nitrogen fertiliser and organic manures to areas of land identified as posing a high risk runoff are prohibited.
- **Spreading Techniques**: Farmers must spread organic manures and manufactured nitrogen fertilisers in as accurate a manner as possible. High trajectory spreading techniques for spreading slurry are strictly prohibited, unless the equipment used can achieve an average slurry application rate of not more than 2mm per hour when operating continuously. Additionally, applications of organic manure to bare soil or stubble will require incorporation into the soil in certain situations.
- **Record Keeping**: Farmers are required to keep a record of all nitrate applications they make to their land. All records must be made available for inspection and kept for at least five years.

Tools for compliance include PLANET software (http://www.planet4farmers.co.uk/), the Fertiliser Manual RB209 (http://www.defra.gov.uk/publications/2011/03/25/fertiliser-manual-rb209/), and a series of nine guidance leaflets published by Defra and the Environment Agency to guide farm practice:

1. Summary of the guidance for farmers in NVZs.
2. Implementing the rules – scope, timing and enforcement.
3. Reference information – standard values, manure sampling protocol and glossary.
4. Storage of organic manures.
5. The livestock manure N farm limit.
6. Planning nitrogen use.
7. The crop nitrogen requirement limit (Nmax).
8. Field application of organic manures.
9. Field application of manufactured nitrogen fertilisers.

http://archive.defra.gov.uk/environment/quality/water/waterquality/diffuse/nitrate/library.htm#advice

Australian approaches to reduce discharge of pollutants from coastal catchments

In north eastern Australia, pollutants transported from catchments draining into the Great Barrier Reef (GBR) lagoon are impairing the condition of corals and associated ecosystems of the GBR World Heritage Area, and also having substantial economic consequences in the region. The pollutants include dissolved N, coming from areas of intensive cropping, commonly on coastal floodplains (Thorburn and Wilkinson, 2012).

In response to this situation, the Australian government has enacted major policy approaches to improve the quality of water leaving agricultural areas. Substantial incentives (totalling AU$146M) have been made available to farmers through the Australian Government's Reef Rescue program (Commonwealth of Australia, 2008) to change management and so improve water quality in relation to defined targets.

This incentive-based approach does not prescribe the changes to management farmers should make. However, there has been substantial investment in developing a quantitative means of evaluating the effect of changed management on water quality. This evaluation program, called the 'Paddock to Reef monitoring and modelling framework' (Carroll *et al.*, 2012) couples surveys of farm management practice with a paddock-to-river mouth modelling framework to predict the change in pollutant discharge arising from the change in management. Predictions are carried out by daily time step field scale models coupled to (daily time-step) catchment models, and results are normalised to a constant time-period (1986–2009) to ensure short-term variations in annual climate (e.g. abnormally wet or dry years) do not bias results.

In this approach existing management practices ('best management practices') are being promoted by government and industry extension agencies. However, there is a risk that universal adoption of these best management practices will not give great enough improvement in water quality to meet pollutant load targets (Thorburn and Wilkinson, 2012). Agricultural industries and individual farmers are free to develop new practices that may better meet water quality targets, while also meeting on-farm logistical and financial constraints and goals.

APPENDIX 2: Review process

In July 2012, FAR assembled an international Expert Working Group (EWG) chaired by Mike Dunbier (Dunbier and Associates Ltd), and facilitated by Roger Williams (FAR), to address the terms of reference set out earlier in this report. Additionally, FAR assembled a wider group of stakeholder representatives (the Stakeholder Consultative Group, SCG) to ensure a transparent and credible process was used and to facilitate dissemination and implementation of findings of the review.

The EWG met three times on 23 August, 1 October and 1 and 2 November 2012. The SCG met on 31 August 2012 and 20 November 2012.

Responsibilities of the EWG were:

1. To undertake a collective, expert peer review of OVERSEER® 6 as per terms of reference;
2. To report (via the chair and during the project) on methodology and findings to a Stakeholder's Consultative Group (SCG) to ensure transparency and buy-in and facilitate rapid dissemination of findings;
3. To prepare a short report for consideration by the FAR Board on conclusion of the project.

Membership of the EWG was:

- Mike Dunbier – Chair, FAR Board member
- Hamish Brown, Plant and Food Research
- Doug Edmeades, Managing Director, agKnowledge NZ
- Reece Hill, Soil Scientist, Waikato Regional Authority
- Alister Metherell, Decision Support Manager, Ravensdown Fertiliser Co-operative Ltd
- Clive Rahn, Principal Consultant - PlantNutrition Consulting, UK
- Peter Thorburn, Leader - Northern Farming Systems Research Group, CSIRO, Australia
- Roger Williams – facilitator, Director of Research Development, FAR

Technical support was provided to the EWG by:

- Mark Shepherd, Team Leader - OVERSEER® Development & Application, AgResearch
- David Wheeler, OVERSEER® Development & Application, AgResearch

Invited participants for the SCG

- Mike Dunbier, Chair
- Chris Arbuckle, MPI
- Sarah Bromley, Plant and Food Research
- Ian Brown, ECan
- Andrew Curtis, CEO, Irrigation New Zealand
- Leo Feitje, ECan
- Anna Heslop, Communications Manager, FAR
- Lionel Hume and Ian MacKenzie, Federated Farmers
- Chris Keenan and Lindsay Fung, HortNZ
- Victoria Lamb, Beef and Lamb
- Philip Mladenov and Greg Sneath, Fertiliser Association
- Jeff Morton, Technical Consultant, Ballance Agri-Nutrients
- Mike Scarsbrook, Dairy NZ
- Roger Williams – Facilitator, FAR

REFERENCES

Anon., 2012. Changes to pastoral N model. OVERSEER® Technical Note 5. http://www.OVERSEER®.org.nz/Portals/0/Technical%20notes/OVERSEER®%20Technical%20Note%205%20August%202012.pdf accessed October 2012.

Bouraoui, F. and Grizzetti, B., 2008. An integrated modelling framework to estimate the fate of nutrients-Application to the Loire (France). *Ecological Modelling* 212, 450–459.

Bromley, S. and Catherwood, D., 2006. Nitrogen management for environmental accountability: A report on the outcomes of a scoping study undertaken as part of the project's milestone zero. MAF Sustainable Farming Fund 05/100.

Cannavo, P., Recous, S., Parnaudeau, V., Reau, R., 2008. Modeling N dynamics to assess environmental impacts of cropped soils. *Advances in Agronomy* 97, 131-174.

Carroll *et al.* 2012. A paddock to reef monitoring and modelling framework for the Great Barrier Reef: Paddock and catchment component. *Marine Pollution Bulletin* 65, 136–149.

Cichota, R., Snow, V.O., 2009. Estimating nutrient loss to waterways—an overview of models of relevance to New Zealand pastoral farms. *New Zealand Journal of Agricultural Research* 52, 239-260.

Cichota R, Brown H, Snow VO, Wheeler DM, Hedderley D, Zyskowski R, Thomas S , 2010. A nitrogen balance model for environmental accountability in cropping systems. *New Zealand Journal of Crop and Horticultural Science* 38, 189-207.

Commonwealth of Australia, 2008. Caring for our Country Business Plan 2009-10. http://www.nrm.gov.au/funding/2008/reef-rescue.html, accessed August 2010.

Del Grosso, S. J., Parton, W. J., Mosier, A. R., Hartman, M. D., Brenner, J., Ojima, D. S., and Schimel, D. S., 2001. Simulated interaction of carbon dynamics and nitrogen trace gas fluxes using the DAYCENT model. In ''*Modeling Carbon and Nitrogen Dynamics for Soil Management*,'' pp. 83, 303–332. CRC Press, Boca Raton, FL.

Del Grosso SJ Parton WJ Mosier AR Walsh MK Ojima DS and Thorntonet PE, 2006. DAYCENT national-scale simulations of nitrous oxide emissions from cropped soils in the United States. *J. Environ. Qual.* 35, 1451-1460.

Goolsby, D. A., W. A. Battaglin, B. T. Aulenbach, and R. P. Hooper, 2001. Nitrogen input to the Gulf of Mexico. *J. Environ. Quality.* 30, 329-336.

Hochman, Z., van Rees, H., Carberry, P.S., Hunt, J.R, McCown, R.L., Gartmann, A., Holzworth,D., van Rees, S., Dalgliesh, N.P., Long, W., Peake, A.S., Poulton, P.L., and McClelland. T., 2009. Re-inventing model-based decision support with Australian dryland farmers. 4. Yield Prophet (R) helps farmers monitor and manage crops in a variable climate. *Crop & Pasture Science* 60, 1057-1070.

Ledgard, S. *et al.* (2006). Nitrogen leaching as affected by dairy intensification and mitigation practices in the Resource Efficient Dairying (RED) trial. In: Implementing sustainable nutrient management strategies in agriculture (Eds. L.D. Currie & J.A. Hanly), Occasional Report No. 19. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. pp. 263-268.

Ledgard S. F. and Waller J. E. 2001. Precision of estimates of nitrate leaching in OVERSEER®. Report to FertResearch. AgResearch Ruakura. 16p.

Oborn I, Edwards AC, Witter E, Oenema O, Ivarsson K, Withers PJA, Nilsson SI, Richert-Stinzing A (2003) Element balances for sustainable nutrient management: a critical appraisal of their merits and limitations within an agronomic and environmental context. *European Journal of Agronomy* 20, 211–225. doi:10.1016/S1161-0301(03)00080-7

Oenema O, Kros H, de Vries W (2003). Approaches and uncertainties in nutrient budgets: implications for nutrient management and environmental policies. *European Journal of Agronomy* 20, 3-16.

Parton, W. J., Ojima, D. S., Cole, C. V., and Schimel, D. S. (1994). A general model for soil organic matter dynamics: Sensitivity to litter chemistry, texture and management. In ''*Quantitative Modeling of Soil Forming Processes*,'' Vol. 39, pp. 147–167. SSSA Spec. Publ., Madison, WI.

Rahn C R 2004 The Use of Models to Optimise Production of Field Vegetable Crops with Minimal Impact on the Environment. *Acta Horticulturae* 654, ISHS 2004

Shaffer, M.J. 2002. Nitrogen modeling for soil management. *Journal of Soil and Water Conservation* 57, 417-425.

Thorburn P.J., Biggs J.S., Weier K.L. and Keating B.A. (2003). Nitrate in groundwaters of intensive agricultural areas in coastal northeastern Australia. *Agriculture Ecosystems and Environment* 94, 49-58.

Thorburn, P.J. and Wilkinson, S.N. (2012). Conceptual frameworks for estimating the water quality benefits of improved agricultural management practices in large catchments. *Agriculture Ecosystems and Environment* in press (doi:10.1016/j.agee.2011.12.021).

Thorpe, K.R., D.B. Jaynes, R.W. Malone, 2008.Simulating the long-term performance of drainage water management across the midwestern USA. *Transactions of the ASABE* 51, 961-976.

Webb TH, Lilburne LR, Francis GS.2001. Validation of the GLEAMS simulation model for estimating net nitrogen mineralisation and nitrate leaching under cropping in Canterbury, New Zealand. *Australian Journal of Soil Research* 39, 1015-1025.