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The CLUES Project:

Predicting the Effects of Land-use on Water Quality – Stage II

NIWA Client Report: CHC2006-096
July 2006

NIWA Project: MAF05502

The CLUES Project:

Predicting the Effects of Land-use on Water Quality – Stage II

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Executive Summary

The Ministry of Agriculture and Forestry (MAF), in association with Ministry for the Environment (MfE), has engaged NIWA and five subcontractors (Lincoln Ventures, Harris Consulting, AgResearch, HortResearch, Landcare Research) in a 3-stage multiyear project to address the effects of landuse change on water quality. The resulting modelling system is called CLUES—Catchment Land Use for Environment Sustainability.

The objective of this project is to develop, under a series of contracts over several years, a computer-based GIS Decision Support Tool that is nationally applicable, relevant on regional and catchment scales, and takes account of socio-economic impacts Its purpose is to assess the links between rural land-use, land use change, and catchment-level effects on surface and groundwater quality.

The CLUES project is intended to provide a “sustainable development” context allowing for community, social and economic inputs in assessing the effects of land use and land use change on water quality. The project was created because there is no quantitative method available to link these factors at the level of detailed required.

This report summarises progress in the second stage of the project, where three main tasks have been carried out (i) improving the user interface of the modelling system; (ii) linking water quality models; (iii) producing case study information which illustrates use of the CLUES modelling system.

At the beginning of Stage 2, in August 2004, a workshop was held to review progress in Stage 1, and agree on proposed objectives for Stage 2. Those 5 objectives formed the basis of the Stage 2 contract:

- **CLUES Catchment Modelling System**: Add new features to CLUES so that users can work more easily with land-use change scenarios; Link more water quality models to the CLUES framework; Redesign the user interface for CLUES in collaboration with Environment Waikato

- **Catchment Scale Water Quality – SPARROW**: Recalibrate the national SPARROW model for total nitrogen; Carry out pilot testing at Environment Waikato; Implement SPARROW model for phosphorus; Improve the SPARROW groundwater model.

- **Triple Bottom Line Effects of Land Use Change**: Develop functional relationships between nutrient/contaminant losses and land-use type and intensity; Develop functional relationships between socio-economic outputs and land-use type and intensity.

- **Enterprise-Scale Modelling**: Develop 5 OVERSEER® scenarios; Create database of SPASMO predictions of nitrogen leaching for many combinations of crop, fertiliser, climate and soils.

- **Mapping of Land Use, Soils, and Pollution Risk**: Create national maps of both land use and soil properties; Revise EnSus nitrogen leaching risk model; Establish and maintain FTP (file transfer protocol) site so that project partners can reliably and efficiently exchange information

The above tasks have been completed, and a review workshop held to discuss the results, which are given in the body of this report. A serious complication arose during Stage 2 of this project, which substantially delayed progress—two main sources of land use information (Land Cover Data Base and AgriBase) proved incompatible. This information was the key to progress of the system as a whole, and caused a number of consequential delays. The incompatibilities have now been resolved by only using AgriBase data where it is consistent with information in the Land Cover Database; otherwise we have used the Land Cover Database.

The review of progress on the project has identified a need to focus in Stage 3 on completing the CLUES nitrogen component. Additional water quality constituents do need to be added (e.g., phosphorus, sediment, faecal contamination), and these items have been included in proposals to Dairy Insight and Envirolink for further development of CLUES.

1. Project Objectives

The Ministry of Agriculture and Forestry (MAF), in association with Ministry for the Environment (MfE), has engaged NIWA and five subcontractors (Lincoln Ventures, Harris Consulting, AgResearch, HortResearch, Landcare Research) on a project to address the effects of land-use change on water quality.

This report covers the second year of a 3-year project. The objective of this project is to develop, under a series of contracts over several years, a computer-based GIS Decision Support Tool that is nationally applicable, relevant on regional and catchment scales, and takes account of socio-economic impacts Its purpose is to assess the links between rural land-use, land use change, and catchment-level effects on surface and groundwater quality..

The project is intended to provide a "sustainable development" context allowing for community, social and economic inputs in assessing the effects of land use and land use change on water quality.

The objectives above are to be achieved by delivering progress reports and computer-based methods which the stakeholders can use to make these assessments. NIWA and its subcontractors will deliver the executable programs and associated documentation needed to make these assessments, and will also deliver copies of computer source code that is created wholly within this project.

2. Project Plan

MAF and MfE have obtained project funding from the Cross Departmental Research Pool for three years, beginning in FY 2003/04. There have been delays in Stage 2 of the project, so Stage 3 will take place in FY 2006/07. A broad outline of the project deliverables has been agreed in principle with MAF, and the tasks for Stage 1 of the project have been completed: these have been reported in Woods et al. (2004). The tasks for Stage 2 are complete. The specific tasks for Stage 2 of the project are listed in Appendix 1. The tasks for the third stage will be finalised early in FY 2006/07.

3. Workshop 2: August 2004

The second project workshop was held in Wellington on 31 August 2004. The objectives of the workshop were to review progress in the first year, and to agree on priorities and likely deliverables for the second year. Introductory presentations were given by Gerald Rys (MAF) and Ross Woods (project leader), and then science presentations were given by each of the science providers.

Details of the workshop are shown in an Appendix (Section 17).

3.1. Proposed ideas from Workshop

- Make a national map of land-use by combining the current Land Cover Data Base (LCDB2) and AgriBase (Landcare to lead).

- From the extensive list of land-use types, generalise to a shorter list, in consultation with other providers (need to include several levels of intensity for some land-uses, especially dairying). This list would be adopted by the project (e.g., in Woods et al. (2004) revise EnSus Table 9-3 columns 1 and 2, revise TBL list).

- Proposals to include phosphorus, and then sediment, and then bugs.

- Need work on land-use scenario generation. MAF have projections for forestry, animal numbers. Need software for scenario generation, as well as overlaying. Need to decide if we want probabilistic treatment of land use where spatial details are unknown.

- TBL (Triple Bottom Line) model needs to expand in type of land-use, and in geographical spread. Will work with OVERSEER® and SPASMO teams in designing models runs.

Potential Milestones for Stage 2

- Trial modelling system installed at Environment Waikato (EW).

- National map of current land use.

- Agreed set of land use types.

- Large set of SPASMO results.

- Have OVERSEER®, EnSus, TBL all linked to modelling system (CLUES).

- SPARROW model delivery and attenuation components recalibrated to include:

    i. OVERSEER®/SPASMO estimates of nutrient sources, instead of SPARROW equations for sources, and

    ii. groundwater processes.

- Agreed classification of rain (5 classes) and soil (5 types).

- Assemble source material to support scenario generation, summarise it, run workshop with EW (and MAF, scientists, planners) to generate scenarios.

4. Workshop 3: July 2005

The third project workshop was held in Hamilton on 27 July 2005. The objectives of the workshop were to review progress in the second stage of the project, and to agree on priorities and likely deliverables for the third stage. Introductory presentations were given by Gerald Rys (MAF) and Ross Woods (project leader), and then science presentations were given by each of the science providers.

Details of the workshop are given in an Appendix (Section 17).

5. Stage II Tasks

The list of potential milestones for Stage 2 were assembled into a proposal to MAF, and after negotiations, a contract for Stage 2 was drawn up between NIWA and MAF (see Appendix 1: Contract Objectives for Stage II), with NIWA subcontracting to the partners. These objectives are reported on in the following sections of this report.

6. Objective 1: CLUES Catchment Modelling Framework (NIWA)

A range of new features and functionality has been added to CLUES GIS framework. A user can now change land use interactively on the screen with the aid of a mouse and subsequently overlay the new scenario on a catchment boundary to predict the yield of nitrogen, the extent of nitrogen leaching and the economic cost of the land use change. These features are the result of integrating SPARROW, OVERSEER® and the HARRIS Consulting (HC) economic models. Some work has also begun on incorporating SPASMO into the framework. At the time of writing, a small amount of cosmetic work remains to be done to improve the interface, in response to comments from end-users.

The main development has been the GIS menu shown below in Figure 6-1, and it builds on the toolbox developed in Stage 1 (Section 5 of Woods et al. 2004). The toolbox is designed to work within ARCGIS 8.3 or ARCGIS 9.

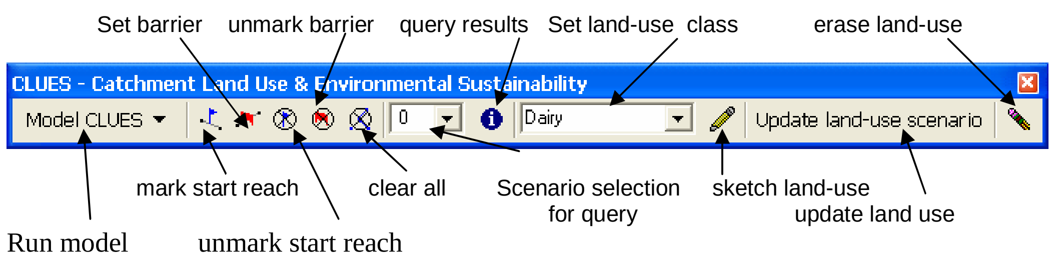

Figure 6-1: CLUES toolbox with new functionality developed in Stage II. This includes tools to sketch, overlay and query new scenarios.

Some of the CLUES user interface capabilities were explained in the Stage 1 report (Section 5 of Woods et al. 2004), and others are demonstrated in the following sub-sections.

6.1. Land use change scenario tool

New land use scenarios can be created "interactively" and up to 5 different scenarios stored and queried. An area on the screen is sketched over an underlying map of catchments and current land use. This is done simply by selecting a drawing tool and sketching over an area of an existing land use map on the screen. The sketch can be edited and changed easily. New land use classes are assigned by using a drop-down tool and selecting a class. Currently the following land use classes can be selected: dairy, sheep and beef, deer, grazing stock, fruit, viticulture, vegetable growing, arable crops, forest and non-pasture.

Figure 6-2 shows a screen shot of a new land use sketch and the drop-down list for selecting land use classes.

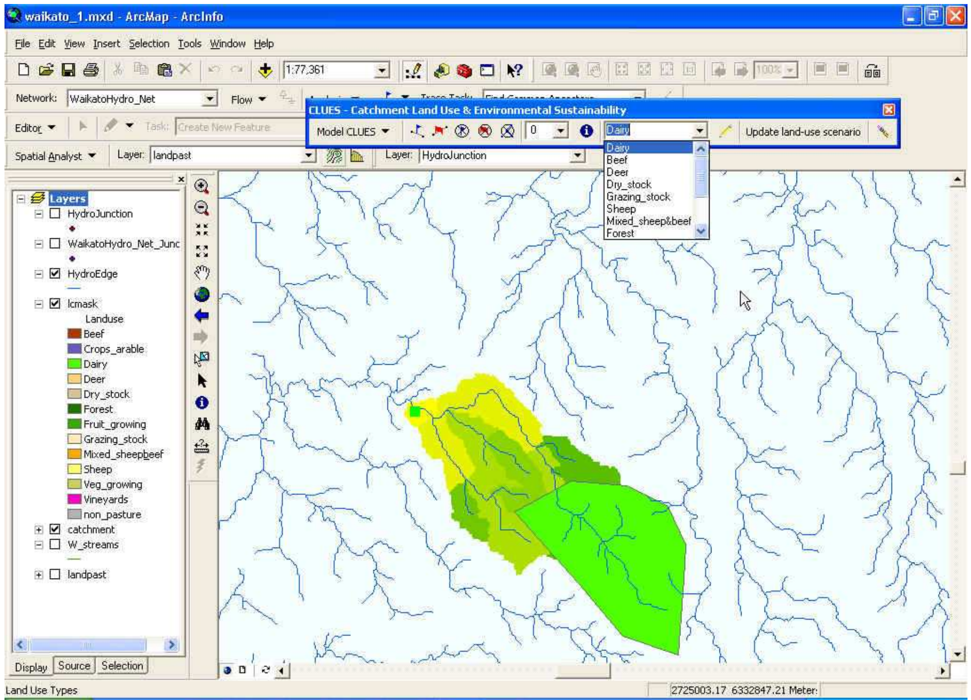

Figure 6-2: A screenshot showing a new area sketched out (in bright green) to represent dairying (where existing land use was "forest"). Land use classes can be selected from a drop-down menu and assigned to new areas sketched.

6.2. Overlay new land use scenarios on catchment boundary

A newly sketched scenario can be overlaid on an existing catchment map and land use areas calculated for each river/stream catchment by using the "update land-use scenario" tool shown in Figure 6-3 below. This function only requires the entry of a scenario number and the relevant catchment map details. The overlay procedure is relatively quick (4 to 5 minutes) and once complete the new scenario is available for a model "run". The overlay procedure will replace existing land use data with the new information entered. Current land use data is retained where no changes were made.

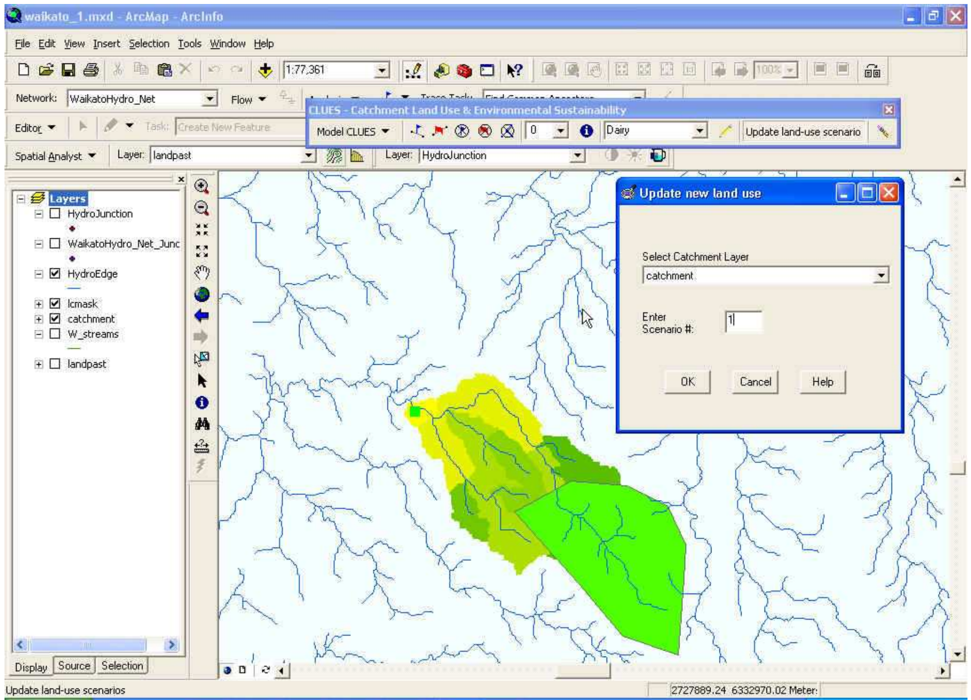

Figure 6-3: Overlaying new land use with existing catchment boundaries consists of simply filling out a form that selects the relevant catchment layer and nominating a scenario number.

6.3. Integration of SPARROW, OVERSEER® and HC (Harris Consulting) models

At the time of writing the SPARROW, OVERSEER® and HC models have been integrated into the GIS environment. When CLUES is executed all three models are invoked to produce outputs of “in-stream” nitrogen, nitrogen leaching amounts and the relevant economic analysis. The SPARROW, OVERSEER® and HC models are described in Section 7.1 (SPARROW), Section 9 (OVERSEER®), and Section 8 (HC).

Figure 6-4 and Figure 6-5 below illustrate model runs before and after a new scenario is sketched and overlaid. The resulting “in-stream” nitrogen loads are shown by the colours of the surrounding catchments for the two scenarios.

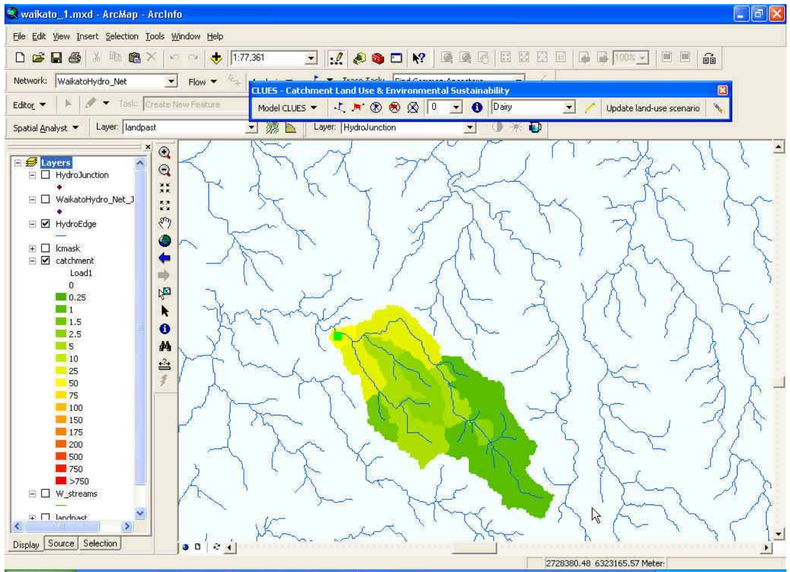

Figure 6-4: A CLUES run with current land use.

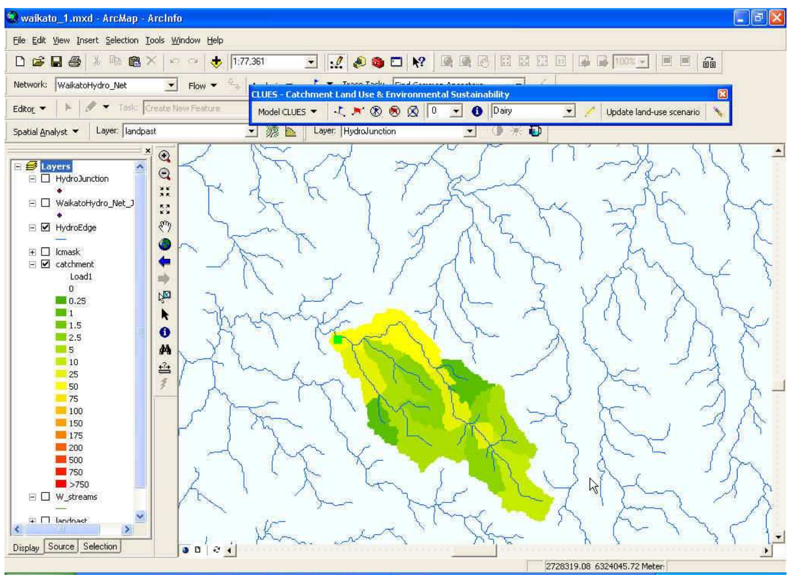

Figure 6-5: A CLUES run with new land use (where a "forested" area of the catchment has been replaced by "dairying").

The results of a model run and its associated calculations can be viewed by using a query tool in the toolbox. Any part of the catchment network can be queried to list values for both current and new scenarios. Examples of values listed are: nitrogen loads, nitrogen leaching (OVERSEER®) and nitrogen loss (HC model), and economic data such as GDP, FTE and CFS (HC). Figure 6-6 shows an example of a screen query of a river reach.

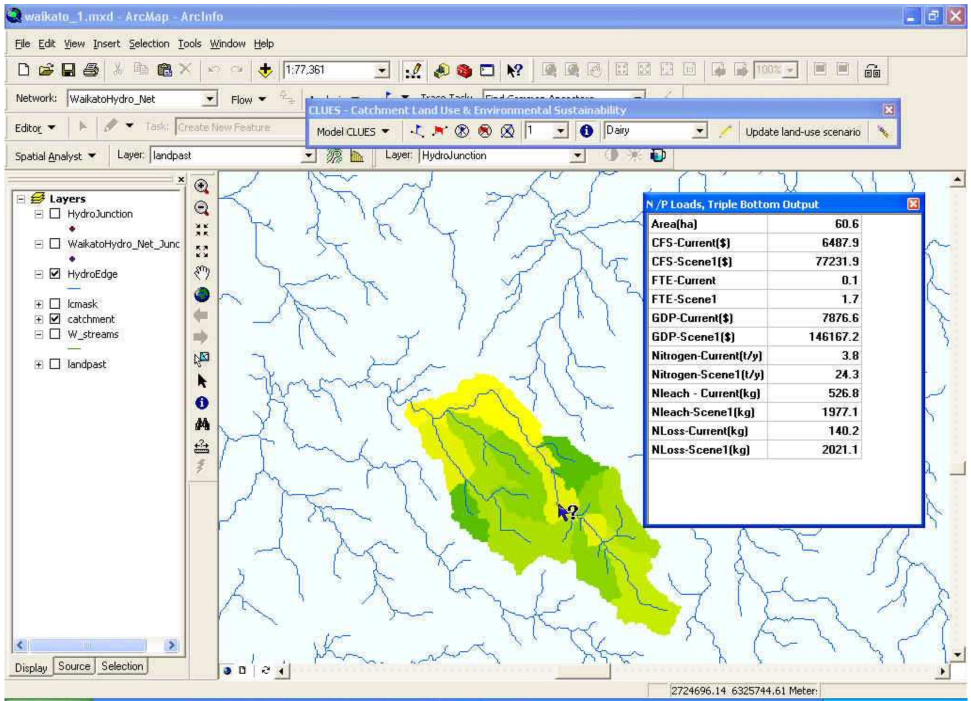

Figure 6-6: A screenshot showing the results of a query at a reach of the catchment where land use has been changed from “forest” to “dairy”.

6.4. Integration of SPARROW phosphorus model

Now that the national SPARROW model for New Zealand has been completed, a first draft model is available for the effect of land-use change on phosphorus loads in rivers. The method for generating the phosphorus loads is described in Section 7.1.3.

To implement this in the CLUES user interface, we have added to the CLUES Toolbar an extra button to allow the CLUES user to toggle between viewing the maps for estimated nitrogen and phosphorus.

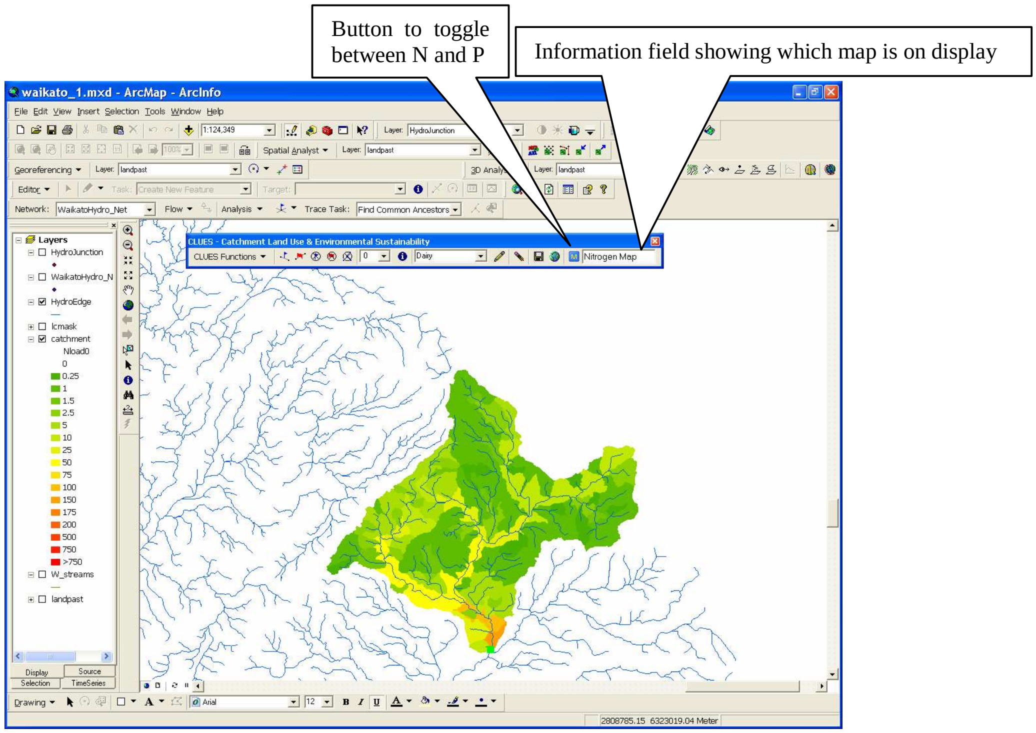

Figure 6-7: Enhanced user interface, allowing user to toggle between N and P maps**.**

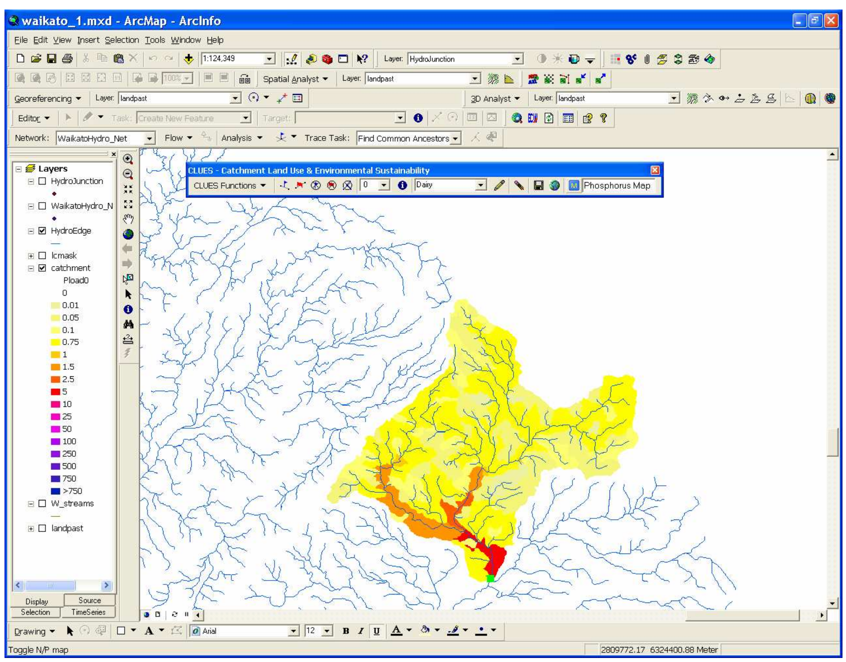

Figure 6-8: Map for phosphorus load, obtained from the screen shown in Figure 6-7 by clicking on the new toggle button. Legend for phosphorus is shown at left**.**

6.5. Proposed next steps

- Add new features to CLUES framework so that users can work with land-use change scenarios.

- Link more models to the CLUES framework: SPASMO, revised OVERSEER®, more Harris Consulting models.

- Finalise user interface for CLUES framework so it is easier to use and understand.

7. Objective 2: Catchment-scale Water Quality – SPARROW

This work has been carried out by NIWA and Lincoln Ventures.

7.1. SPARROW for surface water

7.1.1. Recalibrate the national SPARROW N model

The SPARROW nitrogen model was recalibrated to take into account the new land-use maps (which are discussed in Section 11.1) and the introduction of OVERSEER® nutrient budget model predictions of the nitrogen leaching from pasture as a source term (see Section 9 for a discussion of the OVERSEER® nutrient budget model). The calibration data was the same set of National Rivers Water Quality Network data and point source as was used for the previous SPARROW model included in CLUES (Elliott et al. 2005, Woods et al. 2004).

Introduction of the new land-use

As a first step, the model was re-calibrated using the new land-use maps (see Section 11.1) but applying the model form used previously in CLUES (Elliott et al. 2005). The resulting parameters are given in Table 7-1. The accuracy of the model's fit to measured data and the coefficient values are similar to the values obtained from calibration with the previous land-use. This demonstrates that the new land-use can be used without model deterioration. Considering that the new land-use is based on more complete statistics and opens up the possibilities of adding further land-use classes and an OVERSEER® component, this new land-use data should be used in future applications of CLUES.

One noticeable feature of the new model is that the yield for the 'other' land-use was zero (this coefficient was constrained to be non-negative). This land-use category is dominated by land-uses such as tussock, high-country grazing, ice and rock, so it is not surprising that the yield is small. Part of the reason is that the load at monitoring stations is dominated by land-uses such as trees or other non-pasture land-uses. Therefore, as long as the 'other' land-use has a small yield, the particular value of the small yield does not matter.

Table 7-1: Effect of the new land-use assessment on the model coefficients, for the original national model form (see Table 7-4 for final model parameters).

Coefficient	Coefficient with previous land-use	Coefficient with new land-use	Standard Error, with new land-use
Sources, β			
Point source coefficient (dimensionless)	1.38	1.40	0.82
Dairy pasture land-use yield (kg ha^{-1} yr^{-1})	71.4	83.9	18.6
Trees land-use yield[a] (kg ha^{-1} yr^{-1})	5.87	5.77	0.119
Other pasture land-use yield[b] (kg ha^{-1} yr^{-1})	18.2	11.7	3.11
Other land-use yield [c] (kg ha^{-1} yr^{-1})	0.830	0	.
Land-to-water delivery, α			
Drainage term (per drainage index)[d]	–0.238	–0.266	0.100
Rain term (m^{-1})[e]	0.243	0.188	0.171
Aquatic loss			
Decay coefficient for flow class 1 (Q<0.1 m^3 s^{-1}) (km^{-1})	0.335	0.277	0.171
Decay coefficient for flow class 2 (0.1<Q<1 m^3 s^{-1}) (km^{-1})	0.0917	0.109	0.0547
Decay coefficient for flow class 3 (1<Q<10 m^3 s^{-1}) (km^{-1})	0.0245	0.0204	0.0086
Decay coefficient for flow class 4 (Q>10 m^3 s^{-1}) (km^{-1})	0	0	-
Reservoir settling velocity (m yr^{-1})	12.6	13.6	3.9
Root mean square error (natural log space)	0.33	0.35	
Adjusted R-squared[f]	0.956	0.949	

[a] Trees land-use is the sum of exotic, indigenous, and scrub land-uses.
[b] Other pasture includes intensive and hill country mixed sheep/beef grazing, deer, other animals, and ungrazed pasture areas, but excludes high-country grazing and grazed tussock
[c] Other land-use includes tussock and high-country grazing areas, snow and ice, open water bodies, gravel, urban, horticulture, and cropland areas
[d] Mean-adjusted drainage index used in the regression. The mean drainage index is 4.18.
[e] Mean adjusted rainfall used in the regression. Mean rainfall is 1.855 $m.yr^{-1}$
[e] Squared linear regression coefficient (also called the coefficient of determination), adjusted for the number of parameters in the model

Another feature is the high yield coefficient for dairy pasture land-use. Even after the land-to-water delivery factors of rainfall and soil drainage class are taken into account, the mean predicted yield entering streams for subcatchments dominated by dairying is approximately 80 kg/ha/yr. This is somewhat high in relation to the average OVERSEER®-derived nitrate leaching of approximately 20 kg/ha/yr for subcatchments dominated by dairying. Part of this higher load can be explained by forms of nitrogen loss other than nitrate leaching, such as overland flow, dairy ponds, non-nitrate forms of nitrogen, and direct deposition of wastes into streams that will increase the loss of nitrogen beyond the nitrate leaching value (recall that the SPARROW model addresses *total* nitrogen). The OVERSEER® model is not intended to predict these other forms of nitrogen loss.

In the Waingongoro catchment in Taranaki, which has 81% dairying in the catchment, the predicted source of total nitrogen (from SPARROW) is 61 kg/ha/yr, which is then reduced by in-stream decay to 22.8 kg/ha/yr at the monitoring station, and this compares favourably with the measured yield of 24.6 kg/ha/yr in the river. The mean OVERSEER® leaching prediction for dairying in that catchment is approximately 20 kg/ha/yr.

Continuous in-stream decay coefficient function

Previous applications of SPARROW (Elliott et al. 2005) showed that if the decay coefficient is a continuous function of flow rather than a step-wise function, then there tends to be less overall stream decay and the pasture sources yield is smaller, yet there is in an equally good fit to the monitoring data. Considering the large difference between the OVERSEER® nitrate leaching predictions from dairying and the SPARROW yield coefficient, we investigated the continuous decay function with the new land-use. The resulting parameters, based on a continuous function of flow and using the new land-use, are shown in Table 7-2. In this simulation, the decay exponent was constrained due to numerical convergence difficulties. The model fit (R^2) is comparable to the step-wise decay model and the decay coefficient is now more statistically significant, but now the dairy source term is smaller (53 kg/ha/yr). This suggests that to improve the compatibility between OVERSEER® and SPARROW, the continuous decay function should be used.

Table 7-2: Model parameters with the new land-use for decay coefficient (k) as a continuous function of flow ($k=aQ^B$). See Table 7-1 footnotes for further information. See Table 7-4 for final model parameters.

Coefficient	Coefficient	Standard Error
Sources, β		
Point source coefficient (dimensionless)	1.57	0.88
Dairy pasture land-use yield (kg ha^{-1} yr^{-1})	53.0	0.86
Trees land-use yield[a] (kg ha^{-1} yr^{-1})	4.00	0.61
Other pasture land-use yield[b] (kg ha^{-1} yr^{-1})	8.41	1.87
Other land-use yield[c] (kg ha^{-1} yr^{-1})	0	.
Land-to-water delivery, α		
Drainage term (per drainage index)[d]	–0.226	0.0.098
Rain term (m^{-1})[e]	0.274	0.091
Aquatic loss		
Decay coefficient, a (km^{-1}(m^3 s^{-1})$^{-B}$)	0.0128	0.0047
Decay exponent, B	–0.75	.
Reservoir settling velocity (m yr^{-1})	11.3	3.6
Root mean square error (natural log space)	0.35	
Adjusted R-squared	0.950	

Introduction of additional land-use categories

The above models used four different land use classes: dairy pasture, trees, other pasture and ‘other’. This sub-section shows what happened when we attempted to introduce more of the available detail into the land use classification used for modelling.

Introducing a land-use for combined tussock and high country did not alter the model fit much, and the associated coefficient was zero. The model is not able to discriminate between this land-use and non-pasture land-uses other than trees (such as snow and ice, open water, or urban land-use).

Separating out hill-country pasture and intensive pasture land-use categories from the non-dairy pasture did not improve the model fit. The yield coefficients were similar for these two pasture categories. There is no benefit to be gained from separating out these terms in the model. They could still be treated as separate land-uses in CLUES, but with the same source coefficient.

Separating the high country from tussock did not improve the model fit and did not alter the model coefficient.

Separating out ungrazed pasture (non-tussock pasture with a zero stocking rate) as a separate land-use did improve the R^2 value by 0.5%, but this was only at the expense of decreasing the significance of the stream decay coefficient. The associated source coefficient was 0. These areas mostly occur as slivers between properties, and for convenience should probably be best considered as associated with the pasture land-use.

Introducing a separate deer pasture land-use did not improve the model fit. The coefficient for deer land-use was high (comparable to the dairy term), but had a high standard error. Because of this, there is not sufficient evidence to have the deer coefficient separate from the other non-dairy pasture land-use.

Inclusion of OVERSEER® leaching

An OVERSEER® leaching term was incorporated by running the OVERSEER® DLL for each pasture land area within each River Environment Classification (REC) subcatchment. The rainfall input and characteristic soil type (inputs for OVERSEER®) were assumed to be constant within each subcatchment. The stocking rates passed to OVERSEER® were determined from the standard stocking rates for a given land-use, slope class, and region based on MAF monitor farms (see Section 0). Another option would have been to use the stocking rate assessment derived from AgriBase, but it was considered that the data quality of the stocking rate assessment was not sufficiently robust for that purpose.

Preliminary runs indicated that OVERSEER® over-estimates the nutrient from grazed tussock and high-country grazing areas. This is not unexpected as the version of OVERSEER® used in this assessment is not tuned for tussock areas (David Wheeler, AgResearch, pers. comm.). This could be addressed in future versions of OVERSEER®. Hence, for the time being at least, we did not use the OVERSEER® leaching estimates for such areas: rather, the nutrient yield from those areas was treated as a calibration parameter.

In the first application of the model, we assumed that the OVERSEER® leaching is the sole nutrient source for pasture areas and that the delivery term is not applied to this term. This resulted in an R^2 of 0.932, which is lower than the model based on land-use alone (R^2 of 0.950). This was not improved by applying a multiplicative coefficient to the OVERSEER® source term (the calibrated coefficient was 0.87 with a standard error of 0.14, and R^2 was not improved).

To allow for sources of nitrogen other than the nitrate leaching, we allowed for additional sources of nitrogen to be added to the pasture terms, with some variation of this additional source between land-use classes. This improved the model fit to measured loads (Table 7-3). Further sub-dividing the pasture land-use did not improve the model fit.

The additional dairy term was responsible for the improvement in the model fit (R^2 increased from 0.932 to 0.948), and the coefficient for this term is significantly different from zero. This suggests that the additional source for dairying should be included in the eventual model. This additional dairy term is higher than the mean OVERSEER®-derived nitrate leaching of approximately 20 kg/ha/yr for subcatchments dominated by dairying. This extra term could account for other means of nitrogen loss, such as overland flow, dairy ponds, non-nitrate forms of nitrogen, and direct deposition of wastes into streams. There is no corresponding additional source for other pasture land-uses, which suggests that the additional sources are particularly pronounced for dairying, or that OVERSEER® is under-predicting the leaching from dairying in relation to the leaching from other pasture land-uses. Note that this applies on a national-scale basis: the difference between dairying and other pasture land-use could in part reflect climate, soil, or land-use variations that correlate with land-use yet are not incorporated in or able to be differentiated by the model.

Applying the land-water delivery terms to the OVERSEER® leaching did not improve the model fit. This may be because OVERSEER® already takes rainfall and soil type into account, and the land-water delivery terms reflect the effects of these variables on the nutrient source itself combined with the subsequent processing before the nutrient enters the stream.

Table 7-3: Model parameters with the OVERSEER® nutrient leaching term included. See Table 7-1 footnotes for further details. See Table 7-4 for final model parameters.

Coefficient	Coefficient	Standard Error
Sources, β		
Point source coefficient (dimensionless)	1.70	0.94
OVERSEER® leaching coefficient (dimensionless)	1.0	Fixed
Trees land-use yield[a] (kg ha^{-1} yr^{-1})	4.63	0.77
Additional dairy yield (kg ha^{-1} yr^{-1})	32.7	10.9
Additional other pasture yield[b] (kg ha^{-1} yr^{-1})	0	.
Other land-use yield[c] (kg ha^{-1} yr^{-1})	0	.
Land-to-water delivery, α		
Drainage term (per drainage index)[d]	–0.442	0.167
Rain term (m^{-1})[e]	0.298	0.106
Aquatic loss		
Decay coefficient, *a* (km^{-1}(m^3 s^{-1}))	0.0226	0.0057
Decay exponent *B*	–0.631	0.103
Reservoir settling velocity (m yr^{-1})	11.7	3.9
Root mean square error (natural log space)	0.36	
Adjusted *R*-squared	0.948	

Yields for the urban, cropping and 'other' land-uses

The 'other' land-use includes urban land-use and horticulture/cropping. The SPARROW calibration method does not have sufficient sensitivity to derive loading rates for urban and cropping land-uses, because the monitoring stations do not include much of these land-uses in their catchments and the load from such areas tends to be swamped out by the load from other areas. Nevertheless, end-users of CLUES are likely to want these land-uses included to provide a more complete coverage of different key land-use categories.

Hence, for urban areas, we introduce a fixed nitrogen yield of 8 kg/ha/yr, based on the 'typical' value as recommended by Williamson (1993) based on a review of urban stormwater quality data. This is likely to vary with rainfall, degree of urbanisation, the degree of stormwater disposal by infiltration, and the degree of stormwater treatment. However, we do not have sufficient data to include these factors at present, and so we have applied a uniform yield for all urban areas. For similar reasons, the land-to-water delivery terms are not be applied to the urban term. Introducing this fixed yield did not affect the model performance and had a very small effect on the model parameters.

In the next year of the CLUES project, we intend to include cropping and horticulture land-uses, with nutrient loss determined from lookup tables derived from the HortResearch assessment of losses for these land-uses, as described in Section 10. For the time being, the SPARROW model does not take account of the potential for fairly high per-unit-area losses from these horticultural land-uses compared with other land-uses lumped into the ‘other’ land-use category.

The zero yields calibrated for the ‘other’ land-use may seem somewhat unrealistic for some model users. It therefore seems appropriate to assign a small yield of 0.4 kg/ha/yr to the ‘other land-use’ coefficient (the lowest observed yield, excluding the outlier Hakataramea site—this site is an outlier, and was removed from the SPARROW calibration, Elliott et al. 2005). As with the urban land-use, land-to-water delivery terms were not applied to this source.

Final model version

The model terms and calibrated coefficients for the SPARROW model after taking into account the new land-use maps, incorporating OVERSEER®, and including the urban land-use are shown in Table 7-4.

These coefficients and terms are likely to be modified slightly in Year 3 of the project, to allow for modified leaching predictions from a new version of OVERSEER® and the incorporation of leaching predictions for horticultural and cropping areas.

Given the discrepancies between predicted loads from the OVERSEER® nutrient budget model and SPARROW for dairy farms, it is recommended that in the third year of the project the reasons behinds these discrepancies should be investigated.

Table 7-4: Final nitrogen model parameters.

Coefficient	Coefficient	Standard Error	*P*
Sources, β			
Point source coefficient (dimensionless)	1.65	0.95	0.086
OVERSEER® leaching coefficient (dimensionless)	1.0	fixed	.
Urban yield (kg ha^{-1} yr^{-1})	8	fixed	.
Trees land-use yield[a] (kg ha^{-1} yr^{-1})	4.59	0.79	<0.001
Additional dairy yield (kg ha^{-1} yr^{-1})	33.9	11.3	0.004
Additional other pasture yield[b] (kg ha^{-1} yr^{-1})	0	.	.
Other land-use yield[c] (kg ha^{-1} yr^{-1})[e]	0.4	fixed	.
Land-to-water delivery, α			
Drainage term (per drainage index)[d]	–0.443	0.169	0.010
Rain term (m^{-1})[e]	0.290	0.110	0.010
Aquatic loss			
Decay coefficient, *a* ($km^{-1}(m3.s^{-1})^{-B}$)	0.0233	0.0058	<0.001
Decay exponent *B*	–0.632	0.105	<0.001
Reservoir settling velocity (m yr^{-1})	12.6	4.1	0.005
Root mean square error (natural log space)	0.36		
Adjusted R-squared	0.947		

[a] Trees land-use is the sum of exotic, indigenous, and scrub land-uses.
[b] Other pasture includes intensive and hill country mixed sheep/beef grazing, deer, other animals, and ungrazed pasture areas, but excludes high-country grazing and grazed tussock
[c] Other land-use includes tussock and high-country grazing areas, snow and ice, open water bodies, gravel, horticulture, and cropland areas
[d] Mean-adjusted drainage index used in the regression. The mean drainage index is 4.18.
[e] Mean adjusted rainfall used in the regression. Mean rainfall is 1.855 $m.yr^{-1}$

7.1.2. Pilot testing at Environment Waikato

Progress: CLUES team member Sandy Elliott met with staff from Environment Waikato (leader Peter Singleton) on 3 June 2005 to discuss progress in the CLUES project, and to begin system testing. Environment Waikato provided very useful positive feedback – they are very pleased with the product. They are now working on generating their own land-use change scenarios.

Text of comments from Environment Waikato is shown below in italics:

We were very impressed.

Liked:

- *Ability to increase loads for a particular land use e.g., increase dairying by 10%*

- *Clear presentation on screen and relatively simple to use*

- *Like the 'mask' ability to change land use for a selected area. This would be used as a 'rough and ready' tool. We would mostly use GIS analysis to change land use and import the layer into CLUES.*

Wish list:

- *We would prefer the ability to import our own derived land use scenarios e.g., change pine to dairying on slopes <15 degrees.*

- *In the future we need to have other land uses listed on the 'clues input' panel*

- *Need ability to add user defined land uses e.g., ostrich farms (= sheep/beef + 20%). The user chooses sheep/beef and a 20% increase modification and can name it 'Ostrich'; or intensive dairy (= dairy + 50%); intensive sheep*

- *Another thought - can we have a table where we can input likely N losses (yield) for the land uses that sparrow is currently not calculating. e.g., want to be able to set cropping loss to a figure or give a figure for exotic forestry and indigenous forest (currently is only trees)*

- *Would like to be able to accumulate totals from selected sub-catchments within the main catchment. Selected sub catchments need to remain highlighted in some way so the user knows which ones have been added.*

- *Prefer the OVERSEER® Nleach result only*

- *Nice to have a display option that shows yields on a sub-catchment basis without having to use the GIS tools. Also a sausage option or similar to show the cumulative increase in stream load e.g., line colour in stream goes from blue to red as load increases.*

- *On the toolbar there are many land use options but the model is not using all these in its calculations. need to make it clear some how that these land uses are not being calculated for N losses yet. Suggest a grey font for the ones currently not used and indicate which are classified as 'other' in the model. Maybe a form showing what the actual land uses default to in the model.*

- *What about using actual land use in the catchment model rather than dominant land use.*

- *How about an intensity correction factor based on stock units. This factor then adjusts the % yield effect by an amount (yet to be determined). i.e., the base yield value for the land use becomes variable rather than fixed*

- *An ability to click on individual sub-catchments and bring up a table with current land use % area and being able to interactively edit this and re-run.*

- *Important; we would like to be able to import our own scenario maps into the model in-house.*

Subsequent to the above meetings and review, Environment Waikato has funded the development of additional features added to the CLUES user interface, which will be documented in the final CLUES project report.

7.1.3. Develop a National SPARROW model for phosphorus

A national SPARROW model for phosphorus was developed using funding from the FRST-funded programme “Land Use Intensification: Sustainable Management of Water Quality and Quantity”, contract C01X0304. The development of that model is described in Elliot et al. (2005), and it has been implemented within the CLUES framework as described in Section 6.4.

The methodology for this SPARROW phosphorus model is the same as that used for SPARROW nitrogen in Year 1 of the CLUES project. That is, the SPARROW model makes its own estimates of phosphorus yields for each land use type, without making use of enterprise scale models such as OVERSEER® and SPASMO. As phosphorus predictions become available from such models, we expect to replace the SPARROW yield estimates for some land uses with yield estimates from enterprise-scale models. In the interim, the information from this SPARROW-only model provides a useful initial estimate for the whole country.

As with nitrogen, the modelled phosphorus loads from land areas, point sources, and erosion are routed through the drainage network (576,300 reaches for New Zealand) with first-order stream decay and attenuation in lakes and reservoirs. Results are shown in Figure 7-1. Model parameters were determined by calibration to measured phosphorus loads in the national water quality network (77 sites). The SPARROW model for phosphorus was able to predict the measured loads adequately (R^2 of 0.900

and RMSE of 0.58). The predictions of exported phosphorus yields for streams with catchments > 20 km^2 are larger than the previous measurements for phosphorus. The calibrated stream attenuation and lake/reservoir rates were broadly consistent with previous measurements. The predicted load of total phosphorus (TP) delivered to the coast was 63,100 t yr^{-1}, which is 44% of the loads entering the streams. Reservoir/lake attenuation makes a relatively small contribution to the overall attenuation compared with in-stream attenuation (8.5%). When examining the relative contributions of phosphorus from different land-uses across New Zealand, the highest contribution of the load to the coast is from erosion (53.2%). Point sources contribute only a small proportion of the load to the coast (1.6% for TP). The monitoring network does not include streams with catchments smaller than 10 km^2 so model predictions for streams smaller than 10 km^2 should be used with caution.

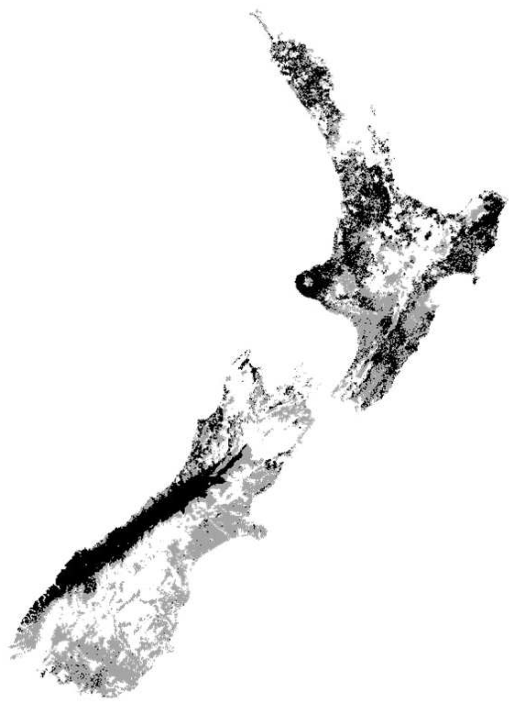

Figure 7-1: Phosphorus yields 0-2.5 (white), 2.5-5 (grey), and >5 (black) kg ha^{-1} yr^{-1}

7.2. SPARROW groundwater extension

7.2.1. Review of SPARROW groundwater extension

The extension of the SPARROW model to include groundwater transport has a groundwater network structure (Figure 7-2) that mimics the surface stream network, and a set of exchange coefficients (*E*) that quantify the transfer of water (and solute mass) between the two. The basic element of these networks is the reach, which is defined in surface-stream terms as linking nodes at which water quality is monitored or predicted.

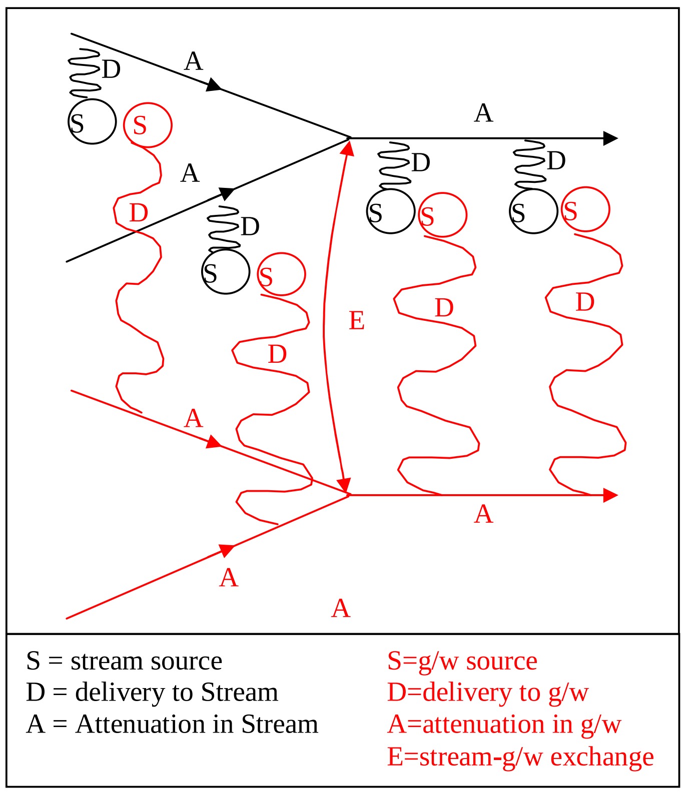

Figure 7-2: Extension to SPARROW to include groundwater (the red lines represent new components associated with groundwater).

The exchange coefficients are intended, in part, to account for the lack of coincidence between groundwater catchments and the topographical features that determine the conventional surface water catchment (Figure 7-3). The values of the coefficients *E* can range from –1: all groundwater contamination exfiltrates to surface water, to +1: all stream contamination infiltrates to groundwater.

The computational procedure within the model can be summarised as:

- Calculate the contaminant load entering each reach of the stream and groundwater networks

- Exchange contaminant mass between corresponding reaches of stream and groundwater

- Calculate the contaminant mass flux at each node

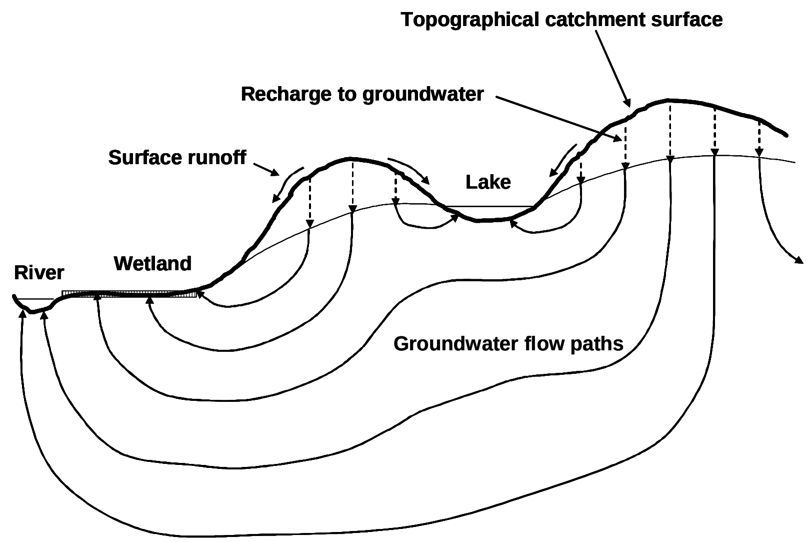

Figure 7-3 Hydrologic section of a hypothetical catchment, showing how surface water bodies can receive groundwater from various parts of the topographical catchment that do not coincide with the upslope areas.

This exchange process within each reach implicitly treats the respective reach as completely mixed. While this is physically valid for a surface water reach, the groundwater flow paths shown in Figure 7-3 illustrate the stratified nature of groundwater that has originated from different parts of the land surface. This aspect is lost in the simple mass flux exchange in each reach, but it is a reasonable approach given that knowledge of groundwater flow paths is unlikely to be available for any particular application of the extended SPARROW model.

The data inputs to SPARROW comprise primarily information about the stream network, and land surface in terms of topography, land use, climate, and soil properties. In order to characterise the nature of the underlying groundwater catchments, in terms of the stream-aquifer exchange coefficients, it is desirable to relate these coefficients to the available input data. In particular, stream network and topographical features are selected for these relationships.

7.2.2. The role of landscape in groundwater catchments

Winter et al. (2003) describe a number of examples of groundwater catchments in relation to combinations of topographical relief and aquifer permeability. They conclude that:

Only if the surface watershed of a research site is at the highest ridge away from major hydrologic sinks such as regional rivers, can one be sure that ground water is not moving into the area from distant sources.

This conclusion is applied to the method described in the present report by incorporating the principle that only in first-order (headwater) catchments does the groundwater originate only from within the topographical catchment area (but not necessarily from all of that area).

At the highest order reach at the downstream end of the catchment, the role of groundwater in transporting nitrate from land use to coastal waters by direct discharge (includes submarine discharge and seepage from shoreline above sea level) is well recognised (e.g., Pitz, 1999).

Groundwater yield from small catchments

Observations of groundwater yield from small catchments provide an indication of how much of the transporting water moves from groundwater to stream within a low-order catchment and how much moves into the next order of catchment before contributing to streamflow.

From an analysis based on stream yield response to tree harvesting, of 32 small research basins of areas 3 – 2500 ha, and annual precipitation 457 – 2641 mm/y, Verry (2003) reports that the average flow of groundwater out of the catchment (deep seepage) is 45% of streamflow. The stream orders within these catchments (mostly in the USA) are not given. This average result can be restated as groundwater outflow proportion being 0.31 and streamflow being 0.69 of total catchment yield (45% ÷ 145% = 0.31).

From streamflow measurement and tracer dilution experiments in a 223 ha, steep forested catchment, Castro and Hornberger (1991) report that subsurface discharge was approximately 47% of the total discharge from the catchment.

Recent analyses for the Pukemanga Stream in Waikato (Stewart and Elliott, 2004), show that yield from the first-order stream in this steep, 3 ha catchment is about 0.5 of that calculated from climatic data.

These results suggest that a practical value for the water flux balance component of the exchange coefficient in low-order catchments is $E = 0.5$.

Bilateral exchange processes between stream and groundwater

Bilateral exchange of water between stream and near-stream subsurface zone, and the consequent mixing of these waters, is generally recognised as contributing to the hyporheic zone. The causes of this mixing of stream and groundwater can arise from spatial variations in streambed slope, profile and horizontal geometry (e.g., Woessner, 2000) as well as the effect of transient streamflow events (Claxton et al. 2003) and seasonal flow variations (Wroblicky et al. 1998).

At the scale of reaches as defined for the SPARROW model, and given the steady-state assumption for this model, these exchange processes can be treated as steady bilateral fluxes per length unit of reach. The lateral scale of this mixing can extend up to tens of metres from the stream, depending on the nature of the alluvial material. Transfer coefficients for this bilateral exchange in three headwater streams of different characteristics have been evaluated by Morrice et al. (1997) from mathematical modelling of tracer experiments in these catchments. The results suggest that the proportion of groundwater involved in these processes is small but the effect on stream quality can be significant for those reaches which appear to have no net flux of groundwater to stream.

This bilateral exchange, with no net transfer of water flux, is ignored in the recommendations presented in this report but it would be feasible to include additional terms in the extension if desired.

Water flux from stream to groundwater

On many alluvial plains there is a net transfer of water from streams to the underlying aquifer. This occurs primarily because the topographical slope of the alluvial outwash is steeper than the piezometric gradient of the underlying groundwater flow in highly permeable materials, and therefore the stream is perched above the aquifer in its upper reaches. Examples of this situation are the major rivers crossing the Canterbury Plains and the Motueka River as it nears the coast.

There are few reliable data about the leakage rate from stream to aquifer because the net loss in several kilometres of a reach is about the same magnitude as the stream gauging error (measured downstream differences in streamflow are used to estimate leakage). Some unpublished results from a mathematical model supporting a groundwater quality study by Di et al. (2005) suggest that the loss rate for the Waimakariri and Rakaia Rivers is about 0.005 times the mean annual flow per kilometre of the perched reaches. Therefore, the total streamflow loss to groundwater could be about 10% for a 20 km reach in this situation.

Conclusions about stream-groundwater exchange processes

The rates of water flux exchange between groundwater and streams are difficult to measure at small scales, and are likely to depend on the particular topography and geological characteristics of a catchment. The key to obtaining estimates of these exchanges is to use all available information on the water balance in the catchment at increasing scales throughout the stream network.

7.2.3. Water-balance approach to estimation of exchange coefficients

Assumptions about availability of hydrological data

It is assumed that the following data are available or can be derived for the SPARROW network:

- Precipitation excess $P_{i,j}$ estimated from climatic data and use of a water balance model for all sub-areas $A_{i,j}$ of the catchment. The value of $P_{i,j}$ is the mean annual total from water balances calculated on a daily basis, and represents the sum of surface water and groundwater flux.

- Observations of streamflow Q_k at various locations k in the stream network, that are expressed as mean annual stream discharge.

Water yield calculations within SPARROW

The following quantities can be calculated for every reach i :

- Total water yield at reach i (surface + groundwater), for contributing areas $A_{i,j}$, is:

$$W_i = \sum_j P_{i,j} A_{i,j} \tag{1}$$

- The surface water contribution W_i^s and groundwater contribution W_i^g to the respective reaches i of the surface and groundwater networks are:

$$\left.\begin{aligned} W_i^s &= \sum_j S_{i,j}^s P_{i,j} A_{i,j} \\ W_i^g &= \sum_j S_{i,j}^g P_{i,j} A_{i,j} \end{aligned}\right\} \tag{2}$$

for which $S_{i,j}^s$ and $S_{i,j}^g$ are the surface and groundwater source splits, respectively, for contributing area $A_{i,j}$. Water flux balance assumes that:

$$\left.\begin{aligned} S_{i,j}^s + S_{i,j}^g &= 1 \\ W_i &= W_i^s + W_i^g \end{aligned}\right\} \tag{3}$$

Use of available streamflow observations

If observations of mean annual streamflow Q_k are available at the downstream end of a subset k of the reaches W_i, then the values of groundwater "underflow" U_k can be calculated for the corresponding catchment areas A_k, where:

$$\left.\begin{aligned} U_k &= W_k - Q_k \\ A_k &= \sum_j A_{k,j} \end{aligned}\right\} \tag{4}$$

Underflow U_k is that portion of groundwater that has not returned to the surface drainage network at reach k and continues on to the next reach of the groundwater network. Figure 7-4 shows the relationship between these variables for the calculations at reach k.

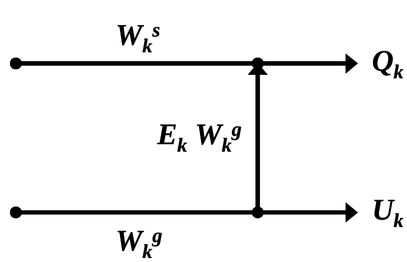

Figure 7-4: A reach element of the SPARROW model, showing the relationships between the variables described in Equations (3) and (4).

From the network of Figure 7-4:

$$Q_k = W_k^s + E_k W_k^g \text{, and therefore } E_k = \frac{\left(Q_k - W_k^s\right)}{W_k^g} \tag{5}$$

Thus there is an estimate of E_k for every observation of mean annual streamflow Q_k, corresponding to a contributing catchment area A_k, so that a plot of E_k versus A_k can be obtained. It is likely that there will be a degree of scatter in this plot, and a smooth curve would be fitted to these data. From this curve, values of E_i can be predicted for all reaches i corresponding to the contributing areas A_i calculated from:

$$A_i = \sum_j A_{i,j} \tag{6}$$

The values of E_k calculated from Equation (5) are positive for exfiltration from groundwater to surface water, so a sign change can be applied for use in extended SPARROW or the computational logic can be altered.

In the absence of streamflow data for the target catchment system, it is likely that some degree of information would be obtainable from regional analysis of catchments with similar topography and geology. For reaches corresponding to headwater catchments a value of $E_i = 0.5$ can be used, on the basis of observations reported in the subsection of Section 7.2.2 entitled *Groundwater yield from small catchments*.

7.2.4. Summary

The transfer of contaminant mass between the groundwater and surface-water networks of the extended SPARROW model is assumed to be due to advective transfer. Therefore, a procedure for estimating the exchange coefficients has been developed from consideration of water flux balance for the twin networks. This procedure uses calculated values of precipitation excess in conjunction with estimates of source split (into groundwater and surface-water components) for the contributing sub-catchment areas within the SPARROW model. Calibration of the procedure is based on the availability of mean annual streamflow data at various levels of contributing catchment area, for comparison with the calculated contributions of precipitation excess. It is suggested that this relationship may be similar for catchments of similar topography and geology, and that some transfer of regional information may be possible.

At this stage there are no plans in the current CLUES project to develop the linkage between surface and groundwater further. The next step to take would be to select a study area where these exchanges are important and for which some data is available, so that the approach described in Section 7.2 can be calibrated and tested. Previous CLUES project meetings have not ranked this item as highly as other items needed to ensure the MAF-funded project CLUES project has achieved its original objectives.

7.3. Data sources for SPARROW component of CLUES

The data sources for SPARROW are summarised in Table 7-5.

Table 7-5: Sources of data for SPARROW component of CLUES.

Data Description	Source of Data	Date	Expected timing of next update	How to obtain updated data
River water quality	National Rivers Water Quality Network	1996-1999	Update once land-use is >2005	Query NIWA water quality and flow databases- re-calculated loads
Point source water quality data	Local council data	1996-2000	As above	Re-survey
River flow data	National hydrometric network	To match water quality	As above	As for water quality
Rainfall	Digitised contours or rainfall normals	1961-1990	Could be updated once more accurate rainfall surfaces become available.	NIWA
River network	River Environment Classification, derived from contours and stream locations on 1:50,000 topo maps	c2001	None planned. Could modify to include small coastal land parcels not associated with streams.	-
Soil drainage class	Land Resources Inventory	2000	None planned.	-
Land use	See Section 11.1	-	-	-
Soils	See Section 11.2	-	-	-

7.4. Proposed next steps

- Recalibrate the national SPARROW N model with finalized OVERSEER® model.

- Conclude pilot testing at Environment Waikato of the Land Use Change Tool being developed in Objective 1, in conjunction with the SPARROW model as it was at the end of Year 2. Test other models (e.g., EnSus, OVERSEER®, SPASMO, Triple-Bottom-Line) as they become available in the framework.

- Respond to Environment Waikato requests as described in Section 7.1.2.

- Investigate methods for breaking the predicted total nitrogen up into separate forms.

- Investigate methods for determining the typical concentration of N in summer.

- Incorporate horticulture leaching terms from the SPASMO model.

- Investigate further reasons for discrepancies between OVERSEER® and SPARROW for dairy areas.

8. Objective 3: Triple bottom line effects of land-use change (Harris Consulting)

This section outlines the relationships to be used for estimating economic output and nutrient loss from different land use types. There are three relationships for each land use based on an area basis[1]:

- Output – the gross output in $ per ha.

- Cash Farm Surplus (CFS) – this is the remainder after farm working expenses, but before interest, leases, wages of management, and capital expenditure. The CFS equation differentiates between variable Farm Working Expenses (FWE) and fixed FWE (administration, legal, accounting, R+M, etc.). Variable FWEs change with the intensity of production, but fixed do not[2]. CFS also takes into account the additional feed and N required to maintain a given level of land use intensity.

- N leached – this is an estimate of the amount of N leached (based on models from MAF Monitoring Farms, supplemented with the results of OVERSEER® and SPASMO models) at a given level of land use intensity using a single rainfall figure for each region.

There are two flow-on multipliers for each land use, which estimate the total impact on the regional economy. These are:

- Total GDP – an estimate of the total value added arising from that land use activity, given as a multiplier of output.

- Total Employment – an estimate of the total employment arising from that land use activity, given as a multiplier of output.

8.1. Sheep, beef, dairy and deer models

The models used were based on the MAF Farm Monitoring models. The models created comprise 6 dairy models, 5 intensive sheep and beef models, 6 hill country sheep and beef models, 1 extensive sheep and beef model (based on the South Island

[1] Note that not all land uses have the option of altering intensity.

[2] This is suitable for short term changes in land use, but long term changes could result in resizing of farms, changes in cost structure etc. so some cognizance should be taken of this for long term planning. (This will result in underestimate of long run CFS).

Merino model), and 2 deer models (North Island and South Island deer models). These models were assigned to regions as shown in Table 8-1.

For each model a set of relationships were generated for cash flow and N leached at different levels of land use intensity. This was undertaken by using a base stocking rate (cows or stock units per hectare, su/ha), then varying the amount of feed which needed to be achieved to increase or decrease the stocking rate from the base rate. Initially cheaper methods were used to increase feed, with N introduced into the property first, then feed bought into the property once a specified maximum rate of N application was achieved. Similarly as the stocking rate decreased from the baseline, feed was initially reduced from the farming operation, then N usage decreased.

A range of stocking rates was set, within which the relationships can be reasonably expected to operate. Figures outside this range are likely to result in poor quality results.

The ratio of N to feed was 15 kg feed for each kg N applied. A stock unit was assumed to consume 550 kg(DM)/ha/year, and a utilisation rate for feed varied between 0.8 and 0.9.

When working out the financial implications of the changes, a base model was produced. This model assumed a fixed relationship between the stocking rate and gross output from the farm and hence revenue. Therefore as stocking rate increased or decreased so did the revenue from the farm. However farm expenses are rarely linear with stocking rate, since there are a number of farm costs which are fixed and cannot be changed with stocking rate. Therefore the Farm Working Expenses (FEW) were divided into fixed and variable working expenses. The Cash Farm Surplus (CFS) was calculated from the combination of Gross Revenue, Variable FEW and Fixed FEW.

Dairy farm effluent disposal was assumed to occur as pond systems. This will understate the nutrients leached since land based disposal is becoming much more common. The sheep to beef ratios are constant across all stocking rates, set at the baseline level for each model type. This is important since the leaching rates are strongly influenced by the presence of cattle.

8.2. Arable model

Developing a model for the arable sector is extremely difficult because of the range of crops involved, and large variation in the mix of crops, use of pasture, and management practice. For this reason we have implemented a single Arable model, again based largely on the MAF farm monitoring model, but also bringing in other modelling runs such as the irrigated arable model from a recently completed project on the implications of water reliability. Intensity and types of land use are not variable.

This model uses a 10 year rotation, with fertiliser estimates based on expenditure patterns rather than actual records of mass application. All crops were assumed to be direct drilled. The nitrate leaching estimate is a weighted average across the farm.

8.3. Horticulture model

The horticultural N leaching estimates were provided by HortResearch as discussed in Section 0. We have taken the average crop production from the model assumptions, and used these to develop farm budgets. Again these are fixed intensity, and the models relate to the whole growing region and do not include sub-regional variations, nor do they include variations for different soils or production levels.

Table 8-1: Assignment of MAF Monitor Farm models to regions and land use classes.

Land Class		40 (intensive)													41 (hill country)						43 and 44
Land use		Dairy						Sheep and Beef					Deer		Sheep and beef						Sheep and Beef
Model Name	Rainfall	Northland	Waikato	Lower NI	Canterbury	Southland	West Coast	Northland	Waikato/Bay of Plenty Intensive	Manawatu/Rangitikei Intensive	Canterbury/Marlborough Breeding and Finishing	Southland/South Otago Intensive	NI Deer	SI Deer	Central NI Hill	Gisborne Large Hill	Hawkes Bay- Hawke's Bay / Wairarapa hill	Canterbury/Marlborough Hill Country	Southland/South Otago Hill Country	Otago Dry Hill	SI merino
Northland	1000 - 1500	x						x					x		x						
Auckland	1000 - 1500	x						x					x		x						
Waikato	1000 - 1500		x						x				x		x						
Bay of Plenty	1000 - 1500		x						x				x		x						
Gisborne	1000 - 1500		x						x				x			x					
Taranaki	1000 - 2000			x						x			x		x						
Hawkes Bay	750 - 1500			x						x			x				x				
Manawatu-Wanganui	750 - 1500			x						x			x		x						
Wellington	750 - 1500			x						x			x				x				
Tasman	1000 - 1500				x						x			x				x			x
Marlborough	500 - 1500				x						x			x				x			x
Canterbury	500 - 1000				x						x			x				x			x
West Coast	2000 - 4000						x					x		x					x		x
Otago	250 - 750					x						x		x						x	x
Southland	750 - 1000					x						x		x					x		x

Table 8-2: Crop rotation and specification.

Crop	Wheat	Wheat	Greenfeed	Barley	Clover	Greenfeed	Peas	Wheat	Greenfeed	Barley	Ryegrass	Ryegrass	Process Peas
Yield	7.5	7.5	7	6.8	0.36	7	4.1	7.5	7	6.8	1.32	1.32	6.0 T
Month sown	1-May	1-May	21-Feb	1-Sep	28-Feb	21-Feb	1-Oct	1-May	21-Feb	1-Sep	1-Mar	5-Jan	15-Oct
Harvested	7-Feb	7-Feb	1-Aug	15-Feb	1-Feb	1-Aug	25-Feb	7-Feb	1-Aug	15-Feb	5-Jan	5-Jan	15-Jan
Post harvest management	Baled	Baled	Grazed	Baled	Grazed	Grazed	Grazed	Baled	Grazed	Baled	Grazed	Grazed	Baled
Irrigation (mm)	400	400	200	400	500	200	500	400	200	400	500	500	300
Fertiliser N (kgN/ha)													
January				70									
February			20			20			20				
March											20	50	
April			50			50			50				
May	20	20						20			50	50	
June			50			50			50				
July													
August	70	70						70					
September	70	70		20				70		20	50	50	
October	70	70						70					
November	70	70		70				70		70			
December				70						70			

8.4. Format of predictive relationships

8.4.1. Output

Sheep, beef, dairy and deer: This is the gross revenue per cow or per su. It should be multiplied by the number of stock units or cows per ha to give the output per ha.

Arable and Horticulture: This is the gross revenue per ha.

8.4.2. Cash farm surplus (CFS)

Sheep, beef, dairy and deer: Cash farm surplus relationships have been generated in a 2nd order polynomial relationship i.e., CFS = $ax^2 + bx + c$. The values in each column represent those for a, b and c. The variable x is a measure of land-use intensity, expressed in units of cows/ha or su/ha, depending on the context.

The R^2 of the calibrated relationships for CFS as a function of landuse intensity for each land use is in excess of 0.9 apart from those which relate to Land Use classes 43 and 44 (Tall Tussock Grassland and Depleted Tussock Grassland, respectively), which are greater than 0.8.

Arable and Horticulture: This is the cash farm surplus per ha.

8.4.3. N leached

Sheep, beef, dairy and deer: The values for N leached are presented as a 3rd order polynomial

i.e.: $N_{(leached)} = ax^3 + bx^2 + cx + d$

Typically the relationships use only a 2nd order polynomial for the sheep and beef models, and the a value is left as 0. The variable x is a measure of land-use intensity, expressed in units of cows/ha or su/ha, depending on the context.

The R^2 of the calibrated relationships for N leached as a function of landuse intensity for each land use is in excess of 0.9 apart from those which relate to Land Use classes 43 and 44 (Tall Tussock Grassland and Depleted Tussock Grassland, respectively), which are greater than 0.8.

Arable: Fixed N leaching estimate per ha

Horticulture: Derived from HortResearch estimates

8.4.4. Total GDP relationship

There is a GDP multiplier for each region for sheep and beef, dairy, arable and horticulture. These give the total GDP change in the regional economy as a result of the changes in land use. It includes all the upstream flow on impacts, but not downstream flow on impacts (i.e., to processors). To use these figures take the output/ha calculated above, and multiply this by the appropriate GDP multiplier for the land use and region.

8.4.5. Total employment

This multiplier gives the total employment impacts as a result of the land use change. It includes upstream impacts but not downstream such as processing. To use these figures take the output/ha calculated above, and multiply this by the appropriate Employment multiplier for the land use and region then divide by 1,000,000.

8.5. Data Sources for Triple-Bottom-Line Component of CLUES

The data sources for Triple-Bottom-Line are summarised in Table 8-3.

Table 8-3: Sources of data for Triple-Bottom-Line component of CLUES.

Data Description	Source of Data	Date	Expected timing of next update	How to obtain updated data
Output, Cash Farm Surplus	MAF Monitoring Farm Reports	2003/04	2005/06	MAF
Regional multipliers	Butcher Partners	2001	April 2006	Check to see if MAF will be purchasing, otherwise direct from Butcher Partners

8.6. Proposed next steps

Extend Triple-Bottom-Line accounting model to include income/jobs associated with:

- Forestry.
- Tourism.

8.7. Sources

- MAF Farm Monitoring Reports www.maf.govt.nz/mafnet/rural-nz/statistics-and-forecasts/farm-monitoring.

- Lincoln University Farm Technical Manual (2003; Editor P.H. Fleming), Lincoln University.

- Woodford, K.W. and Nicol, A. (2004 in press) "A Re-assessment of the Stock Unit System" Report Prepared for MAF, June.

- Utilises SPASMO model runs as reported in Section 10 of this report.

- Harris Consulting et al. (2004). "Regional Economic Implications of Water Allocation and Reliability" Report prepared for MAF and Environment Canterbury. Draft.

- Lincoln Environmental et al. (2003). "Water in New Zealand Agriculture: Resilience and Growth" Report prepared for MAF.

- G.V. Butcher, Butcher Partners, pers. comm. 2002.

- S Ford, Agribusiness Group, pers. comm. 2004.

9. Objective 4a: Enterprise-scale modelling (AgResearch)

9.1. OVERSEER® scenario development

A software component for the OVERSEER® nutrient budget model was provided to NIWA (in the form of a Dynamic Linked Library – DLL). Documentation was provided to explain how to call the software, and it was then linked into the CLUES modelling system, as demonstrated in Section 6. The OVERSEER® DLL supplied to NIWA has capability for five farming scenarios:

- Dairy.
- Sheep/beef lowland.
- Sheep/beef hill country.
- Sheep/beef high country.
- Deer.

For each of the five scenarios, optional stocking numbers may also be supplied. To adequately specify input to OVERSEER®, many other inputs are also needed. Many of these have been set at values that are typical for the farm type and region, making use of MAF Monitor Farm model (MAF 2004 see section 9.7) and other data sources that are described below.

The assignment of MAF Monitor Farm models to regions was done as shown in Table 9-1, plus the following assignments:

- The "intensive" models in Table 9-1 were assigned to Sheep/beef lowland.
- The "hill" models in Table 9-1 were assigned to Sheep/beef hill country.
- Merino model values were assigned to Sheep/beef high country.

Dairy data was obtained from the summary data in Livestock Improvement Corporation (2004), rather than MAF Monitor Farm dairy models

- The MAF Monitor Farm Otago Dry Hill model was not used at this stage.

Table 9-1: Assignment of MAF Monitor Farm models for Sheep and Beef, and Deer, to regional council regions.

Model Name → Region ↓	Waikato/Bay of Plenty Intensive	Manawatu/Rangitikei Intensive	Canterbury/Marlborough Breeding and Finishing	Southland/South Otago Intensive	Northland	Central North Island Hill Country	Gisborne Large Hill Country	Hawke's Bay / Wairarapa Hill Country	Canterbury/Marlborough Hill Country	Southland/South Otago Hill Country	NI Deer	SI Deer
Northland	x				x						x	
Auckland	x					x					x	
Waikato	x					x					x	
Bay of Plenty	x					x					x	
Gisborne		x					x				x	
Taranaki	x					x					x	
Hawkes Bay		x						x			x	
Manawatu-Wanganui		x				x					x	
Wellington	x					x					x	
Tasman			x						x			x
Marlborough			x						x			x
Canterbury			x						x			x
West Coast	x					x						x
Otago				x						x		x
Southland				x						x		x

The OVERSEER® DLL used in CLUES assumes that inputs are within a valid or reasonable range, and that there is internal consistency between inputs e.g., fertiliser inputs and productivity.

The other OVERSEER® inputs which can vary within the CLUES framework are:

- Rainfall (annual average rainfall in mm).
- Region (select one of 15 regional council regions).
- Soil order (one of up to 13 possible soil orders).
- Topography (one of possible classes for the block slope).

Maps are available within CLUES, which provide the information necessary to automatically estimate each of these 4 other input variables, anywhere in New Zealand.

9.2. Calling the OVERSEER® DLL

The standard call for the DLL is:

CluesOvr(scenario, region, soilorder, Topography, rainfall, Sdairy, Ssheep, Sbeef, Sdeer).

The model returns N (usually as nitrate) and P losses associated with each land use.

The definition of each input is:

Scenario: 1–5 for pre-defined scenarios dairy, sheep/beef (lowland), sheep/beef (hill), sheep/beef (high), deer.

Region: Regional council number code (see Table 9-2 for definitions). This code is used to set default regional values for dairy and sheep/beef farms, respectively as shown in Table 9-2 and Table 9-3.

Soilorder: Soil order specified as an integer, based on the following code:

Code	Soil order
1	Allophanic
2	Brown
3	Granular
4	Gley
5	Melanic
6	Organic
7	Oxidic
8	Pallic
9	Podzols
10	Pumice
11	Recent
12	Semiarid
13	Ultic

Slope: average block/subcatchment topography code based on the following table:

Code	Slope Class	Access	Slope	LRI[1] class
1	Flat		0° to 7°	A-B
2	Rolling	Area mostly navigable by tractor	8° to 15°	C
3	Easy	>50% area navigable by tractor	16° to 25°	D-E
4	Steep	<50% area navigable by tractor	26° or more	F-G

[1] LRI = Land Resource Inventory slope class

Rainfall: Average annual rainfall to nearest 100 mm

Sdairy, Ssheep, Sbeef, Sdeer: Optional stocking numbers for dairy, sheep, beef and deer, respectively. If a zero value is provided then a default is used as described in Section 0.

Region default values are based on latest published set of data from Livestock Improvement Corporation (Livestock Improvement Corporation 2004) and MAF Monitor Farms (MAF 2004). These values do change over time due to variations in economics, farm practices and weather, for example. A sensitivity analysis could be done in future to look at the change over time. At this stage, the important factor is that the model has the structure to hold these values. They are relatively easy to change if the basis for calculation was to change (e.g., using a different base year, or using an average over several years, or using a different published set of data). The base for these values may be something that the users would like to have established as a future step in the project. These default values could be updated either within the DLL (in which case a maintenance agreement will be needed) or the DLL needs to be modified so that external data source containing the default values can be accessed.

Note that in Table 9-3 the nitrate-N values are estimated typical (as opposed to average) annual applications obtained from a fertiliser company. So, for example, on Manawatu/Wanganui sheep/beef hill country farms, there are some farmers using nitrate-N in this region, but typically, the application rate is zero. This data was obtained so that the DLL could work with the GIS interface. In theory, the nitrate-N fertiliser rate should be commensurate with the production data used in the DLL, and hence a more reliable source of information of typical nitrate-N fertiliser rates is required.

Table 9-2: Regional categories and associated default values for dairy farms. Animal production data is based on Livestock Improvement Corporation (2004).

Code	Region	Average milk production (kg milksolids/ha/yr)	Average cows (cows/ha)	Average milk per cow (kg milksolids/ha/yr)	N fertiliser (kg N/ha/yr)
1	Northland RC	730	2.33	311	80
2	Auckland RC	1060	2.85	372	200
3	Env Waikato	853	2.67	318	120
4	Env. Bay of Plenty	909	2.80	324	120
5	Gisborne	832	2.56	333	70
6	Hawkes Bay	840	2.62	322	120
7	Taranaki	734	2.54	289	100
8	Manawatu/Wanganui	790	2.48	316	50
9	Wellington	604	2.11	286	80
10	Marlborough	910	2.60	348	100
11	Tasman	885	2.60	341	100
12	West Coast	805	2.71	296	150
13	Canterbury	790	2.49	316	80
14	Otago	734	2.54	289	100
15	Southland	635	2.03	316	150

Table 9-3: Regional categories and associated default values for sheep/beef farms. Animal production data is based on corresponding MAF Monitor Farms in Table 9-1.

Code	Region	Sheep (lowland)				Sheep (hill country)			
		Sheep (SU)	Cattle (SU)	Wool (kg /SU/yr)	N fertiliser (kg N/ha/yr)	Sheep (SU)	Cattle (SU)	Wool (kg /SU/yr)	N fertiliser (kg N/ha/yr)
1	Northland RC	5.17	6.43	4.94	0	6.29	3.71	4.76	30
2	Auckland RC	8.67	2.13	4.8	40	3.2	3.2	4.52	50
3	Env Waikato	5.17	6.43	4.94	0	6.29	3.71	4.76	50
4	Env. Bay of Plenty	5.17	6.43	4.94	30	6.29	3.71	4.76	40
5	Gisborne	6.53	5.86	5.4	40	4.95	3.85	4.96	30
6	Hawkes Bay	6.53	5.86	5.4	60	6.69	3.41	4.6	40
7	Taranaki	6.53	5.86	5.4	50	6.29	3.71	4.76	30
8	Manawatu/Wanganui	8.67	2.13	4.8	30	3.2	3.2	4.52	0
9	Wellington	5.17	6.43	4.94	30	4.23	5.57	5.3	20
10	Marlborough	12.78	0.72	5.74	40	7.48	1.22	4.97	0
11	Tasman	12.78	0.72	5.74	40	7.48	1.22	4.97	30
12	West Coast	5.17	6.43	4.94	0	6.29	3.71	4.76	20
13	Canterbury	8.67	2.13	4.8	0	3.2	3.2	4.52	30
14	Otago	5.17	6.43	4.94	50	6.29	3.71	4.76	30
15	Southland	5.17	6.43	4.94	30	6.29	3.71	4.76	30

9.3. Operation of OVERSEER® DLL

The CLUES system currently calls OVERSEER® with stock rates developed by Hunt (2003), and given by Hunt as his Table 2. The stocking rates from Hunt (2003) depend on slope class (for which CLUES has a detailed map), location (whether North Island or South Island), and livestock category (dairy, sheep, beef, or deer). In future it may be possible to use the stocking rates developed as part of the land use classification reported in Section 16.

For dairy farms

If a scenario is entered, and stock number are all zero then production is calculated as:

Cow numbers = Average regional cow numbers (see Table 9-2)

Milk production = Average regional milk production (see Table 9-2)

If dairy cow numbers are entered (this is the option CLUES uses) then

Cow numbers = entered value

Milk production = cow number x average regional per cow production (see Table 9-2)

It is assumed that effluent is applied as spray irrigation at an application rate of 150 kg TN/ha/yr of effluent, and that nitrate-N fertiliser on the effluent block is reduced.

For sheep beef farms

If a scenario is entered, and stock numbers are all zero then stock units (SU) are calculated as:

For sheep/beef lowland and hill country

Use SU sheep and SU beef values shown in Table 9-3

Wool = (kg/SU/year in Table 9-3) x SU sheep

For high country sheep/beef

SU sheep = 1.3

SU beef = 0.2

Wool = 4.7 x SU sheep

If stock numbers are entered then

SU sheep = Stock number sheep x 1.1

SU beef = Stock number beef x 5

Note that this option to enter stock numbers is in addition to the requirements of the contract, and values used are only approximate. Fully referenced values can be inserted as part of year 3 of the CLUES project.

For deer

If a scenario is entered, and stock numbers are all zero then SU is calculated as:

SU deer = 12.9 for North Island

SU deer = 13.0 for South Island

If stock numbers are entered then

SU deer = Stock number sheep x 2

N fertiliser rate is a regional estimate, based using the values for sheep/beef (lowland) if topography is flat, otherwise Sheep/beef (hill).

9.4. Data sources for OVERSEER® component of CLUES

The data sources for OVERSEER® are summarised in Table 9-4.

Table 9-4: Sources of data for OVERSEER® component of CLUES

Data Description	Source of Data	Date	Expected timing of next update	How to obtain updated data
Stock data	MAF Monitor Farm reports	July 2004	As required, intervals of 6 to 18 months	Obtain new OVERSEER® DLL for use with CLUES or have an external data source which the DLL can access
Dairy data	Dairy statistics from Livestock Improvement Corporation	2003/4		
Fertiliser data	Estimate from company reps			

In addition, the underlying model is updated at 12-18 month intervals, and the OVERSEER® DLL should also be updated at the same time.

9.5. Additional work

To improve the function of the DLL in its current construct it is recommended the following activities occur:

- Upgrade the underlying model to the new version of OVERSEER® nutrient budget model
- Improve the structure of the DLL to improve functionality of the link with the GIS system
- Develop routines to better check for consistency of data

9.6. Proposed next steps

- Upgrade the underlying model to the new version of OVERSEER® nutrient budget model
- Improve the structure of DLL to improve functionality of the link with the GIS system
- Develop routines to better check for consistency of data
- Make visible the default values associated with the 5 current scenarios (tentative)

9.7. References

Livestock Improvement Corporation (2004). Dairy Statistics 2003-2004, Business Information Unit, Livestock Improvement Corporation Limited, Hamilton. (Available at http://www.lic.co.nz/113_7.cfm).

Hunt, C. (2003). A calculation of stock numbers for four livestock categories on seven classes of slope for New Zealand. AgResearch Report prepared for the Ministry of Agriculture and Forestry, June 2003.

MAF (2004) Sheep and beef monitoring report. Ministry of Agriculture and Fisheries, Wellington (Available at http://www.maf.govt.nz/mafnet/rural-nz/statistics-and-forecasts/farm-monitoring/index.htm)

10. Objective 4b: Enterprise-scale modelling (HortResearch)

This section describes HortResearch's contribution to the second stage of a 3-year study to predict the effects of land use activity on water quality. The task was to create a database of predictions of nitrate leaching under various combinations of crop, fertiliser, climate and soils. This section lists the scenarios used, describes the limitations of the results, and outlines the uses for which they are intended.

The Soil Plant Atmosphere System Model (SPASMO Version W1.2) has been used to calculate the nitrogen budget for five enterprise scenarios (each with some internal variations). The calculations were run on a daily time step using 32 years of local climate data (Table 10-1). A wide range of local soils (between 7 and 22 different soils) was modelled for each location. A set fertilizer regime was applied to each crop based on advice from growers and leading plant scientists (Table 10-2). Results from a large number of model runs (~350 in total) are provided as a series of lookup tables for various combinations of crop, fertiliser, climate and soils.

The calculations are summarized in the form of an annual budget that includes the amount of nitrogen that is (1) added as fertilizer, (2) taken up by the plants, (3) removed in the harvested crop, (4) returned to the soil as dead plant material and/or crop residue, (5) mineralised from soil organic matter, and (6) leached below the root-zone (Table 10-3). The intention is for these lookup tables to be included in a computer-based GIS Decision Support Tool that is being developed to assess the links between rural land-use, land use change, and catchment-level effects on surface and groundwater quality.

Table 10-1: The range of horticultural and cropping scenarios that were simulated using SPASMO (indicated by ticks). The calculations are based on a daily time series of weather data (1972-2003) compiled from NIWA's records of global radiation, air temperature, relative humidity, wind speed and rainfall at a representative climate station. Missing records were obtained from the nearest climate station. A total of 130 soil series were represented across the 12 regions.

Region	Climate station	Rainfall [mm/y]	Crop				
			Apple	Grape	Kiwifruit	Onion	Potato
Northland	Kerikeri	1754			√		
Waikato	Ruakura	1155	√		√	√	√
Bay of Plenty	Te Puke	1633	√		√		
East Coast	Gisborne	994		√			
Hawkes Bay	Hastings	727	√	√		√	
Manawatu	Palmerston North	940				√	√
Wairarapa	Masterton	883	√	√			
Nelson	Nelson	968	√	√	√		
Marlborough	Blenheim	664		√			
North Canterbury	Waipara	637	√	√			
Mid Canterbury	Lincoln	633				√	√
Central Otago	Alexandra	383	√	√			

Table 10-2: A set nitrogen-fertilizer regime was adopted for each crop type. Here CAN denotes calcium ammonium nitrate fertilizer, and DAP denotes di-ammonium phosphate fertilizer. Recommended values were derived from the following source:

Crop	Fertilizer	N content	Rate [kg/ha]	Time	Total N [kg/ha/yr]
Grape	CAN	0.27	50	Nov	14
Apple	CAN	0.27	100	Oct + Feb	54
Kiwifruit	CAN	0.27	350	Oct	95
Onion	DAP	0.18	280	Sep + Oct + Nov	150
Potato	CAN	0.27	500	Oct + Nov	270

Grape – this represents current practice on Craggy Range vineyard, Hastings. Dr Mike Trought (Marlborough Wine Research Centre) suggested that Marlborough vines only receive nitrogen when they need it (~10% of a vineyard would typically receive ~150 kg/ha/yr CAN).

Apple – based on advice from Dr John Palmer (HortResearch, Nelson). Typical rates for Braeburn in Nelson are 75 kg/ha CAN spring, 125 kg/ha CAN autumn, and a further 80 kg/ha urea are applied as foliar N during leaf fall. Dr Stuart Tustin (HortResearch, Hastings) suggested lower rates of N are applied in the Hawkes Bay due to higher rates of mineralization.

Kiwifruit – based on advice from Mr Murray Judd (Seeka, Te Puke). The annual dressing of nitrogen fertilizer is typically 100 kgN/ha for gold and 100–150 kgN/ha for Hayward, and this is applied in the spring. Some growers may be applying much higher rates.

Onion – based on actual fertilizer diary from Wilcox Gardens Ltd, Matamata.

Potato **-** based on actual fertilizer diary from Wilcox Gardens Ltd, Matamata.

10.1. Calculation procedure

SPASMO computes the water and nitrogen budget of a 1-dimensional soil profile of 5 m depth, divided into 0.10 m intervals (slabs). The calculation uses local soils with physical, hydraulic, and chemical transport properties deduced from data in the New Zealand Soils Database (Hewitt, 1998). Drainage is modelled using a water capacity approach that considers both mobile and immobile pathways for water and nutrient movement (Hutson and Wagenet, 1993). Following rainfall or irrigation, any dissolved nutrient in the mobile domain can percolate rapidly through the soil profile. Subsequently, on days when there is no significant drainage, there is a slow approach to equilibrium between the mobile and immobile phases, driven by a difference in water content between the two domains. The leaching part of SPASMO has been validated previously against data from grazed pasture (Rosen et al. 2004) and pasture treated with herbicide (Close et al. 2003; Sharma et al. 2004).

SPASMO uses a standard crop-factor approach to relate crop water use to the prevailing weather and time of year (Allen et al. 1999). Parameter values for the tree crops have been determined from our own field experiments where sap flow has been measured in the stems of apple trees, kiwifruit and grapevines (Green et al. 2004a & b). Literature values have been assumed for the remaining field crops (e.g., potato and onion). Each crop is irrigated using a set amount of water (grapes are given 2.5 mm per day while the other crops each receive 25 mm per day). Irrigation is applied on the basis of need, as soon as the root-zone water deficit exceeds a threshold value that depends on certain crop and soil factors.

The nitrogen component of SPASMO is based on a set of balance equations that account for plant uptake, fertilizer, soil exchange and transformation processes, gaseous losses to the atmosphere, and leaching losses below the root zone. Nitrogen uptake is determined from the daily growth of the various plant organs multiplied by their respective nitrogen concentrations. Crop growth depends on the daily amount of intercepted sunlight, and is moderated by air temperature as well as the water and nitrogen status of the soil. A simple allometric relationship is used to partition the daily biomass production into the growth of foliage, shoots, roots and crop components. Figure 10-1 and Figure 10-2 provide a schematic of the plant component of SPASMO. Calculations of dry-matter production and nitrogen accumulation in a kiwifruit vine are compared against comparable data from a nitrogen trial at Te Puke.

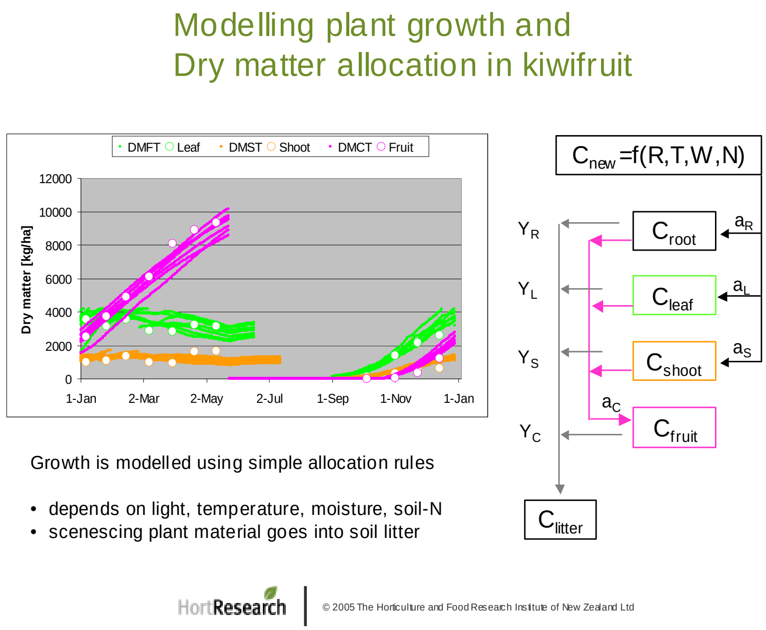

Figure 10-1: Dry matter allocation in kiwifruit. Open symbols are data from an SFF-funded nitrogen trial at Te Puke and the solid lines are model output from SPASMO.

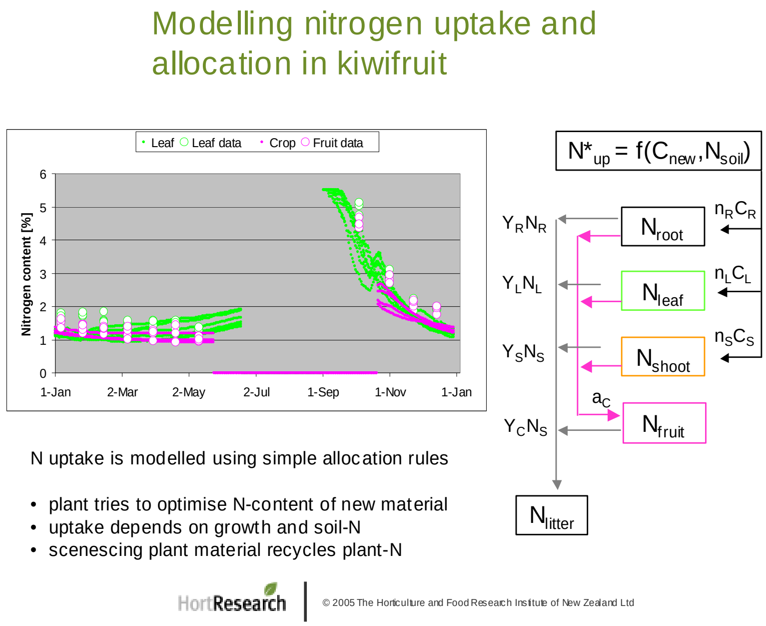

Figure 10-2: Seasonal development of nitrogen in the leaf and fruit of a kiwifruit vine. Open symbols are data from an SFF-funded nitrogen trial at Te Puke and the solid lines are model output from SPASMO.

A large number of parameters (>30) are needed to describe crop growth and nitrogen uptake. Where possible, we have either used our own data or sourced published results to determine parameter values for the plant component of the SPASMO simulations. For nitrate leaching calculations it is important to have reasonable agreement between measured and modelled values (cf. Figs 1 & 2) in order to achieve appropriate levels of nitrogen uptake by the crops.

The soil component of SPASMO considers both organic nitrogen (i.e., in soil biomass) and the mineral nitrogen (i.e., ammonium and nitrate in solution) contained in the soil. Dissolved nitrate is considered to be fully-mobile and to percolate freely through the profile, being carried along with the invading water. The movement of dissolved ammonium is retarded as it to binds to mineral clay particles of the soil.

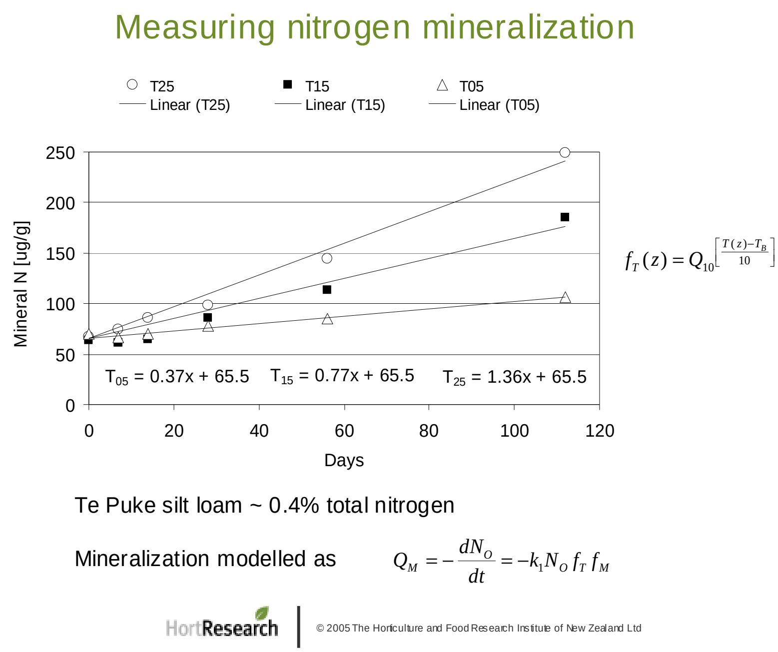

Figure 10-3: Nitrogen mineralization in a Te Puke soil incubated in the laboratory at a set range of temperatures and soil moistures.

The decomposition of soil biomass adds to the amount of mineral nitrogen (NH_4^+ and NO_3^-) in the soil profile. This process is known as mineralization and it is modelled as a first-order process by dividing the total organic matter into two pools – a fast cycling litter pool, and an almost stable humus pool (Bergstrom et al. 1987). The nitrogen demand for the internal cycling of soil-C and soil-N is regulated by the C/N ratio of the soil biomass, r_O, which is one of the model inputs. Figure 10-3 shows nitrogen mineralization in a Te Puke soil. This data is consistent with a first-order rate constant, k_1 equal to 1.5x10^{-5} d^{-1}. Unfortunately there is a dearth of comparable mineralization data for other New Zealand soils. So, for the purpose of modelling, the following approximation has been made. We have set k_1=1.5x10^{-5} for all soils where apples, kiwifruit and grapes are grown. In the case of onions and potatoes, the value of k_1 has been increased to 2.5x10^{-5} in line with the expectation that mineralization is enhanced in 'worked' soils.

10.2. Limitation of the SPASMO calculation

SPASMO calculations are expected to provide a reasonable estimate of the potential nitrate leaching that occurs under each soil-crop-climate combination. However, there are a number of limitations to the model results and their application, as detailed below

- Model results are presented as lookup tables. This is both a good thing (avoids a poor choice of input parameters that could produce misleading or inappropriate model output) and a bad thing (the user has no opportunity to enter their own data or to vary the input parameters at the paddock scale).

- Climate data is limited to one location within each region. It is recognised that large rainfall gradients may exist across a region (e.g., coastal and central Otago) and this will influence both the drainage and leaching losses. This is accounted for to a limited extent by the analysis below (Section 10.3). More account of rainfall variation could be included in the future, especially if irrigation requirements were to be considered.

- In some regions (e.g., Gisborne and Auckland) there is very little soil data available for the SPASMO calculations. There are also a number of important soil processes (e.g., adsorption, mineralization, denitrification) for which parameter values are unknown and best-guesses have been made. Better predictions will result from a better characterization of these soil processes.

- Model output is reported in terms of the mean annual nitrate leaching at a depth of 3 m. No account is taken of the depth to ground water or the slope (and subsequent runoff losses of nitrogen) from the site. Year to year variability is reported in the full look-up tables, yet this information is not utilized at this stage of the CLUES project.

- A single rate of nitrogen fertilizer is applied to each crop. In reality, the amount of fertilizer is likely to vary across soils (more mineralization on heavier soils so that less nitrogen fertilizer is required, all other factors being equal) and across regions (warmer regions will have higher productivity and may required more nitrogen to support increased crop growth).

- The results represent currently represent good behaviour with respect to nitrogen fertilizer that is applied at a rate that approximately matches crop demand. As such, the fertilizer rate cannot be altered and so the tool can not demonstrate the impacts of bad fertilizer practice.

10.3. Results

Almost 350 simulations have been run for this part of the study. Model output from each scenario is summarized in the form of a look up table that includes the amount of nitrogen that is (1) added as fertilizer, (2) taken up by the plants, (3) removed in the harvested crop, (4) returned to the soil as dead plant material and/or crop residue, (5) mineralised from soil organic matter, and (6) leached below the root-zone. The intention is for these lookup tables to be included in CLUES.

Table 10-3: The annual nitrogen budget [kg-N/ha/y] for a range of cropping scenarios simulated using the SPASMO computer model. The shaded region represents the mean annual value (kg/ha/yr) for all soils and all regions, while LQ and UQ represent the corresponding lower and upper quartiles, respectively. Here the net mineralization includes the amount of nitrate-nitrogen that is denitrified.

Crop	Value	Fertilizer	Uptake	Crop	Returned	Net Mineralized	Leached
Grape	LQ		53	22	28	16	4
	Mean	14	61	25	33	23	8
	UQ		71	29	38	29	10
Apple	LQ		97	65	30	26	7
	Mean	54	116	77	37	49	18
	UQ		134	87	42	65	25
Kiwi	LQ		134	87	54	26	27
	Mean	95	149	94	61	46	41
	UQ		165	102	71	65	50
Onion	LQ		186	109	71	7	37
	Mean	150	196	115	76	34	62
	UQ		204	119	80	50	74
Potato	LQ		301	269	26	36	29
	Mean	270	311	275	27	64	50
	UQ		322	285	28	85	61

10.4. Incorporating results into CLUES

The model simulations for each region (Table 10-1) used climate data from a single climate station. In order to account for the effect of rainfall variation within a region, we have analysed the year-to-year variation in modelled N leaching caused by with variations in rainfall. So at each site, for each crop, on each soil, a linear equation has been fitted to the 32 annual pairs of rainfall-leaching data (1972-2003). Figure 10-4 shows an example of the data points and the fitted line, for apples grown at Hamilton on Netherton clay loam. The equation would be used to predict N leaching for apples grown on Netherton clay loam at any location in the Waikato region, using the average annual rainfall at the specific location. So, for example, if apples were grown on Netherton clay loam at a Waikato location with average annual rainfall of 1000 mm, the predicted N leaching would be 0.065x1000 – 38 = 27 kgN/ha/yr. The standard error of the data about the regression line [obtained from Excel function STEYX()] was also calculated, to provide an estimate of the uncertainty in this estimation method. For the example shown in Figure 10-4, the standard error is 12.1 kgN/ha/y, which is 31% of the modelled average annual N leaching of 39.1 kgN/ha/y. This standard error gives an indication of how reliable this rainfall-based approach is for estimating horticultural N leaching at sites without climate stations. The 31% standard error is typical of the results for the complete set of 342 crop-soil-climate combinations. The smallest standard error was 10%, and three-quarters of all the crop-soil-climate combinations had standard errors less than 40%.

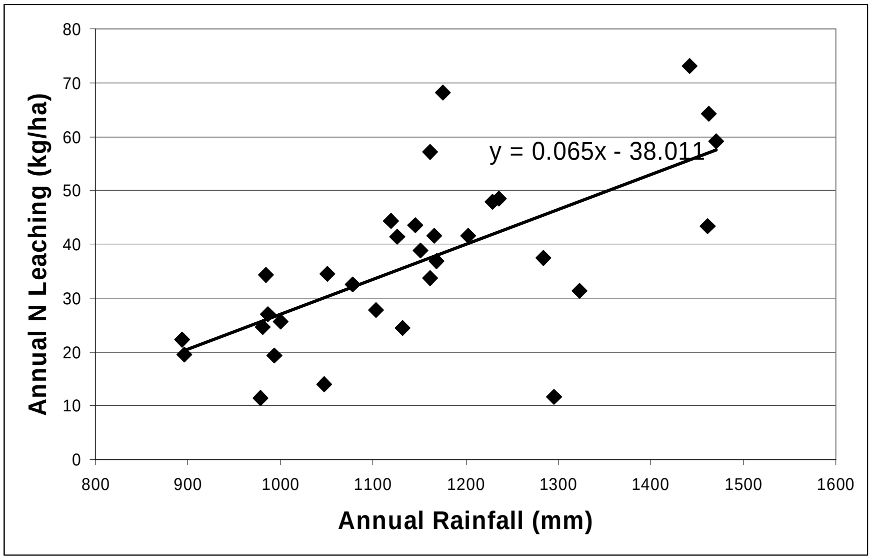

Figure 10-4: Example of the effect of inter-annual rainfall variation on N leaching (example is for apples grown at Hamilton on Netherton clay loam).

10.5. Data sources for SPASMO component of CLUES

The data sources for SPASMO are summarised in Table 10-4.

Table 10-4: Sources of data for SPASMO component of CLUES.

Data Description	Source of Data	Date	Expected timing of next update	How to obtain updated data
Weather	NIWA Climate Database and HortResearch climate network	1972-2003	Continuous additions to SPASMO framework in response to new projects: e.g., Phosphorus, microbes, viruses, heavy metals	HortResearch can make additional SPASMO model calculations and provide tables of results for use with CLUES, on an as required basis
Soils	NZ Soils Database, and HortResearch measurements			
Plant growth	HortResearch trials and measurements, and literature values			

10.6. Proposed next steps

Create database of SPASMO predictions of N leaching under many combinations of fertiliser, climate and soils for:

- Maize/sweetcorn,
- Squash,
- Broccoli /Cabbage/Cauli.

11. Objective 5: Mapping of pollution risk, land use and soils (Landcare Research)

This objective develops national maps of soils and land use for all models in the project to use. The soils and land use information will be in formats which are compatible with all the models. The information will be made available to all project partners on a shared secure computer site. This objective also revises the N pollution risk model developed in Stage 1, to maximize consistency with other models.

11.1. Land use mapping

Early in Stage 2 of the CLUES project a need was identified for a Land Use Classification that was common to all the objectives and hierarchical so that it linked the requirements of Enterprise models to National models. LCDB2 and AgriBase were identified as the primary data sources for national information and the MAF monitor farm types were identified as a suitable set of categories for the finest detail in the classification. A nationwide map of dominant land use was prepared, and is shown in Figure 11-1. The methods use to derive the figure are presented in an Appendix (Section 16).

The data sources used to develop the land use maps are given in Table 11-1.

Table 11-1: Data sources used for classification and mapping of land use.

Data Description	Source of Data	Date	Expected timing of next update	How to obtain updated data
AgriBase	Ministry of Agriculture and Forestry	Sept 2003	Annual	AgriQuality for source data*
Land Cover Data Base	New Zealand Land Cover Data Base v2 (LCDB2), Ministry for the Environment	Imagery 2001/02, Released 2004	Imagery 2006/07, Release 2008.	MfE for source data*
MAF Monitor Farms	Ministry of Agriculture and Forestry http://www.maf.govt.nz/mafnet/rural-nz/statistics-and-forecasts/farm-monitoring/2004/	2004	Annual	MAF for source data*
Pastoral landform	LENZ, Ministry for the Environment and Landcare Research	2002	2006/07	Landcare Research*

* Note: Robert Gibb of Landcare Research can recombine the above data sources and rerun the Land Use Model.

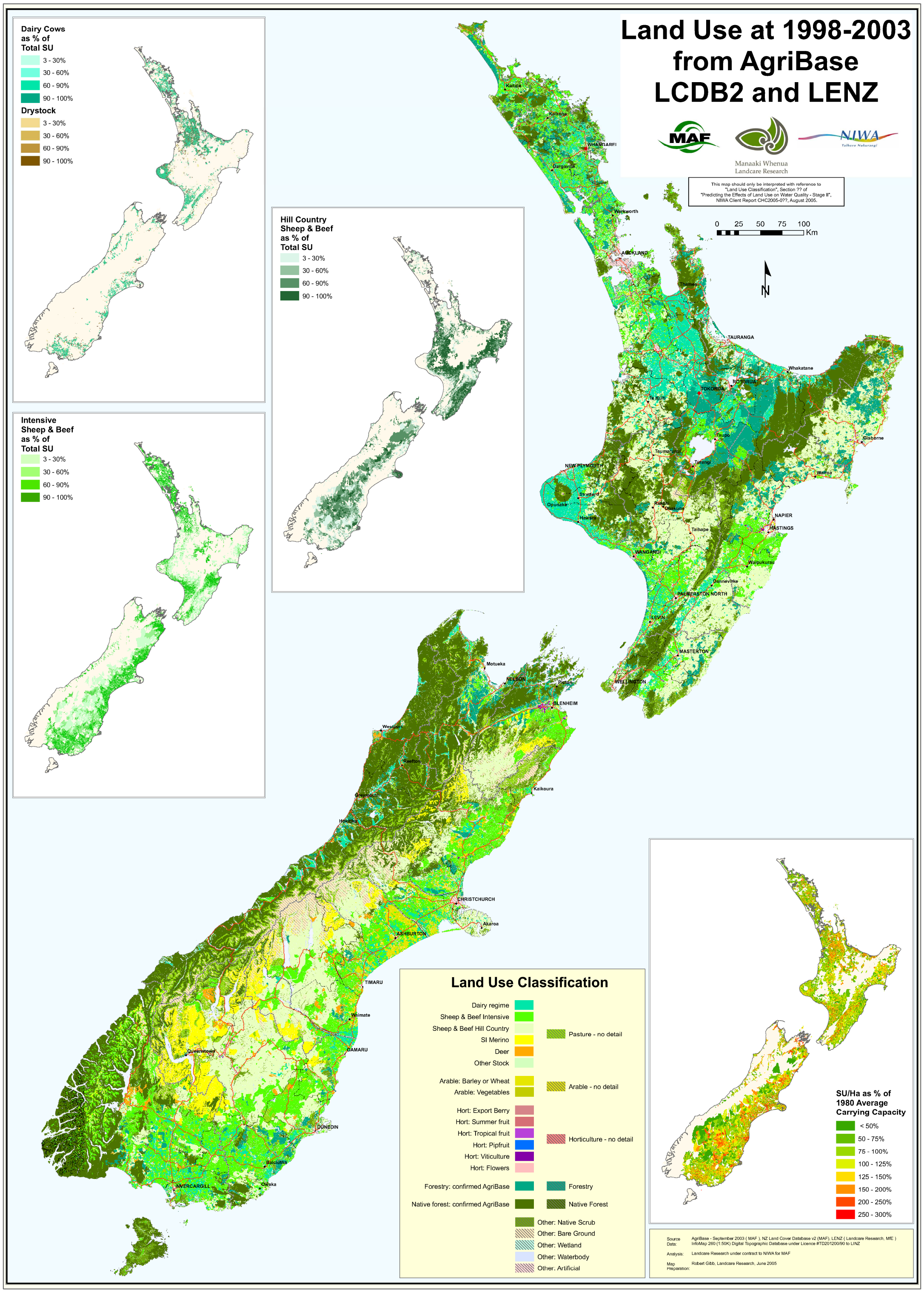

Figure 11-1: Map of Dominant Land Use at 1998-2003 derived from AgriBase, LCDB2 and LENZ.

11.2. Soil data input to CLUES models

The four CLUES models (SPARROW, EnSus, SPASMO and OVERSEER®) require the soil inputs shown in Table 11-3. SPARROW, EnSus and OVERSEER® are relatively light in their soil attribute input requirements, and all data could be supplied. Spatial detail however is lacking and to provide national coverage data was supplied as in the form of the FDLs (Fundamental Data Layers of the NZLRI). More detailed, and more accurate data is available but with patchy coverage, and this needs to be processed to make it accessible.

SPASMO has the highest data requirement. It is not run spatially but run on soil profiles representative of major horticultural soils in regions. Suitable data is contained within the NSD though only a limited number of NSD sites have the soil physics attributes required for the model. An urgent requirement is to address the lack of critical soil physics data by developing pedotransfer functions to predict them from existing soil morphology data.

The data sources used for soil mapping are given in Table 11-2.

Table 11-2: Data sources for soil mapping.

Data Description	Source of Data	Date	Expected timing of next update	How to obtain updated data
Land Resource Inventory (LRI)	Land Resource Information System Database	Edition 2 (1980's)	S-map updates of older LRI and FSL over the next 10 years	Available on the Soils Portal http://soils.landcareresearch. co.nz/contents/index.aspx
Fundamental Soil Layers (FSL)	Land Resource Information System Database	FSL = relate between LRI and NSD data that spans 1960's to 2000's	S-map updates of older LRI and FSL over the next 10 years	Available on the Soils Portal http://soils.landcareresearch. co.nz/contents/index.aspx

Table 11-3: Soil data underpinning CLUES modeling, where, FSL is a Fundamental Soil-data Layer which maps soil attributes to NZLRI polygons, and NSD is the National Soils Database (a database of analysed soil profiles).

Soil attributes required for models	Model	Soil data supplied
PAW	EnSus	FSL: Profile available water (0-90 cm)
Water retention - at least FC, SP and preferably the 1 bar value	Spasmo	NSD: Water retention 10 kPa, 100 kPa, 1500 kPa
Organic Carbon and Nitrogen contents	Spasmo	Modeled surfaces: Carbon and Nitrogen at depths 0-10, 10-30 and 30-100 cm
Stone fraction	Spasmo	FSL: % gravel in topsoil
Bulk density	Spasmo	NSD: Dry bulk density
Sand silt clay fraction	Spasmo	FSL: soil type topsoil texture, and Sand, silt, clay lookup-table by soil group
Soil order	OVERSEER®, EnSus	FSL: Soil classification NSD: Soil order
Soil group	OVERSEER®, EnSus	FSL: Soil classification NSD: Soil group
Soil subgroup	EnSus, EnSus	FSL: Soil classification NSD: Soil subgroup
Soil drainage class	OVERSEER®, SPARROW, EnSus	FSL: Drainage class

11.3. Establish and maintain FTP site

A CLUES ftp area has been established to allow sharing of project information. The URL for this site is ftp://ftp2.landcareresearch.co.nz/clues

All project participants can use the username **clues_usr** in order to read material from any part of the site, and to write material to the /.common area. A password is required.

Each of the science providers has a username which gives them access to read and write files into part of the site. A password is required. These details were sent to a contact person at each science provider in April 2005.

The user names and passwords are administered by Robert Gibb at Landcare Research (GibbR@landcareresearch.co.nz, ph 06-356-7154)

11.4. Introduction to EnSus

In our report for June 2004 (see Section 9 of Woods et al. 2004) we assessed the risk of nitrate leaching from soils under different land uses. We assessed the attenuation (renovation) due to denitrification at 80% for peaty gley soils, 50% for gley soils, and 20% for other poorly drained soils. The NIWA report to CLUES, however, suggested that there was significant loss of total N (by leaching, runoff and erosion) from all these poorly drained soils. In September 2004 we measured nitrate-N in waters in freshly cut drains in a poorly drained soil in Manawatu, and found concentrations of 5 to 20 mgN/L. The concentration of N in the surface runoff following a storm in September was 2.6 mgN/L. This suggests that nitrate-N can be generated in these soils, and can move to water, particularly by runoff.

There have been two recent studies, at the paddock scale, of N losses from poorly drained soils that have artificial drainage. Monaghan et al. (2002) showed that the losses of nitrate-N under dry dairy cows was 25 kgN/ha/y in Southland, with an average concentration of 7 mgN/L. Houlbrooke et al. (2003) showed that the nitrate-N losses were 24.5 kgN/ha/y (average concentration 11 mgN/L), while losses of total dissolved N were 28 kgN/ha/y under dairy cows. Both studies showed that the nitrate-N concentration decreased from >10 mgN/L in autumn to about 2 mgN/L in spring.

This suggests that there can be losses of nitrate-N from poorly drained soils. Whether the loss is by leaching or runoff depends on the artificial drainage and the distribution of macropores that lead to by-pass flow. Barton et al. (1999) in a review of denitrification suggested that, since diffusion of carbon to microsites was important for denitrification, the texture of the soil was important in the degree of denitrification of nitrate to N_2 gas. They suggest that denitrification is highest in loams and that it is low in clays.

Therefore we have modified the risk assessment assuming that gley soils under intensive land use will be artificially drained and have consequently assigned low attenuation factors to such areas. We present maps with and without attenuation. We also present maps that attempt to separate runoff and leaching.

11.5. Loss of soluble N from soils by leaching and run off

We have made a preliminary quantitative assessment of loss of nitrate-N from soils by leaching and runoff under different land-uses (Parfitt et al. 2005; Parfitt et al. 2006). For pastures we estimated drainage and runoff, and (based on our literature review of

N leaching in New Zealand) we assumed the average N concentration in soil solution is 9 mg N/L for dairy (10 mg/L in Waikato and Bay of Plenty), 6 mg N/L for beef, 3 mg N/L for sheep/deer, and 4 mg N/L for sheep/beef. Using the water balance in LENZ, we have estimated the drainage for each land-use in each 100-metre cell in each region (from AgriBase and LCDB2) averaged over 20 years. Multiplying drainage by soil solution concentration gives an estimate for nitrate-N leaching and runoff under grazed pasture for the year. Houlbrooke et al. (2003) showed the dissolved organic N in water draining from pasture was about 10% of dissolved inorganic N, and the N leached has been adjusted by this factor.

We also assume nitrate-N leached from soil is 40 kg/ha/y under cropping, 60 kg/ha/y for horticulture including vegetables, and 1 to 4 kg/ha/y for other land uses (Neary et al. 1978, Mosley et al. 1981, Parfitt et al. 1997, Webb et al. 2001, MAF 2003). We have multiplied these data by the land area for each region. Losses from point sources (sewage, dairy factories, abattoirs) have been taken from Elliott et al. (2005).

The total loss of soluble N was estimated as 261 Gg from pasture (of which 22 Gg was dissolved organic N), 17 Gg for crops, 6.5 Gg for horticulture, 14 Gg for native forests and shrubland, and 2 Gg for plantation forests (Figure 11-2). Point sources (sewage, dairy factories, abattoirs) were assumed to be 6.7 Gg (Elliott et al. 2005), and farm tracks generated 15 Gg. This gives a total of about 300 GgN. Although the concentration of N is soil solution is higher under dairy than sheep and beef, the loss of soluble N in tonnes or Gg is about the same since there is a larger area of land under sheep and beef.

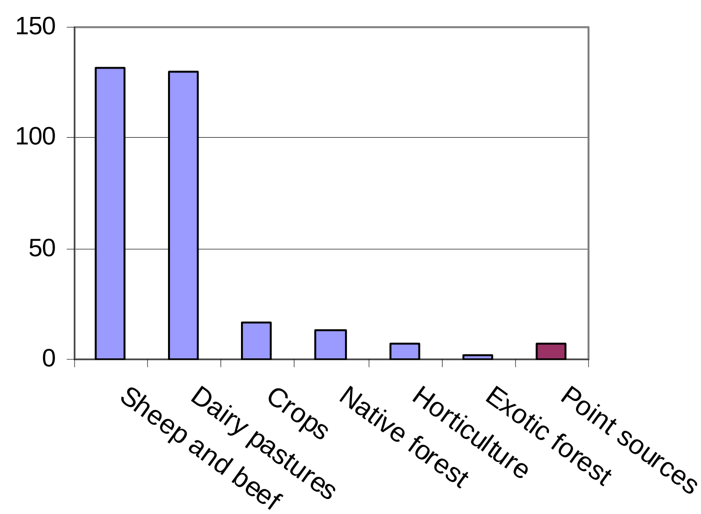

Figure 11-2: Loss of soluble N (Gg) from all NZ soils by leaching and runoff in 2001.

We have also estimated the losses of soluble-N (kg/ha/y) from soils by leaching and runoff, for each of 15 regions together with the total N inputs (kg/ha/y) for each region (Parfitt et al. 2006). The West Coast is an outlier, probably because the region has very high rainfall (3 m plus) and a large area of rain forest. When this data point was excluded the loss of soluble N by leaching and runoff is related (R^2 = 0.68) to the inputs (Figure 11-3). Taranaki and Waikato show the greatest loss of soluble N in kgN/ha. This figure is generally consistent with the map of risk of loss of soluble N from New Zealand.

Regional loss of total N (sediment N plus soluble N) to oceans (kg/ha/y) for 15 regions of New Zealand (Elliott et al. 2005) is shown as a function of the N inputs (kg/ha/y) in Figure 11-4. With West Coast data excluded, there is a significant relationship between N inputs and N exported to the oceans (R^2 = 0.63). The total loss total the oceans is about 170 Gg of which about 100 Gg is soluble N. Therefore there is a loss of 200 Gg soluble N between the soil and the ocean.

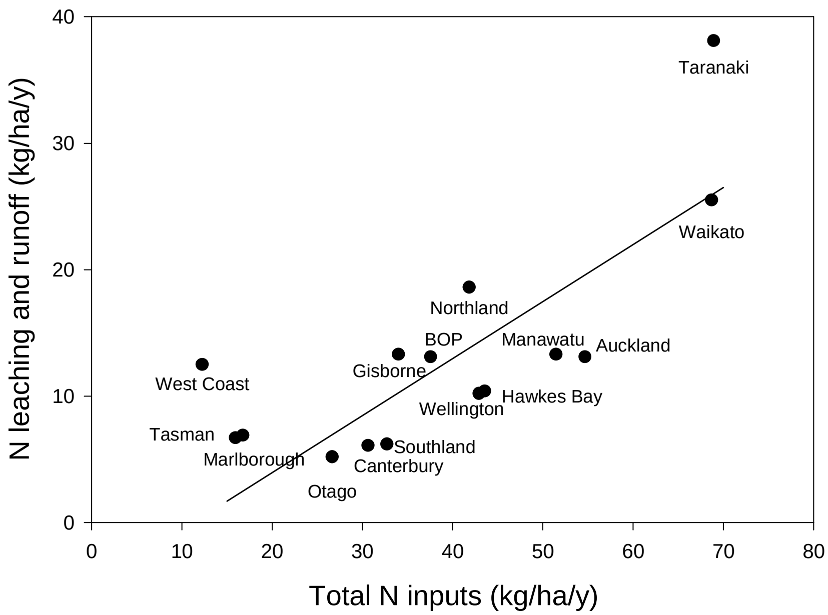

Figure 11-3: The relationship between N input and loss of soluble N from soils for 15 NZ regions.

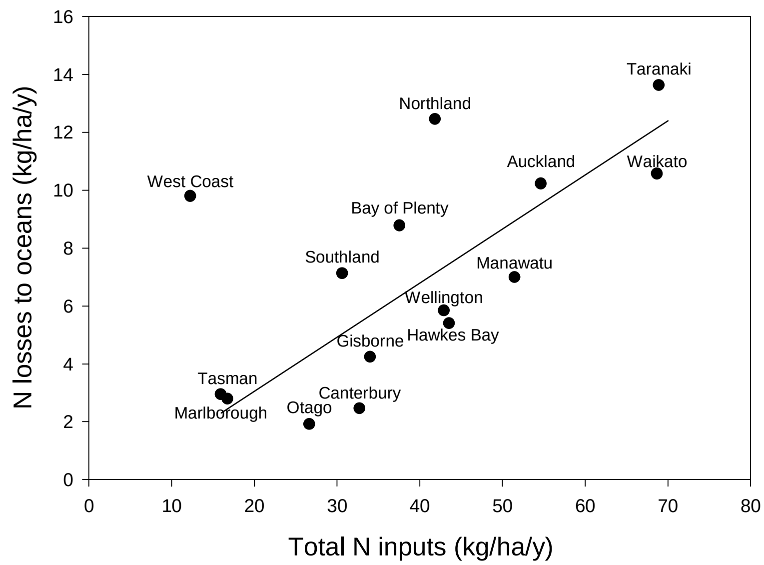

Figure 11-4: The relationship between N input, and loss of total N (sediment N plus soluble N) to oceans in 15 NZ regions**.**

11.6. EnSus

EnSus is a framework for analyzing and mapping the relative risks different land uses pose to soil quality and water quality. EnSus has been used to map relative risk classes of nitrate leakage from soils to surface and ground water bodies. It uses best available knowledge of specified land use pressures and vulnerability of the land to those pressures.

EnSus complements the national SPARROW modelling work for N and P. However the EnSus approach is at finer spatial scales than SPARROW, and does not estimate spatially integrated responses over catchments, or take into account in-stream processes. The EnSus model can be summarised as a set of rules that combine maps of soils attributes, rainfall, and land use/ management into maps of leaching risk. These rules are documented in this section, and can easily be implemented as part of the catchment modelling framework.

The process involved three steps:

- mapping vulnerability of soils to N leaching from the soil;
- mapping land use as an estimate of N input pressure; and
- combining vulnerability and pressure to estimate risk.

Risk maps are provided for New Zealand (200 m raster). These are intended for large catchment, regional, and national applications. More detailed applications would require analysis based on available higher resolution soil maps.

11.7. Vulnerability to leaching

The analysis involves three steps:

- A potential soil leaching index is calculated and mapped to estimate nitrate mobilised from the soil with potential to enter water bodies (either ground water or surface water).

- N attenuation factors are assigned to estimate nitrate losses by denitrification on route to water bodies, by passage through wet, reduced soils.

- N leaching vulnerability is estimated by reducing the potential soil leaching index (step 1) by the N attenuation factors (step 2).

11.7.1. Potential soil leaching index

Potential soil leaching was estimated using the Land Environments of New Zealand national layer of rainfall to evaporation ratio (RF/ET) based on Meteorological Service monthly data modelled as a mean annual national surface. This ratio was modified (1) by a 'PAW Factor' used to increase the index where profile available water (PAW) is lower than 200 mm (to account for extra leaching in low PAW soils), and (2) by a 'slow permeability factor' used to decrease the index where permeability is very slow (to account for loss of potential leaching water as runoff). Maps are also presented, without this second modifying factor, that show leaching plus runoff.

The potential soil leaching index was calculated as (RF/ET) x (PAW Factor) x (Slow permeability factor). This estimates the relative potential for N mobilisation from the soil (without specifying if this is mobilised to surface or ground waters).

The PAW Factor was determined by the relationship between the water surplus modelled and reported by Met Service, and the benchmark PAW values (40, 80, 120 and 160 mm water storage). The PAW multipliers in Table 11-4 provided for soils under mean long term average rainfall of 1000mm or more, and less than 1000mm. It is assumed that there is an insignificant effect of PAW on relative leaching, when PAW exceeds 200mm.

Table 11-4: Factors to calculate potential soil leaching by increasing effective rainfall where PAW is less than 200mm.

PAW	PAW multiplier Rainfall > or = 1000mm	PAW multiplier Rainfall <1000mm
<40	1.4	2.4
40 – 69	1.3	2.1
70 – 99	1.2	1.8
100 – 199	1.1	1.4
>200	1	1

Soils with very slow permeability (saturated hydraulic conductivity <2.5 mm/day) were identified in the NZLRI soil legend. For these soils, the potential leaching index was reduced by a factor of 30%.

11.7.2. Attenuation of N via pathway to water bodies

Attenuation is defined here as denitrification and loss of nitrogen to the atmosphere as either nitrous oxide or nitrogen gas. It is assumed that nitrogen is primarily in the form of nitrate. We do not account for organic-N, or sediment-N. The attenuation layer is an independent layer that may be used to reduce the potential leaching index and provide an estimate of the attenuation of nitrate by passage through soils periodically saturated with water.

Attenuation is estimated by two means:

- Presence of Gley Soils, Organic Soils and imperfectly drained soils that have very slow saturated hydraulic conductivity (less than 2.5 mm/day). The data used are based on the soil theme of the NZLRI.

- Presence of soil associations where gley or organic soils are likely to occur as riparian strips but are too small to be shown on soil maps. These areas were identified by delineating land systems, based on NZLRI land units, in which well expressed drainage catenas were likely to occur.

In Gley Soils that are surface, tile or mole drained, it is likely that nitrate-rich water will pass directly via drainage to water bodies and partly escape attenuation by soil processes. In Table 11-5 we assign attenuation factor multipliers to seven categories of soil. The factors are estimates from available evidence and their absolute accuracy is less important than their ranking. Highest attenuation is assigned to organic soils

(Degens et al. 2000; van Beek et al. 2004). Attenuation factors for Gley Soils and imperfectly drained soils are based on anecdotal evidence and theory. The review of Barton et al. (1999) suggested that texture influences attenuation. We have not used texture because the relationship between texture and the variables driving N attenuation in the set of international soils reviewed was not provided.

The attenuation factors are given in Table 11-5. Maps are also shown with attenuation set to 1 for all soils.

Table 11-5: Attenuation of soil classes used to estimate N leaching vulnerability**.**

Soil class	**Attenuation factors**
Very poorly drained (Organic Soils)	0.1
Peaty-gley subgroups (Peaty subgroups) [NZSC code "xxO"]	0.2
Poorly drained (Gley orders, groups and subgroups) [NZSC code = Gxx, xGx or xxG] <u>And</u> intensive land use (where artificial drainage is assumed)	0.8
Poorly drained (Gley orders, groups and subgroups) [NZSC code = Gxx, xGx or xxG]	0.5
Land with riparian Gley soils	0.7
Imperfectly drained [NZSC code = xxMx] <u>And</u> very slowly permeable	0.6
Remainder	1

11.7.3. Vulnerability classes

The N leaching vulnerability index is estimated by reducing the potential N leaching index by the attenuation factors in Table 11-5. The N leaching vulnerability index ranges from 0 – 44. It was divided into 5 classes with the limits: 0, 2, 3, 4, 7, 44. These limits best express our understanding of potential leaching contrasts across the soil-landform-rainfall pattern. The scale is not linear and strongly influenced by effective rainfall. Class 5 (7 – 44) is mainly confined to mountainous regions with high rainfall.

11.8. Pressure

The pressure of N inputs to soils was estimated from land use classes defined and mapped above (Section 11.1). N inputs were estimated for each land use class based on knowledge of N (kg/ha/yr) leached under different land uses (Parfitt et al. 2006, Ledgard and Meneer, 2005). The input values were then scaled to define an N pressure index.

11.9. Risk of Nitrate leaching and runoff

Relative N leaching risk was derived from the combination of pressure on vulnerability. We did not consider the sensitivity of receiving water to pollution or asset values in this analysis. Only one hazard, nitrate (leaching and runoff) from the soil, is considered. We have not considered organic-N or sediment-N. Vulnerability and pressure are combined in Table 11-6. The N risk estimates are grouped into 5 classes of risk.

Table 11-6: N leaching risk derived from N leaching vulnerability and N pressure, where risk = (N vulnerability index) x (N pressure index).

N leaching risk classes are: very low <3, low = 3-7, mod = 8-16, high = 17-29, very high = 30-50.

Land use class (from the CLUES land use classification)	N pressure (kgN/ha/y)	N pressure index scaled: 0 to 10	N leaching vulnerability index				
			Low (1)	Mod low (2)	Mod (3)	Mod high (4)	High (5)
Pastoral dairy (intensive >12 SU/ha)	50	10	10	20	30	40	50
Horticultural and vegetables	50	10	10	20	30	40	50
Arable	40	8	8	16	24	32	40
Pastoral dairy (non-intensive <=12 SU/ha)	30	6	6	12	18	24	30
Pastoral sheep and beef – SB1	20	4	4	8	12	16	20
Pastoral sheep and beef - SBH	10	2	2	4	6	8	10
Pastoral other animals	10	2	2	4	6	8	10
Pastoral deer	7	1.4	1.4	2.8	4.2	5.6	7
Pastoral sheep and beef –SMO	5	1	1	2	3	4	5
Other – (urban, bare ground etc.)	5	1	1	2	3	4	5
Exotic forest	3	0.6	0.6	1.2	1.8	2.4	3
Native forest	2	0.4	0.4	0.8	1.2	1.6	2

Uncertainty in this analysis is introduced by:

- Accuracy of the index of mean annual rainfall to evapotranspiration layer and its applicability as an index of potential leaching.

- The appropriateness of multipliers for PAW, very slow permeability, and attenuation in wet soils.

- Accuracy of soil map representations of PAW, very slow permeability soils, and wet reduced soil layers including identification of land units with poorly drained riparian strips.

- Choice of vulnerability classes.

- Combination of LCDB land cover classes and AgriBase land use classes, and the estimation of N pressure index.

- Method for combination of pressure and vulnerability, and choice of risk class limits.

It is not possible to express the sensitivity of the result to these uncertainties without further analysis. Use of more detailed scale soil maps where available, will substantially decrease uncertainties in uncertainty category 3.

11.10. Results for Nitrate leaching

Maps of relative risk of nitrate leaching are shown for New Zealand in Figures 4. Risk is expressed in the 5 classes of Table 11-6. The data used to generate the risk maps is available for the following layers:

1. Potential N leaching index (PNLI).

2. PNLI modified by attenuation in combinations of:

    a. undrained Gley and Organic Soils,

    b. riparian Gley and Organic Soils,

    c. drained Gley Soils.

3. Nitrate leaching risk based on land use pressure and PNLI modified by drained or undrained soils.

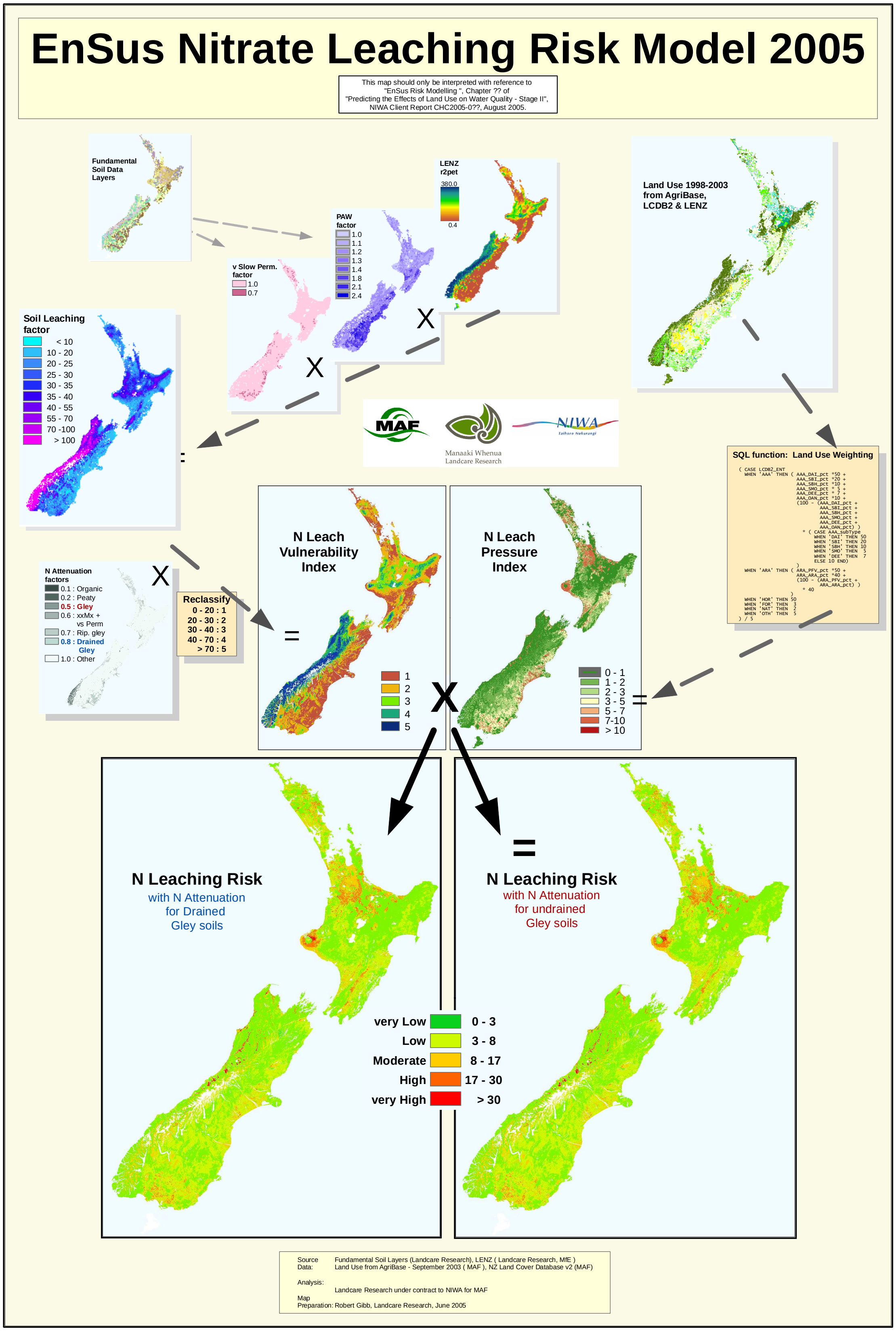

Figure 11-5: Map of N leaching risk, based on EnSus methodology.

11.11. Data sources for EnSus component of CLUES

EnSus uses the data provided by the soil and land use mapping and classification described in Section 11.1 and Section 11.2.

11.12. Proposed next steps

1. Mapping of land use: finalise national map of land use and management. See the Appendix (Section 16) for important additional work that needs to be done to reduce uncertainty in the assignment of land use pressure.

2. With explicit statements of variability and uncertainty in both soil parameters (vulnerability) and land use (pressure) now available, a full Bayesian risk assessment can be achieved.

3. A spatial water balance model is now available at Landcare Research for all of NZ and this should be incorporated into the EnSus analysis.

4. A first-cut spatial representation of leaching in kgN/ha can now be achieved using assumptions of N in soil solution.

5. Assessment of loss of ammonium, dissolved organic N and sediment N can also be achieved.

6. Maintain FTP site so that project partners can reliably and efficiently exchange information.

12. Workshop 3: July 2005

The third project workshop was held in Hamilton on July 26, 2005, to review progress in Year 2, and make plans for Year 3. The program for the day was:

10.00 Welcome by Gerald Rys, introductions as required, outline of goals for the day (review progress to date, propose future work).

10.10 Ross Woods - very brief project overview (5 mins).

10.15 Allan Hewitt and/or Robert Gibb– Mapping of Soils and Land use/management, revision of EnSus mapping of N leaching risk, and CLUES ftp site.

10.30 David Wheeler - OVERSEER® model of pastoral land use impacts on water quality.

10.45 Brent Clothier - SPASMO model of horticultural land use impacts on water quality.

11.00 Coffee break.

11.15 Simon Harris - triple-bottom-line effects of land-use change.

11.30 Sandy Elliott - SPARROW model for P.

11.45 Ude Shankar – developments in CLUES spatial framework.

12.00 Peter Singleton and Sandy Elliott - Trial with EW.

12.15 Discussion – initial response from Gerald and end user reps on progress to date.

12.30 Lunch.

1.15 Gerald Rys to provide initial response on directions for year 3 as he sees them.

1.30 Ross Woods to outline the current ideas for Year 3, based on the original project proposal, issues identified in Workshops 1 & 2, project progress to date, and any email discussion in July 2005. Additional.

2.30 Any other issues.

1. How will the modelling framework be maintained/revised after end of 3-year project?

2. Are there any unresolved issues related to interactions with IRAP?

4.00 Close of meeting and Coffee.

13. Summary

In Stage I of the project, we defined a flexible and robust computer modelling system, capable of linking to several different water quality models. The modelling system acts as the framework for assessing the integrated effect of small-scale activity (e.g., farm-scale) on catchment-scale water quality. Work began on adapting several water quality models so that they could be linked to the modelling system.

In Stage II of the project, the modelling system, now known as CLUES, was extended so CLUES users could conveniently develop new land use scenarios for use with the models. Common national databases for land use and soils were developed, for use by all the models. Several models were linked into the CLUES system, so that a variety of different land uses can be modelled more accurately at the catchment scale than was previously possible. The SPARROW model, which previously used its own independent method for calculating N leaching, can now use N leaching calculated by the OVERSEER® model, and will shortly be able to use SPASMO results as well. A version of OVERSEER® was linked into the CLUES system, and a large lookup table of SPASMO results was generated for use within CLUES. A national SPARROW model for phosphorus was completed, and can be used from within CLUES. The EnSus N leaching risk map for New Zealand has been revised to make use of new information which became available during Stage I of the project.

A significant need now is for implementation of CLUES, to gain experience in the use of the system, so that it can be adapted to improve ease of use, and so that needs for documentation can be assessed. A users guide with worked examples is needed.

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15. Appendix 1: Contract Objectives for Stage II

The following information is taken directly from Schedule II of the contract between NIWA and MAF.

15.1. Objective 1

Objective Title : Catchment Modelling Framework

Objective Leader: Dr Sandy Elliott

Description:

CLUES is the name of the framework used to provide the user interface to models which predict the effects of land use change. It was designed and constructed in year 1 of this project, and it was connected to the SPARROW water quality model. In year 2 it will be enhanced as described below.

Methodology:

- Add new features to CLUES framework so that users can work with land-use change scenarios: (i) tool to create land use scenario from current map of land use and management (ii) tool to overlay catchment boundaries on maps of land use and management. Output will be two new software tools that run in the CLUES GIS framework, and documentation on how to use them
- Link more models to the CLUES framework: OVERSEER® with 5 scenarios (dairy, sheep/beef: high-country/hill-country/lowland, and deer), SPASMO , Triple-Bottom-Line, EnSus, G/W component of SPARROW. This requires cooperation between NIWA and all others. In some cases the individual modellers have to do more work before their model is ready to link. Output will be CLUES software system with links to OVERSEER®, SPASMO, Triple-Bottom-Line, EnSus, G/W component of SPARROW
- Redesign user interface for CLUES framework, in collaboration with Environment Waikato, so CLUES is easier to use (e.g., ensure results shown as both concentrations and loads). Output will be revised software for CLUES interface.

Costing for Objective 1 as in NIWA proposal - $65K incl GST for 2004/05
NIWA $65K incl GST

15.2. Objective 2

Objective Title: SPARROW modelling for surface and groundwater

Objective Leader: Dr Sandy Elliott

Description:

To maximize consistency among the various models used in the project, NIWA will adapt the SPARROW model to use N yields provided by OVERSEER® and SPASMO models, in place of the N yields estimated by SPARROW. This will allow the number of SPARROW model parameters to be reduced – the remaining parameters will be recalibrated in year 2. The main function of the SPARROW model will then be to route and attenuate nutrients through catchments. A second SPARROW model, for phosphorus, will also be added to the CLUES framework. The SPARROW P model has already been calibrated for New Zealand.

NIWA will also conduct pilot testing with EW, focusing on the Land Use Change Tool being developed in Objective 1.

Lincoln Ventures will provide NIWA with best estimates of the parameter values needed to use the groundwater component of the SPARROW model, which was developed in year 1.

Methodology:

- Recalibrate the national SPARROW N model (with/without G/W?) using the N yield values from the OVERSEER® and SPASMO work in Objective 4. Output is new set of SPARROW parameters for delivery and attenuation
- Carry out pilot testing at Environment Waikato of the Land Use Change Tool being developed in Objective 1, in conjunction with the SPARROW model as it was at the end of Year 1. Test other models (e.g., EnSus, OVERSEER®, SPASMO, Triple-Bottom-Line) as they become available in the framework. Output is a workshop with EW to generate land use change scenarios, report by EW on use of CLUES
- Implement SPARROW model for P. Output is CLUES software which predicts P as a function of land use, throughout New Zealand.
- Improve SPARROW G/W model, by developing simple, physically realistic methods to predict the exchange between streams and groundwater bodies. Output is report and software for estimating exchange between streams and groundwater bodies

Costing for Objective 2 - $70K incl GST for 2004/5
NIWA 60K incl. GST
Lincoln Ventures 10K incl. GST

15.3. Objective 3

Objective Title: Triple Bottom Line Effects of Land-Use Change

Objective Leader: Mr Simon Harris

Description:

Develop functional relationships between land-use change and environmental, social and economic parameters at a level of detail appropriate to the intended use of the DSS and in a form that is compatible with ARC-GIS. The outputs will be mathematical equations and parameter values. The key environmental performance indicators will be surface and ground water quality metrics.

In Year 1 these relationships were developed for the Waikato region. In year 2 they will be extended to as many other regions of New Zealand as practical.

Methodology :

- Develop functional relationships between nutrient/contaminant losses and land-use type and intensity. The relationships will be based on published data (eg "Implications of groundwater nitrate standards for agricultural management. Ecolink, MAFpolicy Technical Report 00/15, 2000) and use of models such as OVERSEER®. Relationships will be of the form of "nitrate concentration in leachate water as a function of dairy cows per hectare and use/non-use of BMP's".
- Develop functional relationships between socio-economic outputs and land-use type and intensity, taking into account whether land is irrigated or non-irrigated. Based on production and financial data, use of crop production models, and published relationships between socio-economic metrics and farm-gate output. Relationships will be of the form of "employment per hectare as a function of farm type and intensity of operation".

Costing for Objective 3 - $50K incl GST for 2004/2005
Harris Consulting $50K incl. GST

15.4. Objective 4

Objective Title : Enterprise-scale Modelling

Objective Leader: Mr David Wheeler

Description:

Provide input of water quality and economic parameters to the CLUES framework under different land use systems, and management systems within a given land use type.

Methodology:

The outcomes will be achieved by linking together existing farm-scale and paddock-scale models (OVERSEER® and SPASMO) to the GIS system. This will be achieved by:

- OVERSEER® scenario development for 5 scenarios: dairy, sheep/beef: high-country/hill-country/lowland, and deer. These scenarios must be compatible with the corresponding land use types adopted for land use mapping in Objective 3.Also provide advice as required in other objectives. Output is OVERSEER® dynamic linked library (DLL) with documentation on how to call the library for each of the scenarios
- Create database of SPASMO predictions of N leaching for many combinations of crop, fertiliser, climate and soils. Output is database of results delivered in electronic format, with short report listing the combinations used, describing the limitations of the results, and the uses for which they are intended

Costing for Objective 4 - $60K incl GST for 2004/2005
AgResearch $30K incl. GST for 2004 /05
HortResearch $30K incl. GST for 2004/05

15.5. Objective 5

Objective Title: Mapping of Pollution Risk, Land Use and Soils

Objective Leader: Dr Alan Hewitt

Description:

This objective will develop national maps of soils and land use for all models in the project to use. The soils and land use information will be in formats which are compatible with all the models. The information will be made available to all project partners on a shared secure computer site. This objective will also make minor revisions to the N pollution risk model developed in year 1, to maximize consistency with other models.

Methodology:

- Mapping of land use: (i) Define standard list of types of land use and management, and document their relationship to other lists of land use, in consultation with all project partners (ii) create national map of land use and management which uses these standard types (include irrigated areas and typical amounts? Include presence of small blocks?). (iii) Show links between these farm types and the MAF monitor farm types. Output is short report on standard land use types, including table of correspondences to MAF monitor farms, and digital map data for New Zealand land use
- Mapping of soil type: (i) consult with AgResearch and HortResearch to determine the soil classification appropriate to each model (ii) provide soil type map for use when calling OVERSEER® and SPASMO. Output is electronic versions of soils map(s).
- Revise EnSus N model, by reviewing and justifying attenuation factors, and adding drainage assumptions. Output is report and electronic versions of revised tables, grids and rules for EnSus N.
- Establish and maintain FTP site so that project partners can reliably and efficiently exchange information. Output is operational ftp site.

Costing for Objective 5 ~ $45K incl GST 2004/05

Landcare Research $45K incl. GST

16. Appendix 2: Land use classification and map

Early in year 2 of the CLUES project a need was identified for a Land Use Classification that was common to all the objectives and hierarchical so that it linked the requirements of Enterprise models to National models. LCDB2 and AgriBase were identified as the primary data sources for national information and the MAF monitor farm types were identified as a suitable set of categories for the finest detail in the classification.

Figure 16-1 illustrates the 4 tiers of the classification and

Figure 16-2 is a map of Dominant Land Use at Tier II derived from AgriBase, LCDB2 and LENZ. The following sections discuss the approach used to implement the classification and resolve inconsistencies between the contributing databases.

16.1. Data sources for land use classification in CLUES

The data sources for Land Use Classification are summarised in Table 16-1.

Table 16-1: Sources of data for Land Use Classification**.**

Data Description	Source of Data	Date	Expected timing of next update	How to obtain updated data
Farm types and farm attributes	MAF Monitoring Farm Reports – for details see section 16.2.1	2003/04	Annual	MAF
Farm types and farm attributes	AgriBase – for details see section 16.2.2	Sep 2003	Annual	AgriQuality
Land cover	Land Cover Database v2 (LCDB2) – for details see section 16.2.3	2001/02	Imagery: 2006/07 Release 2007/08	MfE / Landcare Research
Topography	Land Environments of New Zealand (LENZ) – for details see section 16.2.4	2002	2006/07	Landcare Research
Stock Units and Relative Stock Carrying Capacities	H. Clark (pers comm.) – for details see section 16.2.5	2004	unknown	H. Clark

16.2. Contributing database overview

Each contributing database has particular strengths and weaknesses, which are discussed below.

16.2.1. MAF monitor farm types

MAF produces a set of Monitor Farm models "providing a survey of farmers' opinions on their industry and its prospects" available annually from their website <http://www.maf.govt.nz/mafnet/rural-nz/statistics-and-forecasts/farm-monitoring/>. Each Monitor Farm model is derived from a set of 20 or so farms that are representative of farms in a locality. Depending on the model the locality could be national, North or South Island or one of more regions or districts. Models are published annually and provide climatic, production, financial and trade perspectives relevant to the farms. They are therefore rich in on-farm detail and off-farm influences, while falling short of being an actual description of any particular farm. Their definition has only a loosely defined conceptual spatial extent and while they are representative of the primary activity in a region there is no attempt to encompass all the variants in operations of any farm type. The Monitor farm models that have been used are listed in Table 16-4.

16.2.2. AgriBase

AgriBase provides rich detail about on-farm crops, horticultural species and animal numbers for many stock types, but it is incomplete both in spatial coverage (not all farms are present) and in the data-fields farm owners have chosen to fill in. Furthermore its spatial detail is limited to whole farm enterprises. This has four types of consequences a number of which may coincide for a single farm:

1) Where a farm has more than one activity, AgriBase records what the activities are but doesn't record where they take place within the farm.

2) Where a farm uses both land owned by the enterprise and leased from other owners, the AgriBase record may contain conflicting information – such as: the sum of the areas occupied by all the plant types may differ significantly from the recorded total spatial extent of the farm.

3) Where a farmer has not filled in all the data-fields that are relevant to their farm, there will obviously be data gaps leading to uncertainty in the interpretation.

4) Where a farmer has misinterpreted the meaning of one or more data-fields, the data will appear to be inconsistent.

16.2.3. Land cover database v2 (LCDB2)

LCDB2 provides complete, internally consistent national coverage with a nominal spatial resolution of 1ha, but gives no indication of what stock are present on pasture or of crop types or (with a couple of exceptions) of horticultural species.

16.2.4. Land environments of NZ (LENZ)

When looking at matching the MAF Monitor farm categories to the data that was present in AgriBase and LCDB2, it was realised that neither database provided useful information to distinguish between the broad MAF Monitor farm categories of Intensive vs Hill Country vs Steep Hill / Mountain country Sheep and Beef farms. It had been hoped that the LCDB2 categories of High producing pasture, Low producing pasture and Tussock would align with MAF Monitor farm types, but they didn't. To redress this shortfall LENZ was used to create a Flat vs Rolling vs Hill country vs Mountain pastoral landform categorisation that could be used to partition Sheep and Beef farms into the desired Monitor Farm categories. The result is shown in Figure 17-2.

16.2.5. Stock units and relative stock carrying capacities

On farms with more than one type of stock and more than one type of pastoral landform a mechanism was needed to estimate the areas occupied by each stock type as proportions of the available pastoral land. For this purpose, all animal numbers were converted to Stock Units using Table 16-2, and relative carrying capacities for the different LENZ pastoral landforms were used to pro-rata stock units across the pasture. These were derived by spatially correlating LENZ landforms with NZLRI Average Carrying Capacity.

Stock Type	**Stock Units**
Dairy Cows – Taranaki – Elsewhere	4.9 6.65
Beef, Bison	5.3
Horses	4
Deer	1.9
Alpacas	1.9
Donkeys	1.9
Goats	1
Ostriches, Emus	1
Pigs	1
Sheep	0.95
Other	1

Table 16-2: Stock Unit equivalents for AgriBase stock types. (H. Clark pers comm, with the exception of Bison which is only minor and has been lumped with Beef).

LENZ Pastoral Landform	**Relative Stock Carrying Capacity**
Flat	1.1
Rolling	0.66
Steep Hill	0.05
Mountain	0.05

Table 16-3: Relative Stock Carrying Capacities for Pastoral Landforms within a farm.

16.3. Applying the classification

The two primary data sources AgriBase and LCDB2 respectively offer high classification precision for low spatial precision, and low classification precision with high spatial precision. In theory merging the two would produce high classification precision AND high spatial precision. While this has been achieved in many places, the failings and inconsistencies of the two datasets contribute to considerable uncertainty in other places. The aim therefore has been to develop an approach to land use classification that explicitly acknowledges differences in certainty, actual variability in the landscape and farm diversity or complexity.

To achieve this each farm is considered to be a complex of all possible regional monitor farm types for the region, and the database explicitly records a probability associated with each. Where stock are involved the database also records the apparent stocking density for the farm type. In this way the database lends itself to applications where farm inputs and production need to be modelled by comparing the stocking density on the farm with the stocking density for the conceptual monitor farm.

In areas where AgriBase has no record or key pieces of the jig-saw are missing, land use is inferred from the available information for the land parcel – typically Tier I from LCDB2, and the average Tier II-IV probabilities from the similar Tier I land parcels in the surrounding district are applied as an estimate of the missing data.

The probabilities recorded for a farm do not necessarily sum to unity. This occurs when imperfect or conflicting data is available. The sum of probabilities is therefore a measure of the data quality – in general the closer to unity the more consistent and complete the information provided by the different data sources. Other measures of data quality are also provided; the total stock unit equivalents and total land usage areas provided from AgriBase, the computed LCDB2 farm area and the recorded AgriBase farm area. Comparisons of these figures provide useful measures of the quality and completeness of the information available for the land parcel.

So as to provide some detailed information for use in simple analyses, all the probabilities for each parcel were examined and the land use with the highest probability assigned as a dominant land use for each Tier of the classification, and the results are shown in Figure 11-1 in the main body of this report.

16.4. Next steps

Three next steps are identified:

- AgriBase / LCDB2 confusion matrices.
- Testing the LENZ landform to Sheep & Beef Monitor Farm relationship.
- Refining the spatial allocation of the regional MAF Monitor Farm models.

The first provides a means of resolving the primary remaining source of classification confusion in the dataset, the second is necessary to provide robustness to the classification process.

16.4.1. AgriBase / LCDB2 confusion matrices

One concluding step was not possible in the time available and should be undertaken. At present there are two mutually exclusive ways of using the dataset.

Either: Assume LCDB2/LENZ is correct for Tier I and use the information from the surrounding farm for that land use classification to infer the Tier II, II and IV details.

Or: Assume AgriBase is correct, and analyse all the probabilities for the farm enterprise,

The first option provides high spatial detail, and considerable additional classification detail beyond that obtainable from LCDB2 on its own, but it risks ignoring additional plausible detail from AgriBase that might imply a more likely land use. Examination of a particular example will illustrate the situation.

Situation: A farmer has bought a property that is %pasture, %native bush. Their intention is to run a vineyard and they have started installing vines. In the meantime they are running a few stock on the land that hasn't yet been developed as a vineyard.

- The AgriBase record, shows the farm is a vineyard with %Vines, %other Plants and a few beef cattle. This record is actually quite typical, in filling in the form they have failed to record the %pasture occupied by stock, haven't noticed that there is a column for native bush and have lumped it into the other plants category because it isn't vineyard and in their mind never will be.
- LCDB2 shows %pasture and %native bush – quite possibly the vines were too small to show up in the satellite imagery, or it might just be a timing issue that AgriBase in September 2003 post dated the installation of the vines and the imagery of 2000-1 predated it.

The first approach assumes LCDB2 is correct and never asks about the presence of vines, the second approach doesn't know where the vines are but a model would put a % probability of vines at any point on the farm without further distinguishing between the relative probability of conversion of natives versus pasture to vines.

Most people looking at the information would presume with reasonable certainty that the vineyard had been created from part of the pasture, but our analysis is unable to make that inference. The reason is that confusion matrices do not exist for any of the contributing datasets. If they were we could build a table of probabilities that items of one class were likely to be items of a different class in the other dataset and these relationships could be used resolve the discrepancies between the data sources and allocate probabilities to their likely equivalents in the other classification. Such confusion matrices have very wide potential applicability.

There are two possible approaches to building a confusion matrix that relates AgriBase and LCDB2 classifications. Build a confusion matrix for each dataset against an independent source of 'truth' and from that construct an AgriBase – LCDB2 confusion matrix, or build the AgriBase – LCDB2 confusion matrix directly from further analysis of agreements and discrepancies in the data we have. The first approach would be very valuable not only for this project but also for any other project using LCDB2 or AgriBase independently. The second approach would probably solve our immediate problem but would have limited wider application and has the further caveat that I have not yet had the opportunity to consult a statistician on its veracity.

16.4.2. Testing/validating the LENZ landform to sheep & beef monitor farm type relationship

The existing relationship has been developed by reading the landform descriptions in the MAF Monitor Farm spreadsheets and matching them to the descriptions in the LENZ Technical Guide, their spatial extent and general field knowledge. Most categories were achieved with a match at LENZ level 2, but level 3 and 4 distinctions were also required. A more robust verification of the result of this classification should be undertaken before too much emphasis is placed on the result.

16.4.3. Refining the spatial allocation of the regional MAF Monitor Farm models

As a first approximation, MAF Monitor Farm Models have been allocated to groups of Region Council boundaries. A further refinement of the spatial allocation would be to assign models to Districts Council boundaries or to obtain boundaries that are specific to the model design. These could be modelled through NZLRI or LENZ, or mapped in consultation with MAF staff.

MAF Monitor Farm Type	Land Use Classification Code	MAF Monitor Farm Model Name *(and URL to 2004 model report)*	Regional Description *(quote extracted from the introductory paragraph(s) in the 2004 model report)*	Regional Assignment *(RC boundaries)*
Dairy	AAA_DAI_NTH	Northland	calving dairy farms north of Auckland City	Nth, Auck
	AAA_DAI_WAI	Waikato/Bay of Plenty	seasonal supply dairy farms in the Waikato and Bay of Plenty	Wai, BoP, Gis
	AAA_DAI_NIL	Lower North Island	3,235 seasonal supply dairy farms in the bottom half of the North Island, including the regions of Taranaki, Manawatu, Horowhenua, Wairarapa and Southern Hawke's Bay. These dairy farms supply the Fonterra Co-operative Dairy Company.	Tar, HBay, MW, Wgtn
	AAA_DAI_CAN	Canterbury	700 dairy farms throughout Canterbury and North Otago	Tas, Marlb, Cant
	AAA_DAI_STH	Southland	owner operators who supply milk to the Fonterra factory at Edendale	Otago, Sth
	AAA_DAI_WCS	West Coast South Island	West Coast of the South Island	WCoast
Sheep & Beef	AAA_SBI_NTH	Northland	[Northland] easy rolling to moderately steep hill country	Nth, Auck
	AAA_SBI_WAI	Waikato/Bay of Plenty Intensive	1,200 farms bounding the predominantly dairying districts of the Waikato/Bay of Plenty region.	Wai, BoP, Gis
	AAA_SBI_MAN	Manawatu/Rangitikei Intensive	situated on flat to easy rolling country in the Manawatu and Rangitikei districts	Tar, HBay, MW, Wgtn
	AAA_SBI_CAN	Canterbury/Marlborough Breeding & Finishing	sheep and cattle breeding and finishing farms in coastal Marlborough and Canterbury. Farms are located on the dry downs and plains, in irrigated areas, and in the higher rainfall upper plains	Tas, Marlb, Cant
	AAA_SBI_STH	Southland/South Otago Intensive	intensive sheep and beef farms in Southland and South Otago, ranging in size from 100-300 hectares (ha). The farms are on the plains and downlands in normally ample summer rainfall areas	Otago, Sth, WCoast
	AAA_SBH_NIC	Central North Island Hill Country	a range of hill country across the central area of the North Island. It includes the Waitomo, Ruapehu, Taupo, Wanganui and Rangitikei districts, as well as the Taranaki region	Nth, Auck, Wai, BoP, Tar, MW

MAF Monitor Farm Type	Land Use Classification Code	MAF Monitor Farm Model Name *(and URL to 2004 model report)*	Regional Description *(quote extracted from the introductory paragraph(s) in the 2004 model report)*	Regional Assignment *(RC boundaries)*
	AAA_SBH_GIS	Gisborne Large Hill Country	230 farms located from the top of the East Coast through to inland Wairoa, with contours ranging from steep erosion-prone hill country to easy rolling, high producing farmland	Gisb
	AAA_SBH_HBW	Hawke's Bay/Wairarapa Hill Country	hill country properties from Wairoa south, through to Cape Palliser	HBay, Wgtn
	AAA_SBH_CAN	Canterbury/Marlborough Hill Country	hill country farms in Marlborough, Canterbury foothills and Banks Peninsula	Tas, Marlb, Cant
	AAA_SBH_OTA	Otago Dry Hill	400 farms in the Otago area. These farms range in size from 500-4,000 hectares (ha), and are spread from Kurow in North Otago to Millers Flat in Central Otago, with the main concentration being in the Middlemarch and inland Palmerston areas. The model size is 2,000 ha	Otago
	AAA_SBH_STH	Southland/South Otago Hill Country	750 farms in the moderately rolling clay downlands to steeper hill properties in South Otago and Southland. The farms are spread through the Clutha (44%), Southland and Gore (56%) districts	Sth, WCoast
	AAA_SBM_SIM	South Island Merino	200 hill and high country merino properties in the South Island	Sth Island
Deer	AAA_DEE_NTH	North Island Deer	North Island	Nth Island
	AAA_DEE_STH	South Island Deer	represents the deer farms of Southland and South Otago. It is based on a farm running deer only	Sth Island
Arable	ARA_ARA_CAN	Canterbury Arable Cropping	600 properties over 100 hectares (ha) located throughout Canterbury	Can
	ARA_ARA_WAI	Maize (Waikato)	maize growing for silage and grain in the Waikato and Bay of Plenty areas	Wai
	ARA_PFV	Process and Fresh Vegetables	process and fresh vegetable growers throughout New Zealand	
Horticulture	HOR_KIW	Kiwifruit	kiwifruit orchards in the major growing areas of New Zealand. The model budget represents an established owner-operator property in the Bay of Plenty	

MAF Monitor Farm Type	Land Use Classification Code	MAF Monitor Farm Model Name *(and URL to 2004 model report)*	Regional Description *(quote extracted from the introductory paragraph(s) in the 2004 model report)*	Regional Assignment *(RC boundaries)*
	HOR_SUM	Summerfruit	New Zealand summerfruit industry in the two main production regions, Hawke's Bay and Central Otago	
	HOR_TRO	Subtropicals	subtropical crops of avocados, citrus, persimmons, feijoas, tamarillos and passionfruit. These crops are grown in the warmer parts of New Zealand, particularly Gisborne, the coastal Bay of Plenty, greater Auckland and Northland	
	HOR_EXB	Export Berryfruit	export berryfruit crops grown throughout New Zealand. They are grown mainly in Auckland, Waikato, Horowhenua, Nelson and Canterbury	
	Not used	Apiculture	beekeeping activities and products throughout New Zealand	
	HOR_FLO	Floriculture	flower industry in New Zealand	
	HOR_VIT_HAB HOR_VIT_MAR	Viticulture	owner-operator vineyard businesses whereby grape income is the primary income. This excludes the smaller lifestyle properties and the larger corporate businesses. The two budgets represent the Hawke's Bay and Marlborough regions	HBay, Marlb.
Pipfruit	HOR_PIP_HAB	Hawke's Bay Pipfruit	Hawke's Bay is the largest pipfruit-producing district in New Zealand, exporting 50% of the country's pipfruit crop. Most orchards have a mixture of pipfruit varieties and are run by owner-operators	HBay
	HOR_PIP_NEL	Nelson Pipfruit	Nelson is the second largest apple district in New Zealand after Hawke's Bay. Most orchards are a mixture of old and new varieties, typically run by owner-operators	Nelson

Table 16-4: MAF Monitor Farm Models and their Land Use Classification.

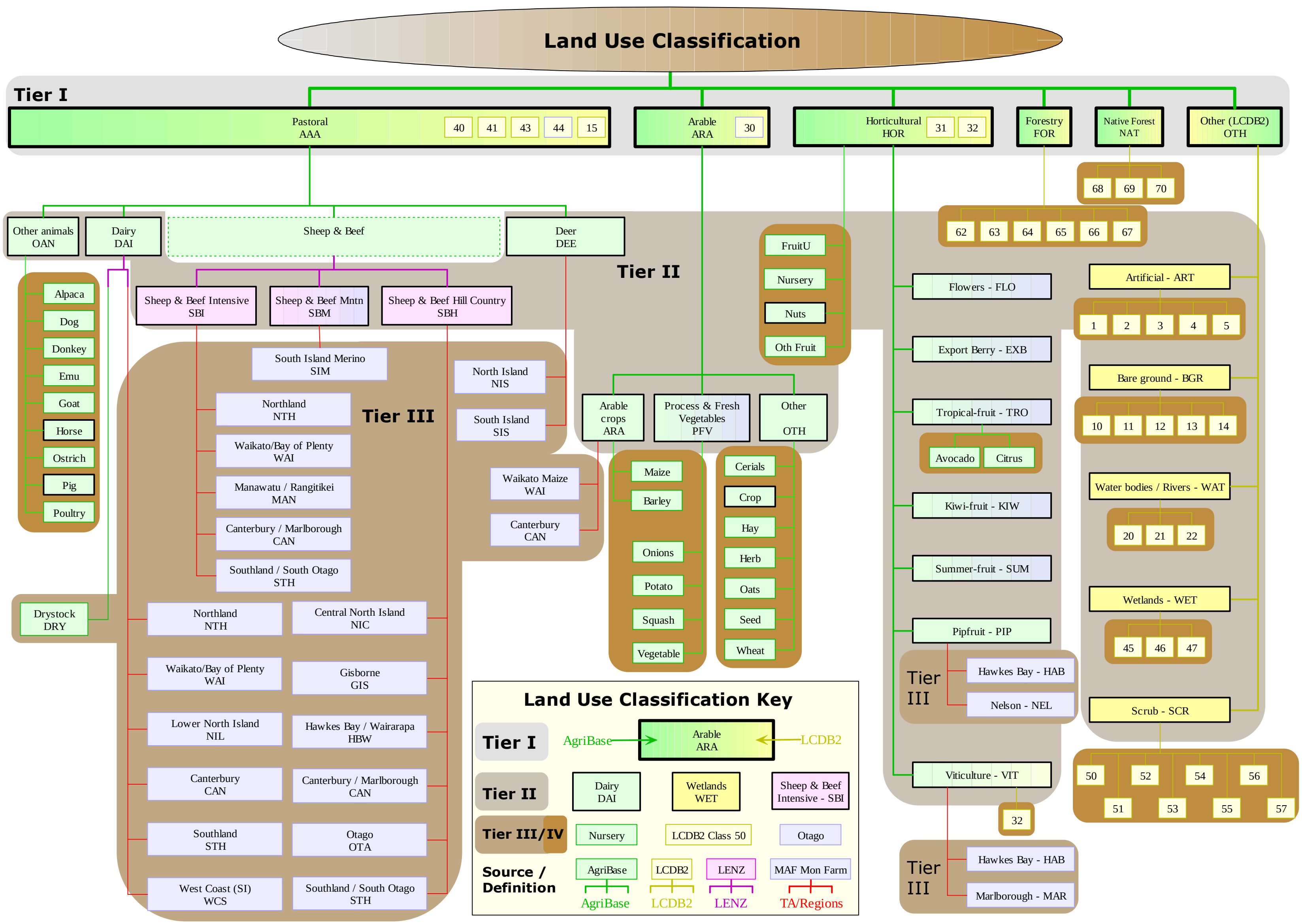

Figure 16-1: Land Use Classification.

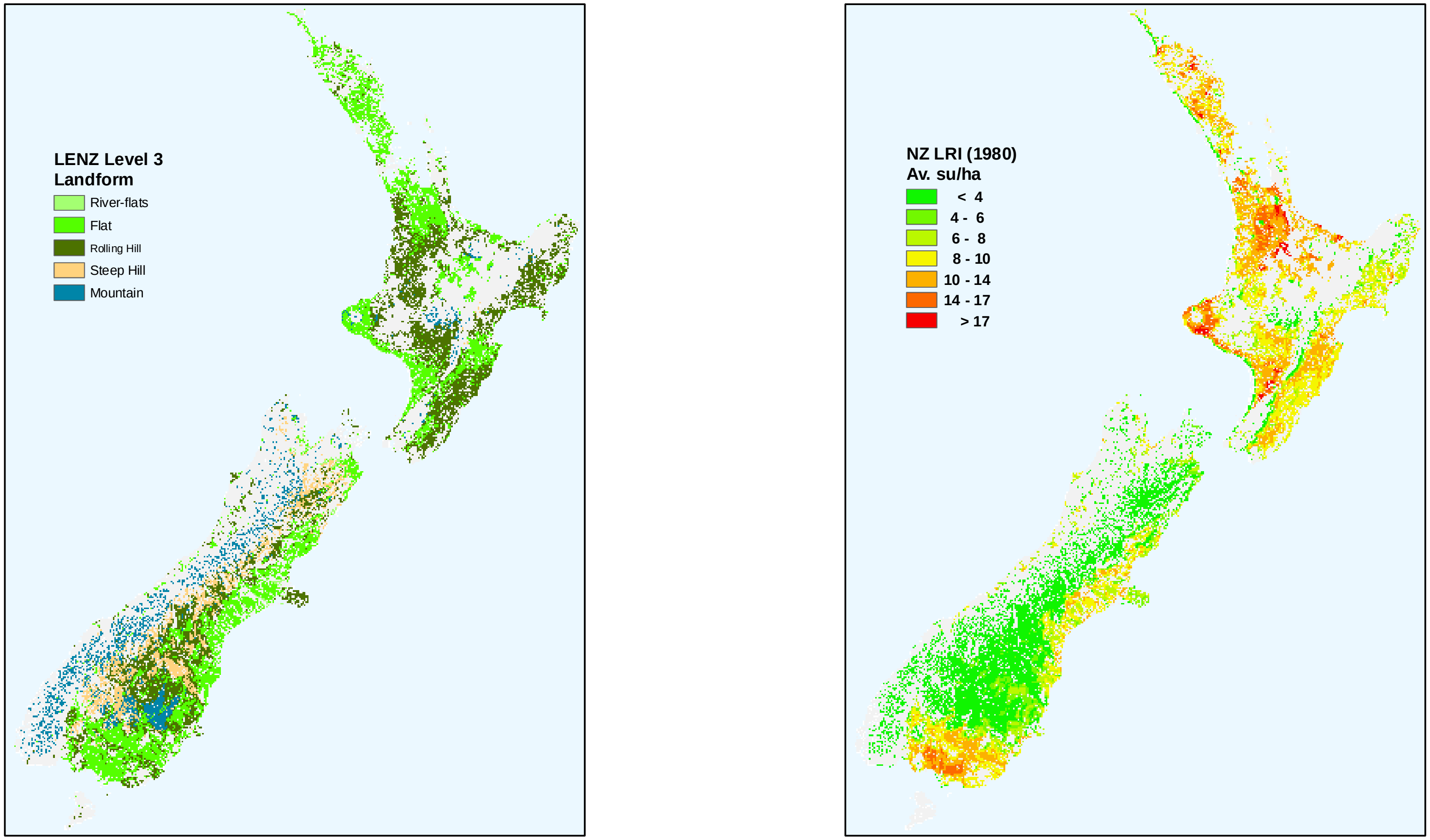

Figure 16-2: Maps of spatial pattern of LENZ Landform (left) and LRI (1980) Average Stock Carrying Capacity for LCDB2 pastoral land. Non pastoral land is shown as light grey on both maps.

17. Appendix 3: Details of Workshop 2: August 2004

17.1. CLUES: Spatial framework that provides the project ‘glue’ - Ude Shankar

- Gerald made it clear he wants to target technically-competent users, not planners working alone. Could have a decision-maker with a technical assistant who can use the model to answer questions

- We need to spend some time in Stage 2 on a clear user interface design (still within Arc), so that marketing is easier – Ross to include item in Y2 proposal.

- Issues raised about building a stand-alone version – Shankar to advise Ross on preferred options

- Need flexibility to present results as both concentrations and loads - Shankar to include in interface design, Ross to include in future reports

17.2. SPARROW model for N - Sandy Elliott

- Willing to replace the SPARROW source equations by OVERSEER®/SPASMO output, and then recalibrate SPARROW delivery and attenuation

- SPARROW source yield for dairy is high, but attenuation in small streams is high too, and very little data in small streams. Perhaps if we constrained source yields to be smaller, then attenuation would not be so high in small streams (even independent of flow!)

17.3. Extending SPARROW model for groundwater - Vince Bidwell

- Willing to compromise on his approach of constant concentration in drainage water for given land-use

- Happy to see his estimates of N concentration superseded by OVERSEER® estimates

17.4. Triple-bottom-line effects of land-use change - Simon Harris

- Not clear how to use this modelling system for scenario of capped N discharge

17.5. EnSus mapping of N leaching risk - Allan Hewitt

- May need to add irrigation to rainfall.

Roger Parfitt (Landcare Research NSOF project)

- Using NIWA data to do national N budgeting.

- Analysing N in Manawatu R – very interested in seasonal dynamics.

17.6. OVERSEER® model of pastoral land use impacts on water quality – David Wheeler

- Watch out for consistency of definitions – especially for slope.

- Will need regional differences in OVERSEER® scenarios.

17.7. SPASMO model of horticultural land use impacts on water quality - Brent Clothier

- Can do many SPASMO model runs to provide lookup tables for all likely scenarios of crop, fertiliser, climate and soils.

17.8. Comments by Gerald Rys

- Need to show robustness – do the results make sense? (next step).

- Simplicity – can accept complex model well done. Users will want to put their own data into it as a way of gaining ownership.

- Comparability of results – are there conflicting estimates of N leached? How do we resolve this? (OVERSEER®/SPASMO can be used to supersede SPARROW, EnSus and TBL estimates).

- Seamless integration would be good. Willing to have a single launch pad for several models (EnSus is different to SPARROW/OVERSEER®/SPASMO/TBL).

- Consistent use of inputs – LCDB2, AgriBase and MAF Monitoring Farm data.

- Flexibility and updating of both data and models.

- Uncertainty – do we want to quantify this? Can we? When?

- Calibration – Gerald keen to see models calibrated – only SPARROW G/W really needs more effort on this aspect.

- Catastrophic events – Gerald interested in effect of floods (on sediment).

- The word "pollutant" is red rag to a bull – can we get rid of it?

- Gerald was surprised there was no effect of slope in the models.

17.9. Cooperative NZ research on soils - Brent Clothier and Liz Wedderburn

- gave a talk on new cooperative FRST research on soils "Our Roots Are in the Soil" – AgResearch, HortResearch, Landcare Research, Crop and Food Research.

17.10. A name for the project

- CLUES **-** Catchment Land Use and Environmental Sustainability.

- CURLEW **-** Computations on Use of Rural Land and Effects on Water.

- EAGLE **-** Estimating Aggregate General Loadings in Environment Systems.

- NO**-**CLUES **-** Nitrogen Output **-** Catchment Land Use and Environmental Sustainability.

- LUMPS **-** Land Use Models for Productive Systems.

The acronym **CLUES -** Catchment Land Use and Environmental Sustainability was chosen as the project name and has been in use since.

18. Appendix 3: Details of Workshop 3: July 2005

18.1. Agenda

- 10.00 Welcome by Gerald Rys, introductions as required, outline of goals for the day (review progress to date, propose future work).

- 10.10 Ross Woods - very brief project overview (5 mins).

- 10.15 Allan Hewitt and/or Robert Gibb– Mapping of Soils and Land use/management, revision of EnSus mapping of N leaching risk, and CLUES ftp site.

- 10.30 David Wheeler - OVERSEER® model of pastoral land use impacts on water quality.

- 10.45 Brent Clothier - SPASMO model of horticultural land use impacts on water quality.

- 11.00 Coffee break.

- 11.15 Simon Harris - triple-bottom-line effects of land-use change.

- 11.30 Sandy Elliott - SPARROW model for P.

- 11.45 Ude Shankar – developments in CLUES spatial framework.

- 12.00 Peter Singleton and Sandy Elliott - Trial with EW.

- 12.15 Discussion – initial response from Gerald and end user reps on progress to date.

- 12.30 Lunch.

- 1.15 Gerald Rys to provide initial response on directions for year 3 as he sees them.

- 1.30 Ross Woods to outline the current ideas for Year 3, based on the original project proposal, issues identified in Workshops 1 & 2, project progress to date, and any email discussion in July 2005.

- 2.30 Any other issues

  - How will the modelling framework be maintained/revised after end of 3-year project?

  - Are there any unresolved issues related to interactions with IRAP?

- 4.00 Close of meeting and Coffee.

18.2. Issues that arose during CLUES project workshop, 27 July, Hamilton

1. How to deliver information which is interesting (e.g., details of land use) but not used directly by models?

   - Provide extra GIS layers with CLUES installation (EnSus output is also in this class).

2. Should we convert EnSus output (e.g., relative risk of N leaching) into quantitative N leaching for comparison with OVERSEER®&SPASMO?

   - No.

3. Should we build a web site for CLUES? Why?

   - No real support for heavy publicity effort - instead, lets make a 2-page leaflet.

4. What happens to CLUES in Year 4? (current funding concludes at end of Yr 3).

   - Seek EnviroLink funding in 2005/06 for some small projects to familiarise a few individual RCs with CLUES: start with Horizons RC?

   - In 2006/07 propose a large EnviroLink project with multiple RC partners.

5. Can users change the default values in OVERSEER®?

   - Not presently. At the very least we need to expose the underlying tables that define the 5 OVERSEER® scenarios.

6. What are the CLUES assumptions/limitations?

- Need a document that defines limitations – will have material specific to particular elements of the model.

7. How will CLUES change with time?

   - We need to define a version number.

   - Describe each release of CLUES as “current version” of the truth.

8. How to generalise SPASMO for other climates?

   - Use annual series of values (rainfall and N leaching) at each modelled location to obtain information on sensitivity. Fit regression equation to that data, and make regression coefficients available to CLUES.

9. How to model sub-optimal mgmt? Is CLUES producing results for BMP or for actual practice?

   - Use multipliers to reflect the differences.

10. Can CLUES produce seasonal outputs?

   - Not yet, but it’s a good idea. Expect to provide regional guidance, but not highly location-specific information

11. How do we account for effectiveness of proposed mitigation measures?

   - By using multipliers that are available in the CLUES interface.

12. Do we need to distinguish N yields of native vs plantation forest?

   - No

18.3. Comments from Gerald Rys

1 Need for use of latest data ie farm monitoring reports, stock number etc. could we have a cross check of all data sources re timing. Possibly need to be incorporated into the model so it can be checked by users. (David, Shankar, Simon)

2 Need for provision to update key elements in time sensitive data ie annual changes ie farm monitoring reports, biophysical data (Shankar, David)

3 Perhaps leave ground water as to hard at this stage but make provision for incorporation into model at later stage (Sandy?)

4 Do phosphate as SPARROW already done and can get inputs from OVERSEER® . This needs some thinking of how other elements are incorporated into the framework and how displayed. Bit hard to do maps that have both nitrogen and phosphate on the same map. (Sandy, Shankar)

5 Keep the ENSUS results and display separately at this stage I am happy that we have two ways of looking but perhaps put the ENSUS as a another tool /way at looking at issues. (Shankar)

6 Need to look at front end so it is pretty, understandable, and able to print of both the maps and the associated data. (Shankar)

7 The background land-use/stock numbers needs to be tied down (David, Shankar)

8 Need to be clear about the form of nitrogen we are looking at nitrate/total nitrogen etc. (Sandy, Roger)

9 I am still not clear how OVERSEER® links to SPARROW etc. to give the outputs on a spatial basis?? Covering all the MAF Farm Monitoring models -Enlighten me!!! (Shankar)

10 Peter Singleton - What do you see as the priorities on your list of MUST have's from LIKE to haves. (Peter)

11 Happy with other decisions to use OVERSEER® and SPASMO N input results.

12 Need for Forestry Economics as a land use change. (Simon)

13 Have not covered uncertainty around the estimates - need to think about it but perhaps not incorporate at this stage.

Summary

- Prettying up framework, expandable, new data additions.

- Background non biophysical databases tight/best available ie land use, stock numbers, farm monitoring reports.

- Finish Nitrogen, incorporate phosphate, eliminate groundwater.

- Put EnSus results in as a separate approach for nitrogen.

19. Appendix 3: Contact details

Table 19-1: Contact details for the people involved in the project.

Name	Organisation	Role	Email	Phone
Gerald Rys	MAF (Wgtn)	Client contact	Gerald.Rys@maf.govt.nz	04 04 819 0711
Ross Woods	NIWA (Chch)	Project leader	r.woods@niwa.co.nz	03 343 7803
Sandy Elliott	NIWA (Ham)	SPARROW	s.elliott@niwa.co.nz	07 859 1839
Ude Shankar	NIWA (Chch)	GIS, database, modelling framework	u.shankar@niwa.co.nz	03 343 7892
Clive Howard-Williams	NIWA (Chch)	NIWA Overview	c.howard-williams@niwa.co.nz	03 348 8987
John Bright	Aqualinc	Groundwater	j.bright@aqualinc.co.nz	03 325 3780
Vince Bidwell	Lincoln Ventures	Groundwater	bidwellv@lvl.co.nz	03-325-3704
Simon Harris	Harris Consulting (Chch)	Triple bottom line impacts	simon@harrisconsulting.co.nz	03 379 6680
David Wheeler	AgResearch (Ham)	OVERSEER® modelling	david.wheeler@agresearch.co.nz	07 856 2836
Liz Wedderburn	AgResearch (Ham)	AgResearch overview	liz.wedderburn@agresearch.co.nz	07 856 2836
Brent Clothier	HortResearch (P/Nth)	SPASMO modelling	bclothier@hortresearch.co.nz	06 356 8080 extn 7733
Steve Green	HortResearch (P/Nth)	SPASMO modelling	sgreen@hortresearch.co.nz	06 356 8080 extn 7751
Allan Hewitt	Landcare Research (Lincoln)	EnSus risk modelling	hewitta@landcare.cri.nz	03 325 6701 extn 3840
Robert Gibb	Landcare Research (Palmerston North)	Soil and land-use mapping	GibbR@LandcareResearch.co.nz	06 356 7154