Predicting the effects of landuse on water quality – Stage I

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Predicting the effects of landuse on water quality – Stage I

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Contents

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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 Stage I of a project to address the effects of landuse change on water quality.

The objective of this 3-year project is to develop, under a series of contracts over several years, a Computer Based GIS Decision Support Tool(s) that is nationally applicable, and regionally and catchment relevant, to assess the links between rural land-use, land use change, and catchment–level (but scalable down or up) 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 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 first year of the project, where three main tasks have been carried out (i) developing a framework for linking water quality models; (ii) adapting existing water quality models to connect to this framework (iii) producing case study information which illustrates use of the various models.

At the beginning of the project, a workshop was held to make all project partners aware of the general framework, to know how their work relates to other work in project, to agree on deliverables and timing for the first stage of the project, and to identify interactions between project sub-contractors which affect the methodology or format of results. In the first year of the project, work is focussed predominantly on the effect of land use on nitrogen as an indicator of water quality, but also investigates the effects of changes in land use on farm income and employment.

In Stage I of the project, we have defined a flexible and robust computer modelling system, which is 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.

A catchment-scale water quality model (known as SPARROW) has been linked to this system, and tested on the Waikato catchment. It provides results in map form for many thousands of streams in a few seconds. This SPARROW model has been extended to include the capability to model groundwater quality, and suitable background information on nutrient movement has been collated to permit the application of this extended model for nitrogen in the Waikato region. This work provides

information at the catchment scale, and a framework for assessing the integrated effect of farm-scale information on catchment-scale water quality.

Three methods for assessing the effects of land use on water quality are in development, in order to provide more detailed information than the SPARROW model. It is intended that all three methods will be linked to the framework described above, in later years of this project.

First, new national maps have been developed to show the relative risk of nitrate leakage from soils to surface and ground waters around New Zealand, using the EnSus framework for analyzing and mapping the relative risks different land uses pose to soil quality and water quality. It uses best available knowledge of specified land use pressures and vulnerability of the land to those pressures. A detailed map of nitrate leaching risk in the Waikato region was also developed. The methods used to develop these maps can also be linked to the modelling framework, to predict the effects of land use change on risk of nitrate leaching.

Second, assessments have been made of the likely nitrate leaching from a range of horticultural crops in typical locations around New Zealand, using the Soil Plant Atmosphere System Model (SPASMO). Crops that have been assessed include Marlborough and Hawke's Bay grapes, Bay of Plenty kiwifruit, Hawke's Bay apples, and Waikato potatoes. This information has been used to assist with development of a triple bottom line accounting model. It is not yet clear how the SPASMO model will be linked to the modelling framework.

Third, the leaching of nitrogen from pastoral agriculture is being assessed using the OVERSEER computer model. Guidelines for the appropriate use of this model in the project have been documented, the input data needed to link the OVERSEER model to the framework have been identified in detail, and a very simple demonstration version of the model has been developed to allow a direct connection between Overseer and the framework developed above.

A triple bottom line examination of the effects of land use change on environmental, economic and social outcomes is being carried out to allow the effects of different policies to be assessed. The three specific outcomes that are being quantified are nitrogen leaching, farm income and employment

A set of proposed future actions has been identified for most parts of the project, and another project workshop is scheduled for August 2004, to report on progress, and clarify directions for the second year of the project.

1. Introduction

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 Stage I of a project to address the effects of landuse change on water quality.

The objective of this 3-year project is to develop, under a series of contracts over several years, a Computer Based GIS Decision Support Tool(s) that is nationally applicable, and regionally and catchment relevant, to assess the links between rural land-use, land use change, and catchment–level (but scalable down or up) 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 (in the second and subsequent years of the project) computer-based methods, which stakeholders (e.g., MAF, MfE, Regional Councils, and other agencies) can use to make these assessments. NIWA and its subcontractors will deliver the executable programs and associated documentation needed to make these assessments.

This report summarises progress in the first year of the project, where three main tasks have been carried out (i) developing a framework for linking water quality models; (ii) adapting existing water quality models to connect to this framework (iii) producing case study information which illustrates use of the various models.

2. Project goal

Context: We assume that a Regional Council or MfE planner/scientist needs to know the potential effects of land use and land use change on water quality for a catchment or region, and has scenarios about how landuse is likely to change in future.

The user starts by using the Tool developed in this project to navigate their way by map to define the region of interest. A current landuse scenario is automatically available, as well as modelled current water quality conditions, and a set of user-defined water quality standards. This provides a broad-scale assessment of current conditions in relation to standards, for a region of perhaps 1000 km^2, with meaningful detail down to perhaps 10 km^2 sub-catchments. The user can then use pre-defined

landuse scenarios (e.g. "new irrigation" or "cap on nutrient runoff"), or develop their own scenarios, and run those scenarios through NIWA's SPARROW model to see maps which give an indication of where runoff source areas are located, and whether water quality is significantly affected.

Suppose a part of the region appears to have a water quality problem. The next step is to use Landcare Research's EnSuS to generate risk maps (high/medium/low risk of generating nutrients from each map unit: spatial scales as fine as 100 m^2), in order to explore which combinations of soils, climate, land use, land management etc pose the highest risk for nutrient runoff and are in need of some resource management intervention or advice (this level of detail is beyond the scope of SPARROW). The user identifies a candidate set of management regimes for typical land uses, and models the new nutrient runoff yields, using paddock-scale models such as AgResearch's OVERSEER (pastoral agriculture) or HortResearch's SPASMO (horticulture). These models will be run for a set of pre-defined farm-types, which can be associated with user-defined parts of the catchment. This provides a refined estimate of the nutrient runoff yields from the catchment, which can be inserted into the SPARROW model to provide new estimates of water quality. The economic returns associated with each scenario will be mapped and summarised by using a lookup table of financial return for each type of landuse, based on farm economic data from MAF, and being collated by Harris Consulting.

MAF and MfE have obtained project funding from the Cross Departmental Research Pool for three years, ending in June 2006. A broad outline of the project deliverables has been agreed in principle with MAF. The specific tasks for year 1 of the project (concluding 30 June 2004) have also been agreed. These are:

1.   Catchment Modelling Framework (NIWA)

2.   Adding Groundwater Component to SPARROW (NIWA, Lincoln Ventures)

3.   Triple Bottom Line Effects of Land-Use Change (Harris Consulting)

4.   Enterprise-scale Modelling (AgResearch and HortResearch)

5.   Pollution Risk Modelling (Landcare Research)

The long-term goal of the project is to have the models used in items 2 to 5 above, all linked to the Catchment Modelling Framework. This will make the models available and useful to potential model users such as Regional Council or MfE planners/scientists.

3.   Reports on Stage I tasks

The overall approach for Stage I of the research was to generate a common framework for all models in this first year, link at least one model (SPARROW) to the framework, and begin to develop linkages between the modelling framework and individual models (e.g., the OVERSEER, SPASMO, and EnSus models). These other models will be linked to the framework in Stages II or III of the project. Section 4 reports on the first project workshop, Sections 5 to 10 summarise progress on individual tasks, and Section 11 offers some suggestions for the work needed in the second and third stages of the project. Sections 14 to 16 contain technical background material for the SPASMO, OVERSEER, and triple bottom line accounting models, while Sections 17 and 18 contain administrative information such as the Stage I contract, and contact details of current project participants.

3.1.   Connections Among Tasks in Sections 5 to 10

This project comprises a number of tasks that are proceeding in parallel, in order to produce a linked modelling system that operates at several levels of spatial detail. The catchment-modelling framework outlined in Section 5.1 is being used to connect models such as SPARROW (Section 5.2 and Section 6), OVERSEER (Section 7), SPASMO (Section 8), EnSus (Section 9), and triple bottom line accounts (Section 10). In every case except the last, an existing modelling technique is being linked to the modelling framework. By using existing models, there are very substantial savings on the cost of model development, and more of the project resource can be put into integration of models, and into case studies.

Because the models have a wide range of approaches, there are significant differences in the style of reporting between the following sections of this report. Some of the modelling techniques being used are more compatible with the framework than others. The following paragraphs outline the current status of the framework, and each model in relation to the framework. These comments should assist in explaining why each of the tasks is being done, and how they contribute to the goals of the project.

The modelling framework (Section 5.1) is in place, and has been designed to be able to link to a wide range of model types. More work is needed to link to models other than SPARROW. The connection between the framework and the SPARROW model is in place and operating very efficiently.

The SPARROW model (Section 5.2) is operating as a component of the modelling framework, and the model for N is complete. The extension of the SPARROW model to include groundwater (Section 6) is also complete, but has not yet been finally linked

to the framework. However, it is so similar to the already-linked standard SPARROW model that very little additional work is needed on the system linkages. Most of the remaining work with the groundwater model is in estimating the model parameters.

The links between the OVERSEER® model (Section 7) and the framework are clearly specified, and no particular difficulties are expected in linking it so that it will provide N leaching results for farms. A detailed design has been completed to specify the information to be exchanged between OVERSEER® and the modelling framework. More work is needed on the identification of representative ranges of rainfall, soils and topography for each of the farm types (scenarios) described in Section 7.2. OVERSEER® is intended to be run automatically from the framework, for representative case studies that cover all pastoral agriculture in the catchment of interest.

Links between the SPASMO model (Section 8) and the framework are not yet clearly defined. The SPASMO model is the most numerically detailed of all the models in this project, and requires a long sequence of site-specific daily climate information as input data. In this first year of the project, it is being used to generate information on N leaching for case studies, and these have been essential for the triple bottom line work (Section 10). Ideally, the SPASMO model would be linked into the modelling framework in the same way as OVERSEER, that is, as a model which can be run automatically from the framework, for representative case studies that cover all horticultural crops in the catchment of interest.

The EnSus results (Section 9) provide a national view of N leaching risk, which complements the national SPARROW modelling work (Section 5.2) for N and P. The EnSus approach is at a finer spatial scale than SPARROW. However, it does not estimate spatially integrated responses over catchments, and does not take account of in-stream attenuation processes. The EnSus model can be summarised as a set of rules that combine maps of soil attributes, rainfall, and land use/management into maps of leaching risk. These rules are documented in Section 9, and can easily be implemented as part of the catchment modelling framework, although no work has begun on that link. Land use/management change scenarios can be investigated by changing the map of land use/management to which the rules are applied.

The triple-bottom line accounting work (Section 10) has produced simple approximate methods to estimate the N leaching, income and employment outcomes of various land uses. The approach used for this work is simpler than the other modelling approaches, and has the advantage that it covers a wider range of land uses than any other model. The model equations (Section 16) are available in a form that is easily linked to the modelling framework, but no work has begun on that linkage.

A summary of the progress of each system component is provided in Table 3-1. Although some of the model components have made little progress on model integration in this first year of the project, this is not in itself a cause for concern. For some of the models, development or application of the model itself was seen as a higher priority in the early stages of the project. For at least two of the models (EnSus and Triple Bottom Line accounting), little work is needed to integrate them into the catchment modelling framework.

Table 3-1: **Summary of progress in model development and model integration. These (admittedly subjective) assessments are not concerned with the quality of work being done, but reflect the complexity of the task, the resources allocated to it so far, and the priorities set by the funding agency.**

System component	Progress on development	Progress on Integration
Modelling Framework	Medium	Medium
SPARROW (N)	Medium	High
SPARROW-G/W (N)	Low	High
OVERSEER	High	Medium
SPASMO	High	Low
EnSus (N)	Medium	Low*
Triple Bottom Line (N, $, jobs)	Medium	Low*

* Relatively little effort will be needed to achieve a high level of model integration

4. Summary of First Project Workshop

An initial project workshop was held in Christchurch on 12 March 2004. The objectives of the workshop were to make all project partners aware of the general framework, know how their work relates to other work in the project, to agree on deliverables and timing for the current financial year, and identify interactions between sub-contractors which affect methodology or format of results. Presentations were given by Gerald Rys (MAF), and by each of the science providers. Additional comments were provided by potential end-users: Peter Singleton (Environment Waikato), Viv Smith (Environment Canterbury, now Environment Waikato), Grant McFadden (MAF).

The following issues were identified for further action:

- A need was identified for the project to have a communication plan, so that all the relevant stakeholders were kept informed. Gerald Rys agreed that he would look into this in future. Particular mention was made of the need to contact Vegfed, Zespri, and Pipfruit New Zealand.

- There was a brief discussion on the question "Who is our end-user/customer?" The following were listed: central government/MAF; regional government; consultants, industry (later). Industry groupings were expected to take up the technology later in the life of the project.

- What is the spatial scale at which the project is expected to provide information? The smallest scale was agreed to be the farm scale, and it is clear from the project specifications that the largest scale is the catchment (up to several thousand square kilometres). Care is needed in the operation of the project, to ensure that differences in scale between the models is handled appropriately. There was extended discussion of the use of Ministry of Agriculture (MAF) monitor farms as representative spatial entities for use by the farm-scale models in the project (e.g. OVERSEER). Regions could be defined which each of the farms is suitable to represent, and catchment boundaries overlaid on these regions.

- What is the temporal scale for the project? Most of the models (but not all) are intended to produce answers for an equilibrium situation, that is, some kind of long-term average over several decades. The current scope of the project is restricted to equilibrium modelling.

- What is the scope of the questions the model will be used to answer? In year 1 the project considers mainly nitrogen runoff. In later years, more social impacts will be considered, and other contaminants will be considered. In year 1, the questions to be addressed are of the kind: "what is the effect on nitrate leaching and nitrate concentrations in water of changing from the existing mix of landuse/management to a future scenario?" There was interest expressed in being able to ask "what is the landuse needed to keep N level below an acceptable threshold", but it was not clear that any unique answer was possible for a question of this nature. Many different mixtures of landuse in a catchment may be able to produce the same acceptable N levels in a river.

- How interactive does the decision support tool need to be? No decisions were made on this question. In year 1 the system will be able to work with landuse maps provided by the user, and the user will be able to specify the catchment area of interest on-screen, within the Waikato region.

- What is degree and nature of integration of models? Exchange of data *vs* source coding and in-between. The approach during stage 1 will be to link models by exchanging appropriate data between them, rather than recoding one model to directly use another model.

- There was a brief discussion on having a decision making process for decisions which affect the project as a whole. No formal structures were created, although it was accepted that the project leader (currently Ross Woods) could in some circumstances act as a representative of the science providers when interacting with MAF. The decision-making process would sometimes take place during project workshops, involving MAF, science providers and stakeholders.

- A requirement was identified for a national data layer of standard farm types and their attributes. AgResearch and MAF to follow up.

- When two or more project partners are modelling the same physical process, it was agreed that it is essential to share data and to produce consistent outputs.

- To plan the work for Stage II, it was agreed that another workshop would be required, early in the FY 2004-05.

- The Waikato region was agreed on as an initial study area for many of the studies

5. Catchment modelling framework (NIWA, Objective 1)

As noted in Section 2, a central element of this project is the development of a Catchment Modelling Framework which links water quality models. Figure 5-1 shows the relationship among the components of the proposed system. In this section we report on the development of the GIS application shown in the centre of Figure 5-1 and also the linking of that system to the SPARROW model.

5.1. Create desktop tool

A water quality modelling toolbox was created and added to ArcGIS: this provides access to the range of modelling tools which the project is developing and linking together, as well as some utilities which are needed to run the system (e.g., to let the user define the study area). This is shown in Figure 5-2.

Tools are available to define the catchment study area, including picking the most downstream point in the catchment, optionally excluding any parts of the catchment which are not of interest, and undoing any of these choices. Figure 5-3 shows an example of using the toolbox to select the most downstream point in the study catchment.
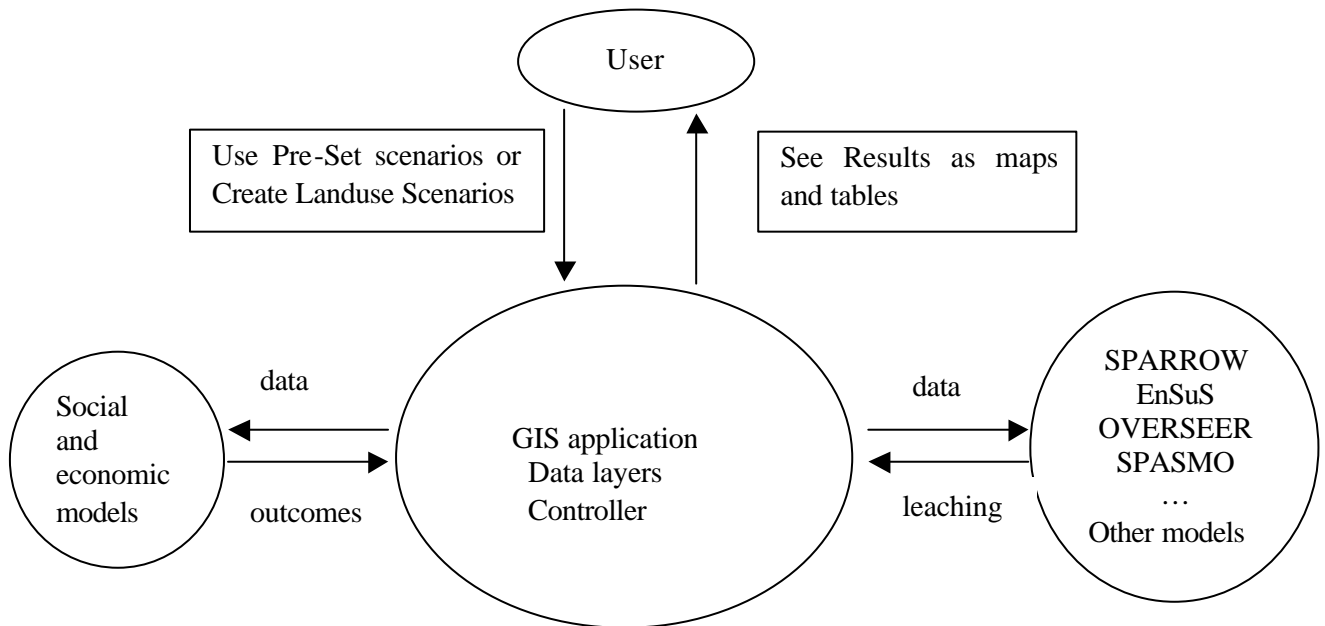
Figure 5-1: **Schematic of the Catchment Modelling Framework being developed over the life of the project**
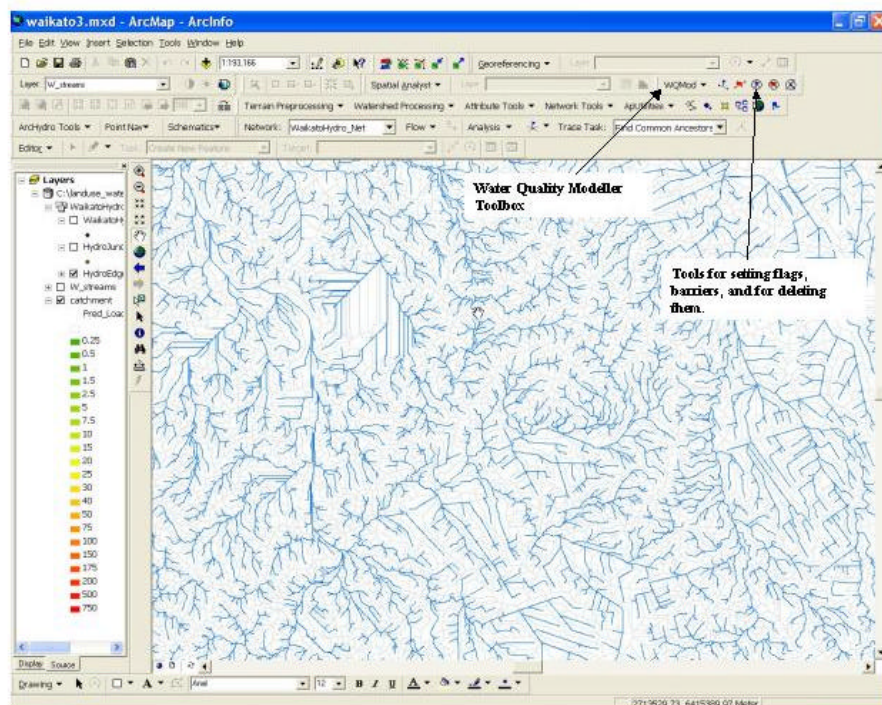
Figure 5-2: **Part of the Waikato River network, with new tools highlighted at upper right. The Water Quality Modeller Toolbox will provide access to models such as SPARROW, OVERSEER, SPASMO and EnSus. See following figures for more details.**
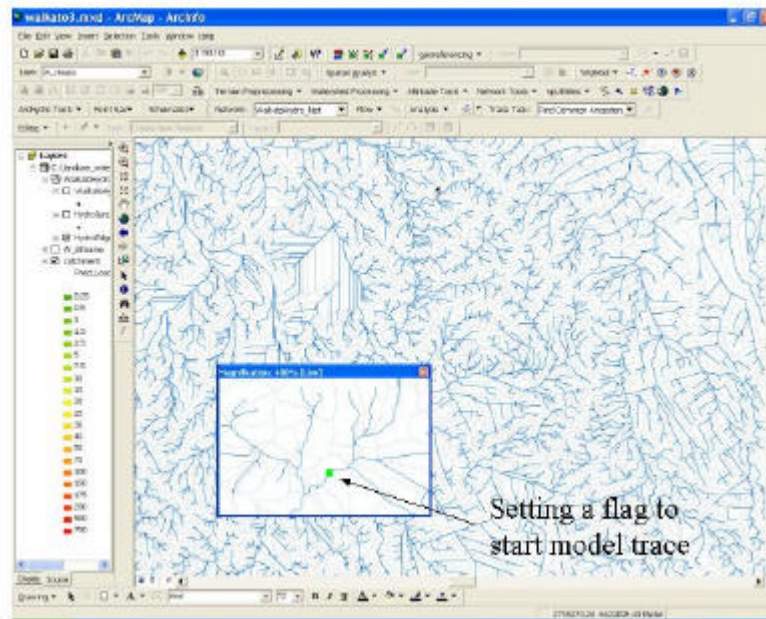
Figure 5-3: **Choosing the most downstream point in the catchment by clicking on the river network**

The model of choice can then be run from a customised menu: at the time of writing the SPARROW model was available. Figure 5-4 shows the menu that allows models to be run. It will be extended and revised as further models are added.
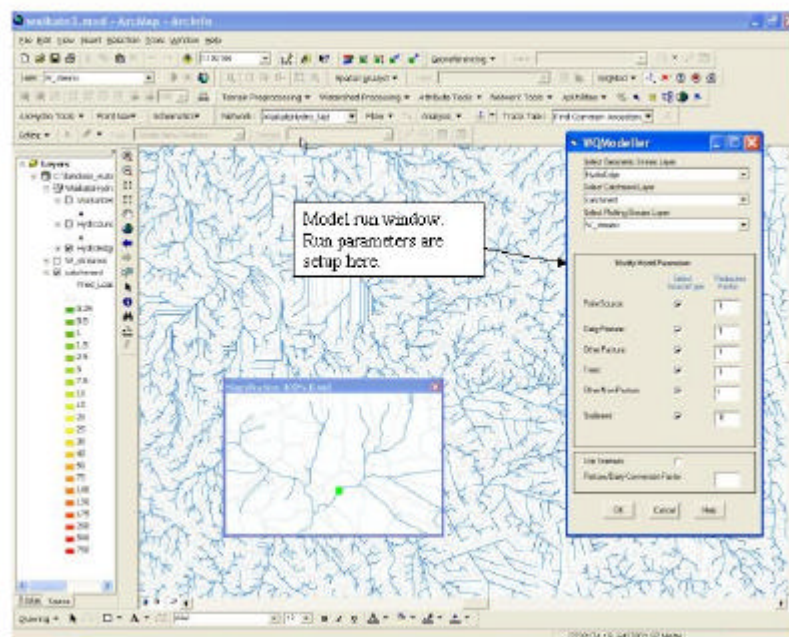
Figure 5-4: **The Water Quality Modelling Toolbox allows the user to choose from a range of pre-prepared land-use scenarios, as well as several other options.**

5.2. Link SPARROW Model to Desktop Tool

The SPARROW model has been linked to the Desktop Tool shown above, so that it can exchange information in ArcGIS formats. The model runs very quickly (25 seconds for the whole Waikato catchment), and has been validated against previous studies.

At the time of writing Water Quality Modelling Toolbox can run the SPARROW model for the entire Waikato River catchment in less than 10 seconds, and present the results as a map, such as Figure 5-5.
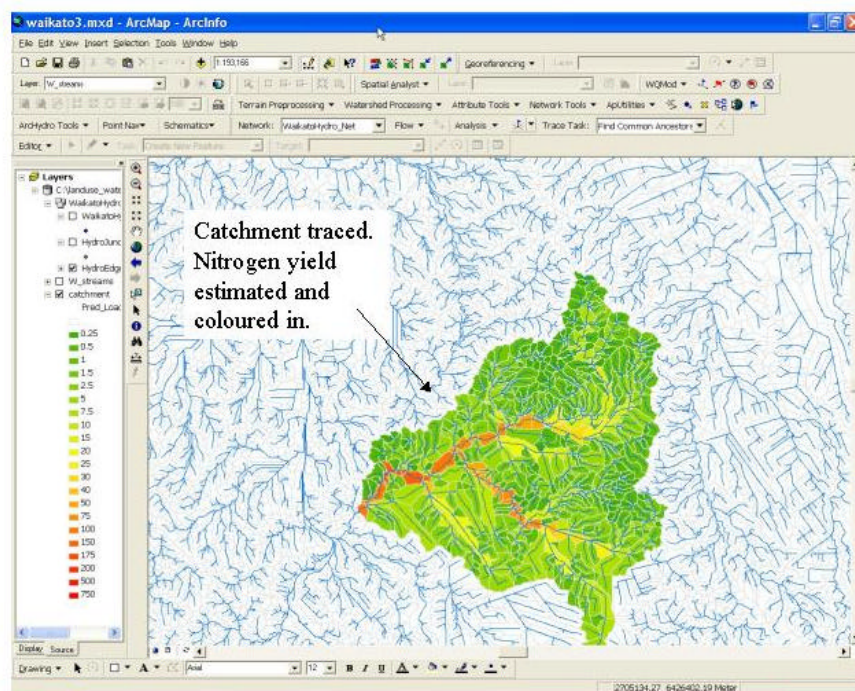
Figure 5-5: **The predicted nitrogen loads from SPARROW are shown as a coloured map for a sample study area**

6. Add groundwater component to SPARROW (NIWA, Lincoln Ventures, Objective 2)

6.1. Physical process descriptions

6.1.1. Nature of the source of N

This section is concerned with nitrogen as a diffuse surface source that is transported through groundwater, ultimately to surface waters. Almost all the nitrogen transported by this pathway is in the form of nitrate ions, because this is the end product of a

series of biochemical processes that convert organic nitrogen to the oxidised mineral state. Nitrate is highly mobile in subsurface waters (unsaturated and saturated) because its negative charge is repelled by the generally negative charge of most soils and other subsurface materials.

The biochemical processes for nitrate production occur almost entirely within the organic soil layer and plant root zone near the land surface. The amount of nitrate available for leaching downwards from the soil depends on the type of land use, which in turn determines the productivity of the soil ecology. Tracer experiments have demonstrated that only a small proportion of applied nitrogen fertiliser is ever leached directly to groundwater. The correlation between fertiliser use and leached nitrate arises from the increased productivity of the whole agricultural system, as quantified by the amount of nitrogen per land area being cycled through soil, plant, and animal.

Increasing productivity of a soil is usually associated with increasing concentration of nitrate in soil water available for plant uptake. When rainfall or irrigation exceeds the water holding capacity of the soil some of the resident soil water, containing nitrate, is displaced below the active soil layer so that the nitrate is no longer accessible to plants. Observations of nitrate leached from highly-productive dairy farming in New Zealand (Figure 6-1) show that the concentration of nitrate in leachate, from this particular management regime, is relatively constant between regions with different hydrology but the mass leached per area (kg/ha/y) depends on the amount of soil-water drainage.
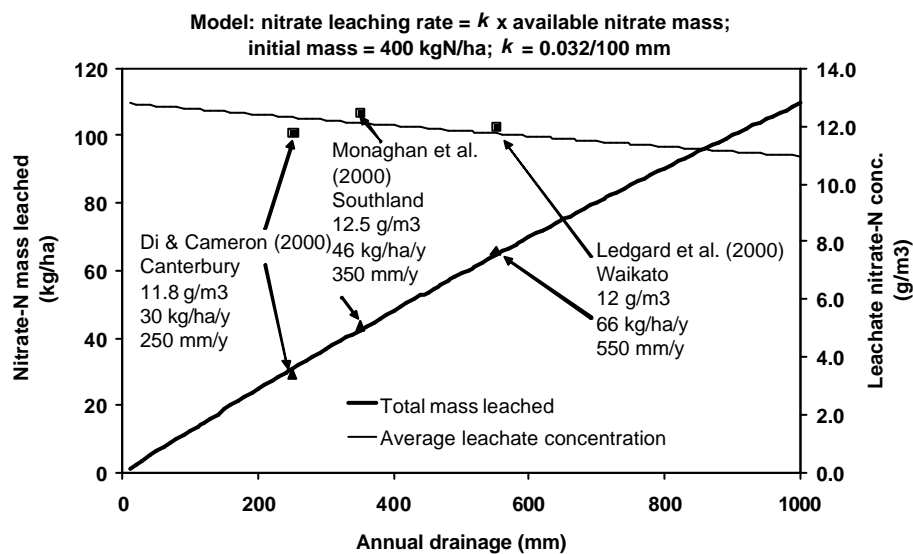
Figure 6-1: **Leached nitrate mass (kg/ha/y) for dairy farming in different regions can be described by a simple leaching model that demonstrates the small variation of nitrate concentration in the leachate (Bidwell, 2002).**

It is now accepted practice for environmental management in New Zealand to characterise the environmental effects of nitrate leaching from rural land use in terms of a value of nitrate concentration (g/m^3 or mg/L) and a value of mean annual drainage (mm/y). The nitrate mass leached ($kg/ha/y$), which may be more familiar to the agricultural community, is derived as:

$$\text{nitrate mass leached (kg/ha/y)} = \frac{\text{nitrate concentration (g/m}^3) \times \text{drainage (mm/y)}}{100} \quad \textbf{(1)}$$

6.1.2. Source split

Most of the nitrogen on rural land, in the nitrate form as a diffuse area source, is resident within the soil profile. Therefore, the relative amounts that are transported to surface water directly, or via groundwater are determined by the interaction of flow processes with soil water. Preliminary results from recent experiments on a steep hillslope in Waikato indicate that as much as 80% of the total drainage from this kind of catchment has passed through the soil profile to groundwater. Overland surface runoff is infrequent and is a small proportion of total drainage. The remaining portion of the 20% non-groundwater flow is considered to be saturated flow above less permeable subsoil, which has passed through the soil profile but may emerge further down the hillslope. The proportion of direct flow to surface waters would be expected to decrease for less steep catchments and those with more permeable subsoil. One exception to this guideline is for pasture with low permeability subsoil (poorly drained soils) in which artificial subsurface drainage is installed. These drainage systems can rapidly deliver soil water, surplus to the soil capacity, to surface streams. The discharges are point sources to the stream, but are more conveniently treated as diffuse sources at catchment scale.

Installed drainage is more likely on lowland catchments with mild surface slopes, where the cost is justified by more productive pasture and improved animal health. Experimental results in Southland (Monaghan et al., 2000) showed that surface runoff from cattle-grazed pasture contained very little ($< 5\,kg\,N/ha/y$) nitrate whereas the installed mole-tile drainage system discharged up to $56\,kg\,N/ha/y$ (for the most intensive treatment). Measurements of water flow from the installed mole-tile system, for one year, (Monaghan et al., 2002) accounted for about 25% – 75% of the total drainage volume (from water balance) of 366 mm, depending on soil type at each of the six experimental plots. The average nitrate concentration ($6.9\,g/m^3$) is consistent with the land use (no applied fertiliser, 2.3 cows/ha). Results of this kind suggest that installed subsurface drainage delivers water of the same nitrate quality as is leached to groundwater, but without the opportunity for further nitrogen transformation.

6.1.3. Delivery to groundwater

Flow of soil water drainage through the vadose zone (the unsaturated soil below the plant roots) to groundwater is predominantly vertical because of the constant influence of gravity in relation to any incipient horizontal pressure gradients that are rapidly equalised by small changes in unsaturated water content. Regions of saturated flow can occur in the vadose zone where there are layers with insufficient vertical hydraulic conductivity, or at the boundaries of layers with certain kinds of contrast in water retention characteristics. At these saturated regions water can move with a horizontal component and appear on the land surface as a seep or spring. However, these horizontal flow paths usually constitute only a very small part of the drainage. Even subsoil layers with hydraulic conductivities of only a few millimetres per day, often deemed to be impermeable, are sufficiently conductive to transmit the mean annual drainage in a catchment that, in Waikato, is typically less than 1000 mm/y (~ 3 mm/d). As water moves deeper into the vadose zone, time variations in drainage from the soil layer become more attenuated and flow rates tend more towards time-averaged values.

The vertical delivery of soil-water drainage to the groundwater surface provides recharge that can be spatially variable as it depends on the drainage rates and nitrate concentrations of the land use directly overhead. There is probably very little lateral (horizontal) dispersion in the vadose zone of vertical recharge between areas of different nitrate production, such as a catchment with areas of forestry (low nitrate, lower recharge) and pasture (higher nitrate, higher recharge). This spatial variation of nitrate delivery is relevant to groundwater interaction with streams (see Section 9.1.2).

6.1.4. Attenuation

Attenuation of nitrate, in the present context, refers to processes that convert nitrate to other forms of nitrogen that are not relevant to in-stream processes. Dilution of nitrate, without transformation, is treated separately by SPARROW. For nitrate that is leached below the root zone, denitrification is the only transformation process that provides a permanent sink for nitrogen (Korom, 1992), in the form of conversion to gaseous nitrous oxide and nitrogen. Denitrification is a microbially mediated process, requiring anaerobic conditions, which can be classified into two types according to whether the electron donor is organic (heterotrophic bacteria) or inorganic (autotrophic bacteria). Suitable inorganic reducing agents commonly found in groundwater are manganese (Mn^{2+}), iron (Fe^{2+}) and sulfides. It is commonly reported that groundwaters containing Fe^{2+} are low in nitrate, and there is some debate about whether this can also occur as an abiotic chemical process (Korom, 1992). Iron and manganese are widespread in New Zealand groundwaters (Daughney, 2003)

The required anaerobic conditions can occur in the saturated regions of the vadose zone, such as in poorly drained soils, in the groundwater itself, or in riparian areas at the aquifer-stream interface. Although these denitrification processes are well recognised and are the subject of experimental investigation there are almost no data that can be applied at catchment scale. However, the possibility of these processes occurring should be recognised in the formulation of the SPARROW model.

6.1.5. Groundwater – stream exchange

Most of the water flowing in streams is from groundwater, but the groundwater "catchment" does not necessarily coincide with the surface topography that is usually considered to delineate a catchment. There are practical difficulties in defining groundwater catchments because (1) they are not observable from the land surface and (2) groundwater flow systems of different magnitudes can be superimposed vertically on one another (Winter et al., 2003). The boundaries of these unconfined groundwater flow systems are defined primarily by the distribution of recharge inflow and the location of outflow surface water bodies rather than geological structures. The boundary of a groundwater system can vary as recharge varies. This disparity between topographical catchment and groundwater extent is especially relevant to lakes and wetlands because they may interact with larger and deeper groundwater systems if the location of the surface water body is further down slope in a topographical catchment. Figure 6-2 illustrates how surface water bodies may have groundwater catchments that differ from the topographical catchment.
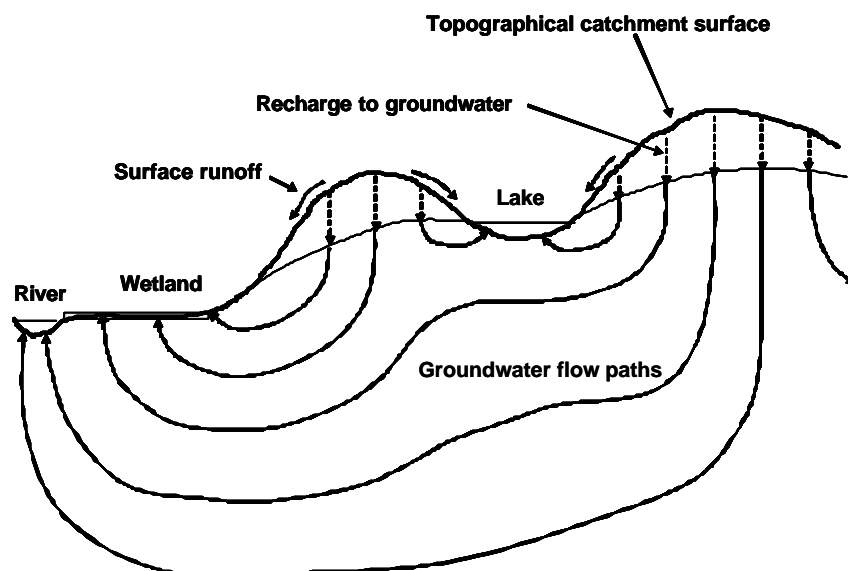
Figure 6-2.: **Hydrologic section of a hypothetical catchment, showing how surface water bodies can receive groundwater from various parts of the topographical catchment that do not coincide with the upslope areas.**

Streams can interact with groundwater by only gain or loss of water within a particular reach, or by gain and loss at different times within the same reach. For some streams on alluvial outwash fans near hills, for example, there is loss of streamflow to groundwater without any interaction between the state of groundwater and the magnitude of this loss.

There is little useful data for quantifying interactions between surface water and groundwater, other than for the more "conventional" catchment for which a workable guideline is that most (> 80% ?) of the recharge through the land surface flows, via groundwater, to the nearest reach of the stream. However, the "unconventional" situations need to be (and can be) recognised within the SPARROW formulation so that simulations can be run for investigating possible causes of anomalous observations of nitrate concentrations in streams. In order to incorporate this kind of modelling capability, cross connections between the groundwater network and the streamflow network do allow for a proportion (not yet quantified) of the nitrate load from an area element to contribute to any of the downstream stream reaches before being subject to instream attenuation.

6.2.   Review of SPARROW model concepts

The existing SPARROW model (Alexander et al, 2002) has 3 conceptual components that are used to model stream water quality:

1.   Source calculation (can be several sources for each stream)

2.   Delivery from Source to Stream (or other water body)

3.   Attenuation within Stream/Reservoir (or other water body)

The existing SPARROW model can be visualised as in Figure 6-3.

S = source calculation
D = delivery to Stream
A = Attenuation in Stream
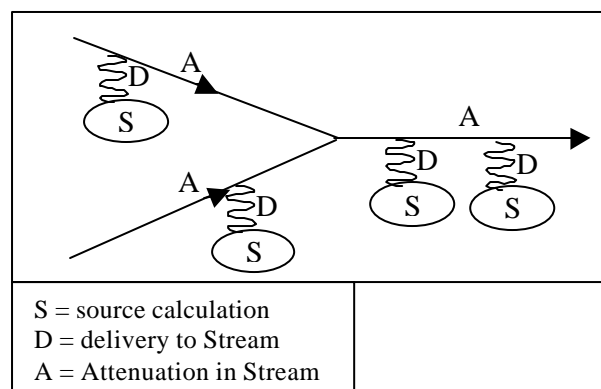
Figure 6-3:   Simple sketch of the SPARROW model

The SPARROW model has now been extended to include a simple groundwater component as shown in red in Figure 6.4.

S = stream source
D = delivery to Stream
A = Attenuation in Stream

S=g/w source
D=delivery to g/w
A=attenuation in g/w
E=stream-g/w exchange
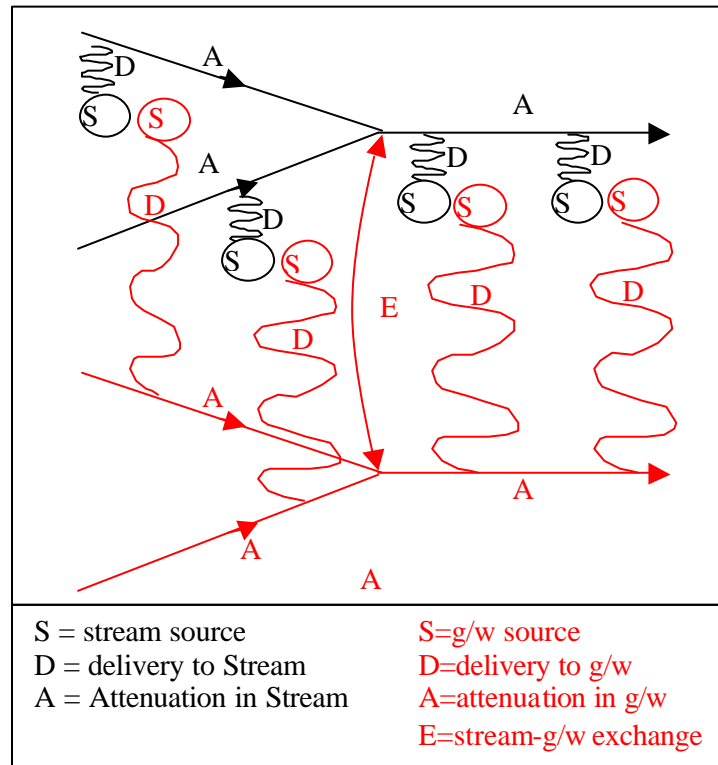
Figure 6-4: **Extension to SPARROW to include groundwater (the red lines represent new components associated with groundwater)**

Several points should be noted about the above extension:

1. Sources (S and S) are split between surface and groundwater (Lincoln Ventures are estimating the surface-vs-g/w proportions). Probably expect point sources to be all 100% surface source

2. Need to parameterise the delivery function (D) for percolation of each contaminant to g/w

3. Need to estimate attenuation (A) of each contaminant in g/w

4. In some settings we may need to estimate the fraction of river water which is diverted to g/w (E: red downward link)

5. May need to estimate fraction of g/w flow which is diverted to river water (E: red upward link)

The extended model has been coded as an enhancement to SPARROW, and will be called from the Desktop Tool using the same approach as shown in Figure 5-4. The parameterisation of the groundwater component is described in the following two sub-sections.

6.3. SPARROW description of groundwater processes

6.3.1. Nature of the source

Each land area polygon within the database can be characterised in terms of:

- Area (ha)

- Mean annual drainage associated with climate and land use (mm)

- A nitrate concentration associate with the land use (g/m^3)

6.3.2. Source split

The split in nitrate flux, between direct to stream and via groundwater, should be calculated from the respective components of water flux and the nitrate concentration associated with each component (Section 6.1.2). Suggested classifications for different split coefficients are:

- Steep slopes

- Mild slopes with no installed drainage

- Mild slopes with installed drainage

6.3.3. Delivery to groundwater

The vertical transport path from land surface to groundwater has the following effects on pathways in groundwater:

- Source areas are associated with particular stream lines in the groundwater flow (Figure 6-2)

- The depth of the stream line below the groundwater surface increases with the distance of the source area from the surface water body that is the outflow location (Figure 6-2)

6.3.4. Attenuation

The length of stream is an important factor in controlling in-stream attenuation of nitrogen, but attenuation in soils is different. Denitrification processes in the soil and vadose zone are not usually associated with a transport distance, so a simple reduction factor is adequate to quantify attenuation, where sufficient information is available. Further information on attenuation in soils is given in Table 9-2, and this, combined with other research, may be used in future to provide quantitative estimates of attenuation by denitrification in the riparian zone.

Chemical reduction within an aquifer (below the soil and vadose zone) is more amenable to inclusion of a transport distance, if such knowledge is available. Therefore, the exponential type of term already used in SPARROW could be retained, with a default rate coefficient equal to zero.

6.3.5. Groundwater – stream exchange

The existing SPARROW formulation allows for the association of surface water reach j with source-related polygons k, each of area $A_{j,k}$. This formulation would be sufficient for relating reaches to source areas through groundwater transport. The set $P(k)$ of polygons could be a subset or superset of those enclosed by the topographical catchment. The concept of a parallel network of groundwater reaches does not directly address the vertical superposition of groundwater bodies within the same topographical catchment. This more sophisticated view of groundwater will need to be accommodated at a later stage of the project.

6.4. Recommended parameter values

6.4.1. Source concentrations

Table 6-1 shows the source nitrate concentration (g/m^3), within the soil profile, for the selected rural land uses. These values are multiplied by mean annual drainage (100 mm/y), as in equation (1) (see Section 6.1.1), to obtain the nitrate flux (kg/ha/y).

The values in Table 6-1 could be replaced by results from appropriate management scenarios for the OVERSEER model.

Table 6-1: **Nitrate concentration in soil-water drainage from rural land uses.**

Land use	Nitrate concentration (g/m^3)
Dairy pasture	12[1]
Cattle pasture	8[2]
Sheep pasture	3[3]
Forest	1[4]

(1) Di and Cameron (2000), Monaghan et al. (2000), Ledgard et al. (2000). See Figure 6-1.

(2) Monaghan et al. (2000); no applied fertiliser.

(3) Ruz-Jerez et al. (1995); New Zealand study of clover-based pasture.

(4) Based on pasture/forest comparison in Quinn and Stroud (2002; Table 3).

6.4.2. Source split

Table 6-2 shows the split between direct runoff to surface waters and drainage to groundwater, for water flux, the ratio of nitrate concentrations in the two water fluxes, and the derived split of nitrate flux as:

$$\text{Nitrate flux fraction} = \frac{\text{Annual drainage fraction} \times \text{Nitrate concentration fraction}}{\text{Total nitrate flux}}$$

$$\text{Example : Steep, undrained} = \frac{0.8 \times 1.0}{0.8 \times 1.0 + 0.2 \times 0.0} = 1.0$$

(2)

Table 6-2: **Source split at land surface: (groundwater: direct runoff).**

Slope & drainage	Mean annual drainage	Nitrate concentration	Nitrate flux[1]
Steep, undrained	0.8 : 0.2	1.0 : 0.0	1.0 : 0.0
Mild undrained	0.9 : 0.1	1.0 : 0.0	1.0 : 0.0
Mild drained	0.6 : 0.4	1.0 : 1.0	0.6 : 0.4

(1): Calculated from equation (2)

6.4.3. Attenuation

In the absence of New Zealand data for nitrate attenuation in groundwater, the rate coefficient in a SPARROW-type formulation should be set to a default value of zero.

6.4.4. Groundwater – stream exchange

In the proposed groundwater extension to SPARROW (Section 6.2), the initial default connections for the network would be to deliver groundwater from the same topographical catchment as the surface runoff to the corresponding stream.

6.5. Initial results

The concept of the groundwater extension as described above was implemented in FORTRAN code into the Sparrow model. Five additional model parameters need to be provided for each subcatchment (Table 6-3). As an initial test, the extended SPARROW model was run with the groundwater component switched off, to check that it produces the same results as the original SPARROW model (Figure 6-5).

Table 6-3: **Additional model parameters for the Sparrow groundwater extension.**

Parameter	Range	Description
SourceSplit	[0,1]	Amount of source quantity going into stream.
		Dependent on catchment characteristics.
DeliveryGW D	[0,1]	Amount of source reaching GW.
		Dependent on subsurface material.
GWFrac F	[0,1]	Diversions from groundwater (for future use)
		Must be gathered from databases per reach.
GWAtt A	[0,1]	Attenuation in aquifer. Measure of fraction of contaminant, which is lost on its way in aquifer.
GWEx E	[-1,1]	Exchange groundwater with stream. −1: all GW contamination exfiltrates to stream; 1: all stream contamination is infiltrating to GW.

The SourceSplit factor was calculated for each subcatchment separately according to Table 6-2. As information about catchment artificial drainage was not yet available, only catchment slope angle was taken into consideration: steep: all to groundwater, mild: 0.8 to groundwater (drainage more likely). Groundwater delivery (D) was modelled as D=1: all source contributions are delivered to the aquifer. No groundwater diversions were incorporated (F=0). Groundwater attenuation (A) was parameterized as 0: no contaminant is lost from the aquifer. Groundwater-stream exchange (E) was modelled in several different scenarios, to test and improve the model performance (Figure 6-6, Figure 6-7). Different, spatially uniform, parameter values for stream-groundwater exchange (E in Table 6-3) were tested, and the results are shown in the next 2 figures.
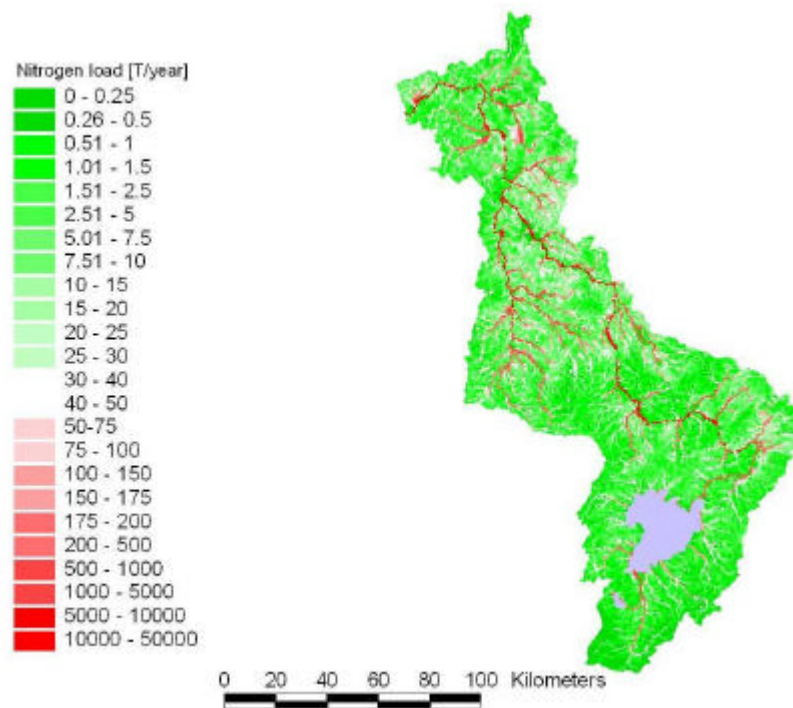
Figure 6-5: Stream nitrogen load from SPARROW, for Waikato catchment. Scenario: no groundwater component. Model calibrated to stream N data. (for comparison with Figure 6-6 and Figure 6-7)
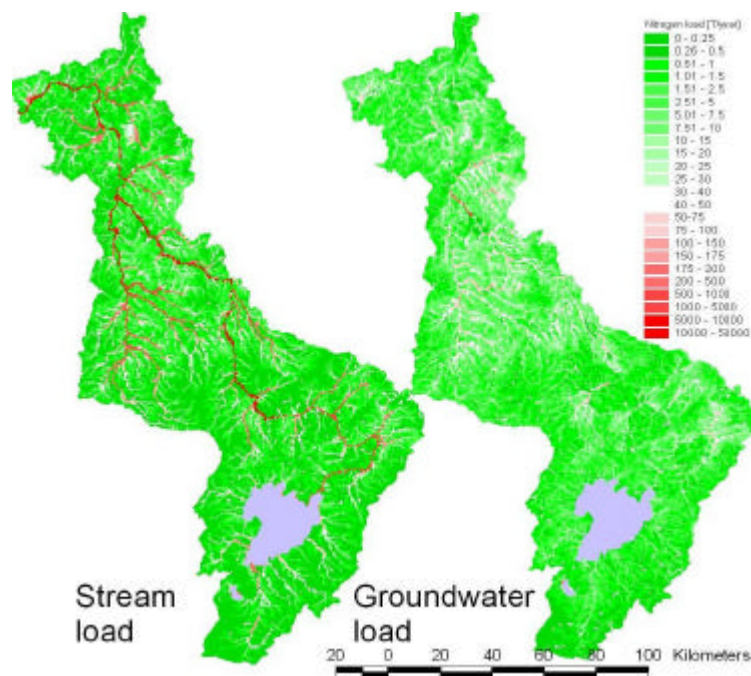
Figure 6-6: Stream and groundwater nitrogen load from extended SPARROW model. Scenario: groundwater component is on, SourceSplit set using Table 6-2, the stream-GW exchange is 20% of G/W flux, from G/W to stream.
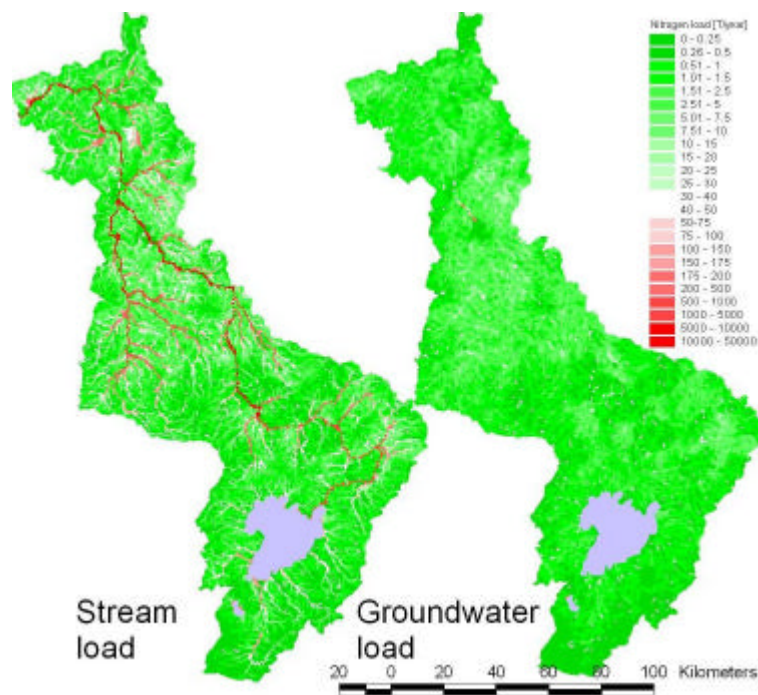
Figure 6-7: **Stream and groundwater nitrogen load from extended SPARROW model. Scenario: groundwater component is on, SourceSplit set using Table 6-2, stream-GW exchange is 50% of G/W flux, from G/W to stream.**

It can be seen that a 50% contaminant exchange from groundwater back into the stream (Figure 6-7) results in a similar spatial pattern to the calibrated SPARROW without a groundwater component (Figure 6-5). The 50% figure means that half of the lateral groundwater flow entering a node is diverted to the stream, and the other 50% continues to flow laterally in the groundwater system. More effort is needed to parameterise the groundwater-stream exchange, so that the spatially-varying emergence of groundwater into streams is adequately represented.

7. Enterprise-scale modelling for pastoral agriculture (AgResearch, Objective 4a)

The OVERSEER® model can be used to estimate N leaching from pastoral agriculture. OVERSEER® is intended to be run automatically from the catchment modelling framework (Section 5), for representative case studies that cover all pastoral agriculture in the catchment of interest. The links between the OVERSEER® model and the framework are clearly specified, and no particular difficulties are expected in linking it so that it will provide N leaching results for a particular farm. A detailed design has been completed to specify the information to be exchanged between OVERSEER® and the modelling framework. More work is needed on the

identification of representative ranges of rainfall, soils and topography for each of the farm types (scenarios) described in Section 7.2.

The proposed method of implementation of the OVERSEER® nutrient budget model into the GIS modelling framework is described within the following section. A more detailed report is available in Section 15, including a description of the OVERSEER® model, its assumptions, input data requirements, and some case studies to illustrate its application.

7.1. Implementation method

The calculation part of the OVERSEER® nutrient budget model will be reworked so that a dynamic linked library (dll) or similar is supplied and linked to the GIS framework. An initialising routine will also be added that translates the scenario number input into OVERSEER® nutrient budget model input data, and performs validation checks.

The model will be initiated with a call to a procedure:

Ovr(Valid, message, Nleach, Ploss, scenario, region, soilorder, rainfall, topography)

where:

Variable	Type	Comment
valid	Boolean	if true then Nleach and Ploss have a value
message	shortstring	description of error
Nleach	real	amount of N leached below the root zone
Ploss	real	amount of P loss in runoff from the block
scenario	integer	selected scenario
region	integer	region (based on regions used in the nutrient budget model)
soilorder	integer	code for soil order
Rainfall	integer	annual average rainfall to nearest 100 mm
Topography	integer	topography

A negative number for soil type, rainfall or topography would imply that a default value is used.

In addition, the following would also need to occur:

- Information will need to be provided to translate supplied soil order data into OVERSEER® nutrient budget soil group or soil order indices. This translation

could be done either at the GIS end or within the OVERSEER® nutrient budget initialisation program.

- Regional layers equivalent to OVERSEER® nutrient budget region layers should be established within the GIS system. These can be developed separately from district council or regional council boundaries or such like. Alternatively, indices of district council or regional areas can be sent to the OVERSEER® nutrient budget model dll and region assigned internally.

- Scenario numbers and descriptions of the scenarios will be supplied. Methods of extending these are detailed in the full report in Section 15.

- Method to estimate block topography would need to be established. Note that it is not the point slope. For P runoff, average slope may be more valid.

- A list of possible input variables from the GIS application will be supplied.

It is also assumed that the GIS application would control calls to the dll. Hence regions with the same input parameters could be populated with the one call.

If the parameter valid is true, no errors were encountered and a valid calculation was performed, with the results stored in Nleach and Ploss. Otherwise, Nleach and Ploss are zero, and a message indicating the possible source of the error is contained in the message string.

The procedure calls can be expanded by increasing the range of valid scenarios allowed and/or adding additional input variables to the call function.

A preliminary simplified dll has been supplied for initial testing as part of this report. This dll can be used to identify issues around integration of computer software. It does not contain any scenarios or OVERSEER® nutrient budget program information and this would need to be covered in another contract (see Section 7.6)

7.2. Initial scenarios

The initial scenarios selected to be included in the first implementation of the OVERSEER® nutrient budget model into the catchment modelling framework (Section 5) will use a range of land uses rather than management options. The reasons for this are that:

- Land use can be identified from current inventory layers, or can be estimated from current broad scale information.

- It is possible to generate typical land use scenarios from current data.

- Currently there is insufficient data to indicate the range and scope of management options that have been implemented within a land use.

- The typical range of land uses and management options will vary considerably between regions

Therefore it is recommended that the initial land use scenarios be:

- Typical dairy farm

- Sheep/beef, including typical high country/extensive, hill country sheep/beef, and a lowland intensive sheep/beef

- Deer farm

7.3. Future scenarios

The method of implementation described above has the ability to expand to include a wider range of scenarios, and/or more productivity data. These are detailed in Section 15.

7.4. Research updates

The OVERSEER® nutrient budget model is being updated at regular intervals as new research becomes available, and as typical farm management changes occur.

Supplying a dynamic linked library (dll) in the form suggested means that it would be relatively simple to update the catchment modelling framework at the same time that the OVERSEER® nutrient budgets model is also updated.

Another consideration is that some of the future developments in the OVERSEER® nutrient budgets model may be covered by third party IP. It is probable, but not certain, that these developments can be passed on to other parties such as the catchment modelling framework, if the information is supplied as above. Past experience has shown that these developments are more easily passed on if they are encapsulated within a more secure software package such as a dll.

7.5. Validations/constraints

Use of scenarios provides a means to generate land use patterns. However, some validations and constraints are required to ensure valid outputs. These are in the following 4 broad categories:

- Input variables are within range. This can be handled within the initialisation program.

- Inputs are aligned with one another. For example, if intensive dairy is selected on low rainfall areas, then it may be necessary to assume that some supplements are being brought onto the farm, or that irrigation is used. Validation routines to cover these types of errors can be included within the initialisation program.

- For a given pixel, any scenario selected can be farmed both practically and economically.

- Realistic assumptions are made about the distribution of land uses within a catchment.

It is also important that the scenarios capture the associated farm management set up. For example, bringing supplements onto the farm can represent a significant import of nutrients onto the farm (Wheeler et al. 2003) and result in the need to increase effluent block sizes to maintain N application rates within an allowed range.

7.6. Creation of call and scenarios

The creation of the dll and initial scenarios will need to be covered in the nest stage of this project. Part of the contract for that work would include a licence agreement to use the OVERSEER® nutrient budget model.

7.7. Recommendations

It is recommended that the OVERSEER nutrient budget model be integrated into the catchment modelling framework as outlined in Section 7.1, with initial scenarios as outlined in Section 7.2.

It is also recommended that further scenarios be developed. In developing these scenarios the following points should be considered:

- Within a land use, N leaching and P leaching/runoff losses usually increase as the farm system is intensified (Power et al. 2002) unless specific mitigation options are used. As nitrogen losses are driven predominately by urine N deposition, the method of intensification (e.g., higher fertiliser use, better pasture utilisation, and increased use of supplements) is less important than the total intake of N.

- Within the OVERSEER® nutrient budget model, the primary drivers for estimation of N intake are milksolids production for dairy systems or number of stock units (SU) for sheep/beef systems. Other factors, e.g., supplement imports, also affect intake calculations.

- Distribution of stock types and farm management systems does vary between regions (Agriculture Statistics 2002). While many of the differences can be covered by defined farm management scenarios (e.g., intensive sheep/beef system), there are some farming systems that are region specific e.g., dryland farming in non-irrigated parts of the East Coast, merino systems in the South Island high country.

- There is a wide range in farm productivity between regions e.g., average milksolids production ranged from 629 to 1024 kg milksolids/ha and average number of cows in milk from 1.8 to 3.0 cows/ha between regions (Dairy Statistics 2001). These ranges in production are probably associated with other farm management system differences such as use of supplements, rates of N fertiliser). Within sheep/beef farms, average stocking rates between regions and farm types varied from 1.5 to 13.5 SU/ha (MAF 2003).

- There are regional differences in the types of supplements. For example, maize silage is mainly used in the North Island, cereal and triticale silages are manly used in the South Island, and vegetable, fruit and processing by-products are confined to areas where these activities occur (P Sharp, feedTech, pers. comm.). The type of supplement can alter the N use efficiency (Ledgard et al. 2000) and hence changes the relationship between intensification and N loss.

- Regional differences in management do occur. For example, grazing animals off over winter or use of a stand-off or feed-pad have the potential to reduce N leaching by up to 60% (de Klein et al. 2000). This practice appears to be more common in Southland than elsewhere.

- For P losses, regional differences are mainly associated with soil and climate differences. However, there are some regional differences in farm management

practices that may affect P losses, e.g., on some Southland soils, a significant amount of P loss was occurring through tile drains (Monaghan et al. 2003).

Given these region differences, it is recommended that typical regional scenarios are developed based on data such as that used by the MAF farm monitoring system. Additional information to that already collected as part of the MAF farm monitoring system would be required and the collection and analysis of the data would be covered under a separate contract.

8. Enterprise-scale modelling for horticulture (HortResearch, Objective 4b)

The Soil Plant Atmosphere System Model (SPASMO) can be used to estimate N leaching from land being used for horticultural cropping. In this first year of the project, it is being used to generate information on N leaching for case studies, which have then been used for the triple bottom line modelling work (Section 10). The SPASMO model is the most numerically detailed of all the models in this project, and requires a long sequence of site-specific daily climate information as input data. Links between the SPASMO model and the catchment modelling framework (Section 5) are not yet clearly defined. Ideally, the SPASMO model would be linked into the modelling framework in the same way as OVERSEER, that is, as a model which can be run automatically from the framework, for representative case studies that cover all horticultural crops in the catchment of interest.

In the initial phase of this work, carried out under contract to NIWA, we have run our Soil Plant Atmosphere System Model (SPASMO Version W1.2) for five enterprise scenarios (each with some internal variations) over 32 years. The output data from these simulations is presented in the form of a daily time-series of the nitrogen concentration in the soil solution, in mg-N/L, as it leaches below the root zone. Also provided is a statistical analysis of the cumulative probability of exceedence of the N-concentration in that leachate water which enters groundwater, at the specified depth. Because the flux of drainage water is also calculated as part of the SPASMO simulations, the calculations can also be given in terms of the loading of nitrogen (kg/ha/day) upon the groundwater. Details of the SPASMO model are given in Section 13 of this report. The five scenarios we have examined are:

Grapes - Marlborough (Fairhall stony silt loam) with a water table at 2, 3, and 4 m deep, and 20 kg-N/ha of Calcium Ammonium Nitrate fertilizer (Ca.NH4.(NO3)2) applied in mid-October. The varying water table reflects local variations to cover the range experienced in this local region.

Grapes - Hawkes Bay (Maraekakaho) with a water table at 3, 5 and 7 m, and 30 kg - N/ha of CAN applied in mid-October. This covers water-table variations experienced in this area.

Kiwifruit - Bay of Plenty (Maketu) with a shallow water table at 3.5 m and totals of 100, 200 or 400 kg - N/ha applied in two split applications: September and November.

Apples - Hawkes Bay (Twyford) with a water table at 3 m and 50 or 100 kg - N/ha applied in spring.

Potatoes - Waikato (Matamata) with 200 kg - N/ha applied over the year according to grower practice with a water table at 3 m.

Results are given below for each of the five scenarios.

8.1.   Grapes - Marlborough

Grapes - Marlborough (Fairhall stony silt loam) with a water table at 2, 3, and 4 m deep, and 20 kg-N/ha of calcium ammonium nitrate (CAN) applied in mid-October.

The results from applying our SPASMO model to these scenarios are shown in Figure 8-1 and Figure 8-2 for nitrate-N, and summarised in Table 8-1. As part of these calculations, ammonium-N concentrations are always calculated, although these are not presented here. In Figure 8-1, the daily nitrate-N concentrations are shown for a 10-year window.
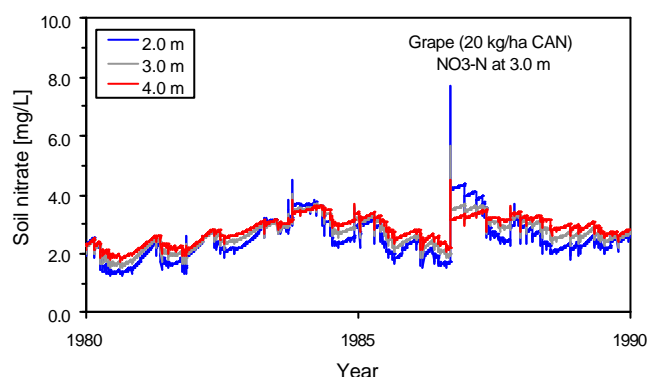
Figure 8-1:   **The SPASMO-Predicted concentration of nitrate at a depth of 2.0, 3.0 and 4.0 m under a vineyard growing on the Fairhall stony silt loam in Marlborough. A single dose of $CaNH_4(NO_3)_2$ fertilizer was applied at a rate of 20 kg-N/ha on the 15th October each year. The World Health Organization has set the maximum allowable value (MAV) of 11.3 mg-N/L for nitrate in the drinking water. While the nitrate levels are elevated, the concentrations are less than half the MAV.**
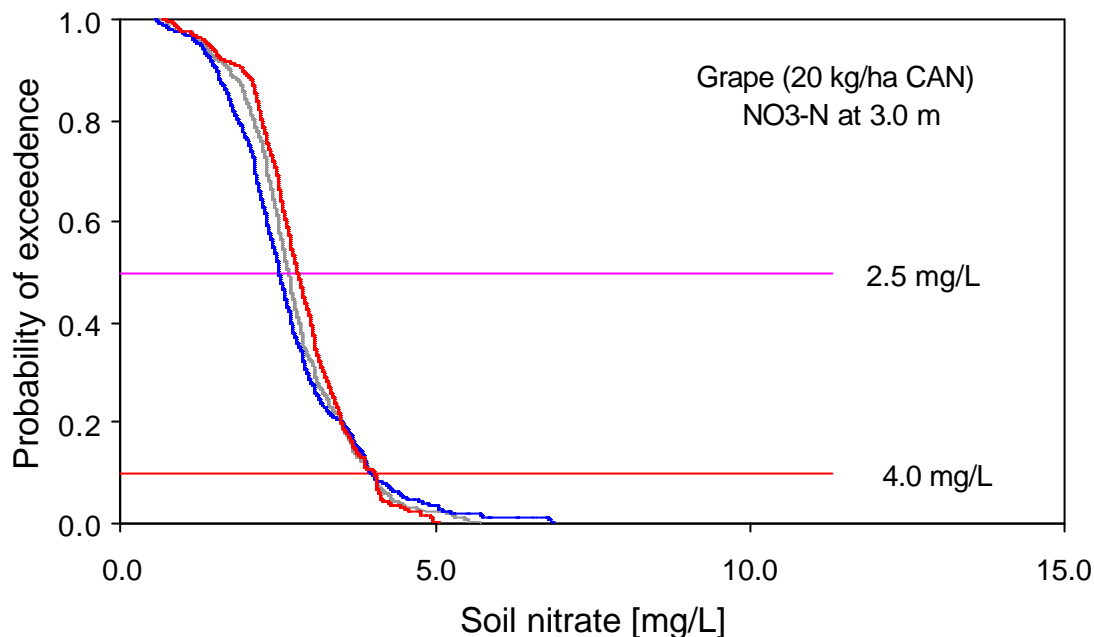
Figure 8-2: Probability of exceedence for nitrate concentration under a vineyard growing on the Renwick stony silt loam in Marlborough. The nitrate-N concentration below the root zone is almost always less than the MAV of 11.3 mg-N/L. The concentration does not change much with depth because denitrification losses are small below the root zone. Nitrate poses a small threat of contamination to the shallow groundwater.

Table 8-1: Annual nitrogen budget for a grape vineyard in Marlborough. Total nitrogen uptake by the grape vines is 54 kg/ha. Some 13 kg is in the harvested fruit, 50 kg N/ha is returned to the soil in the form of leaves and roots, and winter prunings, and ~13 kg/ha is lost back to the atmosphere as volatilisation and denitrification. In this scenario, surplus nitrogen is consigned to drainage water.

Nitrogen budget of grapes [kg/ha N]	
Fertilizer	20
N uptake	54
fruit	-13
recycled	50
volatilization	-7
denitrification	-6
mineralization	44
drainage	-10

In Figure 8-2, the cumulative distribution of the probability of exceedence is shown for nitrate-N, considering the water-table to be at various depths. These data derive from the nearly 12,000 daily-values simulated over the 32-year period using actual weather data from Woodbourne

8.2. Grapes - Hawkes Bay

Grapes - Hawkes Bay (Takapau sandy loam) with a water table at 2, 3 and 4 m, and 20 kg - N/ha of CAN applied in mid-October. This scenario covers the shallow water-table variations experienced in this area.

A SPASMO simulation was carried out to consider the establishment of a new vineyard at Maraekakaho (Figure 8-3). New vineyards are being developed in this area, where the grapes are grown on permeable soils overlying an unconfined aquifer.
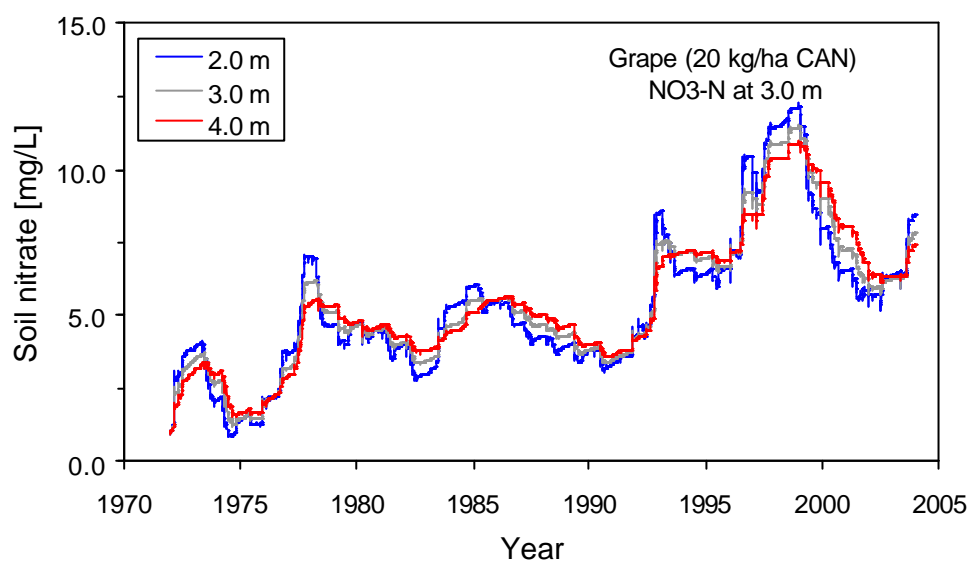
Figure 8-3: **Predicted concentration of nitrate in the soil under a vineyard at Maraekakaho that receives an annual dressing of nitrogen fertilizer at a rate of 20 kg-N/ha. The concentration is trending towards the WHO drinking water standard of 11.3 mg-l for nitrate.**

As can be seen from Figure 8-3, as the vineyard becomes established, the fertiliser practices of just 20 kg-N/ha/yr will lift leachate levels close to the WHO limit, depending on the depth of the aquifer. Only about 15 kg-N/ha is removed in the grape berries, and all the prunings are returned to the soil. These results are summarised in Table 8-2

Table 8-2: Annual nitrogen budget for a grape vineyard near Maraekakaho. Total nitrogen uptake by the grape vines is 75 kg/ha. Some 15 kg is in the harvested fruit, 61 kg N/ha is returned to the soil in the form of leaves and roots, and winter prunings, and ~17 kg/ha is lost back to the atmosphere as volatilisation and denitrification. The leaching losses under a vineyard at Maraekakaho is calculated to be some 17 kg N/ha, on average, each year.

Nitrogen budget of grapes [kg/ha N]	
Fertilizer	20
N uptake	75
fruit	-15
recycled	61
volatilization	-11
denitrification	-6
mineralization	77
drainage	-17

8.3. Kiwifruit - Bay of Plenty

Kiwifruit - Bay of Plenty (Maketu) on a Katikati silt loam with totals of 200 and 400 kgN/ha as CAN applied in two split applications: September and November. Vines were irrigated using 25 mm of water applied on the basis of need. Elevated levels of nitrate exceeding the MAV value of 11.3 mg/L nitrate-N are predicted more than half of the time (Figure 8-4, Figure 8.5 and Figure 8.6). There is a 10% probability that the soil-nitrate solution concentration will exceed 20 mg/L. The results are summarised in Table 8-3
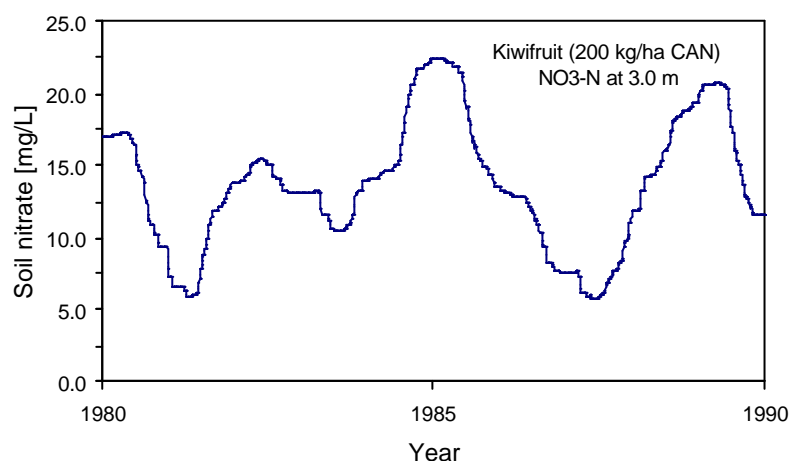
Figure 8-4: Predicted concentration of soil nitrate in drainage water under a kiwifruit vineyard at Maketu near Te Puke. An annual dressing of nitrogen fertilizer has been applied at a rate of 200 kg-N/ha.
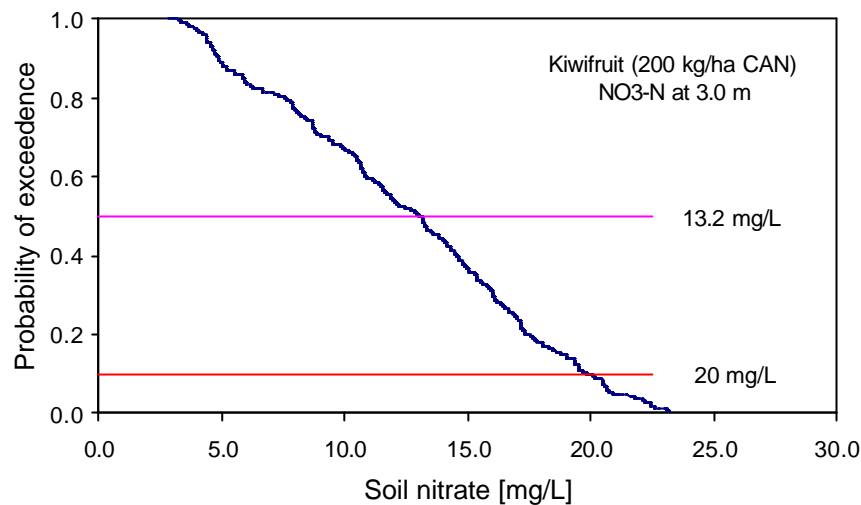
Figure 8-5: Probability of exceedence for nitrate concentration under a kiwifruit vineyard at Maketu near Te Puke that receives 200 kgN/ha nitrogen fertilizer. The nitrate-N concentration below the root zone exceeds the MAV of 13.2 mg-N/L more than half of the time. There is a 10% probability that nitrate concentration exceeds 20 mg/L. Nitrate poses some threat of contamination to the shallow groundwater.
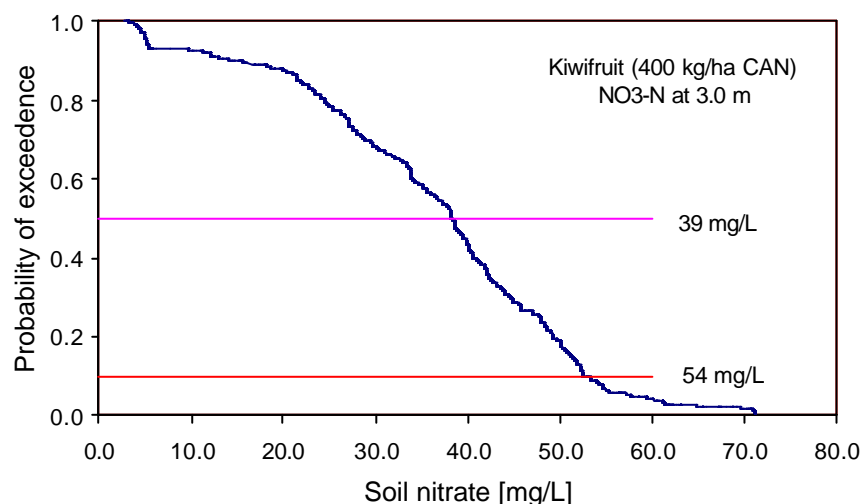
Figure 8-6: Probability of exceedence for nitrate concentration under a kiwifruit vineyard at Maketu near Te Puke that receives an annual dressing of 400 kg-N/ha as CAN. The nitrate-N concentration below the root zone exceeds 39 mg/L more than half of the time. Nitrate poses a much greater threat of contamination to the shallow groundwater.

Table 8-3: **Annual nitrogen budget for a kiwifruit vine yard at Maketu near Te Puke. Total nitrogen uptake by the vines is 165 kg/ha. Some 68 kg is in the harvested fruit, 96 kg N/ha is returned to the soil in the form of leaves and winter prunings, and 60-80 kg/ha is lost back to the atmosphere as volatilisation and denitrification. In this scenario, extra nitrogen fertilizer is consigned to drainage.**

Nitrogen budget of kiwifruit [kg/ha/y N]		
Fertilizer	200	400
N uptake	165	164
Fruit	-68	-68
Recycled	96	96
Volatilization	-24	-44
Denitrification	-33	-45
Mineralization	103	103
Drainage	-106	-295

8.4. Apples - Hawkes Bay

Apples - Hawkes Bay (Twyford) with a water table at 3 m and a nitrogen fertilizer application of 50 & 100 kg - N/ha applied every year in spring. The soil is a Takapau sandy loam (80 % stones beyond 1 m depth). Irrigation of 25 mm is applied each time, on the basis of need. Apple yield is about 50 T/ha. The annual nitrogen balance is presented in Table 8-4. The nitrogen concentration in the drainage water quitting the root zone is low and always less than the MAV of 11.3 mg/L under the 50 kg/ha fertilizer scenario. Figure 8-7, Figure 8-8, Figure 8-9, and Figure 8-10 give details.

Table 8-4: **The annual nitrogen budget for an apple orchard near Hastings. Total nitrogen uptake by the trees is calculated to be 185-200 kg/ha. Some 60 kg of nitrogen is in the harvested fruit, 133 kg N/ha is returned to the soil in the form of leaves and winter prunings, and 18-26 kg/ha is lost back to the atmosphere as volatilisation and denitrification. Nitrate leaching losses are low (~7 kg-N/ha) for the low fertilizer input, and are moderate (35 kg-N/ha) for the high fertiliser input.**

Nitrogen budget of apple [kg/ha/y N]		
Fertilizer	**50**	**100**
N uptake	185	200
Fruit	-60	-60
Recycled	133	133
Volatilization	-15	-18
Denitrification	-3	-8
Mineralization	159	159
Drainage	-7	-35
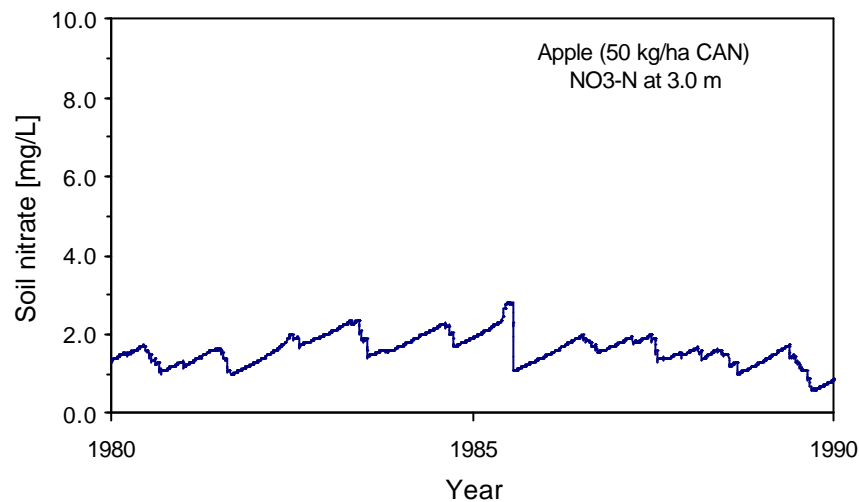
Figure 8-7: **Predicted concentration of soil nitrate in drainage water under an apple orchard near Hastings. An annual dressing of nitrogen fertilizer has been applied at a rate of 50 kg-N/ha. The soil is a free-draining Takapau silt loam with coarse gravel (> 80% stones) beyond a depth of 1.0 m.**
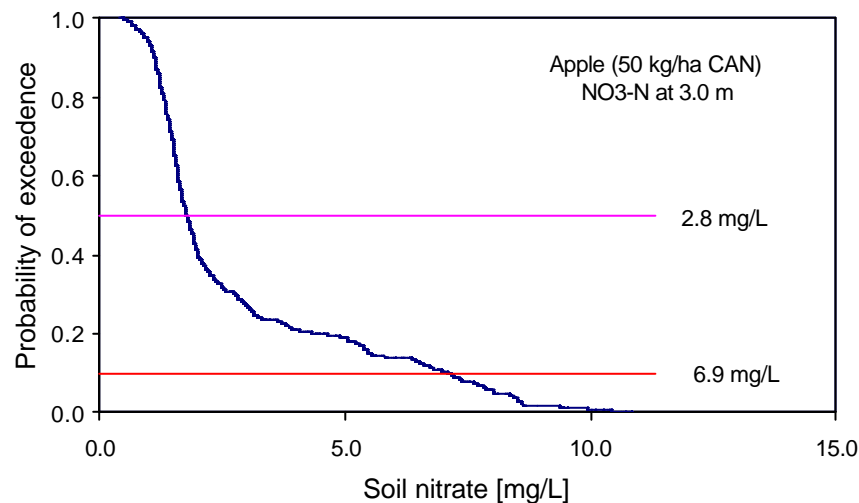
Figure 8-8: **Probability distribution for nitrate concentration under an apple orchard near Hastings that receives an annual nitrogen application of 50 kg-N/ha. The nitrate-N concentration below the root zone exceeds 2.8 mg/L more than half of the time. Nitrate poses little threat of contamination to the shallow groundwater since the concentration in the drainage water is always less than the MAV of 11.3 mg/L.**
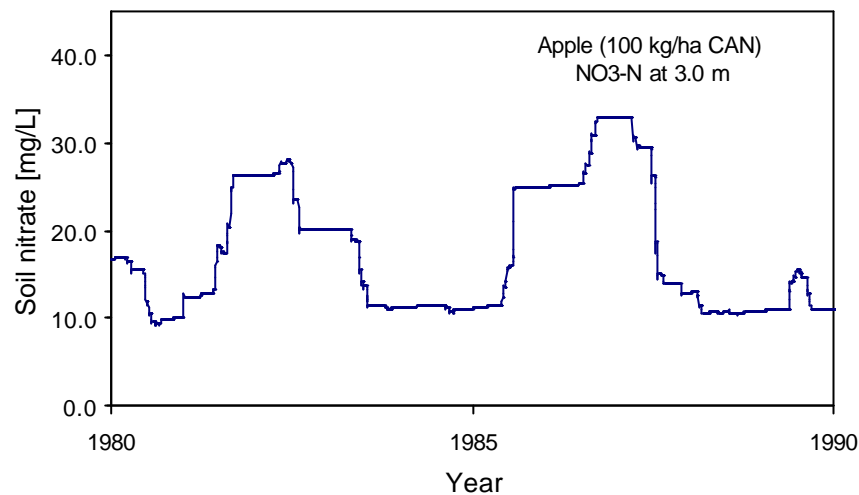
Figure 8-9: Predicted concentration of soil nitrate in drainage water under an apple orchard near Hastings. An annual dressing of nitrogen fertilizer has been applied at a rate of 100 kg-N/ha. Nitrate poses a risk of contamination to the shallow ground water.
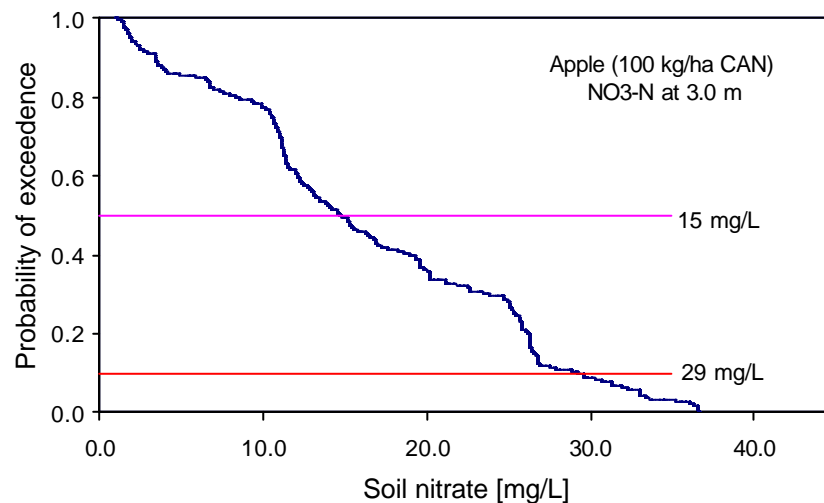
Figure 8-10: Probability distribution for nitrate concentration under an apple orchard receiving 100 kg-N/ha nitrogen fertiliser. The nitrate-N concentration exceeds 15 mg/L some 50% of the time. Nitrate in the drainage water could a threat of contamination to the shallow groundwater. However, drainage losses (see Table 8-4) are moderate because of the low rainfall in the Hawkes Bay.

8.5. Potatoes - Waikato

Potatoes - Waikato (Matamata) with 200 kg - N/ha applied over the year according to grower practice with a water table at 3 m. The soil is a free-draining Horotiu silt loam. Potatoes have a tuber yield of 50T/ha, a dry matter content of 20% and a nitrogen content of about 1.8% in the tubers. See Figure 8-11 for details, and Table 8-5 for a summary of the results.
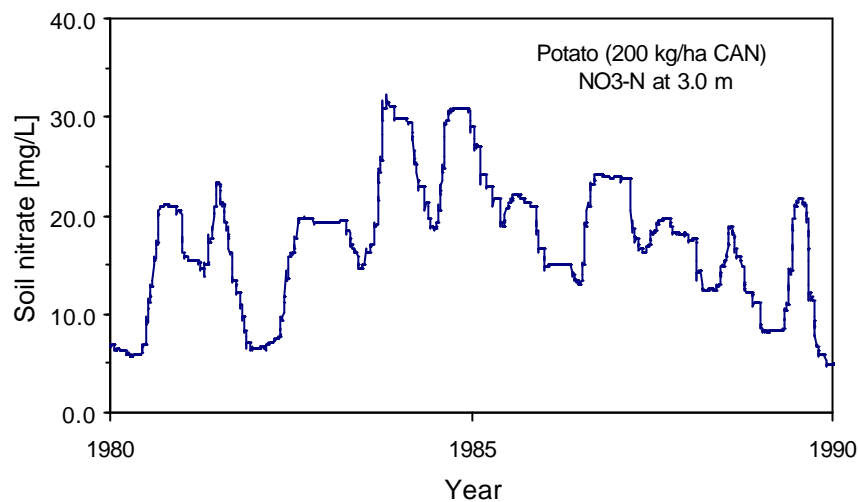
Figure 8-11: **Predicted concentration of soil nitrate in drainage water under a potato field near Matamata. The soil is a free-draining Horotiu silt loam. An annual dressing of nitrogen fertilizer has been applied at a rate of 200 kg-N/ha. Nitrate poses a risk of contamination to the shallow ground water.**

Table 8-5: **The annual nitrogen budget for a potato crop near Matamata. Total nitrogen uptake by the crop is calculated to be 136 kg-N/ha. Some 85 kg of nitrogen is in the harvested in the tubers, 51 kg N/ha is returned to the soil in the form of leaves and winter prunings, and some 59 kg/ha is lost back to the atmosphere as volatilisation and denitrification. Nitrate leaching losses are high (> 100 kg/ha/year) for this level of fertilizer input. A cover crop would normally be used to mop up this excess nitrogen. Here we have simulated the worst case scenario, with bare soil between annual crops.**

Nitrogen budget of potato [kg/ha/y N]	
Fertilizer	200
N uptake	136
Tubers	-85
recycled	51
volatilization	-36
denitrification	-23
mineralization	94
drainage	-113

8.6. Summary of Results for Horticulture Landuse

The average annual leaching losses of nitrate (kg N/ha) are presented in Table 8-6 for a range of horticultural crops. In the case of grapes receiving an annual dressing of some 20 kg N/ha, the annual leaching losses are quite small (i.e. 10-17 kg N/ha). This is because the additional nitrogen fertilizer matches approximately the amount of nitrogen taken off in the grape crop. Similarly, low levels of nitrate leaching (~ 7 kg N/ha) are expected under apples in the Hawkes Bay when nitrogen fertilizer is applied at a rate of just 50 kg N/ha. However, if nitrogen fertilizer is applied at a rate that exceeds the annual crop requirement, than the excess is available to leach. Three scenarios in Table 8-6 (i.e. apples at 100 kg N/ha and kiwifruit at 200 & 400 kg N/ha) have annual leaching losses that will impact on the quality of the shallow ground water. The modelling and risk assessment tools being developed here will help identify those at risk locations and/or poor fertilizer practices.

Table 8-6: **Summary of the average annual nitrogen budget for horticultural land use.**

Crop	Location	Soil series	Fertilizer [kg N/ha]	Uptake [kg N/ha]	Crop [kg N/ha]	Drainage [kg N/ha]
Grapes	Marlborough	Renwick	20	54	13	10
	Hawkes Bay	Takapau	20	75	15	17
Kiwifruit	Bay of Plenty	Katikati	200	164	68	106
			400	165	69	295
Apples	Hawkes Bay	Twyford	50	185	60	7
			100	200	60	35
Potatoes	Waikato	Horotiu	200	136	85	113

9. Pollution Risk Modelling (Landcare Research, Objective 5)

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 waters. 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 (Section 5.2) 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 account of in-stream attenuation processes. The EnSus model can be summarised as a set of rules that combine maps of soil 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 the South Island, North Island (200m raster), and Waikato lowlands. The South Island and North Island maps are intended for large catchment, regional, and national applications. More detailed applications will require analysis based on available higher resolution soil maps. The Waikato lowlands map is provided to show the results that may be obtained from a higher resolution soil map.

9.1.   Vulnerability to Leaching

Three outputs are produced

1. Potential N leaching index for nitrate mobilised from the soil that is likely to contribute to either ground water or surface water N runoff.

2. Likely attenuation of nitrate on route to water bodies, by passage through wet, reduced soils.

3. Intersection of 1 and 2 as an indicator of relative risk of nitrate leaching to water bodies.

9.1.1.   Potential N leaching index

Potential 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 200mm (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).

The potential leaching index was calculated as (RF/ET) * (PAW Factor) * (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 160mm water storage). The PAW multipliers in Table 9-1 are 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 9-1: **Factors to calculate the potential 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%.

9.1.2. 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. 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.

The effect of tile or mole drains where potential attenuation is bypassed is not considered. Attenuation is predicted by two means:

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

2. 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.

The attenuation effect is expressed as a multiplier in Table 9-2.

Table 9-2: **Combination of attenuation by soil class and riparian class (a small multiplier indicates that leaching is greatly reduced by that drainage class).**

Attenuating Drainage class	Multiplier
Very poorly drained (Organic Soils)	0.01
Poorly drained (Gley orders, groups and subgroups)	0.5
Peaty-gley subgroups	0.2
For remainder, Land with riparian Gley soils	0.5
Imperfectly drained & very slowly permeable soils in land with likely riparian Gley soils	0.7
Imperfectly drained & very slowly permeable soils in land without riparian Gley soils	0.8
For remainder, land with likely riparian Gley soils	0.8
For remainder	1

9.1.3. Vulnerability classes

The potential N leaching index which ranges from 0 – 44, 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.

9.2. Pressure

The pressure of N inputs to soils was estimated from land use classes based on Agribase and with the addition of LCDB1 to fill in the gaps. Agribase and LCDB1 categories were combined into nine land use classes (see column 1 of Table 9-3). N pressure index was assigned to the land use classes. This was estimated based on knowledge of N (kg/ha/yr) leached from land uses at a relatively low number of sites.

Dairying was divided into 2 classes; high intensity (>200 cows/farm) and moderate intensity (<= 200 cows/farm), based on stock numbers from Agribase.

9.3. Risk of nitrate leaching

In this analysis relative risk is derived from the combination of pressure on vulnerability. We do not consider sensitivity or asset value in this analysis. Only one hazard, N leaching from the soil, is considered. Vulnerability and pressure are combined in Table 9-3. It produces 3 classes of risk, but can be modified to provide more classes.

Table 9-3: **Combination of N leaching vulnerability and N pressure to derive relative risk, where risk = vulnerability index * pressure index, with risk classes: very low <3, low = 3-7, mod = 8-16, high = 17-29, very high 30-50.**

Land use class and N pressure index		N leaching vulnerability				
		Low (1)	Mod low (2)	Mod (3)	Mod High (4)	H (5)
ARA arable	10	10	20	30	40	50
DAI2 dairy >200	10	10	20	30	40	50
DAI1 dairy 0-200	8	8	16	24	32	40
SBO sheep beef +	3	3	6	8	10	12
NAR non arable	2	2	4	6	8	10
FOR exotic forest	1	1	2	3	4	5
NAT native	0.5	0.5	1	1.5	2	2.5
TUSS tussock	0.5	0.5	1	1.5	2	2.5
ARTIF urban etc.	0.5	0.5	1	1.5	2	2.5

Uncertainty in this analysis is introduced by:

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

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

3. 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.

4. Choice of vulnerability classes.

5.   Combination of Agribase land use categories, and estimation of N pressure index.

6.   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 category 3.

9.4.   Results for Nitrate Leaching

Maps of relative risk of nitrate leaching are shown for the North Island and South Island in Figure 9-1 and Figure 9-2, respectively. Risk is expressed in the 5 classes of Table 9-3. The maximum resolution of the data is 200m. A smaller map indicates uncertainty in the underlying soil data.

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 Gley and Organic Soils (Ren1)

3.   PNLI modified by attenuation in riparian Gley and Organic Soils (Ren2)

4.   PNLI modified by combined Ren1 and Ren2

5.   Nitrate leaching risk based on land use pressure and PNLI modified by combined Ren1 and Ren2

A nitrate leaching risk map of Waikato lowlands (Figure 9-3) shows the five risk classes (Table 9-3) at 25m resolution. It is based on more detailed soil maps than the soil data underpinning the national maps. Comparison is provided with the same area clipped from the 200m-resolution national map. Compared to the 200m map, the more detailed 25m map shows finer scale patterns of risk (for example lower risk along stream lines in the southern end of the area) and changes in risk due to improved soil data, particularly in areas of peat soils. Greater contrast between risk information based on the older national map and that based on recent more detailed maps would be expected in other parts of New Zealand where resurvey has radically upgraded the older information.
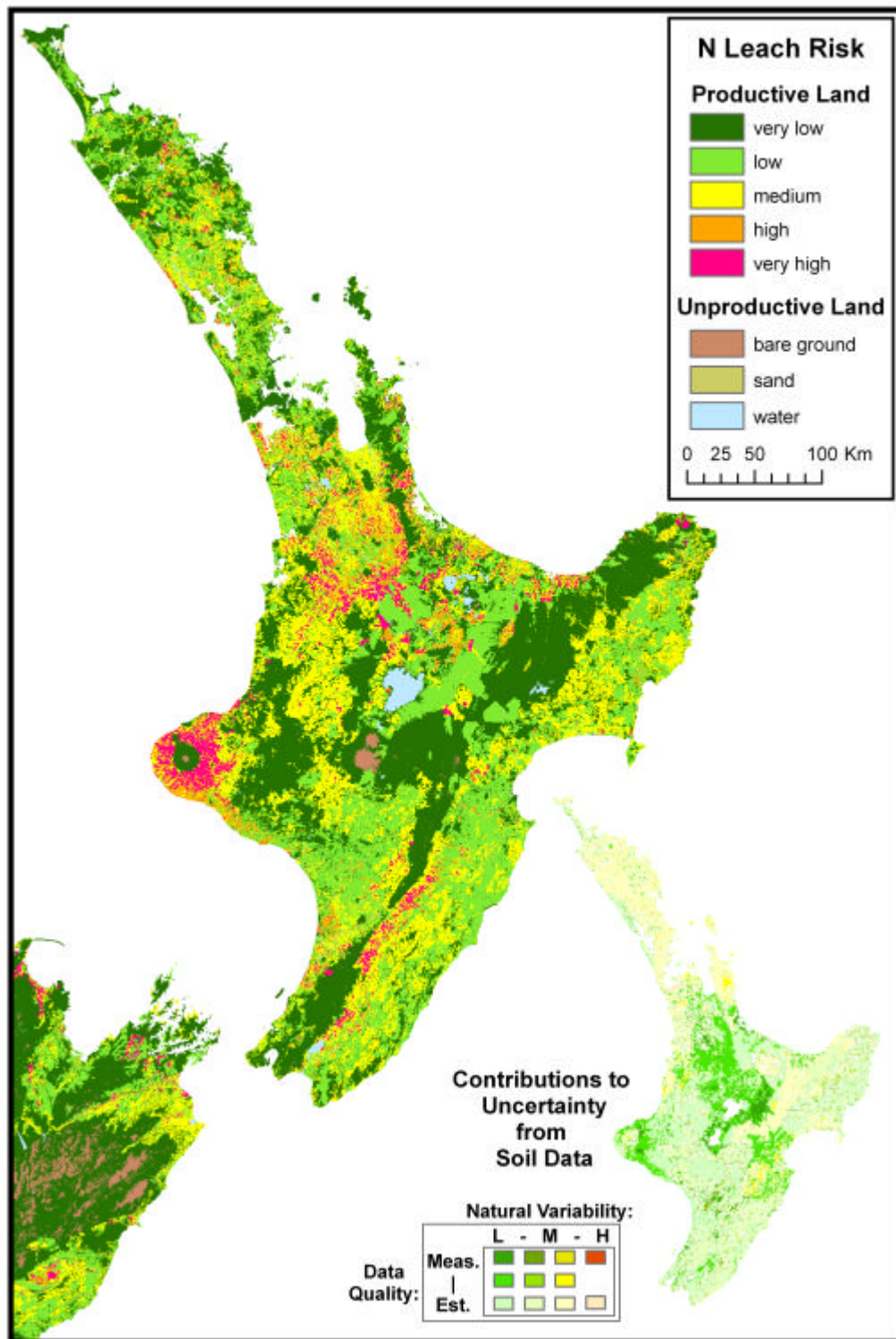
Figure 9-1: **Relative risk of nitrate leaching for the North Island**
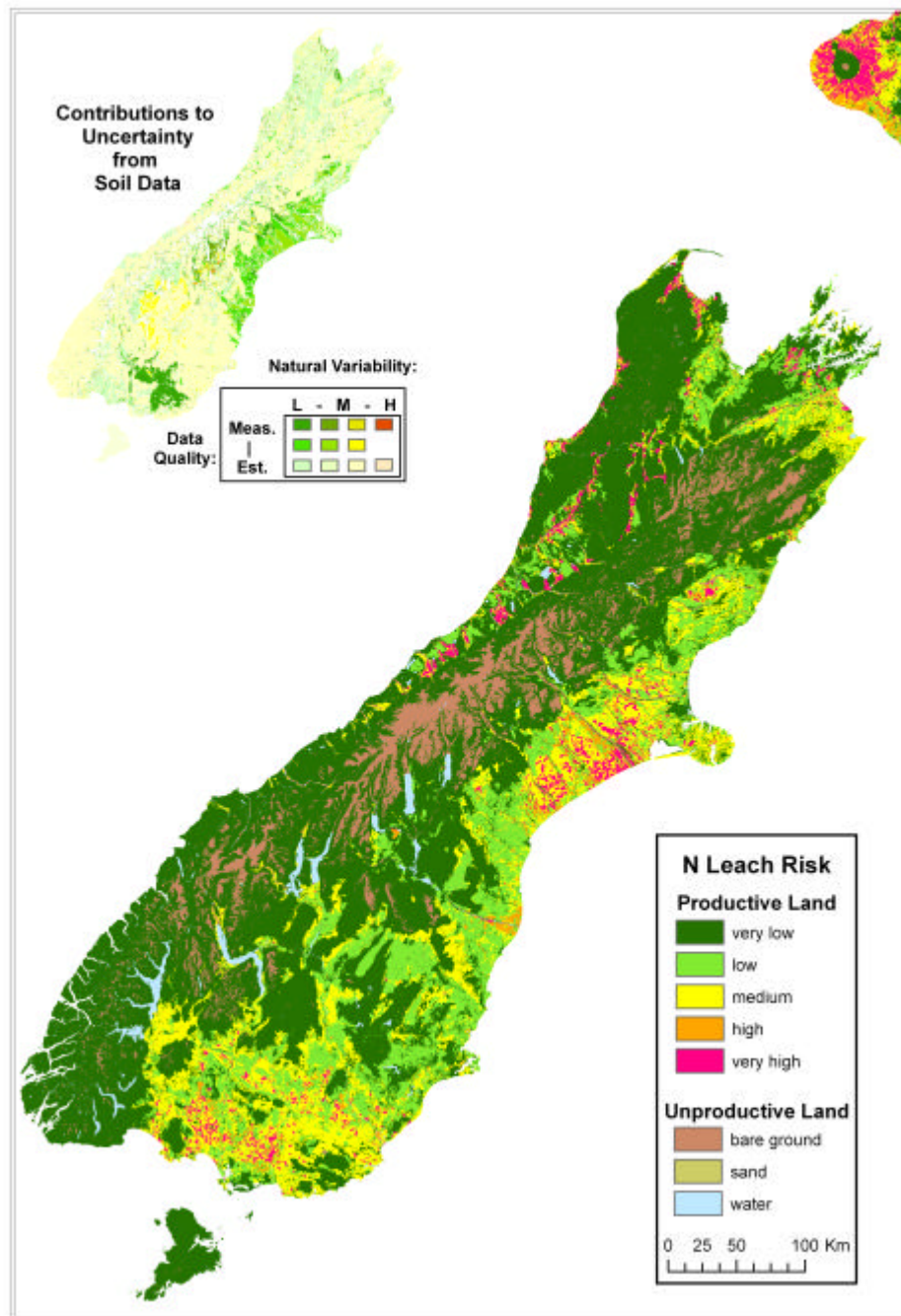
Figure 9-2: **Relative risk of nitrate leaching for the South Island**

N Leach Risk

Productive Land
- very low
- low
- medium
- high
- very high

Unproductive Land
- bare ground
- sand
- water

Classification changes as a result of using higher resolution soils data

Classsification using 25m pixels

Classsification using 200m pixels

HAMILTON

0 5 10 Km

0 5 10 Km

Cambridge

Areas showing lesser risk using 25m pixels

Areas showing greater risk using 25m pixels

Confusion matrix with #s of 25m pixels classified each way

	WAI: 1	WAI: 2	WAI: 3	WAI: 4	WAI: 5
NZ: 1	62022	162			
NZ: 2	1189	267825	460		
NZ: 3		51415	315785	9079	
NZ: 4			43912	38495	322
NZ: 5			24047	28107	582

Figure 9-3: **Relative risk of nitrate leaching for the Waikato, showing the effect of improved soils data.**

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

10.1. Overview

Harris Consulting (HC) is contracted to contribute the following matters to the Cross Departmental Research Pool water quality modelling project:

- A gross relationship between farm output and N leaching

- The triple bottom line accounting of a particular scenario being assessed.

In parallel with this, AgResearch and HortResearch will be working on integrating their OVERSEER (Section 7) and SPASMO (Section 8) models into the catchment modelling framework, which will provide a more detailed understanding of N leaching implications of different management practices. In order to maximise consistency across different parts of the model, the HC input will be based on the processes and assumptions used in these models.

The triple-bottom line accounting approach produces approximate methods to estimate the N leaching, income and employment outcomes of many land uses. The approach used for this work is simpler than the other modelling approaches, and has the advantage that it covers a wider range of land uses than any other model. The model equations (Section 16) are available in a form that will be easily linked to the modelling framework.

Triple bottom line reporting refers to the incorporation of:

- Economic,

- Social, and

- Environmental

factors within the overall reporting framework. In this exercise we will focus on:

- GDP as a measure of economic impact. This is equivalent to value added, and is very close to the concept of Economic Farm Surplus as used by MAF, and Cash Farm Surplus which is a typically used measure for the returns to a land use (ex capital and management charges.

- N leaching as a measure of environmental impact, with subsequent addition of other nutrients such as P.

- Employment changes will be the main indicator of social impacts. Farm numbers will be explored as a possible measure, although difficulties arise in estimating farm numbers with changes in intensity, and standard measures may not work well in this model.

10.2.   Model use

The model is likely to be used by regional councils and other stakeholders to identify:

- Whether problems exist and where they exist

- The causes of those problems

- And to choose possible mechanisms for addressing the problems.

Four potential mechanisms exist for addressing any N leachate problems through regulation. These are:

- Limit particular land uses

- Limit the intensity of particular land uses

- Prescribe management practices

- Cap discharges

The option of prescribing management practices is the most complex and least preferred from both a regulatory and modelling point of view (see Harris, 2004[1]). The recommendation is that the model focus on changes in land use, intensity and defined discharge levels as the inputs for regulatory management.

10.3.   Proposed approach

The model is already hugely complex, and simplification is required at all steps. Furthermore, some situations will be extremely difficult to include in the modelling

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[1] Harris, S. 2004. "Property Rights in Water Quality - A Review of Stakeholders' Understanding and Behaviour" Report Prepared for Ministry for the Environment. Harris Consulting, Agribusiness Group.

framework. Cropping and broadacre horticulture for example have a huge range of different management practices, crops and rotations, all of which impact on the N output from the system. Standing horticulture is more easily managed with a limited number of scenarios, but the relationships between N and $ outputs are difficult.

The proposed approaches to including gross $:N relationships for each of the land uses to be included are set out below.

10.3.1. Horticulture and cropping

There are two types of horticulture to be accommodated – permanent and broadacre horticultural cropping.

One level of N leaching will be used for each category of Apples, Kiwifruit, Grapes. The level of investment in permanent horticulture is such that N needs to be applied to a level which optimises plant uptake under BMP. Additional N beyond this level would be of no benefit (e.g. see Table 10-1), so the additional application would not be Best Management Practice (BMP). A lower level of N application would not provide optimal return on fixed investment costs, although some experimentation could be worthwhile with lower levels of N to determine the impact, but this is likely to be an expensive means of achieving reductions in N. It is recommended that the N management regime for these crops be based on BMP, and on this basis regulatory management options would be confined to limiting area at the first stage.

For broadacre horticulture and cropping the range of possible crops and management practices makes predicting a N leaching impact and associated $ return too complex to be accommodated in a gross model. Again it is proposed that a single level of return and N leachate be chosen for each of broadacre horticulture and arable cropping. Regulation would have to be achieved by capping discharge or limiting area only at the first stage, with no true relationship between the cap on discharge and resulting economic impact. Refinement of broadacre input/output parameters will require user reference to SPASMO.

10.3.2. Sheep and beef and dairy

Three classes of sheep and beef property are to be used (see Section 7.2) – extensive, hill and intensive. Intensity is the primary driver of N leaching, with physical factors less dominant. The changes in N and GDP outputs will be based on changes in intensity – with stock units as the measure of intensity for sheep and beef, and milksolids for dairy. The model will use standard sheep to beef ratios, standard management practices and standard returns per stock unit for a region. This will allow

regulatory measures of limiting land use, limiting intensity, and capping discharges to be tested (although the impact of a cap on discharges would be rudimentary).

10.3.3. Other land uses

A single N discharge rate will be included for other land uses. These will probably be confined to Forestry, non-productive, and urban.

10.3.4. Other influences

Soils, drainage and slope all have an influence on N leaching, although these are less of a factor than management changes. These influences will be included when the full integration of OVERSEER and SPASMO within the model occurs, but the gross relationships described by HC could also be modified to reflect these influences. This would provide greater heterogeneity at a spatial scale without greatly increasing the data or computing requirements. Some difficulties in relating soil and drainage classes to the OVERSEER model would be anticipated, but this aspect of the model development should be investigated further in subsequent stages.

10.3.5. Matters not addressed in gross relationships

- History of paddock

- Partitioning surface vs. groundwater leaching

- Fertiliser and management regimes, which would need to be covered in detailed assessments.

10.4. Overview of model outputs

The information shown in Table 10-1 provides an overview of how the modelled information on land use, water quality and socio-economic indicators could be presented. Further discussion is required to link this approach to the draft user interface presented in Figure 5-4.

10.5. Initial results

The draft report in Section 16 shows relationships which could be used to estimate economic output and nutrient loss from different land use types. The results are in a form that is suitable for linking to the catchment modelling framework.

Table 10-1:   Proposed Output for a "Point of Interest" in the catchment

Concentration of N – Surface: **xx**   Concentration of N – Groundwater: **xx**   Drinking Water Standard: **xx**   (Surface vs. ground??)

Land use	Area	kgN (or %) contributed to point concentration	GDP from land use	$GDP/kgN	Jobs/kgN	Change Intensity	Change area	Cap discharge
Arable								
Kiwifruit								
Apples								
Grapes								
Broadacre Horticulture								
Sheep and Beef Extensive								
Sheep and Beef Hill Country								
Sheep and Beef Intensive								
Dairy								
Forestry								
Non producing								
Total								

Results for contributing area | User input options

11. Next Steps

11.1. Objective 1: Catchment Modelling Framework

- Extend SPARROW to include sediment (especially forestry impacts) (year 2), and to work with Harris Consulting to estimate economic impacts of landuse change (e.g., using MAF data)

- In year 1 the focus will be on model integration inside a simple map (GIS) interface, with the emphasis on efficiency of data transfer between models and seamless processing of the models, and in years 2 and 3 more sophisticated GIS interface will be developed.

- A system for speedily incorporating changes or revisions of models in any of the objectives will be developed.

- Work with Landcare on integration of risk maps into Catchment Modelling Framework

- Work with AgResearch and HortResearch to establish connection of both OVERSEER and SPASMO models so that they can be used by the Catchment Modelling Framework

11.2. Objective 2: Adding Groundwater Component to SPARROW

- In Year 2 NIWA and Lincoln Ventures will apply the expanded SPARROW model in collaboration with an end-user to a study catchment where long-term data for both streamflow and groundwater quality are available for calibration.

11.3. Objective 3: Triple Bottom Line Effects of Land-Use Change

- To be determined during workshop in August 2004.

11.4. Objective 4: Enterprise-scale Modelling

- Create a range of management and land use scenarios for pastoral (OVERSEER) and horticultural (pipfruit, kiwifruit vineyards) and vegetable (SPAMSO) land uses.

- Establish connection of both OVERSEER and SPASMO models so that they can be used by the Catchment Modelling Framework

- Subdivide Waikato region into effectively homogeneous regions, so we can link a few OVERSEER/SPASMO to the spatial regions they represent.

11.5. Objective 5: Pollution Risk Modelling

- Integration of risk maps into Catchment Modelling Framework. A decision is needed on the extent to which the information in the leaching risk maps needs to be integrated into the catchment modelling framework, as opposed to simply making the maps available in digital form as an optional data layer for viewing.

12. Summary

At the beginning of the project, a workshop was held to make all project partners aware of the general framework, to know how their work relates to other work in project, to agree on deliverables and timing for the first stage of the project, and to identify interactions between project sub-contractors which affect the methodology or format of results. In the first year of the project, work is focussed predominantly on the effect of land use on nitrogen as an indicator of water quality, but also with some on the effects of changes in land use on farm income and employment.

In Stage I of the project, we have defined a flexible and robust computer modelling system, which is 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.

A catchment-scale water quality model (known as SPARROW) has been linked to this system, and tested on the Waikato catchment. It provides rapid results in map form for many thousands of streams. This SPARROW model has been extended to include the capability to model groundwater quality, and suitable background information on nutrient movement has been collated to permit the application of this extended model for nitrogen in the Waikato region. This extended SPARRROW model has been applied to estimate current water quality of surface and groundwater for the Waikato River catchment, but more attention is needed to setting parameter values in the model. This work provides information at the catchment scale, and a framework for assessing the integrated effect of farm-scale information on catchment-scale water quality.

Three more detailed methods for assessing of effects of land use on water quality are in development, to supply more detailed information than the SPARROW model provides. It is intended that all three methods will be linked to the framework described above, in later years of this project.

First, the leaching of nitrogen from pastoral agriculture is being assessed using the Overseer computer model. Guidelines for the appropriate use of this model in the project have been documented, the input data needed to operate the model have been identified in detail, and a very simple demonstration version of the model has been developed to allow a direct connection between Overseer and the framework developed above.

Second, assessments have been made of the likely nitrate leaching from a range of horticultural crops in typical locations around New Zealand, using the Soil Plant Atmosphere System Model (SPASMO). Crops that have been assessed include Marlborough and Hawke's Bay grapes, Bay of Plenty kiwifruit, Hawke's Bay apples, and Waikato potatoes.

Third, new national maps have been developed to show the relative risk of nitrate leakage from soils to surface and ground waters around New Zealand, using the EnSus framework for analyzing and mapping the relative risks different land uses pose to soil quality and water quality. It uses best available knowledge of specified land use pressures and vulnerability of the land to those pressures. A detailed map of nitrate leaching risk in the Waikato region was also developed.

A triple bottom line examination of the effects of land use change on nitrogen leaching, farm income and employment is being carried out to allow the effects of different policies to be assessed.

A set of proposed future actions has been identified for most parts of the project, and another project workshop is scheduled for August 2004, to report on progress, and clarify directions for the second year of the project.

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14. Appendix 1: SPASMO Model (HortResearch)

14.1. A general description of the SPASMO model

The SPASMO model considers a 1-dimensional soil profile of 7 m depth, divided into 0.25 m intervals (slabs). Water transport through the soil profile is modelled using a water capacity approach (Hutson and Wagenet, 1993) that considers the soil to have both mobile and immobile pathways for water and solute transport. The mobile domain is used to represent the soil's macropores (e.g. old root channels, worm holes and cracks) and the immobile domain represents the soil matrix. After rainfall or irrigation any dissolved solute is allowed to percolate rapidly through the soil in the mobile domain only. Subsequently, on days when there is no significant rainfall, there is a slow approach to equilibrium between the mobile and immobile phases, driven by a difference in water content between the two domains.

14.2. Crop water use

The model calculations run on a daily time step and are based on a simple water balance of the vineyard. A standard crop-factor approach is used to relate the water use of the grapevines to the prevailing weather and time of year (Allen et al., 1999). Plant water use depends on both the ambient meteorological conditions and the physiological stage of plant development. A two-step procedure is used to calculate plant water use, based on guidelines given by the Food and Agriculture Administration (FAO) of the United Nations (Doorenbos and Pruitt, 1977; Allen et al, 1999). Measured values of global radiation, air temperature, relative humidity and wind speed were used to calculate a reference evaporation rate, ET_o [mm d^{-1}]. From the modified Penman-Monteith equation, we obtain

$$ET_0 = \left(\frac{s}{s+\boldsymbol{g}} \right) R_N + \left(\frac{\boldsymbol{g}\, f(U)}{s+\boldsymbol{g}} \right) D_A$$

where R_n [mm d^{-1}] is the net radiation is expressed in units of an equivalent evaporation rate, D_a [kPa] is the difference between the saturation vapour pressure at mean air temperature and the mean actual vapour pressure of the air, s [Pa ^{o}C^{-1}] is the slope of the saturation vapour-pressure versus temperature curve, γ [66.1 Pa] is the psychrometric constant, and f(U) is a wind-related function given by

$$f(U) = 2.7\ (1+U/100)$$

Here U [km d^{-1}] is the 24-hr wind run at 2-m height. This reference value, ET_o, defines the rate of evaporation expected from an extensive surface of green grass cover of short, uniform height, actively growing, completely shading the ground, and not short of water.

To account for the effect of plant physiological characteristics, a crop coefficient, K_c, is used to relate the reference evaporation rate, ET_o, to the actual crop water use, ET. For routine calculations of crop evapotranspiration, the following equation is used:

$$ET = K_C . ET_O$$

where K_c is a dimensionless number that normally varies between about 0.2 and 1.1. The particular value of the crop coefficient, K_c, determines the evapotranspiration of a disease-free crop grown in a large field under optimum soil water and fertility conditions and achieving full production potential under a given growing environment. In other words it defines the maximum rate of water use expected from a particular crop. Various factors affect the value of K_c, including crop characteristics, crop planting or sowing dates, rate of crop development, length of growing season and climatic conditions. Here we have used standard values for K_c, set to a maximum of 0.70 during mid season, but reducing when the plants are under water or nutrient stress (Allen et al., 1999).

14.2.1. Crop water balance

Water uptake by the vines is assumed to be in proportion to the density of fine roots. For grapes, we have assumed the roots will ramify the soil profile to a depth of 1.5 m, with an exponential profile of root-length that places ¾ of the roots in the top ¼ of the root zone.

Irrigation is applied automatically to the grapes, whenever ½ of the available soil water has been consumed from within the root zone.

Because of the stony nature of the soils we have assumed them to be free draining so that no run off component has been included in the calculations. Instead, all the rain that falls is added to the soil profile.

Drainage through the soil profile is assumed to occur whenever the soil water content exceeds 'field capacity'. The soil's physical, hydraulic, and chemical transport properties are prescribed within each soil slab, and these data are obtained from the New Zealand Soils Database (Landcare, 1999).

14.3. Nitrogen transport through the soil

As water percolates through the soil profile it carries with it any dissolved solutes, such as fertilizer or pesticide. The nitrogen transport component of SPASMO is based on a simple nitrogen balance that accounts for plant uptake, the application of mineral fertilizer, exchange and transformation processes in the soil, losses of gaseous nitrogen to the atmosphere, and the leaching of nitrogen below the root zone. The SPASMO model considers both the organic nitrogen (i.e. in soil biomass) and the mineral nitrogen (i.e. ammonium and nitrate in solution) contained in the soil and the plant biomass. Dissolved nitrate is considered to be fully-mobile and to percolate freely through the profile, being carried along with the invading water. In contrast, the movement of dissolved ammonium is retarded as it to binds to mineral clay particles of the soil. The soil can receive inputs of organic carbon and nitrogen from plant residues, which is added to the litter layer of the top 0.25 m of soil, and inputs of mineral fertilizer which is applied to the soil surface during in spring time.

14.3.1. Crop growth

Plants play a key role in the nitrogen dynamics of the root zone, and so first it is necessary to 'grow' plants in the model. We assume that the amount of soil nitrogen removed by the grape vines will be determined by vine growth, and we estimate the nitrogen uptake from the growth of the various plant organs multiplied by their respective nitrogen concentrations. For the purpose of modelling the vine growth, the daily biomass is given a potential production rate per unit ground area, G (kg/m^2/d) that is related, via a conversion efficiency, ε (kg/MJ), to the amount of solar radiant energy, Φ (MJ/m^2/d), intercepted by the plant foliage,

$$G = \varepsilon \, \Phi.$$

The value of ε is related to the water and nitrogen status of the soil, while Φ depends on the daily sunshine, air temperature and the leaf area of the vines (King, 1993). We use an allometric relationship to partition the daily biomass production into the growth of foliage, shoots, roots and berry components. We also assume that plant growth will achieve a maximum only if soil water and soil nitrogen are non-limiting.

14.3.2. Net production of above and below ground biomass

Plant biomass is expressed in terms of the growth and senescence of the plant organs. For each plant organ we use a simple mass balance equation that considers:

- inputs of dry matter (DM) due to carbon allocation

- losses of DM as the plants senescence, and

- removal of DM at harvest (or thinning)

14.3.3. Nitrogen uptake by the crop

The model assumes that plant growth will achieve the maximum potential only if soil water and soil nitrogen (NO_3^- and NH_4^+) are non-limiting. The net uptake of nitrogen from the soil is set equal to the amount of nitrogen incorporated into the new biomass, minus the fraction of nitrogen that has been retranslocated, λ, from the old or senescing tissues. Uptake of nitrogen from the soil is assumed to be in proportional to the depthwise distribution of the fine roots.
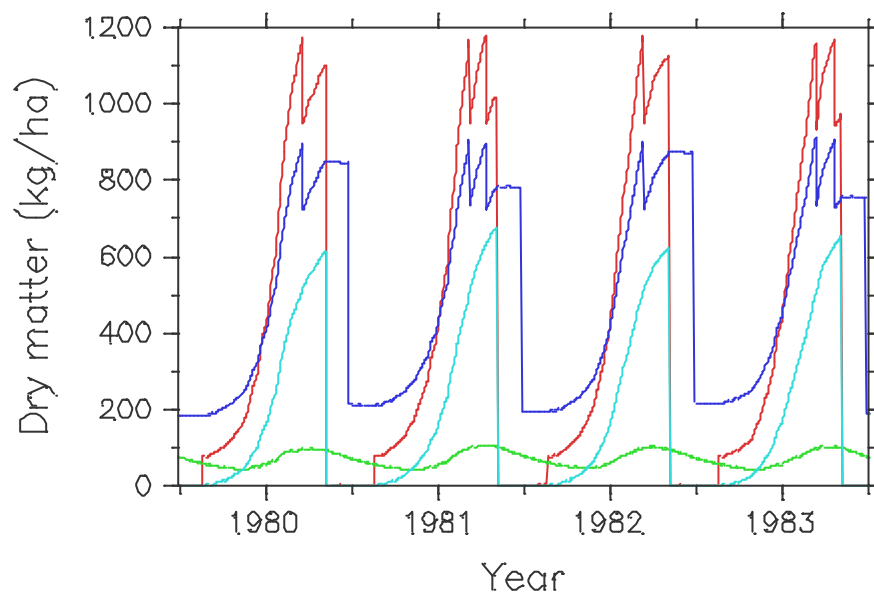
Figure 14-1:   **Annual cycle of dry matter in a grape vineyard. The lines reflect the seasonal change in the biomass of the leaves (red), shoots (dark blue), fine roots (green) and berries (light blue).**

Figure 14-1 shows the modelled seasonal pattern of vine growth which has been parameterized using data for sauvignon grapes reported by Coombe et al., (1988) and Gladstones (1992). We have assumed the grape vines are trimmed during summer, to control their vigour. Thus, in the model, as soon as the total above-ground dry matter (shoot plus foliage) reaches 2 Mg/ha, the vines are thinned by removing 20% of this DM. This results in 1 or 2 thinnings each year, which is in accord with normal management practice. Leaf fall was assumed to occur in mid May and the shoots were pruned in mid June by removing 75% of the shoot dry matter. Any vegetation

removed during thinning and leaf fall was deposited back onto the soil surface. 'Fresh organic matter' slowly decomposes, returning the stored carbon and nitrogen to the litter and humus components of the soil biomass (see below).

The daily values of plant growth can be integrated over the whole season to provide an estimate of the annual nitrogen balance of the grape vines. From our model, we estimate the annual N-uptake to be about 60 kg-N/ha/yr. Approximately 2/3 of this nitrogen is returned to the soil biomass as leaf litter and shoot prunings. The remaining 1/3 of the nitrogen taken up by the plants is either removed in the grapes at harvest time, or recycled internally in the stem and roots of the grape vine. This 'stored' nitrogen is eventually remobilized during bud burst of the following spring. Thus, the harvest of grapes represents a small loss of nitrogen from the system, which we estimate to be just 16 kg-N/ha/yr. It is normal practice to add a dressing of mineral fertilizer in the spring time, if petiole analysis reveals a decline in leaf-N.

Table 14-1:   Model output of the nitrogen balance of the grape vines.

Component of Nitrogen Balance [1]	Mean (kg-N/ha/yr)	Std. Dev. (kg/ha/yr)
Plant Uptake	59.8	8.1
Removal in grapes	16.1	2.3
Stored in wood	3.5	0.1
Plant Returns to soil	40.2	5.7

[1] Plant Uptake = Removal in grapes + Stored in wood + Plant Returns to soil

14.4.   Carbon and nitrogen dynamics of the soil organic matter

The decomposition of soil biomass adds to the amount of mineral nitrogen in the soil. This process is known as mineralization. Mineralization is modelled by dividing the soil organic matter into two pools – a fast cycling litter pool and an almost stable humus pool following Johnsson et al. (1987). This two-pool model then considers the amount of soil carbon and soil nitrogen that cycle within soil organic material. The relative amounts of these two components change daily to reflect inputs of new biomass and losses of older biomass as it decomposes. 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.

Decomposition of soil litter carbon (C_L) is a function of a specific rate constant (K_L) which is influenced by temperature and soil moisture. The products of decomposition

are CO_2, stabilized organic material (humus) and, conceptually, microbial biomass and metabolites. The relative amounts of these products are determined by a synthesis efficiency constant (f_E) and a humification fraction (f_H). During harvest and leaf fall we assume 10% of the fresh organic matter goes into the litter pool while the remaining 90% is added to the stable humus pool.

A similar set of mass balance equations are used to describe the turn-over of carbon and nitrogen in the humus pool. Decomposition of soil humus (C_H) is assumed to follow first-order kinetics with a specific rate constant (K_H) which depends on temperature and soil moisture.

14.5.   Mineralization of soil organic matter

All carbon and nitrogen turn-over reactions can result in a net production (mineralization) or a net consumption (immobilization) of ammonium, depending on the C/N ratio of the biomass, r_O, in the two pools. From a consideration of mass balances, any increase in NH_4^+-N, due to mineralization, must be equal the decrease in organic-N from the two organic matter pools. The model also recognises that, if no ammonium is available for immobilization, then nitrate can be used.

During all simulations reported here we chose typical values for most of the parameters: the rate constants were K_L=0.015 d^{-1} and K_H=0.00005 d^{-1}; constant values were used for the efficiency of carbon turn-over, f_E=0.4, the humification fraction, f_H=0.2, and the C/N ratio of the soil biomass, r_O=10.0, as suggested by Johnnson et al. (1987).

14.6.   Mass-balance equations for fertilizer

The Fertilizer transport model allows for an input of mineral nitrogen in the form of either Urea, Ammonium or Nitrate. This option allows us to simulate different forms of mineral fertilizer that are broadcast onto the soil surface. Here we are considering just the application of $CaNH_4(NO_3)_2$ and so the amount of urea added is set equal to zero.

Once the ammonium is applied to the soil surface, its fate is determined by six competing processes:

- inputs from the mineralization of soil biomass

- retardation due to the adsorption of ammonium to the soil particles

- losses due to the volatilization of ammonia gas

- losses due to the nitrification of ammonium into nitrate

- losses due to the drainage of ammonium below the root zone

- losses due to plant uptake

Similarly, once the nitrate is applied to the soil surface its fate is determined by the two inputs and the following five processes:

- Inputs of Nitrate from fertilizer application,

- Inputs from the nitrification of ammonium

- Retardation due to the adsorption of nitrate (= 0 in Renwick stoney silt loam)

- Losses due to immobilization

- Losses from denitrification,

- Losses due to plant uptake

- Losses due to the drainage of nitrogen beyond the root zone.

We consider denitrification to be a microbial process that is rate-limited by the amount of soil organic carbon (the energy source) and mineral nitrogen (the nutrient source) available to the microbes.

14.7. Mass-balance equations for pesticide

The pesticide transport model allows for a wide range of pesticides to be applied onto the soil. Here, we are concerned only with simazine and we characterize its transport properties via a K_{OC} and a $T_{1/2}$ value. The K_{OC} value reflects the mobility of a pesticide, and it is a measure of the affinity of the pesticide to bind to the organic matter in the soil. The half-life, $T_{1/2}$, reflects the persistence of a given pesticide, and it is a measure of the time it takes for half of the pesticide to be degraded by the soil microbes.

Once the pesticide is applied to the soil surface, its fate is determined by five competing processes

- Retardation due to pesticide binding to the soil organic matter

- Degradation due to microbial activity

- Losses due to volatilization to the atmosphere

- Losses due to uptake by plants (assumed =0)

- Losses due to deep drainage

14.8. Model calculation procedure

The above mass-balance equations are solved numerically, to generate the depthwise distribution of the average concentration of dissolved ammonium, nitrate and pesticide within the soil profile. Each of the rate constants that describe the various transformation processes are based on laboratory-measured reference values using standard functions F_W and F_T to account for the effects of soil moisture and temperature (Johnsson et al., 1987). We have used a standard modelling approach that we consider to be appropriate for this report because (1) it has a sound theoretical basis, (2) it has proven successful in other simulations, (3) it uses local weather and soil data as input, and (4) the results are expressed in term of a risk analysis for a given input of fertilizer and/or pesticide.

15. Appendix 2: OVERSEER® nutrient budget model (AgResearch)

Issues relating to the use of the OVERSEER® nutrient budget model within the Land Use, Land Use Change and Water Quality framework model program

This section of the report examines in detail how the OVERSEER® nutrient budgets model could be integrated into the catchment modelling framework (Section 5), and issues associated with its integration. The key points from this section are summarised in Section 7 of this report, and some items from that section are repeated here for ease of reading.

The catchment modelling framework consists of a GIS interface containing layers of water, soil and land use data (see Figure 5-1).

It is envisaged that a user would identify a candidate set of management regimes for typical land uses, and model the nutrient yields from pastoral lands using the OVERSEER® nutrient budget model. The integrated models will be run for a set of pre-defined farm-types, which could be associated with user-defined parts of the catchment. This would provide a refined estimate of the nutrient yields from the catchment, which could be inserted into the SPARROW model to provide estimates of water quality. The economic returns associated with each scenario would be mapped and summarised by using a lookup table of financial returns for each type of landuse, based on farm economic data from MAF.

The catchment modelling framework could be used by a Regional Council or MfE planner/scientist who is interested in the relationship between land use and water quality for a catchment or region, and has some ideas about how land use is likely to change in future. By selecting appropriate scenarios, the user could map the effect of these changes on water quality.

15.1. Overview of OVERSEER^â nutrient budget model

15.1.1. General assumptions

There are five basic underlying assumptions within the OVERSEER® nutrient budget model. It is important that when integrating the OVERSEER® nutrient budgets model in the catchment modelling framework that these assumptions are not violated.

Actual and reasonable data

Within the model, use is made of input data to assess other parameters that are usually hard to obtain. This also has the effect of integrating other management effects (e.g. stock health, grazing management, pasture management, animal management) into the model without having to request a lot of input data. Thus it is assumed that:

- the input data is achievable (physically, biologically and managerially) on the farm.

- if any input data is changed from the current situation, then it is assumed that the user also changes all other associated input data that might occur with that change. For example, if fertiliser N is changed, then in all probability the production (milksolids, stocking rate) will also change. Similarly, if the stocking rate is increased due to capital fertiliser inputs, then soil test values should also be increased.

Annual average

The model estimates annual average losses from a system using annual average inputs. There can be a large variation in losses from year to year caused by different climatic regimes. However, OVERSEER® nutrient budget model only estimates the average losses.

Inputs are also based on an annual average basis. Adjusting rainfall to assess the effects of a wet or a dry season will result in poor predictions. However, if annual average rainfall was to increase due to climatic change then this would be a valid change, provided that any other management effects (e.g. higher production due to improved rain) are also taken into account.

Equilibrium

The model assumes that a near equilibrium situation has occurred. The model does allow for some transitional effects through the use of the development status input parameter, and the farm management changes that also occur during these transition periods. However the values the model return are the annual average if the system was maintained in that condition, rather than an average value over the transition period, or the expected value at the end of the transition period.

Best management practices

The model assumes that reasonable best management practices are followed. Those associated with fertiliser are outlined in the Fertiliser Code of Practice.

If these practices are not implemented, then losses are expected to be higher than those estimated by the OVERSEER® nutrient budget model.

Catastrophic or unusual events

The OVERSEER® nutrient budget model currently does not account for unusual or catastrophic effects. Such events include the large sediment losses associated with heavy rainfall. The model also does not take into account losses associated with wind erosion.

15.1.2.   N and P models

The following is a brief outline of the N and P models used within the OVERSEER® nutrient budget model. Both of these sub-models have been calibrated against available field trial data within New Zealand.

N leaching losses

On pastoral farms, N losses are mainly derived from animal urine patches and the inherit inefficiency in nutrient cycling within these patches (e.g., Ledgard 2001). The estimate of N leaching is determined primarily from calculation of the amount of N excreted in urine and dung, and factors for leaching which vary with form (urine or dung), animal type, soil group, drainage status and rainfall (Wheeler et al. 2003). Thus, the main determinant factors on a farm are the amount of feed consumed (calculated from milk production or stocking rate and the energy intake model) and its N concentration (e.g., higher for N-fertilised pasture and differs between supplements). Direct leaching of fertiliser and effluent N is also accounted for, particularly when applied during the high risk months between May and July. Leaching losses from effluent N applied to land from the farm dairy and winter feed pads are also estimated. Leaching losses associated with the transfer of N in animal excreta to raceways and the dairy shed are also accounted for.

Nitrogen use efficiency

Nitrogen use efficiency is defined as the sum of product N removed divided by the sum of N inputs. N use efficiency has been shown to vary from about 20% to nearly 50%, and it represents how non-nutrient farm management practices (e.g. animal genetics, animal health, pasture management) are integrated into the model without the need to specifically request such information. Typically, N use efficiency is higher on well managed farms (high conversion of intake into product). It can also be increased if winter feed pads are used and the excreta is collected and applied to the land in spring/summer (Chadwick and Ledgard 2002), or if N fertilised grass is substituted with a low protein supplement such as maize silage (Ledgard et al. 2000).

P loss

P loss in runoff (overland flow and surface drainage) is driven primarily by soil P status, and transport and management factors (McDowell et al. 2003). In the model, the loss of P from agricultural landscapes is split into background and incidental losses. A conceptual diagram of model structure is shown in the following diagram:
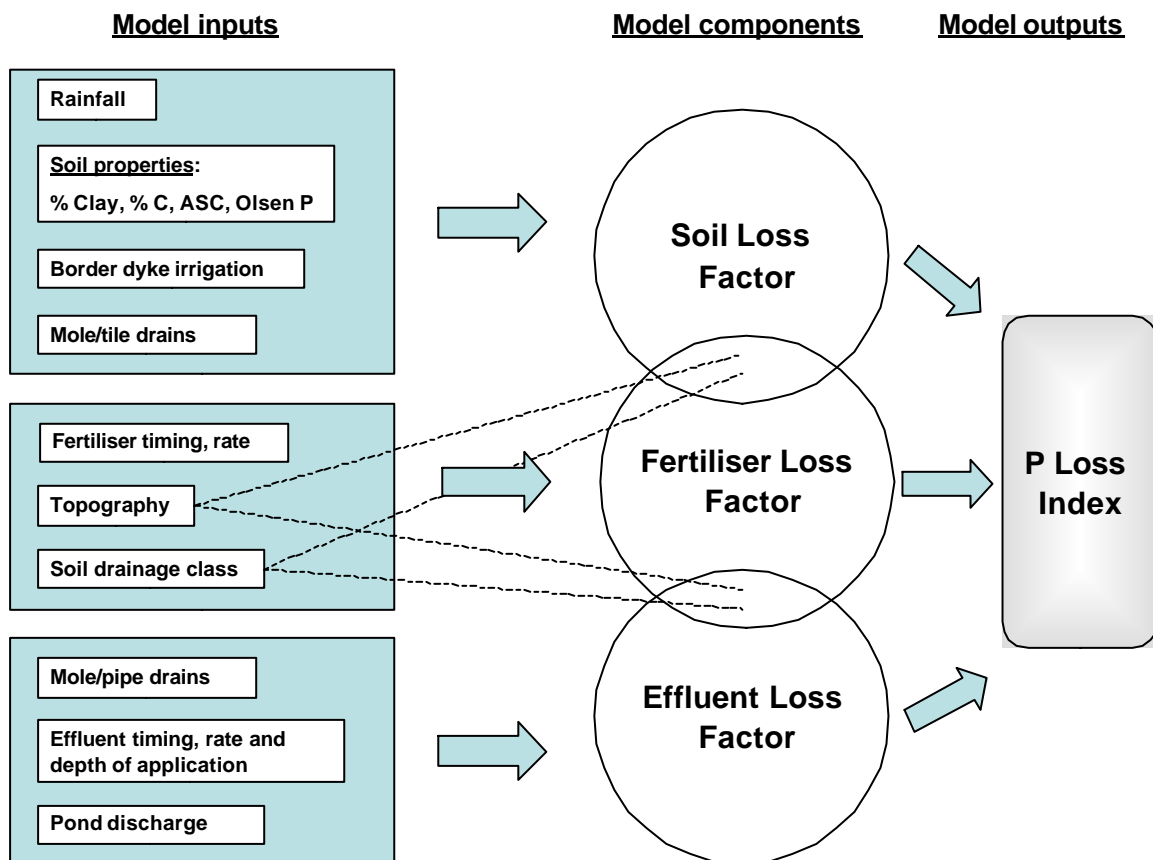
Background P losses

Background losses arise from P that has had an opportunity to react with the soil and is lost in flow events throughout the year. Background losses are determined from P concentration and transport factors to give total annual loading (McDowell and Condron 2004), and includes management factors likely to influence P loss in the long-term such as tile-drainage and border-dyke irrigation.

In general, P loss from lowland pastures is dominated by dissolved reactive P (DRP) and is estimated from Olsen P and ASC (anion storage capacity). Total P loss also incorporates factors that relate to the loss of P in particulate form, largely from soil erosion. A modified structural vulnerability model of Hewitt and Shepherd (1997) is used to estimate soil resistance to physical degradation as a surrogate for inherent soil erosion potential, and is calculated from ASC, total organic carbon and clay content.

Transport factors include topography, precipitation and overland flow potential, as well as unique management factors that alter the flow path and duration of P loss e.g., tile-drainage and border-dyke irrigation. The potential for overland flow is estimated from the product of soil drainage class and a slaking/dispersion index. Drainage class (range 0-1) is based on the USDA curve number method for determining soil hydrologic class and utilises soil texture. Soils with a coarse texture will have less potential for saturation (low drainage class) than fine textured soils, not accounting for their position in the landscape. The slaking/dispersion index, based on soil order or soil group, takes into account the potential for soil damage to influence soil hydrology.

Incidental P loss

Incidental P losses occur in situations where a concentrated source of available P and a flow event coincide. Incidental P losses from fertiliser or effluent are derived from the transport factors, nutrient rates and the timing of the application.

The primary factor in determining P loss via fertiliser and effluent (from farm dairy or feed pads) is the rate of application and transport factors. For effluent, recent research has indicated that too fast a rate of application can lead to bypass flow and direct P loss (Monaghan et al., 2002).

In addition to topography and drainage class, another factor important to the incidental loss of P from fertiliser or effluent is the timing of application. Most farmers will try to apply effluent when the soil is not wet. However, if applied when wet then the rate of application and presence or absence of mole-tile drains influences the risk of P loss accordingly. The time of year of fertiliser and effluent application also influences P

loss. Following superphosphate application, the potential for P loss is enhanced for a period up to 60 days (McColl et al., 1975; Sharpley and Syers, 1979). If water flow occurs during this period then an incidental P loss occurs. To account for this, the month of year when P is applied is combined with the probability of overland flow for regions around New Zealand. A month is deemed as high risk if the percentage frequency of months when saturation-excess overland flow (calculated from a water balance model) is $> 60\%$. The risk of incidental P loss from land where reactive phosphate rock (RPR) is applied is significantly less than if soluble P forms are used, particularly in high risk months (McDowell et al., 2003b; Nguyen et al., 2002). These effects are included in the model.

For effluent, a sliding scale is used to rank P loss risk according to risk months. Direct discharge to a waterway from an effluent pond is also accounted for by the model.

P loss model application

The P runoff model has been calibrated against all P runoff trials conducted in New Zealand on pastoral land, with scales ranging from much less than 1 ha to catchments up to 1500 ha. It is also well known that in some catchments up to 90% of P loss may come from only 10% of the catchment area (Sharpley et al. 1999). These areas are called 'critical source areas' (CSAs). The model has been designed to operate at a block scale (McDowell et al. 2004) and integrates across the CSA typically found within a block. By using the developed model for separate blocks, such as effluent blocks, a degree of resolution is gained.

The P runoff model has recently been updated (July 2004) due to the availability of additional research data (McDowell et al. 2004).

15.1.3. OVERSEER[â] nutrient budget parameters

In the following section, the main OVERSEER[®] parameters that affect N and P loss are listed, as well as the impact on N and P loss. Only parameters that influence N and P are listed

Input parameters

OVERSEER[®] makes a distinction between farm and block parameters. Block parameters can be ascribed to a given area of land (paddock or block (collection of paddocks)). Farm parameters are those that are measured at the gate (e.g. milksolids), or are independent of the paddock (e.g. feed pad, lane and farm dairy transfers).

Farm parameters

Region of New Zealand	Sets some default background data used in the calculation of the animal intake model
Stock class (dairy, beef, sheep, deer)	Important as they define the urine deposition pattern and differences in susceptibility to loss.
Stock productivity	Measured as milksolids (dairy) or stock units (calculated to take account of stock growth and productivity). Wool and velvet production can also be included, but default values would normally suffice for the catchment modelling framework
Supplements	Supplements brought in to a farm. These can be important when the rates are high. Currently, rates vary from none to about half the animal's total intake.
Management practices	Practices including the effluent processing system, use of feed pads and factors that influence the transfer and losses of nutrients.

Block parameters

Rainfall	Affects estimates of drainage and hence N leaching, and of drainage class (likelihood of surface runoff occurring) and hence P loss
Soil group, soil order or soil type	Has some impact on N leaching. Has a large impact on drainage class and hence P loss. Also used to define default values for ASC, drainage class and structural integrity used in the P loss model, but these can be replaced by actual values for ASC, carbon and clay contents, and soil texture.
Soil profile drainage class	Along with soil group, soil order or soil type, is used to estimate drainage class.
Topography	Block topography influences grazing pattern of stock, and hence urine deposition pattern. This has a significant effect on transfer of nutrients due to stock camping but has a relatively small effect on total N losses. However, it can have a relatively large effect on the susceptibility to P runoff losses (see next section for definition of slope classes).
Stock classes and types within a block	Can be important if there are differences in stock management and types between blocks, but for the catchment modelling framework it can initially be ignored.
Soil tests	Little effect on N model for pastoral systems. Olsen P test level is important for the P runoff model. P runoff model also can use anion storage capacity (ASC), carbon and clay contents and bulk density to override default settings.
Effluent blocks	Identification of effluent blocks can be important, particularly if the effluent block is small for the amount of effluent being applied. This can typically occur when farm amalgamation has occurred, or increased use of supplements or feed pads have been added.
Supplement removal	Can influence N and P losses associated with excreta returns. Is a method of mitigating high nutrient inputs on some blocks
Fertiliser rate, type and timing	Can have a large effect on N losses, and are greater when applied in high risk periods. Type of P applied also has an impact on P loss
Irrigation	Small effect unless using high N concentration waters. For P loss, applying fertiliser P close to the time of irrigation on farms with border dykes leads to high losses.

The model accounts for the internal transfers of nutrients in animal excreta from the main area of a paddock to campsites. The rate of transfer is largely determined by topography. This means that the smallest scale of operation of the model is the paddock (or block). It should also be noted that topography refers to the general topography of the paddock (which may contain a mix of flat and steep areas) rather than the point slope of a piece of land. For the P runoff model, slope can refer to the point slope although some modifications to the model will be required to implement this properly.

For nitrogen losses, most of the important drivers are at a farm scale, or are management inputs. In contrast, for P loss the soil characteristics have a more important effect and hence block parameters are more important.

Many of the important drivers of N or P losses are under management control. The main exceptions are topography, rainfall and soil type, although these also affect management decisions made. Data related to management control are generally not available on a national scale, although stock class, and possibly some productivity data may be available. For the rest of the required data, scenarios, or typical farm set ups, provide a means to be able to include these factors in to the GIS model.

Given the role of management, it is also recommended that the OVERSEER® nutrient budget is used to calculate an integrated N and P loss over the whole farm, even though the data may be applied at a point source. For example, on dairy farms, a whole farm value should be used as it is unlikely to be able to identify where effluent blocks are.

Selecting topography classes

The following table is a general description of topography classes used within the OVERSEER® nutrient budget model. The slope is the average slope for the typical parts of the block excluding stock camps.

Slope Class	Access	Slope	LRI1 class
Flat		0° to 7°	A-B
Rolling	Area mostly navigable by tractor	8° to 15°	C
Easy	>50% area navigable by tractor	16° to 25°	D-E
Steep	<50% area navigable by tractor	26° or more	F-G

[1] LRI = Land Resource Inventory slope class

15.1.4. Example of effects of some input parameters on estimated N loss

The following table has examples of estimated N losses to illustrate the range in leaching losses that can occur under different management strategies. These values should not be used as typical values, but the effects are typical of what can occur. The effect of management changes on productivity was taken into account.

Management	N leached
0 N (base situation)	19
+ 100 N	29
+ 200 N	38
+ Supplements (2T/ha maize silage)	18
+ Supplements (2T/ha maize silage, half fed on feedpad) + animals on feedpad May–July	12
Change soil type	22
Change topography	20
Change rainfall (1200 to 2000 mm/year)	25

What this table illustrates is that management options rather than physical attributes of an area are more likely to affect N leaching below the root zone. Therefore the CRDP program needs to capture typical management options for a given area if it is to realistically depict the current state of a region.

15.1.5. Example of effects of some input parameters on estimated P loss

The impact of different input parameters affecting P loss are summarised in the following table.

Factor	Effect on P runoff
Olsen P	P losses increase as Olsen P levels increase.
Anion storage capacity (ASC)	P losses increase as ASC levels decrease. The rate of loss increases when ASC < 20.
Drainage class	Estimated from soil drainage class and soil type, or from soil texture (increases as texture becomes heavier) or a default based on soil order and a dispersion/slaking coefficient, which is based on soil order. P losses increase as drainage class increases, except if excessive subsurface flow losses occur.
Structural integrity	Estimated from ASC and carbon and clay contents if provided, otherwise a default value based on soil order is used. Increased particulate P loss at low structural integrity.
Topography	Modifies drainage class / structural integrity. P loss increases as topography increases.
Soil texture	Used to estimate drainage class
Soil group	Provides default estimates of ASC, carbon and clay contents, structural integrity and textural component of the drainage class.
Tile drained	P losses are higher under tile drainage.
Incidental losses	
Fertiliser rate	P loss increase as fertiliser P rate increases
Fertiliser type	P loss is higher with super than RPR, particularly if fertiliser is applied in high risk months
Fertiliser timing	Potential P losses are high when fertiliser is applied in a month when the potential runoff is high (due to soil saturation or hydrophobic conditions), or when applied within 3 weeks of a border dyke irrigation event. Losses in these months are higher with soluble P than RPR.
Effluent rate	Calculated internally within the model – also includes effluent from feed pads. P loss increases as the effluent P application rate increases.
Effluent timing	Similar to fertiliser timing.
Effluent application rate	P losses increase as application rate increases, particularly on soils prone to saturation or sealing.
Border dyke irrigation	If fertiliser is applied within 3 weeks or irrigation then P loss is higher.

Some example total P losses are shown in Table 15-1. These tables illustrate that the main factor that influences P loss are soil characteristics (e.g., ASC, soil order, texture, soil drainage) and management factors (e.g., Olsen P status, fertiliser type and timing, tile drainage).

Table 15-1: **Examples of P loss outputs estimated using the Overseer® nutrient budgets model for some example pastoral farms.**

Region	Soil type	Total P loss (kg P/ha/yr)	category
Canterbury	Templeton	0.3	low
	Temuka (border dyke irrigated)	3.2	high
West Coast	Hari Hari	8.0	extreme
Southland	Fleming	0.2	low
	Fleming (tile-drained)	0.5	low
	Waikoikoi (tile-drained)	0.8	low
	Waikoikoi (tiled, effluent applied, medium rate)	1.5	medium
Northland	Pakotai clay	3.2	high
Manawatu	Tokomaru	1.8	medium
	Tokomaru (fertiliser applied in high risk months)	3.6	high

15.1.6. Losses from effluent pond systems

The OVERSEER® nutrient budget model estimates the amount of N lost from 'efficient' nutrient pond systems based on a survey of nutrient pond outputs in the Waikato region (Ledgard et al. 1996). In a survey of nutrient budget outputs in the Waikato region (Judge and Ledgard 2004, internal report), N outputs to waterways from dairy effluent ponds was estimated at the equivalent of 2-7 kg N/ha/yr, with an average of 5 kg N/ha/yr.

An example of N losses from a typical dairy farm is shown in the following table. In this example, 200 kg N fertiliser/ha was applied to the main non-effluent block areas, and effluent block areas were either non-existent (pond system used) or received 0 or 100 N as fertiliser in addition to the effluent.

	N loss (kg N/ha/yr)			
	Main	Effluent	Pond	Total farm
200N main, 0 N effluent	39	19	0	38
200 N main + 100 N effluent	39	27	0	39
200 N, pond	39	n/a	3	42

This example shows that the combined loss of N from the farm (paddock N leaching + pond losses) when ponds were used was higher (3-4 kg N/ha/yr) then when effluent was applied as spray.

This table also emphasises the need to use values for total farm N losses unless management methods can be apportioned to each block. For the above example, losses from the effluent block ranges from 19 to 39 kg N/ha/yr depending on N fertiliser rate and whether effluent was applied. However, total farm losses ranged from 38-42 kg N/ha/yr. These figures will change from site to site, depending on the size of effluent block, supplementation, pasture productivity, and the use of feed pads.

P outputs to waterways from dairy effluent ponds in the Waikato region were estimated at the equivalent of 0.3-1.1 kg P/ha/yr, with an average of 0.8 kg P/ha/yr (Judge and Ledgard 2004, internal report). Generally, P losses from applying effluent to land are small. The exception is if effluent is applied to soils prone to runoff, is applied at a fast application rate, particularly on soils prone to runoff, or is applied to soils with subsurface drainage (such as those with tile drains). For these situations, P loss from effluent application can exceed that lost from ponds.

Losses from pond systems in other parts of New Zealand are expected to be similar. The model assumes that the pond systems are 'relatively' secure and that no subsurface drainage occurs. In poorly constructed ponds, losses would be higher.

15.2. Integration of Overseer into catchment modelling framework

The proposed method of implementation of the OVERSEER$^®$ nutrient budget model is described within the following section, and repeats some of Section 7.

15.2.1. Implementation method

The calculation part of the OVERSEER$^®$ nutrient budget model will be reworked so that a dll or similar is supplied and linked to the GIS framework. An initialising routine will also be added that translates the scenario number input into OVERSEER$^®$ nutrient budget model input data, and performs validation checks.

The model will be initiated with a call to a procedure:

Ovr(Valid, message, Nleach, Ploss, scenario, region, soilorder, rainfall, topography)

where:

Variable	Type	Comment
valid	Boolean	if true then Nleach and Ploss have a value
message	shortstring	description of error
Nleach	real	amount of N leached below the root zone
Ploss	real	amount of P loss in runoff from the block
scenario	integer	selected scenario
region	integer	region (based on regions used in the nutrient budget model)
soilorder	integer	code for soil order
Rainfall	integer	annual average rainfall to nearest 100 mm
Topography	integer	topography

A negative number for soil type, rainfall or topography would imply that a default value is used.

In addition, the following would also need to occur:

- Information will need to be provided to translate supplied soil order data into OVERSEER® nutrient budget soil group or soil order indices. This translation could be done either at the GIS end or within the OVERSEER® nutrient budget initialisation program.

- Regional layers equivalent to OVERSEER® nutrient budget region layers should be established within the GIS system. This can be developed separately from district council or regional council boundaries or such like. Alternatively, indices to district council or regional areas can be sent to the OVERSEER® nutrient budget model dll and region assigned internally.

- Scenario numbers and descriptions of the scenarios will be supplied. Methods of extending these are detailed in the full report.

- Method to estimate block topography would need to be established. Note that it is not the point slope. For P runoff, average slope may be more valid.

- A list of possible input variables from the GIS application will be supplied.

It is also assumed that the GIS application would control calls to the dll. Hence regions with the same input parameters could be populated with the one call.

If the parameter valid is true, no errors were encountered and a valid calculation was performed, with the results stored in Nleach and Ploss. Otherwise, Nleach and Ploss

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are zero, and a message indicating the possible source of the error is contained in the message string.

The procedure calls can be expanded by increasing the range of valid scenarios allowed and/or adding additional input variables to the call function.

A preliminary simplified dll has been supplied for initial testing as part of this report. This dll can be used to identify issues around integration of computer software. It does not contain any scenarios or OVERSEER® nutrient budget program information and this would need to be covered in another contract (see Section 7.6)

15.2.2. Initial scenarios

The initial scenarios selected to be included in the first implementation of the OVERSEER® nutrient budget model into the catchment modelling framework will use a range of land uses rather than management options. The reasons for this are that:

- Land use can be identified from current inventory layers, or can be estimated from current broad scale information.

- It is possible to generate typical land use scenarios from current data.

- Currently there is insufficient data to indicate the range and scope of management options that have been implemented within a land use.

- The typical range of land uses and management options will vary considerably between regions

Therefore it is recommended that the initial land use scenarios be:

- typical dairy farm

- sheep/beef, including typical high country/extensive, hill country sheep/beef, and a lowland intensive sheep/beef

- deer farm

15.2.3. Future scenarios

The method of implementation described above has the ability to expand to include a wider range of scenarios, and/or more productivity data.

Additional scenarios

The range of scenarios can be expanded as new areas are identified e.g., irrigated or non-irrigated farms in the Canterbury plains. This would require altering the scenario-setting part of the supplied model dll only, and increasing the range of scenarios that the user can select. This should create no backwards capability issues.

In practice, there are a range of regional differences in the types and ranges of scenarios. The most appropriate option would be to develop a typical regional scenario based on data such as that used by the MAF farm monitoring farm system. Additional information would need to be collected under a separate contract.

Additional biophysical data

As more biophysical data becomes available, this could be included in the scenario by increasing the range of input parameters in the initial call to the OVERSEER® nutrient budget model. This may create some backwards capability issues (i.e. old jobs may need modifying to update to the new call statement).

As full data sets are unlikely to be available in the short term, then the initial approach will require methods to adjust the scenario selected for given data (see validations/constraints).

Mitigation options

Mitigation options could also be included in later scenario development. Such mitigation options would need to take account of all management changes that are likely to occur when a mitigation option is used. This is important as model simulations have shown that these other management factors can either enhance or partially negate any benefits the mitigation option may have (unpublished data).

Addition of mitigation options into the GIS system would be seen as a later development.

15.2.4. Research updates

The OVERSEER® nutrient budget model is being updated at regular intervals as new research becomes available, and as typical farm management changes occur.

Supplying a dll in the form suggested means that it would be relatively simple to update the catchment modelling framework at the same time that the OVERSEER® nutrient budgets model is also updated.

Another consideration is that some of the future developments in the OVERSEER® nutrient budgets model may be covered by third party IP. It is probable, but not certain, that these developments can be passed on to other parties such as the catchment modelling framework if the information is supplied as above. Past experience has shown that these developments are more easily passed on if they are encapsulated within a more secure software package such as a dll.

15.2.5. Validations/constraints

Use of scenarios provides a means to generate land use patterns. However, some validations and constraints are required to ensure valid outputs. These are in the following 4 broad categories:

- Input variables are within range. This can be handled within the initialisation program.

- Inputs are aligned with one another. For example, if intensive dairy is selected on low rainfall areas, then it may be necessary to assume that some supplements are being brought onto the farm, or that irrigation is used. Validation routines to cover these types of errors can be included within the initialisation program.

- For a given pixel, any scenario selected can be farmed both practically and economically.

- Realistic assumptions are made about the distribution of land uses within a catchment.

It is also important that the scenarios capture the associated farm management set up. For example, bringing supplements onto the farm can represent a significant import of nutrients onto the farm (Wheeler et al. 2003) and result in the need to increase effluent block sizes to maintain N application rates within an allowed range. Creation of call and scenarios

15.2.6. Creation of call and scenarios

The creation of the dll and initial scenarios will need to be covered by a separate contract. Part of this contract would include a licence agreement to use the OVERSEER® nutrient budget model.

15.3. Recommendations

It is recommended that the OVERSEER nutrient budget model be integrated into the catchment modelling framework as outlined in Section 7.1, with initial scenarios as outlined in 7.2.

It is also recommended that further scenarios be developed. In developing these scenarios the following points should be considered:

- Within a land use, N leaching and P leaching/runoff losses usually increase as the farm system is intensified (Power et al. 2002) unless specific mitigation options are used. As nitrogen losses are driven predominately by urine N deposition, the method of intensification (e.g., higher fertiliser use, better pasture utilisation, and increased use of supplements) is less important than the total intake of N.

- Within the OVERSEER® nutrient budget model, the primary drivers for estimation of N intake are milksolids production for dairy systems or number of stock units (SU) for sheep/beef systems. Other factors, e.g., supplement imports, also affect intake calculations.

- Distribution of stock types and farm management systems does vary between regions (Agriculture Statistics 2002). While many of the differences can be covered by defined farm management scenarios (e.g., intensive sheep/beef system), there are some farming systems that are region specific e.g., dryland farming in non-irrigated parts of the East Coast, merino systems in the South Island high country.

- There is a wide range in farm productivity between regions e.g., average milksolids production ranged from 629 to 1024 kg milksolids/ha and average number of cows in milk from 1.8 to 3.0 cows/ha between regions (Dairy Statistics 2001). These ranges in production are probably associated with other farm management system differences such as use of supplements, rates of N fertiliser). Within sheep/beef farms, average stocking rates between regions and farm types varied from 1.5 to 13.5 SU/ha (MAF 2003).

- There are regional differences in the types of supplements. For example, maize silage is mainly used in the North Island, cereal and triticale silages are manly used in the South Island, and vegetable, fruit and processing by-products are confined to areas where these activities occur (P Sharp, feedTech, pers. comm.). The type of supplement can alter the N use efficiency (Ledgard et al. 2000) and hence changes the relationship between intensification and N loss.

- Regional differences in management do occur. For example, grazing animals off over winter or use of a stand-off or feed-pad have the potential to reduce N leaching by up to 60% (de Klein et al. 2000). This practice appears to be more common in Southland than elsewhere.

- For P losses, regional differences are mainly associated with soil and climate differences. However, there are some regional differences in farm management practices that may affect P losses, e.g., on some Southland soils, a significant amount of P loss was occurring through tile drains (Monaghan et al. 2003).

Given these region differences, it is recommended that typical regional scenarios are developed based on data such as that used by the MAF farm monitoring system. Additional information to that already collected as part of the MAF farm monitoring system would be required and the collection and analysis of the data would be covered under a separate contract.

16. Appendix 3: Output, Cash Farm Surplus and N loss Relationships change (Harris Consulting, Objective 3)

This section provides equations for triple bottom line accounting under a variety of land uses. Section 10 of the report outlines the rationale for this work. The equations here can be incorporated into the catchment modelling framework in later years of the project.

16.1. Background

This paper 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[2]:

- 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[3]. CFS also takes into account additional feed and N required to achieve a level of land use intensity.

- N leached – this is an estimate of the amount of N leached at a given level of land use intensity using 1200mm rainfall for Waikato.

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.

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[2] Note that not all land uses have the option of altering intensity.
[3] 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).

Six land uses have been addressed for the Waikato region: Hill Country Sheep and Beef, Intensive Sheep and Beef, Dairy, Kiwifruit, Process vegetables, and Grapes.

16.2.   Hill Country Sheep and Beef

Applies to Easy and Steep topography (or alternately to areas geographically defined). This category allows different intensity of operation to be entered by the user. It assumes a standard sheep to beef ratio of 1.6 sheep su to 1 beef su. This category assumes minor applications of N at the default stocking rate, increasing to 50kg/ha at 11su/ha. It assumes a 15:1 response ratio for N applications, 550kgDm/su and a 0.8 utilisation rate.

The range of intensity allowed is: 3 – 11 su/ha

The default intensity should be set at 9.7su/ha

Output(\$/ha) = \$110*su

CFS (\$/ha) = 86*su – 73

N loss (kgN/ha) = $0.5709 * e^{(0.1956*su)}$

Total GDP (\$) = Output * 0.53

Total Employment (FTEs) = Output * 5.32/1000000

16.3.   Intensive Sheep and Beef

This category applies to rolling and flat topography. It assumes a 45% sheep : 55% beef ratio, and applications of 30kgN/ha at the default stocking rate. Applications of N are increased to accommodate increased stocking rates, at a 15:1 conversion rate, 550kgDM/su and 0.85 utilisation rate.

The range of intensity allowed for this class is 6 – 17su/ha.

The default stocking rate is 11.1su/ha.

Output (\$/ha) = 157*su

CFS (\$/ha) = 1114*Ln(su) - 1347

N leached (kgN/ha) = $1.53 * e^{(0.2057*su)}$

Total GDP ($) = Output * 0.53

Total Employment (FTEs) = Output * 5.32/1000000

16.4. Dairy

The dairy land use is based on cows/ha rather than su. It uses a standard ratio of milk solids/cow (858), and assumes 150kgN/ha at the default stocking rate of 2.6cows/ha. Changes from this initially add or subtract N at a rate of 11kgDM/kgMS with a 15:1 conversion ratio for N:DM and a utilisation of 0.9. N is limited to 200kg/ha, at which point supplementary feeding kicks in using good quality pasture silage and a conversion of 1.2kg silage to 1kg pasture DM.

Range 1 – 4 cows/ha

Default value = 2.6 cows/ha

Output ($/ha) = 1411* cows/ha

Cash Farm Surplus ($/ha) = 729*cows – 235

N loss (kgN/ha) = $7.6*\text{cows}^{1.785}$

Total GDP ($) = Output * 0.84

Total Employment (FTEs) = Output * 10.06/1000000

16.5. Kiwifruit

Only one value is used for kiwifruit, with the option for users of adding or subtracting land area rather than changing intensity. N applied is 175 – 200kg/ha

Output ($/ha) = $45,000/ha

CFS ($/ha) = $19,000/ha

N loss = 100kgN/ha

Total GDP ($) = Output * 0.99

Total Employment (FTEs) = Output * 19.38/1000000

16.6. Process Vegetables

Again only one value is given for this land use. Output and CFS are based on a weighted average of Waikato crop types (weighted for national areas), and N loss is based on potatoes at 200kgN applied/ha.

Output ($/ha) = $14900/ha

CFS ($/ha) = $3130/ha

N loss = 110kgN/ha

Total GDP ($) = Output * 0.99

Total Employment (FTEs) = Output * 19.38/1000000

16.7. Viticulture

Again only one value is given for this land use, with change in intensity not a realistic option. Output, CFS and N loss are based on the MAF Hawkes Bay model.

Output ($/ha) = $20,550/ha

CFS ($/ha) = $8290/ha

N loss = 17 kgN/ha

Total GDP ($) = Output * 0.95

Total Employment (FTEs) = Output * 14.26/1000000

16.8. 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 2004.

Utilises SPASMO model runs as reported in Section 8.

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.

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

17. Appendix 4: Contract Objectives for Stage I

The following information is taken directly from Schedule II of the 2004 contract between NIWA and MAF. Some of the deliverables are specific to the first or second years only, while others cover the entire project.

17.1. Objective 1

Objective Title :   Catchment Modelling Framework

Objective Leader   :Dr Sandy Elliott

Description :

The national SPARROW model will be modified and incorporated into a desktop tool that will perform water quality analysis at a catchment scale for different land use scenarios and provide the necessary input to the pollution risk model (Objective 2) and the enterprise-scale economic analysis models of Objective 3. This objective will link together the models and databases of the other two objectives, and interact directly with spatial data provided through NIWA's river environment classification network (REC) through a GIS. A GIS interface will be developed to provide a means for users to specify an area of interest on a map, and this information will be used subsequently to obtain the relevant spatial data for SPARROW processing and interaction with the other models. Risk/economic analysis information provided by the other models will be displayed through the GIS interface developed in this objective.

Methodology:

The catchment modelling framework will be built inside a staged GIS system.

- The initial stages of the development will focus on adapting the SPARROW model to work inside a GIS and to utilise the summarised spatial information in the River Environment Classification for N and P production for different landuse scenarios. Test with Environment Waikato.

- Extend SPARROW to include sediment (especially forestry impacts) (year 2), to use new FRST-derived results on pathogen pollution (year 3), and to estimate economic impacts of landuse change (using MAF data)

- A standard database will be designed to optimise the data structures that will be shared between the various models. Appropriate software routines will be written to access and populate this database during use.

- Models developed in Objectives 2 and 3 will be incorporated into the same GIS environment and software developed to integrate the processing between these models. Both input and output will be standardised so that the user only has to interact with one map interface.

- In year 1 the focus will be on model integration inside a simple map (GIS) interface, with the emphasis on efficiency of data transfer between models and seamless processing of the models, and in years 2 and 3 more sophisticated GIS interface will be developed.

- A system for speedily incorporating changes or revisions of models in any of the objectives will be developed.

Costing for Objective 1 as in NIWA proposal ~ 0.35 FTE/y for 3 years, ~ $65K/ Govt. financial year.

NIWA only

17.2. Objective 2

Objective Title :   Adding Groundwater Component to SPARROW

Objective Leader :   Dr Sandy Elliott

Description :

Generalise the SPARROW model so that it includes a groundwater nutrient modelling component. The average annual nutrient yield from each modelled sub-catchment will be partitioned between surface and groundwater, and then routed separately through each of these domains. The model will need to be tested in a study catchment using water quality data for N and P in both streams and groundwater.

Methodology :

NIWA will extend the existing SPARROW equations so that pollutants can follow either a groundwater path or a surface water path. In Year 1, the groundwater flow direction will be assumed to follow the river flow direction, but NIWA will implement

this so that it can be generalised at a later stage in the project (e.g., to use information from a groundwater flow model). Lincoln Ventures will implement a simple method to estimate the proportion of pollutant that enters the groundwater (based on their previous FRST research on groundwater recharge by rainfall). Lincoln Ventures will also implement a simple method to estimate pollutant attenuation in groundwater, in a way that is compatible with the SPARROW framework. The expanded model will be functioning by the end of Year 1. In Year 2 NIWA and Lincoln Ventures will apply the expanded SPARROW model in collaboration with an end-user to a study catchment where long-term data for both streamflow and groundwater quality are available for calibration.

Costing for Objective 2 ~ $70K/yr for years 2003/4 and 2004/5

NIWA 0.2 FTE in each of years 1 and 2

Lincoln Ventures 0.2 FTE in each of years 1 and 2

17.3. 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.

Methodology:

Develop functional relationships between nutrient/contaminant losses and land-use type and intensity. The relationships will be based on published data (e.g. "Implications of groundwater nitrate standards for agricultural management. Ecolink, MAF Policy 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 ~ $35K 2003/2004, $17K in years 2004/2005 and 2005/2006.

Simon Harris and others 0.2 FTE in year 1, 0.1 FTE in years 2 and 3.

17.4.   Objective 4

Objective Title :   Enterprise-scale Modelling

Objective Leader: Mr David Wheeler

Description:

Provide input of water quality and economic parameters to the GIS model 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:

Modifying the OVERSEER nutrient budget model to link directly to the GIS system (year 1).

Creating a range of management and land use scenarios for pastoral (OVERSEER) and horticultural (pipfruit, kiwifruit vineyards) and vegetable (SPAMSO) land uses. These scenarios will provide users the means to investigate changes in land use management without the need to gather the information to run the full base models.

- Using more detailed models such as SPAMSO as a means to explore the integral impact of specific local management practices on receiving water quality at the catchment scale. This will then be used to modify the above.

- Investigate methods of integrating the effects of irrigation, and a gross margin based model to determine economic effects of land use change. These methods will be added to the integrated model in year 3.

Costing for Objective 4

Agresearch $30K for 2004

HortResearch $30K for 2004

17.5. Objective 5

Objective Title :   Pollution Risk Modelling

Objective Leader   Dr Alan Hewitt

Description

The pollution risk modeling objective will locate, at more detailed scales, the areas within catchments that contribute highly to poor water quality. This objective will generate risk maps showing high/medium/low risk of generating pollutant runoff from each map unit. The user will be able to target specific areas that pose the highest risk for pollution and may examine tradeoffs with areas where risks are lower, or with changes in management practices.

Methodology:

The pollution risk model will be developed using the EnSus framework that has been in development at Landcare Research for the past 5 years.

- The hazards to be assessed (e.g., sediment, N or P loss to ground water) will be defined and the major biophysical and land use factors that attenuate or intensify this pollution risk deduced from existing science knowledge and experience. For example, greater ground water pollution hazard exists for soils with high bypass flow.

- The vulnerability of land to each hazard will be determined by a set of rules that match soil, landform and climate attributes to levels of hazard. For example, the level of vulnerability of land to N leaching will depend on the magnitude of bypass flow. The rule sets will be developed from expert knowledge, published and unpublished sources, and the results of process modelling (Objective 7).

These rules will then be applied to spatial information on soil, landform, and climate maps to produce hazard vulnerability maps. These maps may be applied at generalised scales to display vulnerability at national, regional and district extents down to farm scale at 1: 50 00 scale.

- Existing land use pressures will be mapped from available spatial land cover and land use data. Key land management practices will be listed for each land use. The relationships between these key land management practices and hazards will be evaluated, to identify beneficial, neutral or adverse practices.

The analysis will be done within an expert system shell. The model will provide transparency to the rules, propagation of uncertainty in data and rules to results, and backward traceability of outputs to rules and data.

Costing for Objective 5 ~ $55K 2004

Landcare Research

18. Appendix 5: Contact Details

Table 18-1: **Contact details for the people involved in the project**

Name	Organisation	Role	Email	Phone
Gerald Rys	MAF (Wgtn)	Client contact	rysg@maf.govt.nz	04 498 9941
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
Jochen Schmidt	NIWA (Chch)	GIS, modelling	j.schmidt@niwa.co.nz	03 343 8058
Clive Howard-Williams	NIWA (Chch)	NIWA Overview	c.howard-williams@niwa.co.nz	03 348 8987
Kathryne Farnsworth	NIWA (Ham)	Advising on subcontracts	k.farnsworth@niwa.co.nz	07 856 1764
Vince Bidwell	Lincoln Ventures	Groundwater	Bidwellv@lincoln.ac.nz	03 325 3704
John Bright	Aqualinc (ex Lincoln Ventures)	Groundwater	j.bright@aqualinc.co.nz	03 325 3780
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