Overview of Catchment Scale Nutrient Modelling in New Zealand

Outcomes from Workshop
Wellington, July 2009

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Executive Summary

Catchment scale nutrient models are increasingly being used by regional councils and unitary authorities to investigate the impacts of intensive land use on the environment and to develop policy to manage these effects.

The objectives of the workshop held in Wellington in July 2009 were to raise potential end user understanding of these models, share some lessons learnt and promote cross discipline discussion. Emphasis was also on improving collaboration between councils and research providers, and to identify actions to improve the understanding and uptake of these models.

This report provides an overview of catchment modelling concepts, outlines points to consider when establishing a modelling project, selecting models and using the results. It also contains summary information on the range of models currently used in New Zealand. The report also captures the feedback and recommendations from the workshop.

Three catchment scale nutrient models were presented as case studies to the workshop:

- ROTAN – Lake Rotorua, NIWA and Environment Bay of Plenty
- AquiferSim – Canterbury Plains, IRAP and Environment Canterbury
- CLUES – Upper Waikato, NIWA and Environment Waikato

Summary information on these three models is reported and information is provided on additional models which operate at other scales.

Discussion during the workshop brought out these key points:

- Defining the problem and the system is the first key step as it will guide the potential use and type of model required.
- There is a lack of overview and 'user friendly' information on models, which make comparison between them difficult.
- Choosing a model, and then applying it in a robust way can be a difficult process and some form of standard guideline could assist the process and improve confidence in results
- Using results of modelling for policy development and engaging a community in this process can be challenging. Some councils have learnt a lot in this area in recent years. There would be value in capturing and sharing these learnings for other Regions

Ideas were sought from workshop participants on how to improve the uptake and use of catchment models. These have been grouped into five main themes:

- Central model library of resource material
- Improved data sets
- Productive collaboration
- Education on Models
- Intellectual Property

The issues and barriers are outlined under each theme and recommendations made to improve the general uptake and use of catchment scale models. These include developing further resources to meet end user needs, establishment of a central model library, formation of a specific catchment modelling group, and promoting an 'open-source' approach to models and data.

The outcomes of this workshop and the recommendations are seen to be well aligned with the goals and objectives of Regional Councils – Research for the Environment Strategy (RC – SAG, 2009). It is therefore proposed to present these findings to the Regional Councils Resource Managers Group and Science Advisory Group.

Acknowledgements

Holding the workshop and preparing this report was made possible through the assistance of a number of people.

Firstly, thank you to the workshop presenters, Vince Bidwell, Linda Lilburne, Raymond Ford, Sandy Elliott, Reece Hill, Kit Rutherford, and Andy Bruere. Your input provided both the basis for a productive workshop and information for this report.

Thank you also to the 'planning team' of Dougall Gordan, Linda Lilburne, Tina von Pein, Carl Hanson, Kathleen Crisley, Reece Hill, and Viv Smith for their input to developing the workshop. Finally Greater Wellington (Doug McAlister) for assistance in hosting the workshop is acknowledged.

This workshop and report were made possible through Envirolink funding.

1. Background

This report has been prepared as part of an Envirolink funded project. The project included a workshop on catchment scale nutrient modelling for Regional Council and Unitary Authority science and policy staff. This workshop was held at Greater Wellington's office in Wellington on 27th July 2009.

The objectives for the workshop were to:

- Inform potential users of the catchment-scale nutrient modelling tools and what they can, and can't do
- Identify lessons learnt in the use of models to date
- Initiate cross-disciplinary discussions about existing modelling tools and how they can be used to develop policy
- Improve collaborative links between and among regional councils and research providers
- Identify what needs to happen next to build understanding and uptake of catchment models.

The purpose of this report is to capture the discussion and thinking from the workshop, including the case studies presented and to provide some broader discussion and background on models and their use in managing diffuse discharge. It also gives recommendations that could improve the understanding and implementation of models in resource management decisions.

It is not within the scope of this report to undertake detailed comparisons of different models available, or to clearly define a robust process for problem definition/conceptualisation and model selection. These issues were clearly raised at the workshop and need future attention but are outside of the objectives and resourcing of this report.

2. Introduction

A model is a mathematical representation of a system, a simplified abstract view of the complex reality. Models are typically used when it is either impossible or impractical to create experimental conditions in which scientists can directly measure outcomes. An environmental model represents empirical objects and physical processes in a logical way and is intended to simulate the changes in natural processes over time and predict an outcome for an area or issue of interest. When predicting outcomes, models use assumptions, while measurements do not. As the number of assumptions in a model increases, the accuracy and relevance of the model diminishes.

Catchment scale models have been used for decades to study and improve resource management of catchments. In New Zealand they have been primarily used to manage water yield from rivers and groundwater and for flooding and sediment control in rivers. More recently there has been considerable focus on the need to develop and use models to help manage nutrient losses from non-point discharges associated with intensive land use. Considerable research effort has occurred and is continuing to develop models appropriate to New Zealand conditions. Most of the research effort has been undertaken by Crown Research Agencies with input and/or collaboration with end users (PCE, 2004).

Generally end users are Regional Councils and Unitary Authorities who have responsibility for managing land and water resources under the Resource Management Act (RMA). Land and water resources of a catchment are strongly inter-related and modelling tools can be used to understand both current and potential future affects of land use management

practices on soil health, water quality and water quantity. Figure 1 represents potential opportunities when trying to achieve the outcome of sustainable land and water management.

From these modelling opportunities presented in Figure 1 this report focuses only on nutrient losses and subsequent transport via groundwater, streams, and rivers on a catchment scale.

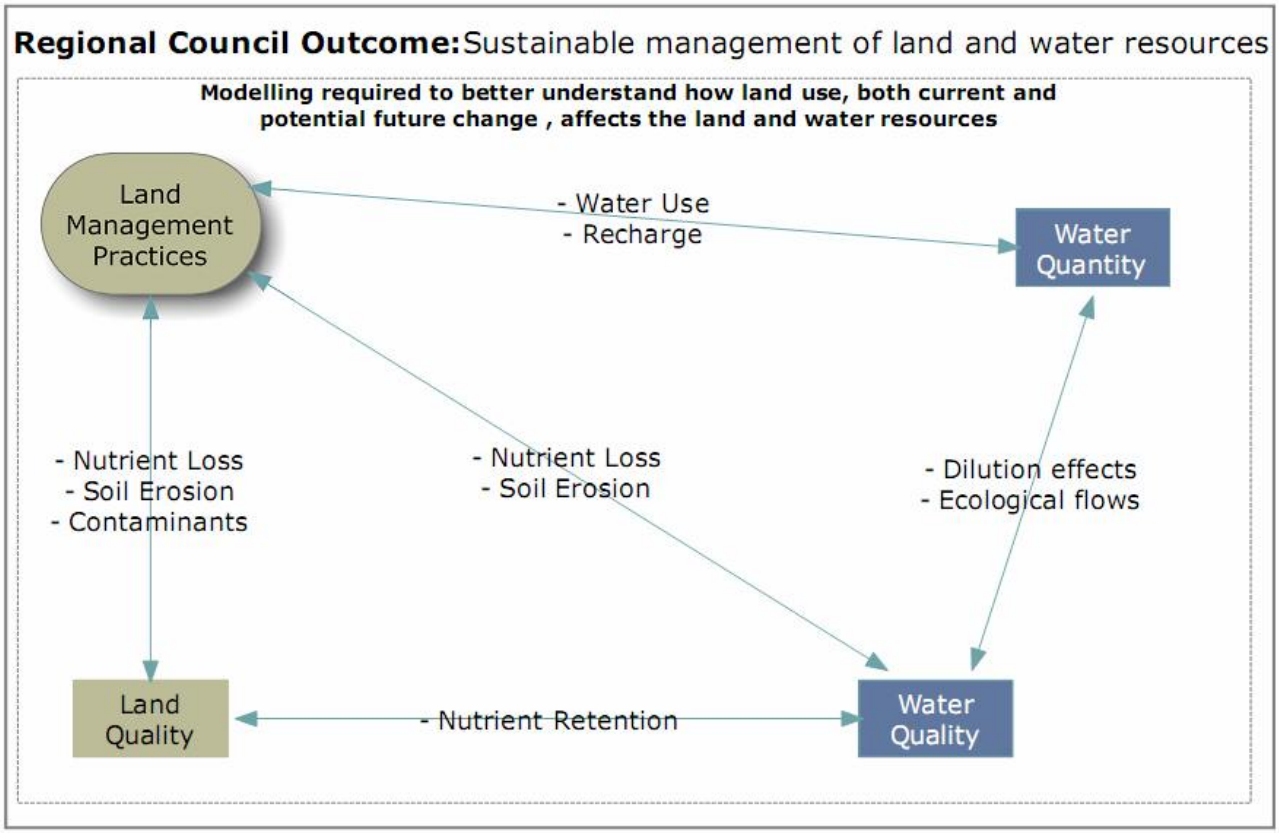

Figure 1: Potential opportunities for modelling changes in land and water resources.

3. Modelling Tools for Land and Water Management

Modelling tools are increasingly being used by Councils for the development and implementation of RMA policies for sustainable land management. The RMA policy development process (Figure 2) is normally based on responding to existing or emerging management issues that are identified through environmental monitoring and reporting. The next step, particularly for water quality issues, can be the development of a particular target parameter to reach an outcome set by the community. This target then forms the basis for developing policy options and tools to address the resource issue(s).

Nutrient models can be used to inform the RMA policy process in several areas (Figure 2). At the large catchment and sub catchment scale, models can be very useful in assessing significance of land use effects on water quality or can be used to investigate the implications of 'what if' scenarios. At this scale, nutrient models can also be used to determine the extent of changes to land management that may be required to meet a specific water quality target and outcome.

At the smaller farm or paddock scale, nutrient models can be used in conjunction with catchment models to assess the effectiveness and feasibility of specific policy options at meeting the required environmental outcomes. These can also be used to assess the

feasibility of implementation and compliance with specific policies. Farm and paddock scale models provide useful data input and/or calibration for catchment models.

The July workshop focused on catchment scale models, but some reference will be made in this report to paddock and farm scale nutrient models.

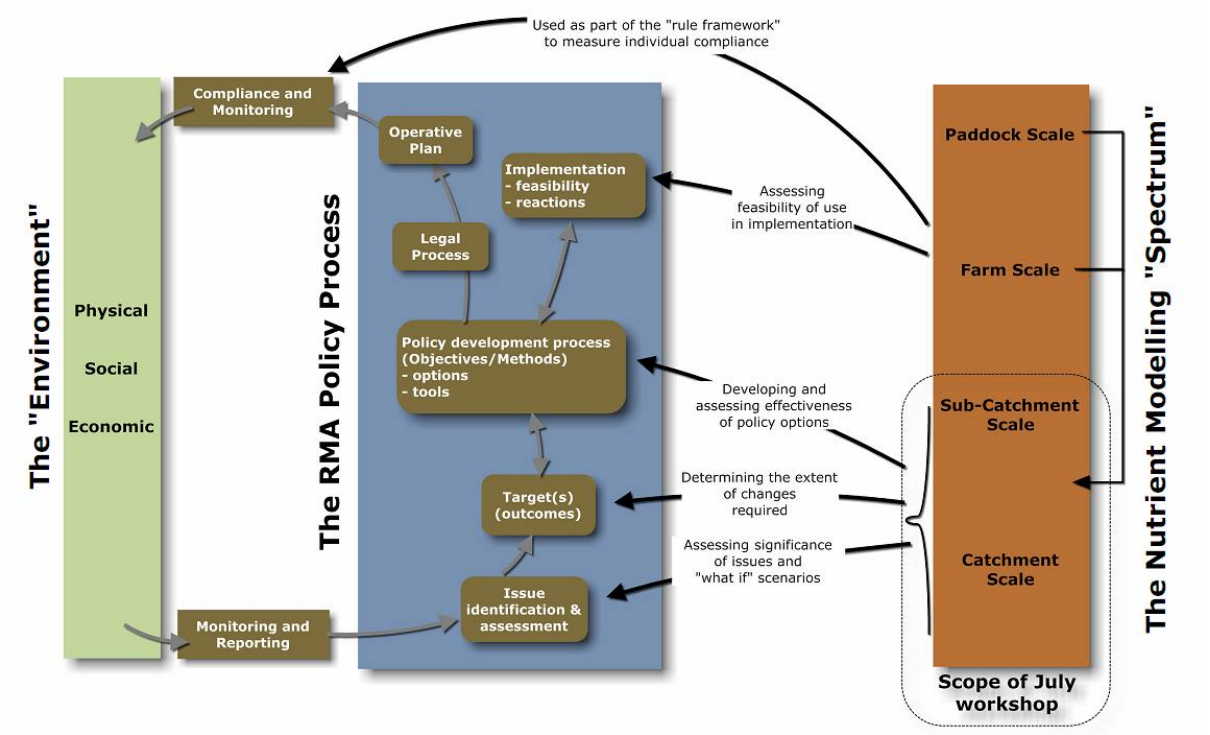

Figure 2: The relationship between RMA policy process and Nutrient modelling

Questions for Models to Answer

Models can be used to answer both generic questions or can be developed to answer more specific questions. It is important to be clear during the project development process what the questions the model needs to answer, and to be aware of what the limitations of the model are. Some examples to these are provided:

Question catchment scale nutrient models can help to answer

- Are monitoring results representative of an issue?
- What is causing the issue?
- Which areas are contributing the most? (spatial variability/proximity, 'hot spots')
- What would happen in future if we …? (range of scenarios)
    - Did nothing
    - Capped nutrient levels now
    - Bring about land use management change now or at some other specified time in the future.
- How much change in land use is required to meet particular targets or outcomes?
- Which areas and/or changes would give us the best bang for our buck?

More specific questions should be considered for each project depending on the system being studied and aspects or inter-linkages of interest.

Questions catchment scale nutrient models are unable to answer

- What is an acceptable target for future water quality? – although model results are useful in undertaking a community discussion to establish targets.

- Economic implications (i.e. effect of land use change on employment FTE's, Gross Regional Product) – although economic models can be linked into catchment models to provide this type of information (See CLUES – Section 4.3)

Section 4 provides more specific information about catchment scale models that are currently available and being used.

Using Model Results

Modelling results can be used in a range of roles through the policy development process. Being clear about the system[1] and questions for modelling will influence the usefulness of the results. This helps to identify the important parameters to be modelled for meaningful results and helps to clarify limitations and assumptions so that results can be used in the right context. Catchment scale models have significant value in helping understand what is happening within a groundwater or catchment system to help inform both community discussion, and policy or political decision making processes.

Communicating the results of modelling in an accurate and meaningful way is probably one of the challenging steps; yet achieving this has a great bearing on the usefulness of the modelling process in achieving the required environmental outcomes. In utilising and communicating any modelling results some key aspects to consider are:

- identification and management of the uncertainty associated with specific model outputs
- the assumptions and limitations should be carefully explained to stakeholder and decision makers to put the relative accuracy of modeled results into context.

Developing a range of meaningful scenarios for your system that can be modeled can be a very useful outcome of catchment modelling. The results from modelling these scenarios can be used to show relative changes in outcomes rather than a specific expected outcome. This provides useful information for organisational and community discussion and strategy development.

Case Studies

A number of models have already been used by different Regional Councils in developing policy to manage the effects of land use. Three Case studies were presented at the beginning of the workshop (ROTAN – Lake Rotorua [NIWA, Environment Bay of Plenty], AquiferSim – Canterbury Plans [IRAP, Environment Canterbury, and CLUES – Upper Waikato Catchment [NIWA, Environment Waikato).

Presentations for these case studies are in Section 7 - Appendix 2. Section 4 provides more specific information about catchment scale models that are available and being used, and provides some guidance on the capabilities of these models.

[1] System is defined as the inter-linked geophysical attributes of the landscape that need to be quantified and understood as part of the modelling (i.e. diverse land use pattern, large multiple aquifers, spring fed streams, lakes, recharge zones)

4. Overview of Catchment Scale Nutrient Modelling

4.1 Background and Overview

This section provides an overview of the types of catchment scale models that are available and provides some specific information about the main catchment scale models currently being used in New Zealand.

Catchment scale nutrient models calculate nutrient loss from the land surface and route this through the catchment. Modeled results can depict loads of nutrient through that catchment and concentrations of nutrient at points of interest throughout a catchment. Models can be used to model one or more components of the hydrological flow and associated nutrient loads throughout a catchment (Figure 4). Groundwater models with spring outflows [discharge] (i.e. AquiferSim) are commonly used to model large groundwater systems such as in Canterbury. Surface water models are used to model nutrient loss and transport through stream and river systems (i.e. CLUES). More complex models, often consisting of linked components, can be used to model several type of water in a catchment, such as groundwater, stream and lake (i.e. ROTAN).

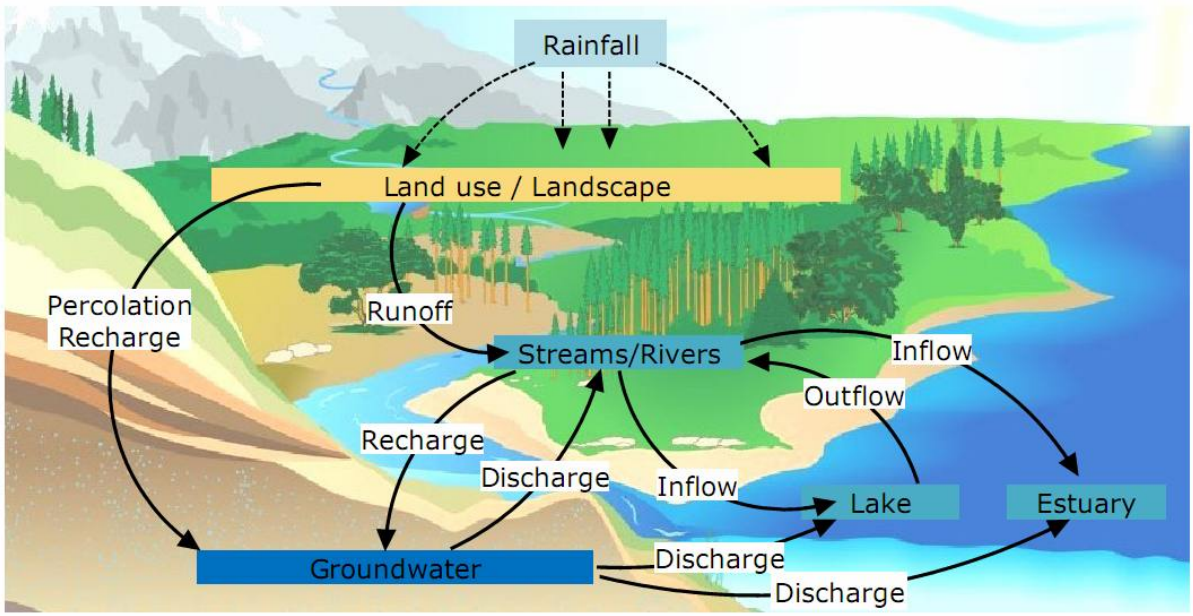

Figure 4: Hydrological flows –Deciding what to model

Do you need a model?

Before answering this question it is worth considering the definition of a model. Many assume it is some complex software programme that needs expert input and a thick manual, which is true in many cases. However, a model can also be as simple as a computer spreadsheet of data with some linked equations.

Working through the answer to this question is the first significant step that should be carefully undertaken before proceeding. The following points provide some guidance to answering the question:

- A robust project 'conceptualisation' process is a starting point. This should clearly define the issues/problems, the associated questions that need to be answered to solve the problem, and define the systems to be modeled.

- This process should provide clarity on points such as:
    - What information is required to address or answer these?
    - How much detail and certainty in the result is required?
    - How complex is the system under investigation?
    - How well do you understand the systems?
    - What information is already available about the issues and the system?
- Having a clear understanding of the natural system is also important as this is required to establish the right model(s) for addressing the management issue/problem(s).
- In some cases developing a 'back of the envelope' model will help to identify the extent of an issues, identify further information needs and add to the conceptualisation process required for a model complex model.

How Models Work

Models are a mathematical representation of a system. This representation is often visually portrayed as a framework of boxes and arrows. The boxes can be seen to represent 'stores' of water and contaminants in different part of the systems, and the arrows represent the 'flow' or movement of water and contaminants from on part of the system to the next. A generic representation of this concept is shown in Figure 5.

Figure 5 represents the:

- Landscape losses (in a model the landscape is divided into a grid and each squares is calculated in the model – only one grid square is shown in Figure 5), the model would calculate the water losses (run-off, drainage) from each landscape unit and these would be transferred to the next 'store' (river flow, subsurface flow). A nutrient loss model (i.e. Overseer™) is used to calculate the associated flow of nutrients that would occur with the runoff and drainage. These numbers are then carrier through the rest of the modelling to provide flow, nutrient concentration and hence nutrient load data.

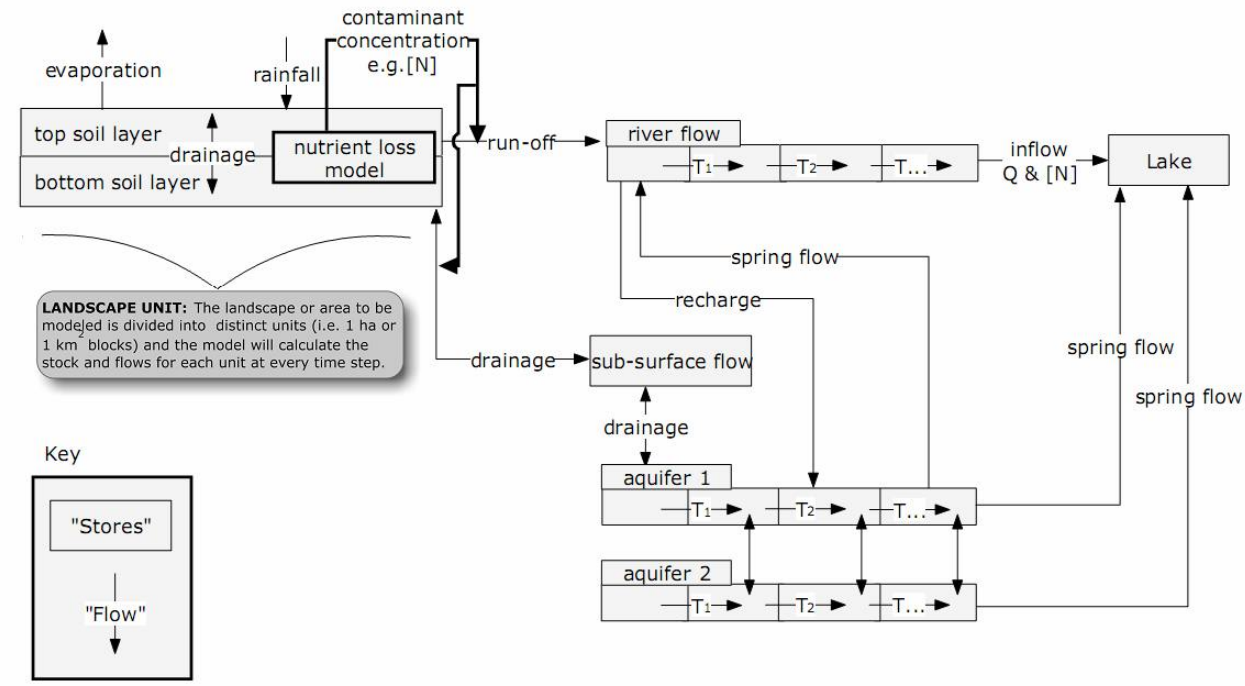

Figure 5: Conceptual Modelling Processes

- Surface flow of solute (water and dissolved nutrients) is collected and routed along the drainage network at each time step. The model is also able to transfer from the river store into either a lake or groundwater store to represent inflows, or recharge respectively that may occur within the system.

- Groundwater receives drainage from subsurface flow or recharge from surface river flow. A model can represent more than one aquifer and can be defined to best represent the systems being studied. This can included routing solute along and between aquifers at each time step based on the aquifer parameters and the discharge of solute to surface water (lakes and rivers) via springs.

Results from the modelling can be presented as in a range of ways, from time series graphs for point or grouped data (i.e. runoff volumes) to two or three dimensional representations of a specific parameter (i.e. nutrient loss levels across a landscape [2D], or nutrient concentrations through an aquifer [3D]). The type of results will be dependant on the system being modeled and the type and complexity of the model used.

Choosing a Model

When you have completed the planning process and come to the conclusion that you require a model to assist in a resource management or policy development process, the next challenge is to decide which model(s) would best suit your needs.

This process can require further research and investigation. Taking the issue definition, questions and system characteristic for your situation, the process can start with a comparison of the relative strengths, limitations and data requirements for a range of models that could model your systems (i.e. groundwater, rivers, lakes). This can be followed up with some expert advice from peers who have undertaken modelling or model developers.

Other factors that should be considered are in the selection process:

- Data, computing and technical requirements to run a model
- What is in the 'black box'
- Are the assumptions acceptable
- What level of certainty is require in the outputs
- How sensitive are parameters
- Usability of model, interfaces, outputs
- Support for model – documentation, case studies
- Need for multiple components (ground water, steams) can you find them in one model
- Time and spatial scales
- Are there significant ground water lags

There are a number of nutrient models currently used that have been developed both in New Zealand and overseas (Figure 6). They range from one dimensional paddock scale to regional models. Some of the large scale models incorporate as part of their design other existing models, such as farm or paddock scale nutrient loss models whose results are amalgamated into the larger scale model (e.g. AquiferSim, CLUES).

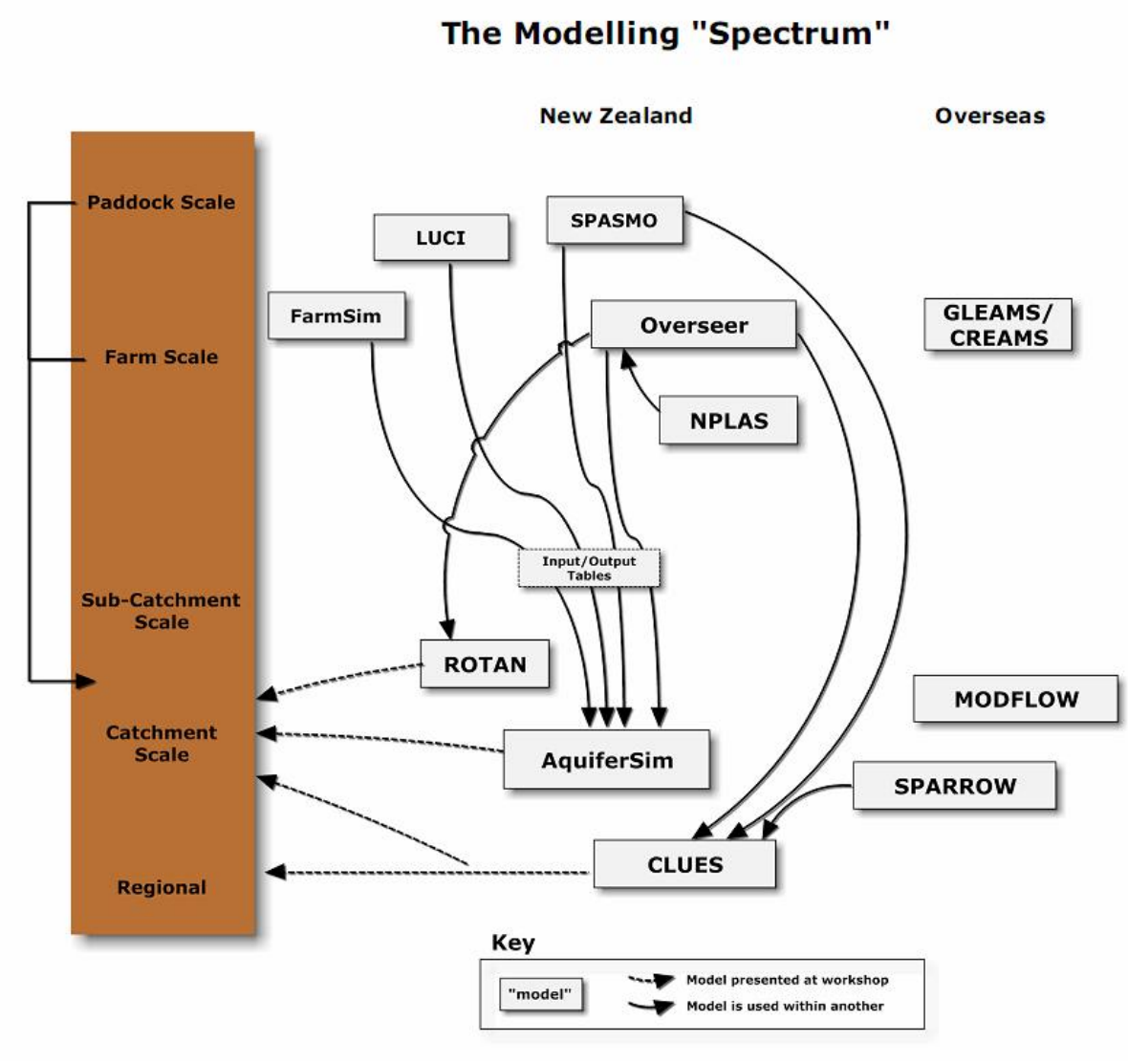

Figure 6: Examples of the different scales of nutrient models

Comparative information on a range of models is provided in Table 1. More specific information is provided on the case study models presented at the workshop (see Section 4.2-4.4).

All Catchment Scale models have a 'nutrient sub-model' which determines the quantum of nutrients lost from the landscape. This is done generally at a paddock or farm scale, so there are direct linkages between the smaller scale models and catchment scale (Figure 6).

Some models are developed for specific issues and locations such as ROTAN, developed for Rotorua and Taupo lakes, and AquiferSim developed to model groundwater under alluvial plains (e.g., Canterbury). This does not mean that they can not be applied elsewhere, they would only need to be specifically set up and calibrated for a new area. CLUES on the other hand is a more 'generic' model that can be applied nationally or regionally using larger scale spatial data sets. It is, however, primarily a surface water model that does not factor in ground water processes and lag, but it is designed with a user friendly interface that allows for visual outputs of spatial results.

Name	Main NZ Developer	Spatial scale	Temporal scale	Contaminant	Zone of prediction	Type
Luci	Plant & Food	Paddock	Daily	Nutrients	Root zone	Process based
FarmSim	IRAP	Farm	Daily	Nutrients	Root zone	Process based
Spasmo	Plant & Food	Farm	Daily	Nutrients	Root zone	Process based
NPLAS	NIWA	Farm	Mean annual	Nutrients	Surface water	
Overseer	AgResearch	Farm	Mean annual	nutrients	Root zone	Empirical
ROTAN	NIWA	Catchment	Daily	Nutrients	Surface and groundwater	Semi-mechanistic
SPARROW	NIWA	Catchment/ National	Mean annual	Nutrient / microbes / sediment	Surface water	Empirical
AquiferSim	IRAP	Catchment/ Regional	Mean annual	Nutrients	Groundwater / springs	Process based
CLUES	MAF/ NIWA	Catchment/ National	Mean annual	Nutrient / microbes / sediment	Surface water	Empirical
GLEAMS / CREAMS		Paddock	Daily	Nutrients	Root zone	Process based
MODflow		Catchment/ Regional	Daily	Nutrients	Groundwater /springs	Process based

Table 1: Summary information on a range of models.

When you have chosen a model or models to use, the next process is to set up the model to represent your catchment. This can involve setting the catchment boundaries and boundary conditions, defining land use, soil and aquifer properties, and sourcing other data sets, such as climate records and water quality monitoring data for the selected catchment.

The process of this set up and calibration of the model can be a technical undertaking requiring either modelling experience or expert advice.

The following points were raised at the workshop for consideration when applying models:

- The assumptions incorporated into the model need to be clearly defined and expressed with output results.
- The model should not be operated outside its limitation (i.e., too far beyond calibration data)
- The output information will need to suit its purpose. Models can be both decision support tools and management tools. Result to be used with communities as part of a decision process will need to be presented to suit the audience, and supported with information about how the model works and why.
- Validating results and providing information on the level of uncertainty within the model need to be undertaken and clearly shown or communicated when using the results.

4.2 ROTAN

Name	Main NZ Developer	Spatial scale	Temporal scale	Contaminant	Zone of prediction	Type
ROTAN	NIWA	Catchment	Daily	Nutrients	Surface water and groundwater	Semi-mechanistic

Strengths:	Limitations:	Data Requirements:
- Is dynamic and time-step able to be altered - Includes groundwater - Accounts for time-lags in exports of nutrients - Able to account for both temporal and spatial changes in land use - Is based in ArcGIS - Code readily accessible	- Requires a ROTAN "expert" to set the model up correctly and run it	- Rainfall - Land use - Soil types - Point sources: spatial information and amount of nutrient export from each

ROTAN (ROtorua and TAupo Nitrogen model) catchment scale model is a daily time-step, conceptual rainfall-runoff-groundwater model. The model runs within ArcGIS using Microsoft Access® databases (Rutherford, et al. 2009; Rucinski et al. 2006) In ROTAN there is a single land use layer comprising a number of functional units (FU) which is underlain by 1-3 aquifer layers (Figure 6). FUs are defined by intersecting GIS layers of surface catchment boundaries, vegetation cover, land use, soil drainage and rainfall.

Water balance calculations are performed on each FU and the results combined to estimate stream flows and drainage rates into any underlying aquifers. Each FU has a characteristic set of coefficients that quantify interception, infiltration, drainage, and evapotranspiration. FU coefficients do not vary over time but land use changes are simulated by allowing the spatial distribution of FUs to change.

Within each FU there are 4 sub-layers (Figure 6). The top 2 sub-layers encompass the root-zone in which are simulated interception, infiltration, evapotranspiration and drainage. Surface runoff is simulated by infiltration-excess and saturation-excess runoff during heavy rain. The bottom 2 sub-layers are conceptual reservoirs that represent quick-flow (viz., shallow sub-surface flow to streams with a time scale of days) and slow-flow (viz., sub-surface flow to streams with a time scale of weeks-months (Rutherford et al, 2009).

Each FU is assigned a nitrogen export rate estimated using Overseer®. Nitrogen can be exported from each of the 4 sub-layers. The rate of release of nitrogen, evapotranspiration (sub-layer 1 only), drainage and runoff determines the nitrogen concentration in water exported from each sub-layer. By sub-dividing the total nitrogen export between sub-layers, the model simulates different pathways to the lake and different delivery times. Therefore nitrogen generated in sub-layer 3 (Figure 6) reaches the stream and hence the receiving water body (e.g., lake) soon after it is generated via quickflow following rainfall, whereas nitrogen generated in sub-layers that drain to groundwater reaches the receiving water body years-decades after it is generated. Note that this exercise could also be done for phosphorus if required.

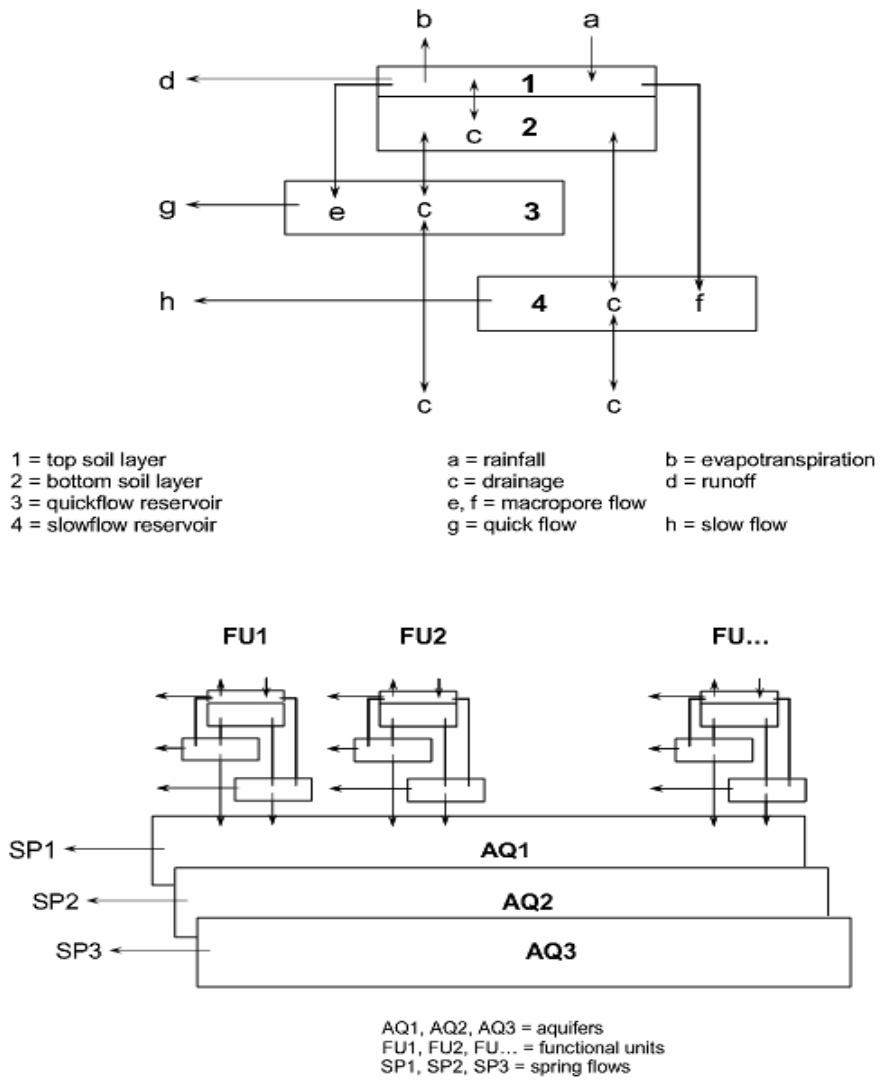

Figure 6: ROTAN conceptual model that operates in each Functional Unit (FU) and connections between FUs, Aquifers (AQs), and Springs (SPs) (source: Rutherford et, al. 2009)

The application of the ROTAN model to the Lake Rotorua catchment has be supported by groundwater research and modelling undertaken by the Institute of Geological and Nuclear Sciences (GNS). GNS have applied the FEMWATER model to the Lake Rotorua Catchment (See section 4.5).

4.3 AquiferSim

Name	Main NZ Developer	Spatial scale	Temporal scale	Contaminant	Zone of prediction	Type
AquiferSim	IRAP Vince Bidwell, Lincoln Ventures Ltd Linda Lilburne, Landcare Research	Catchment/ regional	Steady state; simulates groundwater age & time lag	Any conservative solute; first-order decay (denitrification)	Groundwater (depth variation); groundwater discharge to surface waters	Process-based; heterogeneous aquifers

Strengths:	Limitations:	Data Requirements:
- Catchments up to 10,000 km^2 at 1 ha land surface resolution - Fast model run time for scenario and uncertainty studies - User interface and visual outputs - Outputs and inputs can be customised in ArcGIS	- Currently linked to ArcGIS; - not a transient model	- Mean annual nitrate discharge values for desired land uses. - Land use and soil layers - Hydrological knowledge about aquifer boundary conditions, Groundwater recharge/discharge quantities and location - Aquifer properties, nice to have but not essential.

AquiferSim, is a regional-scale model of nitrate transport in groundwater and is part of the research programme Integrated Research for Aquifer Protection (IRAP)[2], whose members are Lincoln Ventures Ltd, Landcare Research, Environment Canterbury, Plant & Food, AgResearch, Dexcel , ESR and Aqualinc.

The model predicts the long-term effects of agricultural land use on groundwater quality in the underlying aquifers and groundwater discharge to surface waters. The aim is to help inform decisions about the future of land-use and water resource planning at a national level.

AquiferSim works in tandem with another model under development by Lincoln Ventures, called FarmSim (see Appendix 2), which predicts the effect of different agricultural land uses at the root zone level, while AquiferSim looks at the cumulative effect on the groundwater as a whole (Figure 8). The root-zone nitrate concentration and recharge information can also be supplied by other models e.g., Overseer, Spasmo.

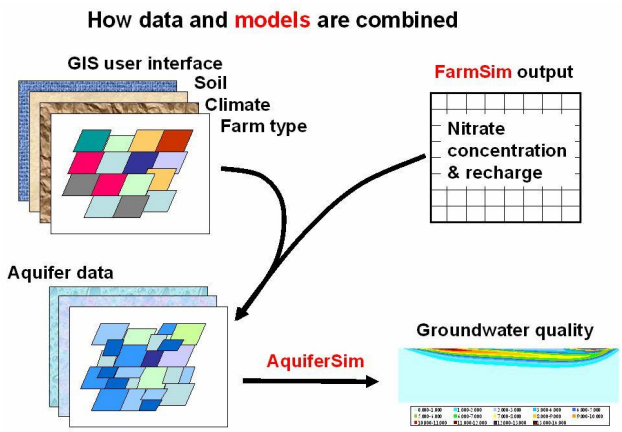

Figure 8: Model combination for AquiferSim (after Lilburne et. al., 2006)

[2] http://www.irap.org.nz/index.php

AquiferSim is intended to assist answer two main questions:
1. What is the long-term effect of a land-use change (such as a conversion from sheep to dairy) on groundwater in various parts of a system?
2. How long will it take to achieve this long-term effect?

Prediction of the 3D pattern of nitrate concentration in groundwater requires the GIS nitrate discharge map in conjunction with knowledge of river recharge, surface water discharge, and aquifer properties provided by the groundwater flow model. These are combined in a nitrate transport model "AquiferSim" that has been developed specifically for rapid computation of the long term pattern of groundwater nitrate concentration for a specified pattern of land use. The current status of the model is that it can predict the spatial pattern of groundwater nitrate concentration at specified depths, vertical views similar to Figure 8 (Bidwell and Good, 2007), and nitrate loads to groundwater-fed springs.

4.4 CLUES

Name	Main NZ Developer	Spatial scale	Temporal scale	Contaminant	Zone of prediction	Type
CLUES	MAF, NIWA, AgResearch, Harris Consulting, Landcare Research, Plant and Food	Catchment/ national	Mean annual	Nutrients, E. Coli, sediment	Surface water	Empirical

Strengths:	Limitations:	Data Requirements:
- Visual outputs - User interface - National datasets provided - Model calibrated to national data - Allows scenarios to be investigated - Outputs and inputs can be customised in ArcGIS - Runs quickly - Models both N and P	- Does not account for time lags in catchment response to land use change - Spatial resolution limited to subcatchments (typically 0.5 km^2) with proportions of land use within subcathments - Fixed soils, land use types, soils - Currently linked to ArcGIS	- National datasets are provided with the programme, including: - Current land use (user can enter their own) - Stream network - Climate - Annual rainfall - Slope - Soil order and drainage class - Point sources and lakes - Mean annual flow rate - Erosion terrains

CLUES (Catchment Land Use for Environmental Sustainability) is a catchment or regionally model framework for nitrogen,phosphorus, E. coli, and sediment loads in any streams nationally under different land-use scenarios. Links to socio-economic models mean that the effects of a change in land-use, say from grazing livestock to viticulture, on local communities can also be predicted. Recently, predictions for nutrient concentrations have also been incorporated into the model.

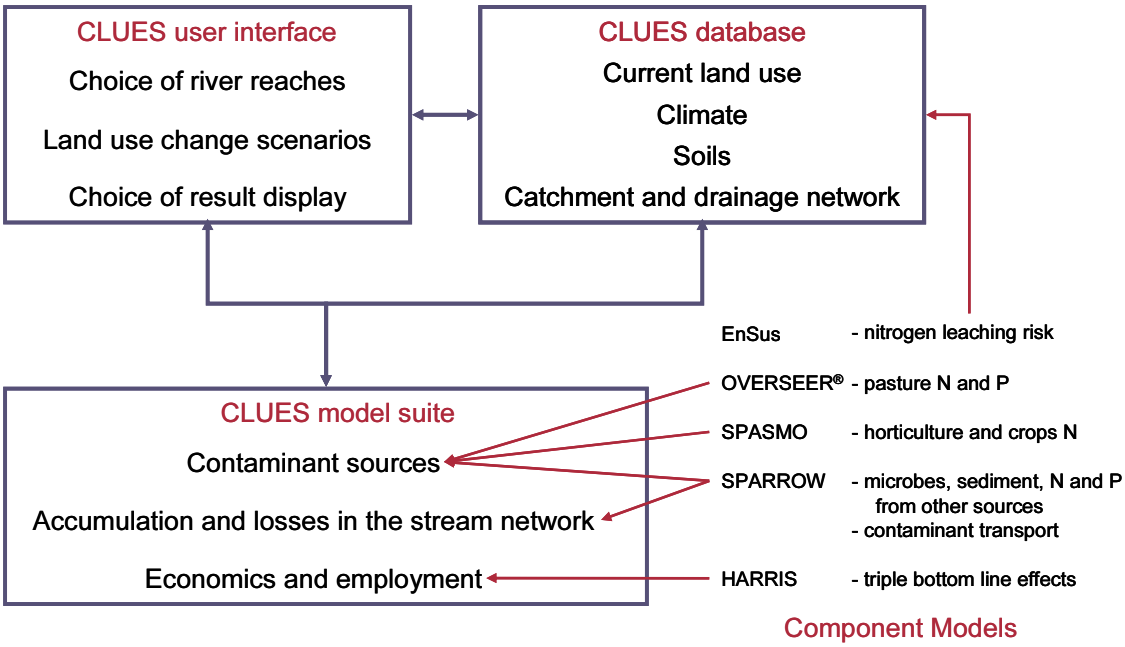

Figure 9: CLUES model framework (Semadeni-Davies et al, 2009)

CLUES links several component models together and provides a flexible user interface.

The CLUES project included the development of a spatial database of land use, soils, climate, stream network and lakes, and linking to this to component models for prediction of contaminant sources. Land-use types which can be analysed include arable, horticulture, forestry, and several pastoral farming variations.

Information on CLUES, the user manual, and links to download sites are available at http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/clues/

SPARROW (SPAtially Referenced Regressions On Watershed attributes) is a watershed modelling technique developed by USGS scientist. SPARROW is used as a sub model within CLUES, however it has been used on a national scale in New Zealand to predict nutrient transport (Elliot et. al., 2005). The core of the model consists of a nonlinear regression equation describing the non-conservative transport of contaminants from point and non-point (or “diffuse”) sources on land to rivers and through the stream and river network.

The model estimates contaminant concentrations, fluxes (or “mass,” which is the product of concentration and streamflow), and yields in streams (mass of nutrients entering a stream per acre of land), and evaluates the contributions of selected contaminant sources and watershed properties that control transport throughout large river networks. It empirically estimates the origin and fate of contaminants in streams and receiving bodies, and quantifies uncertainties in these estimates based on coefficient error and unexplained variability in the observed data.

For more information on SPARROW:
http://water.usgs.gov/nawqa/sparrow/FAQs/faq.html#20

4.5 Other Models

MODFLOW

MODFLOW is the U.S. Geological Survey modular finite-difference flow model. MODFLOW is a three-dimensional finite-difference ground-water model that was first published in 1984. It has a modular structure that allows it to be easily modified to adapt the code for a particular application. Many new capabilities have been added to the original model.

MODFLOW-2005 simulates steady and non-steady flow in an irregularly shaped flow system in which aquifer layers can be confined, unconfined, or a combination of confined and unconfined. Flow from external stresses, such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through river beds, can be simulated.

In addition to simulating ground-water flow, the scope of MODFLOW-2005 has been expanded to incorporate related capabilities such as solute transport and ground-water management.

For more information on MODFLOW:
http://water.usgs.gov/nrp/gwsoftware/modflow2005/modflow2005.html

FEMWATER

FEMWATER is a three-dimensional finite element ground water model. It can be used to simulate flow and transport in both the saturated and the unsaturated zone. Furthermore, the flow and transport can be coupled to simulate density dependent problems such as salinity intrusion. FEMWATER is a modern implementation of the two older models, 3DFEMWATER (flow) and 3DLEWASTE (transport).

FEMWATER has been used by GNS in the Lake Rotorua catchment to support the development of ROTAN (Rutherford et. al., 2009).

For more information on FEMWATER : ftp.gtk.fi/mirrors/gms/gms/gms3.0/docs/femwref.pdf

5. Improving the Uptake and Use of Modelling Tools

During the workshop a number of barriers were identified that participants thought had affected the uptake and use of catchment scale nutrient models. A number of actions were identified by workshop participants to improve future uptake of catchment nutrient models and for improving their outcomes. The barriers and recommendations have been grouped into four main themes:

- Central model library of resource material
- Improved data sets
- Productive collaboration
- Education on Models
- Intellectual Property

Section 7.1.4 outlines additional suggestions that were captured from workshop participants. Only the priority suggestions under the main outcome areas have been presented.

The work being undertaken by Regional Council staff who attended this workshop is strongly aligned with the research strategy that has been developed by Regional Councils (RC – SAG, 2009), in particular, the enhancement of science delivery and facilitating the uptake of science.

Recommendations:

1. This workshop report and specifically its recommendations, are presented to the Regional Councils Resource Managers Group and Science Advisory Group.
2. That the recommendation below in this report be put forward for inclusion into the Research Strategy – Annual Operating Plan where appropriate.

Catchment Model Library:
Establishment of a central Model Library with a range of web based resources was the most strongly supported suggestion. This could include model software, documentation, case studies, and interactive forum.

Such a library will need a coordinated effort to bring together suitable material for the wide range of potential library users. This report is a starting point for a brief overview of modelling and model application New Zealand which will be useful for raising the awareness and understanding of modelling. There was however, considerable interest from a number of workshop participants to have more detailed reporting on problem conceptualisation, model selection, model comparison and detailed case studies. Most of the material produced by model developer is generally in the form of client reports, conference or academic papers, which are not always readily up taken by Council staff.

The key recommendations for a model library are:

3. Request through the Resource Manager Group (RMG), that MfE establish and support the development of a web based library of modelling resources, this should be initiated by providing support for developing a business plan which outlines how such a resource repository will be structured, developed, used and updated.

4. Seek further funding resources (Envirolink, SMF, SFF, or Regional contributions) to develop the following key resources which would be most useful to improving model uptake and can become part of a library when established:
    - Guideline document on project conceptualisation, model selection and calibration, similar to the Groundwater Model Audit Guidelines (PDP, 2002).

- Detailed model descriptions and comparisons - including what they do and do not do, data input and other operating requirements, advantages, assumption used, limitations, and contact organisation/person.
- Case studies of model use, including application to a range of scenarios and explanation of model structure and sensitivity

5. Signal to FRST that there is a gap between end-user expectations for resources on catchment modelling and the outputs favoured by researchers (i.e. client reports and papers). Also request the future end user outputs from modelling research should aim to add value to the model library.

Data improvements

Availability and access to required data sets to run catchment models can be a significant limitation to model use. There is also uncertainty about data requirements for particular models. The current types and quality of data sets were seen as an impediment to productive use of many models.

The key recommendations for data improvements are:

6. Advocate, through RMG, to central government for improved national data sets, particularly land use
7. Through implementation of recommendation 4 - Improve the understanding of the key input parameters and datasets required for specific models.

More Collaboration between Regional Councils and with CRI's

There is a strong demand from Regional Council staff to understand and use catchment scale nutrient models. A more structured approach to collaboration both between regional councils and with researchers from CRI's was considered by workshop participants to be highly beneficial (i.e. if you don't know where you're going, you'll never get there). A structured approach would improve shared learning, be more resource efficient and create more consistent application and development of models.

The key recommendations for improved collaboration are:

8. Establish a new Regional Council special interest group (SIG) for catchment modelling. A users group of 'regional champions' (Planners and Scientists and Modelers) tasked with improving collaboration and modelling outcomes
9. Request that MfE take on a role as a national champion to improve collaboration and end-user uptake for catchment modelling (i.e., hosting annual exchanges of current practice, co-coordinating body for use protocols, guidelines, and further tool development program (with FRST).
10. Catchment Modelling SIG develops a structured plan of specific actions for improving collaboration between regional council staff, and with researchers. This could include:
    - Workshops or forum for model learning and development.
    - Identifying collaborative modelling project opportunities for using and developing models, based around questions that are widely applicable.
    - Advocating that Envirolink funding is available to for secondments (short-term) between regional council staff so those councils with experiences can share with those that are following.
    - Workshops that bridge the gap between modelling and Regional Council approaches to nutrient management policy

These recommendations would strongly support the goals and objectives of the research strategy (RC – SAG, 2009) - Goal 2: To catalyse and enhance science delivery; Goal 3: To facilitate science uptake.

Education on Models and their Application
There is a pressing need for more education on the different types of models and their use. Achievement of the required education actions raised by participants would require the recommendations under 'Catchment Model Library' (No. 3-5) and 'Collaboration' (No. 8-10) sections to be advanced. The education theme is seen to have two audiences:

- council staff who need to understand enough about models to be able to use them and their results effectively, and
- decision makers or key stakeholders who need to understand what the results mean and how they were developed and what assumption/limitations and hence relative 'certainty' are associated with modelling outputs.

The key recommendations for education on models are:

11. Develop a guideline document on using modelling results that provides presentation and communications advice to get the best from model outputs. Include learnings from others' experiences (Environment Waikato, EBOP), via case studies showing how models have informed policy, and how they could better inform policy.
12. Develop and provide specific courses on individual models and their use.
13. Investigate the use of Envirolink funding to transfer model skills for a particular key issue

Intellectual Property
Issues with IP were seen to affect both the uptake of models and collaboration in model development and integration. Model code should be open-source or open to scrutiny, especially when results of modelling were used to develop 'restrictive' land use policies. A move toward reducing IP restrictions and taking a more 'open source' approach seen as the best approach to reduce this barrier. Although specific examples or issues were not identified or discussed at the workshop it was seen as an issue to be addressed primarily by central government research funders.

The key recommendations for intellectual property are:

14. Advocate to research funders and agencies that IP restriction on data set and models are removed to facilitate the use of these resources.

6. References and Useful links

References

Bidwell, V.J. and Good, J.M. (2007) Development of the AquiferSim Model of Cumulative Effect on Groundwater of Nitrate Discharge from Heterogeneous Land Use over Large Regions. In Oxley, L. and Kulasiri, D. (eds) MODSIM 2007 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2007, pp. 74-80. ISBN : 978-0-9758400-4-7. http:/www.mssanz.au/modsim07/Papers

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Elliott, A.H., Alexander, R.B., Schwarz, G.E., Shanker, U., Sukis, J.P.S., and McBride, G.B. (2005) Estimation of nutrient sources and transport for New Zealand using the hybrid mechanistic-statistical model SPARROW. Journal of Hydrology (NZ) 44(1): 1-27.

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Lilburne, L., Bright, J., Francis, G., Close, M., Bidwell. V., Snow, V., Thorrold. B., Crisley. V., and mith, V. (2006) The IRAP project: Predictive farm and regional scale tools for assessing land use impacts on groundwater quality. Occasional Report No. 19, Fertiliser and Lime Research Centre, Palmerton North. Pp. 440-444.

PCE, (2004): Growing for good: Intensive farming, sustainability and New Zealand's environment. Parliamentary Commissioner for the Environment.

PDP (2002): Groundwater Model Audit Guidelines. Prepared for MFE, Pattle Delamore Partners Ltd.

RC – SAG (2009) Research for the Environment. A Research Science and Technology Strategy for Regional Councils. Regional Council Science Advisory Group. http://www.envirolink.govt.nz/strategy.htm#Heading3

Rucinski, D., Wadhwa, S,. Rutherford, J.C. (2006). ROTAN Users Guide – Version 1. NIWA Technical Report. July 2006.

Rutherford, K., Palliser, C., Wadhwa, S. (2009). Nitrogen exports from the Lake Rotorua catchment - calibration of the ROTAN model. NIWA Client Report: HAM2009-019.

Semandeni-Davies, A., Shanker, U., Elliot, S. (2007) The CLUES Project: Tutorial manual for CLUES 1.4. NIWA Client Report HAM2007-170.

Links

AquiferSim

http://www.lvl.co.nz/news/aquifersimdemo.html
http://www.irap.org.nz/publications.php
http://www.canterburywater.org.nz/background-documents/

CLUES

www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/clues/
www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/clues/manual/

SPARROW
http://water.usgs.gov/nawqa/sparrow/

7. Appendices

7.1 Appendix 1: Notes from Workshop – 27th July 2009, Greater Wellington, Wellington

7.1.1 Workshop Agenda:

- Introductions and workshop purpose
- Presentation of three catchment-scale nutrient models, from both model developers and end users:
    - AquiferSim
    - CLUES
    - ROTAN

- Interactive workshop discussion
  a) Policy Questions: What are the questions that need to be answered and what can and can't models answer?
  b) Issues and Limitations when using models: What are they and how can they be minimised or overcome?
  c) Lessons learnt to date by researchers and end users.
  d) Improving model understanding, use and collaboration in future.

- Observations and perspectives from MfE & MAF

- Review workshop outcomes, action points and where to next

The whiteboard notes taken during the workshop have been summarised and grouped into key topic areas.

7.1.2 Lessons Learnt from Using Catchment Models

<u>Defining the problem and questions to answer:</u>

- The first step should be a well thought out 'Conceptualisation' process that defines – What issues/questions are you trying to address, what information is required to address or answer these? How much certainty in the result is required? Do you actually need a complex model to get this information?
- It is also important to conceptualize your natural system. This is required to establish the right model(s) for addressing the management issue/problem(s).

<u>Knowing the tools:</u>
It is important to research and understand the different modelling tools that are available. This includes considering:

- Different models have different features – need to know benefits/weaknesses of different models and limitations and applicability to different settings
- Information requirements vary and need to be defined. Running a model may help identify these as you can start running model with limited information
- Need to match model with the question

Understanding the limitations:
The robustness and use of the results will be strongly influenced by the limitations of both the model and data sets. Consideration needs to be given to:

- Available data types and quality used by the model
- Balancing simplicity with uncertainty. More complex model has higher information requirements and more complex model takes longer to develop and test and you may have to act sooner. So it can be important to first determine what level of certainty you can live with and plan from that.
- Appreciate the specific limitations of a model, and know what they account for and don't
- Modelling can be very resource demanding, both in dollars and time

Fitting into the RMA process:
Models can provide valuable information to policy development and decision processes. Some observations were:

- Identifying and managing the uncertainty associated with model outputs is difficult
- It is useful to involve those affected by model their development and application
- For policy development need to identify a useful range of scenarios to evaluate using a model
- Consider 'fit for purpose' mantra during policy development process. Start with simple initial model then move to more complex as knowledge of issues and policy options develop.
- A range of models can be required from large or significant issues. Covering both the policy development and then policy implementation phases, or several zones of modelling might be required to understand issues (paddock, stream, ground water, lake)

7.1.3 Limitations and Other Issues with Model Use

Data
Available and accurate data set is seen as a primary limitation to model application. Issues included:

- When you have data gaps and/or need data updates – where best to spend funding
- Need for accurate core data set – land use/soils/climate
- Land use data is often limiting due to accuracy and classification. There are data quality and management issues with Agribase
- Data availability can be a barrier
- Leaching data difficult to be consistent. Differing outputs can be provided (Overseer vs LUCI/SPASMO) depending on how underlying assumptions are set).

Intellectual Property
Issues around the existence and management of intellectual property are seen to hold up the use of models and to consume resources in sorting out IP. IP issues include both models and data set.

Using Results
There are a number of challenges in using the results from modelling:

- Other ecosystem responses to an issues are not represented
- Level of detail required to make policy decisions may differ from outputs and a process of verification/validation/auditing of model outcomes may be required

- Sensitivities/assumptions in model need to be spelt out, and relative accuracy of model may differ from monitoring
- How to use the results and explain the models functioning when working with the community to develop targets
- Need to be careful that the model is not operated outside its limitation – i.e., calibrations
- Models can be both decision support tools that minimise uncertainty and address specific questions, or management tools that track on progress or changes in activities.
- Communication concepts and resulted to community and politicians
- Living with uncertainty – setting and defending policy

Defining System

Defining the questions and the systems to be modeled are key starting points for successful modelling:

- Deciding on right model for your system and calibrating it
- Understanding and defining attenuation
- Representing seasonal variation in processes
- Lag of effects from land use vs long term steady state

7.1.4 What Should Happen Next to Advance Model Use

Catchment Model Library:

There was strong demand for a model library or central repository for catchment models. This library would need to be supported nationally (MfE) and could undertake a role of coordinating further model development and use. This library could be a web based facility that provides:

- Introductory material on catchment models and their uses including summary tables that compare and contrast models and modelling options
- A more detailed description of each model. What it does and does not do, data input and other operating requirements, advantages and limitations, and contact organisation/person.
- Case studies of model use, including application to a range of scenarios and explanation of model structure and sensitivity.
- An interactive area (blog or wiki pages) to share experiences or questions on a particular model and interact with model creators.
- A library area containing downloadable material for available models – software, manuals, case studies, datasets.
- A repository for national data sets that can be used in catchment modelling, and consistent default data such leaching rates from specified land uses.
- The library could also provide guidance on the status of model, such stage of development, tested successfully on specific application, or some 'certified' status.

Data improvements

Availability and access to required data set to run catchment models can be a significant limitation to model use. There is also uncertainty about data requirement for particular models.

- Improvement of data sets was seen as a priority by workshop participants. The current types and quality of data sets were seen as an impediment to productive use of many models

- A particular priority was a national land use data set that would be regularly updated
- Improving the understanding of the key input parameters and datasets required for specific model would also assist model uptake and use.

More Collaboration between Regional Councils and with CRI's

There is a strong demand from Regional Council staff to understand and use catchment scale nutrient models. A more structure approach to collaboration both between regional councils and with researchers from CRI's would be highly beneficial. It would improve shared learning, be more resource efficient and create more consistent application and development of models. This could be achieved through:

- Holding workshops or forum more regularly, based around a plan (with clear goals and objectives) for model learning and development. This could include specific working groups, seminars or conferences.
- Establishing a national catchment modelling users group of 'regional champions' (Planners and Scientists and Modelers) tasked with improving collaboration and modelling outcomes.
- Identifying collaborative modelling project opportunities for using and developing models, based around questions that are widely applicable.
- Advocating that Envirolink funding is available to for secondments (short-term) between regional council staff so those councils with experiences can share with those that are following.
- Encouraging MfE to be national champion to improve collaboration – i.e hosting annual exchange of current practice, being co-ordinating body for use protocols, guidelines, and further tool development program (with FRST)
- A workshop similar to this with the topic: What are Regional Councils doing on nutrient management policy

Education on Models and their Application

There is a pressing need for more education on the different types of models and their use. Achievement of the required education actions would require the outcomes under 'Catchment Model Library' and 'Collaboration' sections to be advanced. The education theme is seen to have two audiences: council staff who need to understand enough about model to be able to use them and the results effectively, and decision makers or key stakeholders who need to understand how the result were developed and what assumption/limitations and hence relative 'certainty' are associated with modelling outputs. This could also be expressed as 'Knowing how to get results for a specific issue or question' and 'Knowing how to use those results and understand them'. Specific suggestions included:

- Develop a 'guiding document' that assists the process of conceptualizing the problem, defining the need for a model, considerations in selecting a model, over view of current models and case studies.
- Effectively engaging with stakeholders to show usefulness of models and their outputs in resolving issues in practice. Also need to learn how to convey to stakeholder the role and limitations of models (i.e convey realisation that the output is not 100%)
- Provide guidance on how to use model outputs. Learning from others experiences (Environment Waikato, EBOP, Horizons), explore, through case studies, how models have informed policy, how they cold better inform policy.
- Investigate the use of Envirolink funding to transfer model skills for a particular key issue.
- Develop and provide specific courses on individual models and their use, this could form the basis of developing/training for 'certified' operators'

- Hold advanced modelling “understanding the black box” workshop – all models together (CLUES, Overseer, Spasmo etc)

Intellectual Property
Issues with IP were seen to affect both the uptake of models and collaboration in model development and integration. Although specific examples or issues were not identified or discussed it was seen as an issues to be addressed by central government. Other suggestions were:

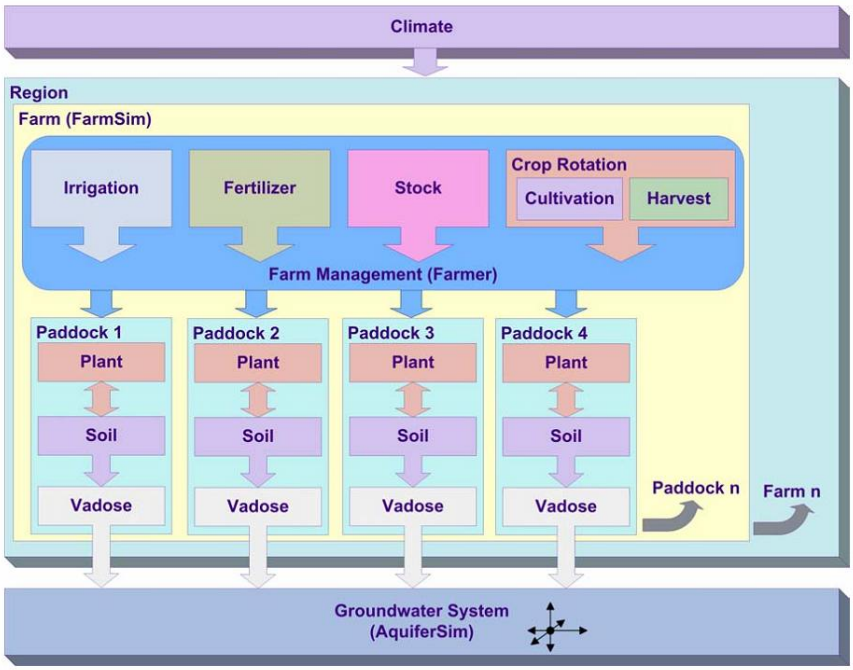
- Improve collaboration by relinquishing any IP rights and put model in public domain
- Persuade central government to fully fund tool development and data sets of land use etc and make freely available
- Model code to be open-source or open to scrutiny, especially when results of modelling were used to develop ‘restrictive’ land use policies.

7.2 Appendix 2: Farm Scale Models - overview

The following brief summaries of paddock and farm scale models are provided for completeness, and provide some information on the other models and linkages shown in Figure 5.

7.2.1 FARMSIM[3]

FarmSim is essentially a daily time step simulation of a single unit of agricultural production on alluvial plains, where run-off transfer is not a feature. The simulation responds to time-varying inputs from the climate and daily farm-level management decisions. The farm model responds to these inputs and the state changes of the various components can be analysed. Of these state changes, the daily drainage flux and nitrate concentration from the vadose zone model component can then be passed to the AquiferSim



7.2.2 Overseer™ [4]

Overseer™ is a decision support tool for nutrient management. It includes consideration of nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, sodium, and acidity and greenhouse gas and energy accounting. Overseer™ can account for pastoral, cropping, and horticulture land uses but there is greater development on the pastoral land use modules of the model. Overseer™ calculates nutrient use and flows from fertiliser, effluent, supplements, transfer by animals, and removal in products. Overseer™ can be used to investigate mitigation options. Overseer™ is designed to be used by farmers, consultants and scientists. AgResearch is currently in the process of publishing the scientific basis of Overseer™ in peer reviewed journals.

[3] Good J. & Bright J.(2005)
[4] This summary is from Environment Waikato (2007) and is part of the section 32 analysis for the Lake Taupo policy

Assumptions, Limitations, Features

- Overseer™ estimates long-term annual averages; it is not designed to predict the outcomes within a particular year or resulting from extreme events within a year. Doc # 1093829 Page 71
- The model relies on the user supplying actual and reasonable inputs. Because Overseer™ is designed to be run by farmers and there is little restriction on how inputs can be entered, quality-control of the inputs is an important issue. In implementing the Variation, Overseer™ will be run by Certified Consultants or Contracted Waikato Regional Council staff to ensure consistency and quality control.
- Overseer™ is an empirical model that has been extensively calibrated for a wide range of climates and soil types. The quality of the calibration is dependent on the data available so has its greatest reliability and accuracy in determining nutrient flows from conventional farming systems.
- Overseer™ can not be used as a management tool for within season decisions, for example, Overseer™ can be used to estimate average nitrogen required for a crop but cannot be used to make decisions about nitrogen required for a particular year.

Applications

- Overseer™ is used by the three major fertiliser companies as part of the nutrient budgeting for their clients. It is the most widely used nutrient management tool in New Zealand.
- Available free of charge from MAF or the website.

Future Developments

- Overseer™ is under continual update/upgrade in response to users needs. It is intended to make improvements to some of the calibrations for some of the components of the model that are thought to be weaker and add mitigation options to the model as they become available and understood/tested. As detailed above, AgResearch has a multi year Foundation for Research Science and Technology (FRST) funded programme on low nitrogen emitting farming systems and nitrogen leaching trials so that Overseer™ can be refined for the Taupo Catchment.

7.2.3 SPASMO [5]

SPASMO is a simulation model which requires daily information so that it can run on a daily time step that allows the investigation of timing-weather interactions. The SPASMO model looks at the processes of water, plant growth, and nitrogen. The model setup is very flexible so it can be used to address a very wide range of questions. SPASMO is primarily applied to horticultural systems but can also be applied to cropping and pastoral systems. SPASMO is designed to be run by HortResearch scientists but can be set up in various ways to make it more generally available for public use.

Assumptions, Limitations, Features

- Short-term and long-term variability is evident in results from the model.
- The model inputs are set by HortResearch scientists and therefore automatically come with a quality-control on use and inputs. The 'cost' of this is that the model is not available to individual users.
- SPASMO could be used as a management tool for within-season decisions however in practice this would be too slow because of the need to engage a scientist to run each simulation.

Possible Future Developments

- SPASMO developments are driven by demand from users. It is anticipated that the model will be developed to include more crops, more soils, and different land practices.

[5] This summary is from Environment Waikato (2007) and is part of the section 32 analysis for the Lake Taupo policy

7.2.4 NPLAS [6]

NPLAS has been designed to test if proposed land use changes around the Rotorua Lakes comply with the Regional Plan regulation which requires a cap in nitrogen or phosphorus leaving the property. NPLAS calculates the long-term annual average load of nitrogen and phosphorus entering the streams on a property or leaving the property in groundwater. NPLAS is a web-based programme and has been designed to be run easily by any user without specific training. The NPLAS model is specific to the Rotorua Lakes district but is an example of what could be developed for other locations.

Assumptions, Limitations, Features

- The NPLAS model can assess pastoral nitrogen leaching estimates from a basic version of OverseerTM, pastoral phosphorus loss and overland flow loss from GLEAMS simulations, direct animal deposition to waterways, nitrogen and phosphorus loads from houses/wastewater. NPLAS includes a consideration of the effects of fertiliser, rain, soil drainage, slope, and wintering-off.
- NPLAS can account for on-site mitigation through ponds, riparian strips, and wetlands.
- All these predictions are specific to the Rotorua Lakes environment.

Future Developments

- Developments of the NPLAS model in the immediate future will be centred on refinement and testing of the model. There is also a possibility for extending the system to other regions.

Preferred Model [3]

Overseer™ is Environment Waikato's preferred model for managing Nutrients under the regulation of the Variation, because it is the most detailed and accurate farm systems model and the inputs for the model are known by or readily accessible to farmers. Waikato Regional Council sought to ensure farmers had a tool that best met their on farm management needs because it was the farm management systems that were to be modified. In addition it is recognised that Overseer™ does have the capability to include mitigation measures including attenuation of nitrogen through wetlands and AgResearch are looking to include this information in the model in the near future.

It is noted that a comparison of modelling outputs from Overseer™ and SPASMO in the Taupo Catchment was commissioned by Waikato Regional Council and Hort Research. The result of this comparison concluded that there is a reasonable agreement between the predictions from the two models.

[6] This summary is from Environment Waikato (2007) and is part of the section 32 analysis for the Lake Taupo policy

7.3 Appendix 3: Case Study Presentations from Workshop – 27th July 2009

Case Study 1a AquiferSim: Research Presentation – Vince Bidwell, Lincoln Ventures Ltd; Linda Lilburne, Landcare Research Ltd

Case Study 1b AquiferSim: End User Presentation – Raymond Ford, Environment Canterbury

Case Study 2a CLUES: Researcher Presentation – Sandy Elliot, NIWA

Case Study 2b CLUES: End User Presentation – Reece Hill, Environment Waikato

Case Study 3a ROTAN – Researcher Presentation – Kit Rutherford, NIWA

Case Study 3b ROTAN – End User Presentation – Andy Bruere, Environment Bay of Plenty

Case Study 1a AquiferSim: Research Presentation – Vince Bidwell, Lincoln Ventures; Linda Lilburne, Landcare Research.

INTEGRATED RESEARCH FOR AQUIFER PROTECTION 1

Modelling nitrate transport from land to water – the AquiferSim approach

Vince Bidwell, *Lincoln Ventures Ltd*
Linda Lilburne, *Landcare Research*
John Good, *Lincoln Ventures Ltd*

Catchment Scale Nutrient Modelling Workshop, Wellington, 27 July 2009

INTEGRATED RESEARCH FOR AQUIFER PROTECTION 2

Outline

- Catchment type and scale
- Types of prediction
- Assumptions
- Data requirements
- Implementation
- Future potential

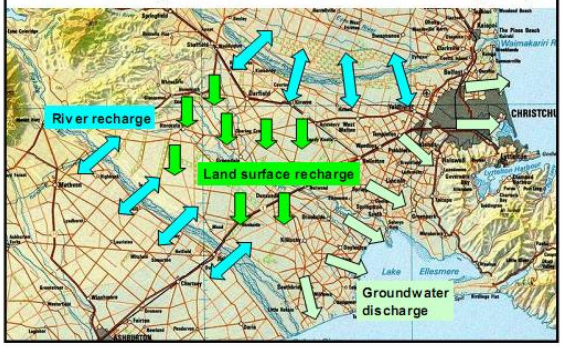
INTEGRATED RESEARCH FOR AQUIFER PROTECTION 3

Catchment type and scale

- Transport of nitrate from land to surface water, by groundwater
- Can simulate denitrification
- Catchment located within model area of 1000 x 1000 cells (100 km x 100 km at 1 ha resolution)
- Larger catchments accommodated with cells bigger than 100 m x 100 m

INTEGRATED RESEARCH FOR AQUIFER PROTECTION 4

Accounts for groundwater mass balance and quality

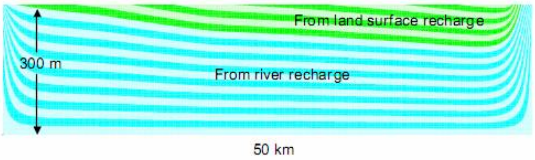


INTEGRATED RESEARCH FOR AQUIFER PROTECTION 5

Flow & quality computed along groundwater flow paths

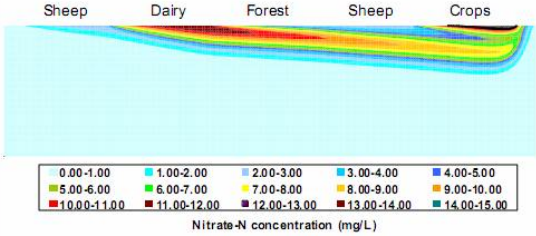
INTEGRATED RESEARCH FOR AQUIFER PROTECTION 6

Groundwater flow processes – vertical slice view



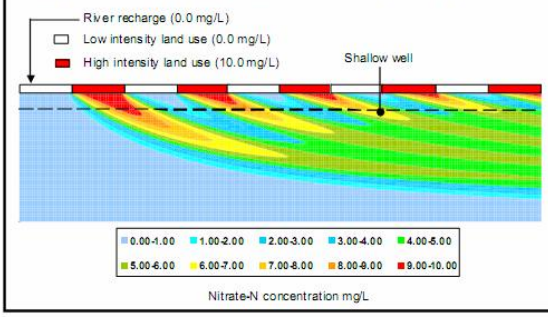
INTEGRATED RESEARCH FOR AQUIFER PROTECTION 7

Contaminant transport processes – vertical slice view



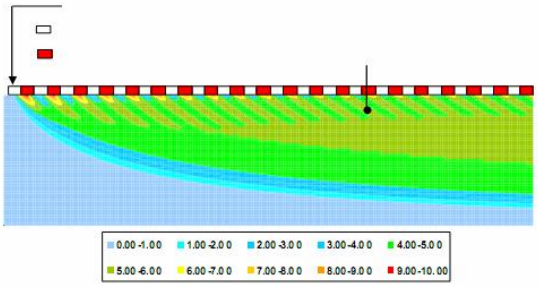
Shallow groundwater quality (along dashed line) is a dispersed, or smoothed, version of the pattern of nitrate discharge from the soil.

This groundwater dispersion can be approximated by smoothing the pattern of nitrate discharge from soil beneath the various land uses



INTEGRATED RESEARCH FOR AQUIFER PROTECTION 9

Small areas of high-intensity land uses (high nitrate) can allow shallow-well access to groundwater of drinking water quality



INTEGRATED RESEARCH FOR AQUIFER PROTECTION 10

Assumptions

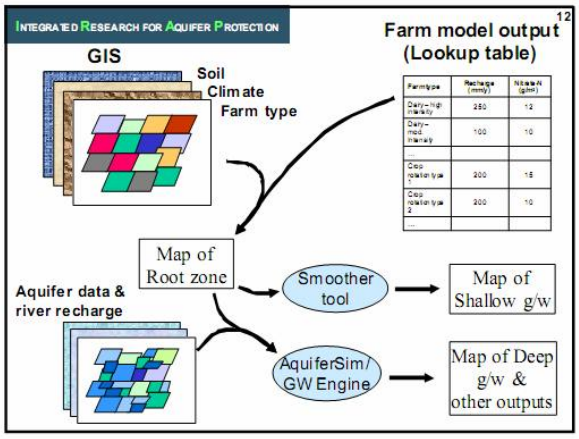
- Groundwater flow and transport is steady-state
- Groundwater age predictions provide estimate of time-lag for effects of land use change
- Groundwater model is 2D/3D: constructed of slices along groundwater flow paths
- Aquifer can be heterogeneous-isotropic horizontal, and heterogeneous-anisotropic in vertical plane
- Denitrification is a first-order process

INTEGRATED RESEARCH FOR AQUIFER PROTECTION 11

Types of prediction (steady-state)

- Near-surface groundwater concentration: no groundwater model; GIS area filtering
- Groundwater nitrate concentration at any location and depth
- Groundwater age at any location and depth
- Groundwater catchment of surface water bodies
- Nitrate concentration in groundwater discharge to surface waters

INTEGRATED RESEARCH FOR AQUIFER PROTECTION 12



INTEGRATED RESEARCH FOR AQUIFER PROTECTION 13

Input data: the full set

- GIS maps of land use, soil type, climate zone
- Table of long-term average soil-water drainage and nitrate concentration for each land use, soil type, climate combination
- Surface water recharge to groundwater; and groundwater discharge to surface water
- Aquifer properties: thickness, porosity, hydraulic conductivities

INTEGRATED RESEARCH FOR AQUIFER PROTECTION 14

Input data – the basics for a GIS map at 1 ha resolution

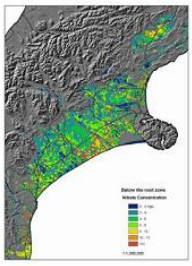
- Water and nitrate mass :
  - land surface recharge & nitrate concentration
  - surface water losses to groundwater
  - groundwater discharge to surface waters
- Aquifer characteristics:
  - boundaries; no flow & specified head (affects groundwater discharge to surface waters)
  - thickness (if vertical distribution of quality is an issue)

INTEGRATED RESEARCH FOR AQUIFER PROTECTION 15

Implementation examples: below-root-zone nitrate concentration

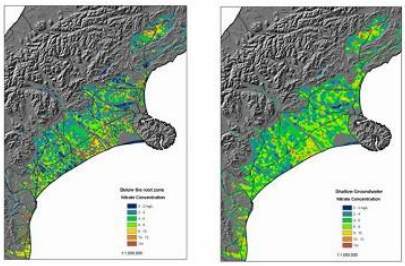
GIS Data:
- Land use
- Soil type
- Climate

Look-up table:
- Soil-water drainage
- Nitrate concentration



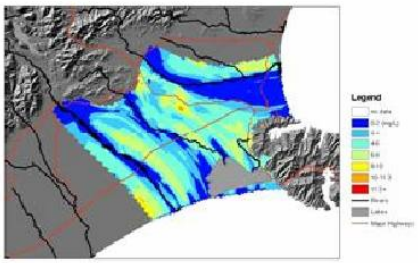
INTEGRATED RESEARCH FOR AQUIFER PROTECTION 16

Shallow groundwater nitrate concentration - GIS area filter; 1 km radius



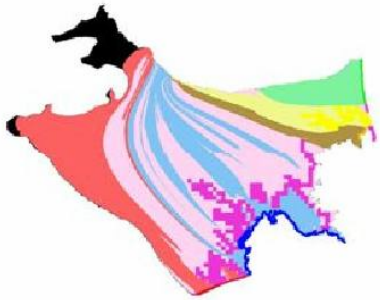
INTEGRATED RESEARCH FOR AQUIFER PROTECTION 17

Deep groundwater nitrate concentration - aquifer data from a groundwater model



INTEGRATED RESEARCH FOR AQUIFER PROTECTION 18

Nitrate discharge catchments for surface waters



INTEGRATED RESEARCH FOR AQUIFER PROTECTION 19

AquiferSim is a living document

- Computational times are up to a few minutes
- Land use change scenarios easily evaluated
- New knowledge about nitrate discharge rates is easily incorporated
- Uncertainty about hydrological and geological knowledge can be assessed

INTEGRATED RESEARCH FOR AQUIFER PROTECTION 20

Some potential not yet implemented

- Use of geological data to assign complex aquifer properties
- Assign zones of denitrification, specified by rate parameters
- Calibration of model with groundwater age data
- Relevance to hill country

Case Study 1b AquiferSim: End User Presentation – Raymond Ford, Environment Canterbury

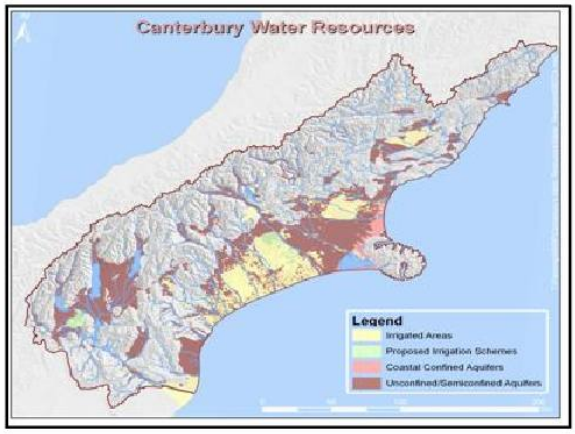
Managing cumulative effects of nutrients on water quality

Raymond Ford,
Environment Canterbury

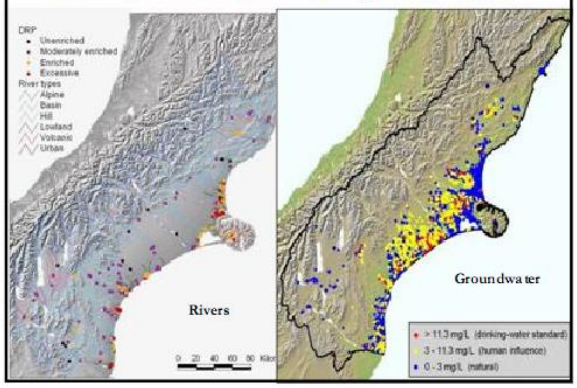
Dr Linda Lilburne
Landcare Research

Catchment Scale Nutrient Modelling Workshop, Wellington, 27 July 2009

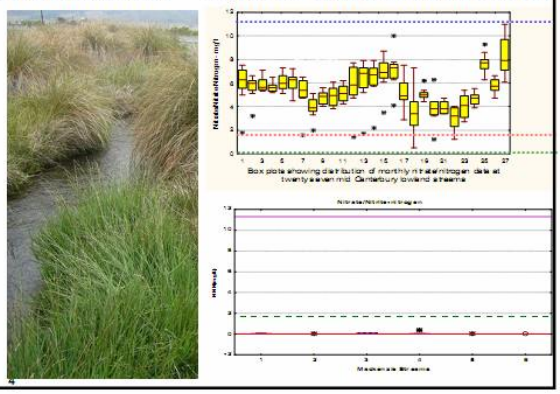
1



Nutrients in surface and groundwater



Groundwater – surface water interactions



Environment Canterbury's response

- Canterbury Strategic Water study (Mayoral Forum)
  - Overview of supply & demand region's water resources
  - Concern - effects of agriculture on gw quality
  - AquiferSim used to model nitrate leaching
- NRRP Variation 27 Set limits on catchment loads of nutrients
  - Use 'AquiferSim' & 'Clues' – to test scenarios & estimate contributions from diffuse sources

5

Canterbury Strategic Water Study – nitrate study

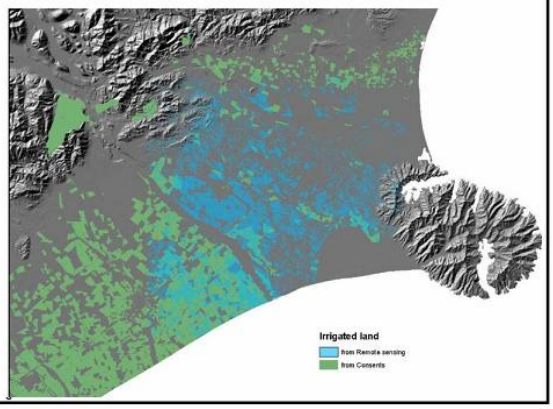
- Purpose
  - Spatial patterns of nitrate leaching under current land uses
  - Compare quality in shallow vs deep groundwater
  - Show changes in gw quality if leaching rates change
- Method – used AquiferSim
  - 'Look up table' - nitrate discharge rates for soils, climate & land use
  - Estimated leaching rates - OVERSEER, LUCI, SPASMO & literature review
  - Simulated different river recharge assumptions
- Results
  - River recharge maintains deep groundwater quality
  - Agricultural land uses - most effect on shallow groundwater.

6

Setting up the data

- Soils layer – Landcare Research
- Climate – NIWA surfaces / or climate stations
- Land use – Agribase & LCDB2
  - Derive more detailed farm type classes using Agribase e.g. level of intensity
  - Irrigation (consents data and remote sensing)
  - Some accuracy issues with Agribase and irrigation layers

7



Nitrate Leaching Lookup Table

- 2 Science workshops - key farm-scale modellers, scientists, industry reps.
- Many issues to resolve:
  - OVERSEER – leaching sensitive to management,
  - LUCI, SPASMO – leaching sensitive to climate & soil
  - handling urine patches, e.g. SPASMO, LUCI
  - shallow stony soils, poor draining soils
  - differing assumptions e.g. optimal/ best / standard practice

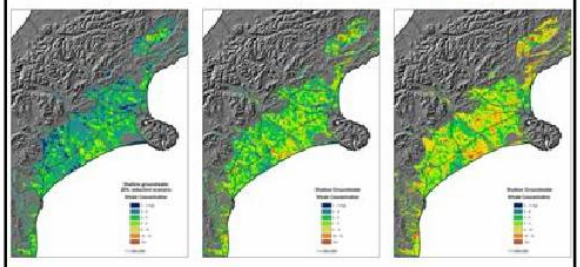
9

Different scenarios

20% general reduction in nitrate leaching

30% random increase land use intensification

All extensive land use converts to intensive land use



10

River recharge/discharge layer

Derived from groundwater model (steady state mode)

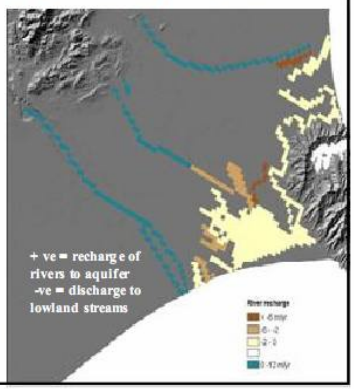
Other data:

Boundary layer (no flow and constant head boundary)

Aquifer thickness of 250m

Porosity of 0.3

Transmissivity (from GW model) - could use a constant



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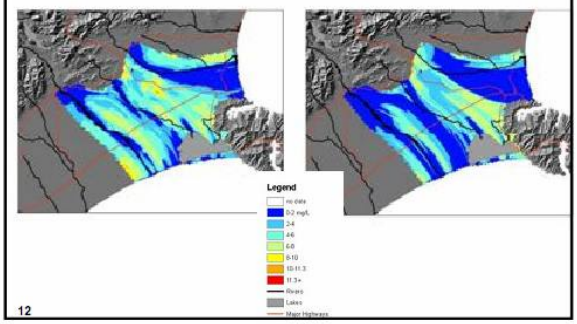
Modelling results:

Interpolated maps of average nitrate between 0 and 50 m

Interpolated maps of average nitrate between 100 and 150 m

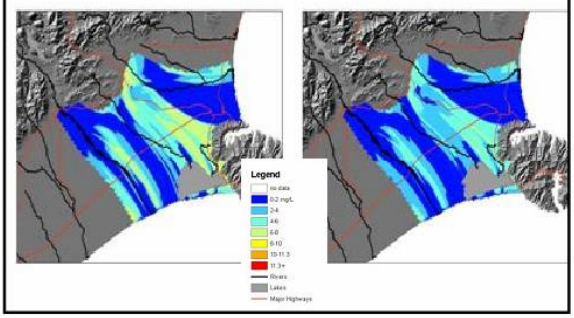


12

Different scenarios for groundwater between 100 & 150 m

Land use intensification scenario

Nitrate reduction scenario



Lessons learned

- Inputs need more work
  - Different models give different results !!!!
  - Review underlying assumptions used in models
    - check key parameters (e.g., soils) are influencing results
    - know whether results are for optimal/best or standard practice
- Check quality of input data
  - Uncertainty over defining "average" leaching values for different land uses.
  - Impractical to model every combination of land use e.g. arable farming
  - Need accurate land use/soils/climate data
- Need independent scientific advice
- Do case studies - takes a lot of time and effort but lessons are worthwhile !!

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Where to from here?

- NRRP Variation 27
  - Establish collaborative working group – primary industry reps, NGO's, Ngai Tahu
  - 3rd Science workshop - refine leaching figures for 'look up' table
  - Case studies - 1 or 2 catchments
    - Collect data & set up models
    - Use models to estimate relative contributions from point source non-point sources
    - Model range of future land uses
    - Assess effects against measurable objectives in NRRP
- Future use of catchment models
  - Align Aquifer Sim & Clues e.g. common data sets
  - Information transfer to regional council e.g. modelling expertise
  - Need to manage uncertainty

15

Case Study 2a CLUES: Researcher Presentation – Sandy Elliot, NIWA

CLUES

Catchment Land Use for Environmental Sustainability

Harris Consulting

1

CLUES

- Brief description
- Screen shots of the model interface
- Current work and wish-list

2

Rationale

- How does land-use affect water quality in streams
  - What if the land-use were to change?
  - Impact of land-use on economics and employment?
  - At catchment, national and regional level
- Link existing models in a common spatial framework with an interface
- CDRP funded (2003-6)
- Current funding (P21, EnviroLink)

3

What does CLUES predict?

- Mean annual load of:
  - Total Nitrogen
  - Total Phosphorus
  - E. coli
  - Sediment
- Farm employment, economics
- Median and summer concentrations (new)

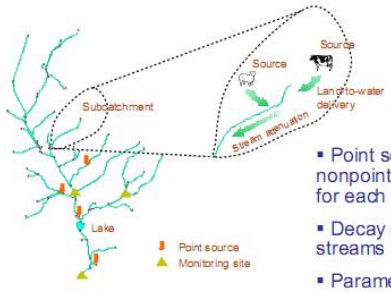
4

Where to get it

- Reports and manual
  - MAF website (search "MAF" and "Clues")
- Programme
  - Ude Shankar, NIWA (DVD)

5

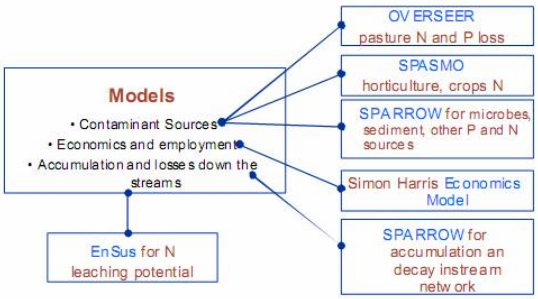
Catchment model



- Point sources and nonpoint source yields for each subcatchment
- Decay and routing in streams and lakes
- Parameters from calibration

6

Component models



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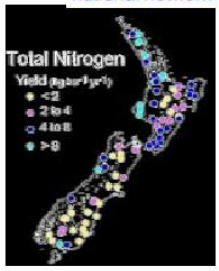
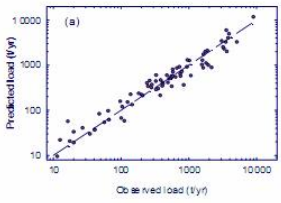
Calibration

Calibrated to measured loads in national network





8

Socio-economic Model (TBL)

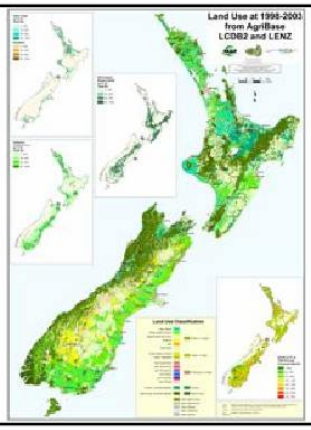
- Simple models for effect of land use on:
  - Cash farm surplus (CFS)
    - Developed from MAF monitor farm models
    - Take stocking rate into account
  - Gross domestic product (GDP)
    - Multiplier of farm gross revenue. No downstream component (e.g. processing plants)
  - Employment: Full Time Equivalents (FTE)
    - Multiplier of farm gross revenue
- Pasture, horticulture, forestry and cropping

9

Spatial Datasets
(model set to go at national scale)

- Current land-use (proportions in each subcatchment)
- REC stream network and sub-catchments
- Climate
- Slope
- Soil order and drainage classes
- Point sources, lakes

10



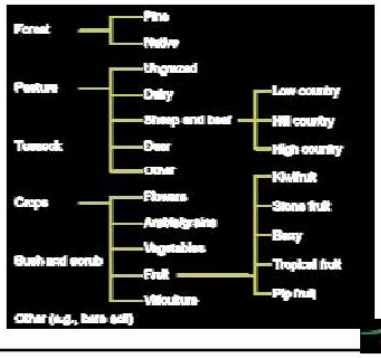
Land-Use Maps

- LCDB2
- Agribase
- Lenz

-User can import their own land use

11

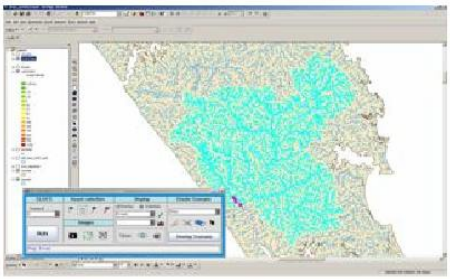
Land uses modelled



Running the model

13

Selecting terminal reaches



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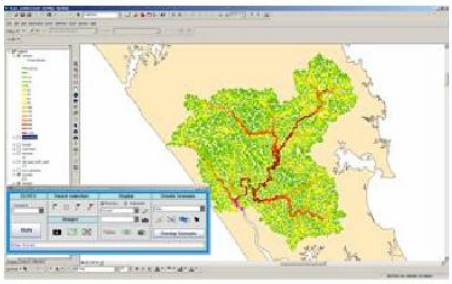
Running CLUES

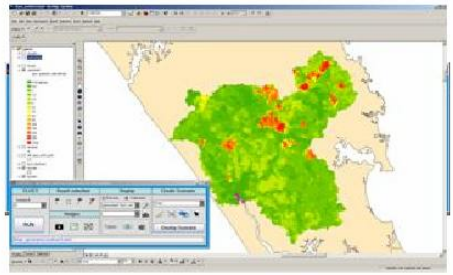
15

Alternative display



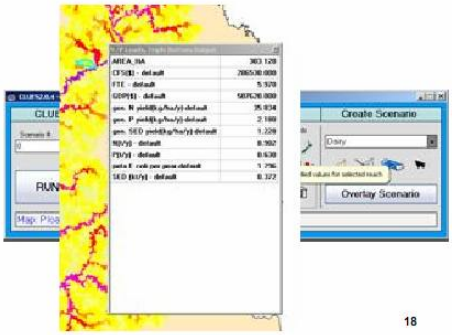
16

Yields



17

Tables: results for a reach



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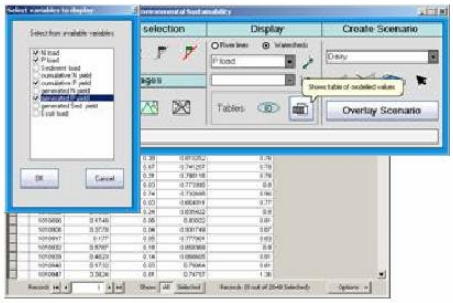
Tables: Catchment summary



19

Quick draw land use change

20

Recent/current work

- Identification of impact catchments in Waikato
- Application to Dairy Focus Catchments
- Region-specific calibrations
- Mitigation measures (as percentage reduction)
- Stocking rate adjustment
- Concentrations

21

What we would like to do

- Greenhouse gases (from Overseer)
- Finer spatial resolution, farm-scale
- Water resources
- More Overseer options available
- Irrigation
- Groundwater component
- Temporal component (time lags)
- Link with dynamic land-use generator

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Case Study 2b CLUES: End User Presentation – Reece Hill, Environment Waikato

1

CLUES
Catchment Land Use for Environmental Sustainability

A regional council perspective

Reece Hill & Dan Borman
Environment Waikato

2

Catchment Land Use for Environmental Sustainability

Background

- Assessing the impacts of land use on water quality
- Creating land use change scenarios
- A catchment based visualisation tool
- Improving suitability for policy development
  - seasonality
  - local calibration

3

Catchment Land Use for Environmental Sustainability

Application

- at different scales
  - Waikato River Catchment
  - Waikato River sub-catchments (Upper Waikato)
- modelling the impacts of actual land use change
  - Waikato River sub-catchments (Upper Waikato)
    - Waipapa
    - Little Waipa
- developing land use change scenarios
  - Waikato River Catchment
    - Afforestation of steep land
    - Matching land use with capability

4

Catchment Land Use for Environmental Sustainability

1. Sub-catchments example

- *Using* CLUES 2002 land use and actual 2008 land use
- *Using* catchments with different land use change patterns
  - Waipapa
  - Little Waipa
- *Comparison* with other N load estimates

5

Catchments: *Waipapa and Little Waipa*

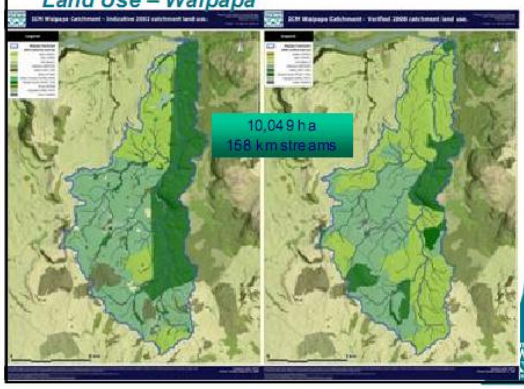
Waipapa
Upper Waikato
10,049 ha
158 km streams
41 farms (18 dairy)

Little Waipa
Upper Waikato
12,210 ha
188 km streams
113 (80 dairy)

6

Catchment Land Use for Environmental Sustainability

Land Use – Waipapa



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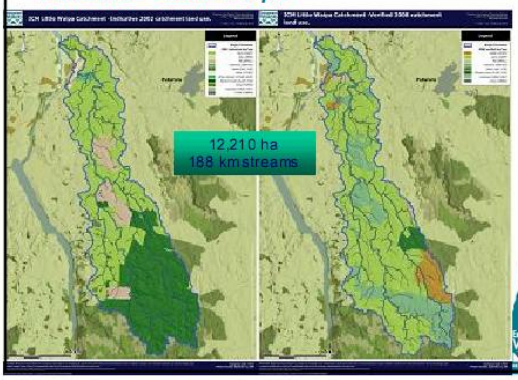
Catchment Land Use for Environmental Sustainability

Land Use – Little Waipa



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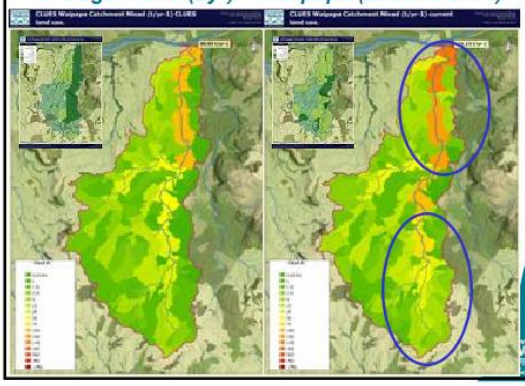
Catchment Land Use for Environmental Sustainability

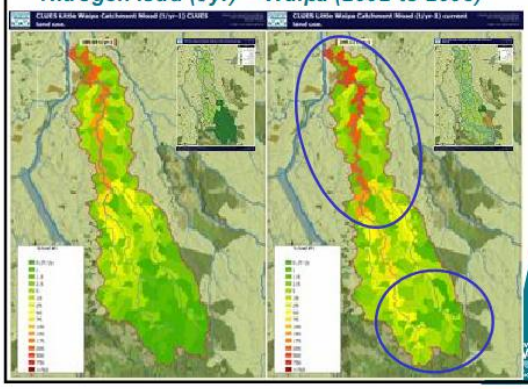
Nitrogen load (t/yr) – Waipapa (2002 to 2008)



Catchment Land Use for Environmental Sustainability

9

Nitrogen load (t/yr) – Waipa (2002 to 2008)



Catchment Land Use for Environmental Sustainability

10

Nitrogen load from catchment (t/yr)

Waipapa	2002	2008	% change
CLUES	90	171	+90
Bill Vant	127	195	+54
Little Waipa			
CLUES	190	249	+31
Bill Vant	235	371	+58

Catchment Land Use for Environmental Sustainability

11

Observations

- Recent conversion to intensive pasture
  - Little Waipa > Waipapa
  - Little Waipa - in the upper catchment
  - Waipapa - in the eastern catchment
- Little Waipa shows greater N load than Waipapa reflecting greater land use intensity
- The positioning of intensive landuse in a catchment is likely to affect the N load from the catchment
- Attenuation is an important factor (ranges: 7 to 29% and 19 to 33%)

Catchment Land Use for Environmental Sustainability

12

2. Waikato Catchment example

- *Using* CLUES 2002 land use
- Changes in N load following:

A. Soil conservation on LUC class 6e, 7 and 8

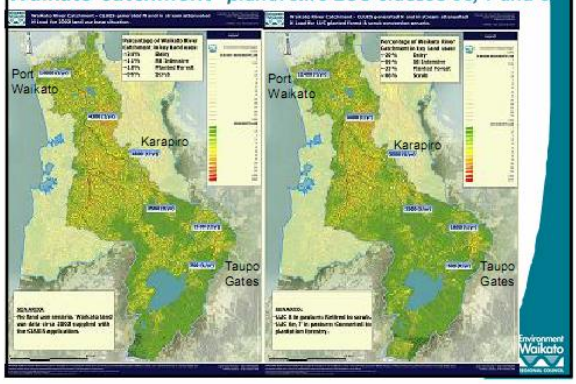
B. Matching land use to LUC

- *Dairy on LUC 1-4*
- *Intensive Sheep and Beef on LUC 5-6*
- *Pines on LUC 6e-7*
- *Shrub on LUC 8*

Catchment Land Use for Environmental Sustainability

13

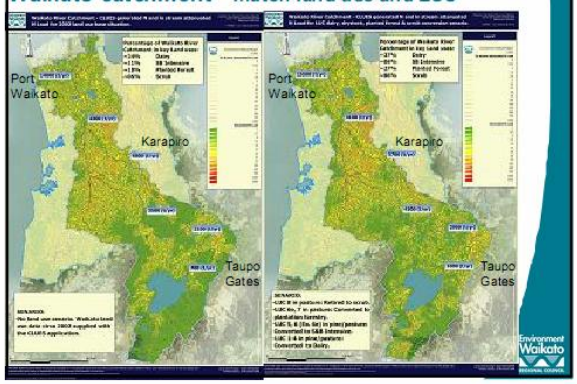
Waikato catchment –plant/retire LUC classes 6e, 7 and 8



Catchment Land Use for Environmental Sustainability

14

Waikato catchment – match land use and LUC



Catchment Land Use for Environmental Sustainability

15

Nitrogen load from catchment (t/yr)

	2002	6e, 7 & 8	% change
Taupo gates	700	500	-29 (-1)*
Karapiro	4800	3500	-27 (-9)*
Port Waikato	14000	11400	-19 (-19)*

	2002	LUC	
Taupo gates	700	1000	+43 (+2)*
Karapiro	4800	5700	+19 (+6)*
Port Waikato	14000	15500	+11 (+11)*

* Change as a percentage of Port Waikato 2002 N load

Catchment Land Use for Environmental Sustainability

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Observations

- Soil conservation planting and retirement are likely to reduce N load in the Waikato catchment (c.f. 2002 land use)
- Matching land use to LUC will likely increase N load in the Waikato catchment (c.f. 2002 land use)
- The positioning of intensive land use in the Waikato catchment is likely to affect the N load from the catchment

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Catchment Land Use for Environmental Sustainability

Benefits

- Nationally consistent model
- All outputs are part of a single spatial framework
- Includes attenuation
- Underlying models are more likely to be accepted and defendable
- Promotes consistent policy approaches and/or ability to compare across regions
- Ministry and industry involvement and support

Environment Waikato

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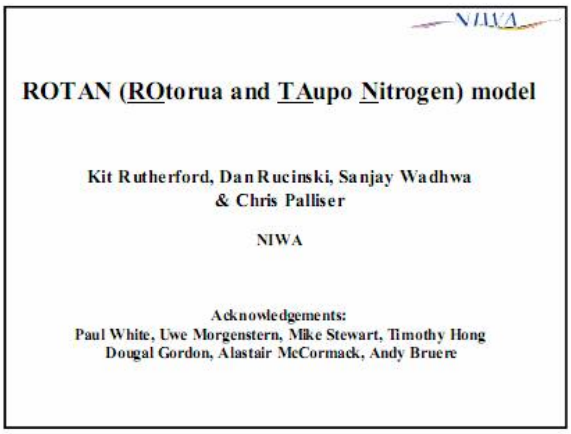
Catchment Land Use for Environmental Sustainability

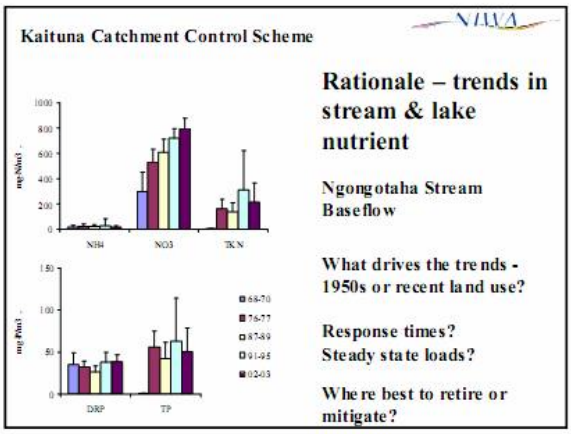
Challenges

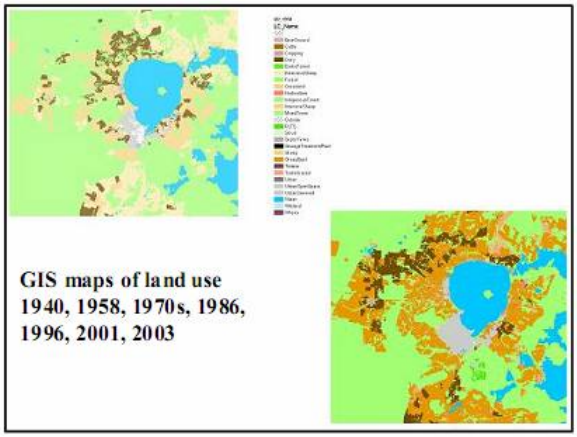
- Comparison of models and approaches
- Accurate land use data
- The importance of input data updates
- Attenuation
- Developing useful scenarios

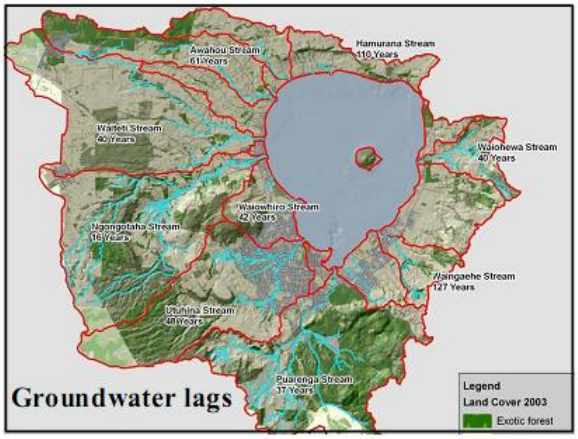
Environment Waikato

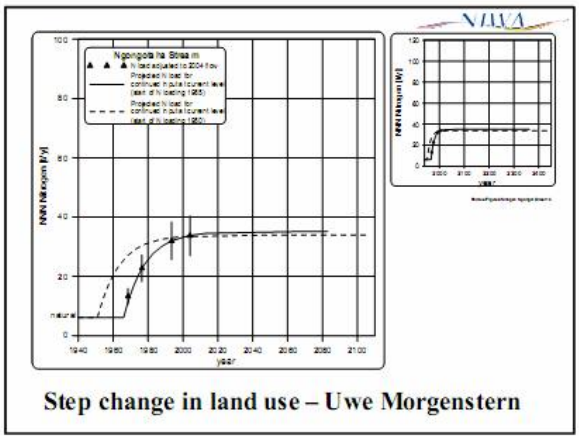
Case Study 3a ROTAN – Researcher Presentation – Kit Rutherford, NIWA

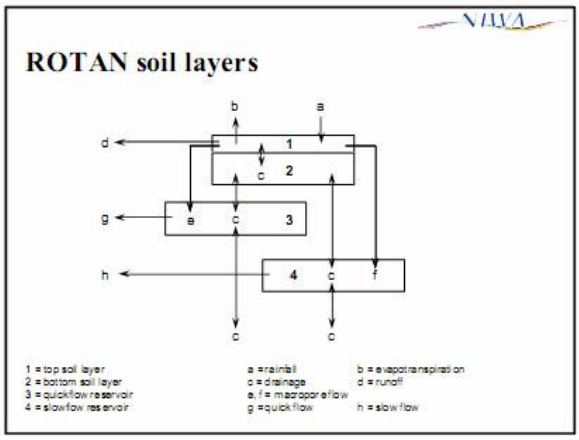


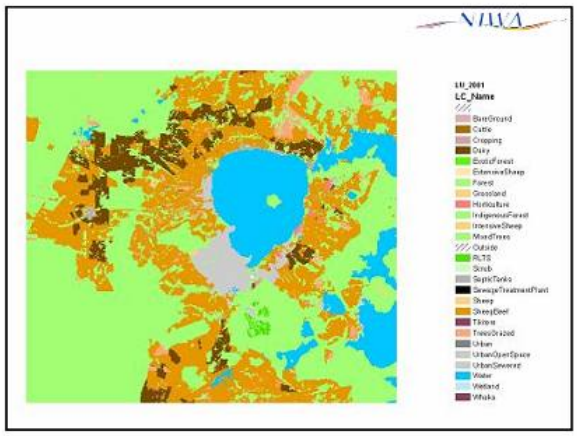


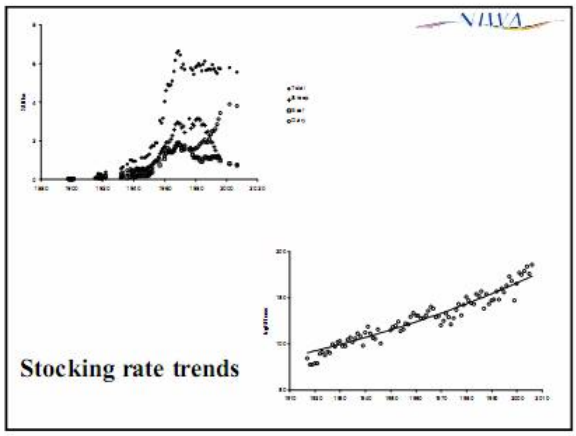


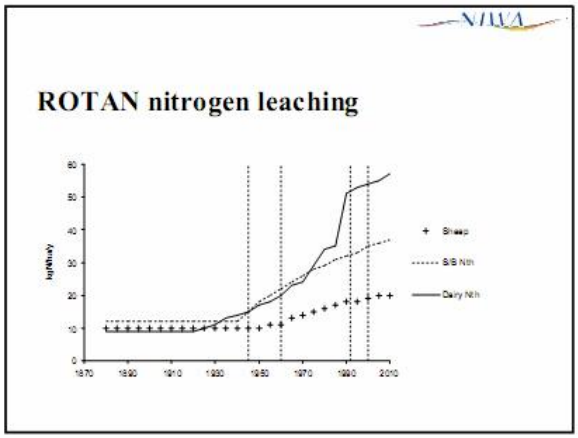


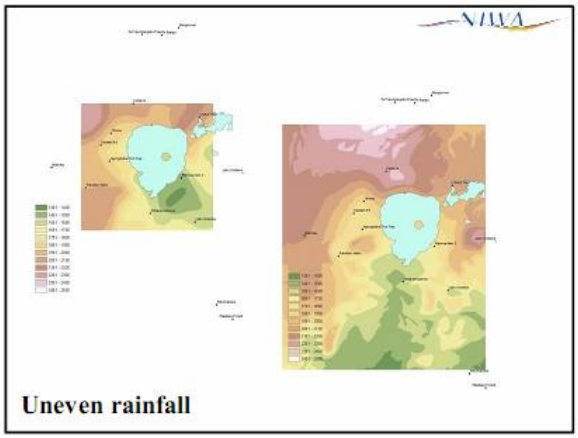


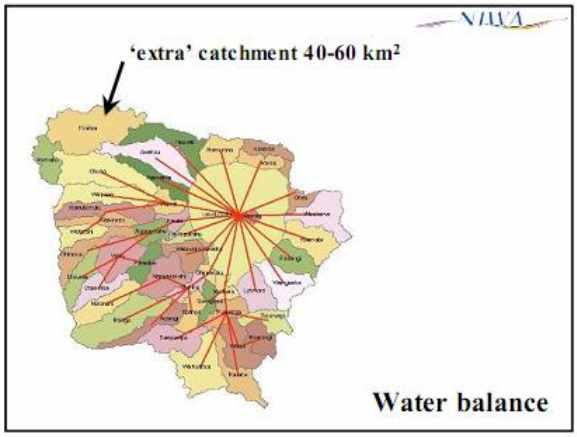


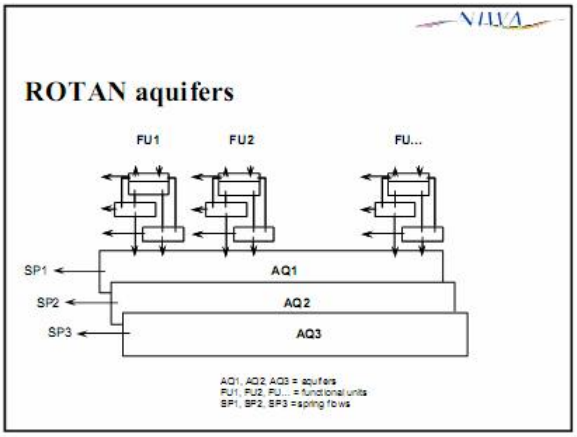


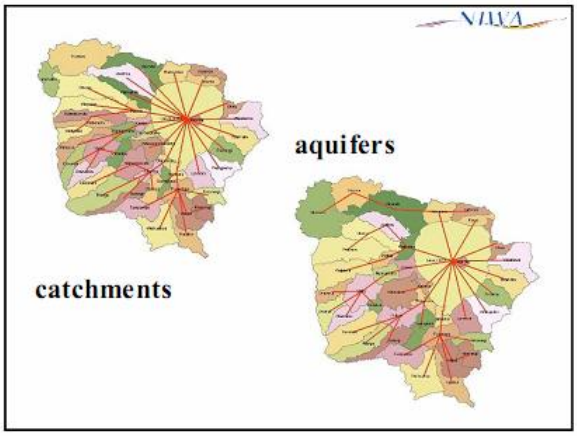


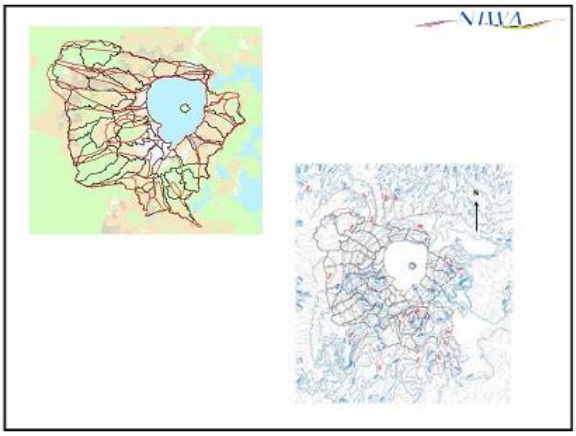

ROTAN nitrogen leaching
kg/N/ha/y
Sheep
S/B Nth
Dairy Nth

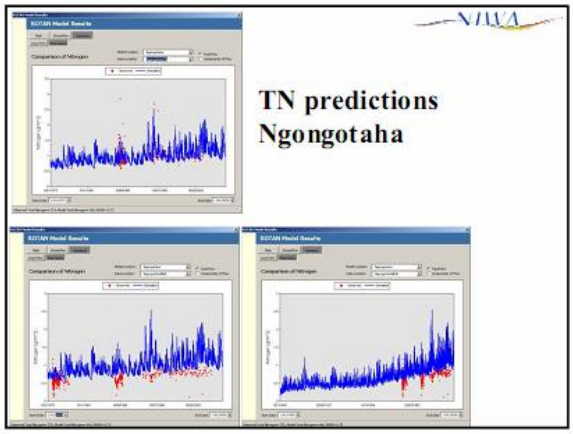

Uneven rainfall

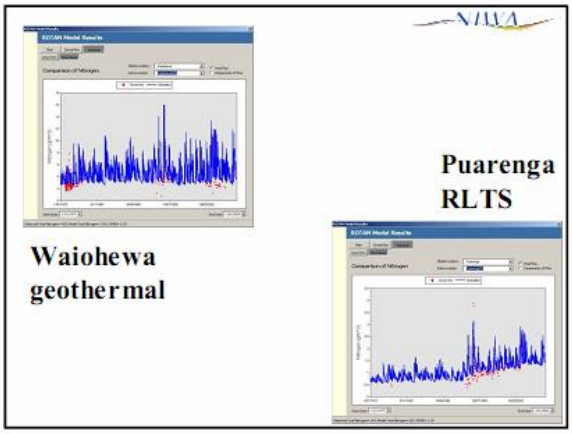

'extra' catchment 40-60 km²
Water balance

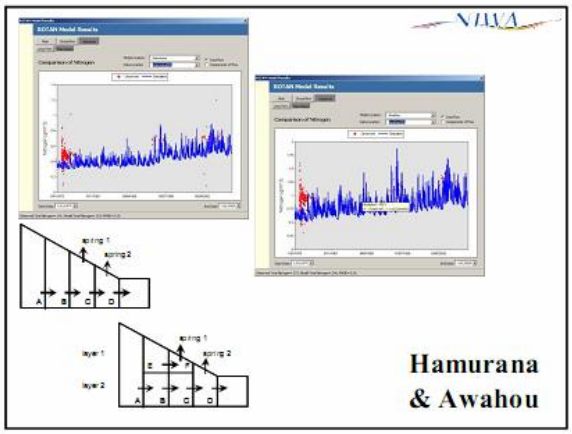

ROTAN aquifers
FU1
FU2
FU...
SP1
SP2
SP3
AQ1
AQ2
AQ3
AQ1, AQ2, AQ3 = aquifers
FU1, FU2, FU... = functional units
SP1, SP2, SP3 = spring flows

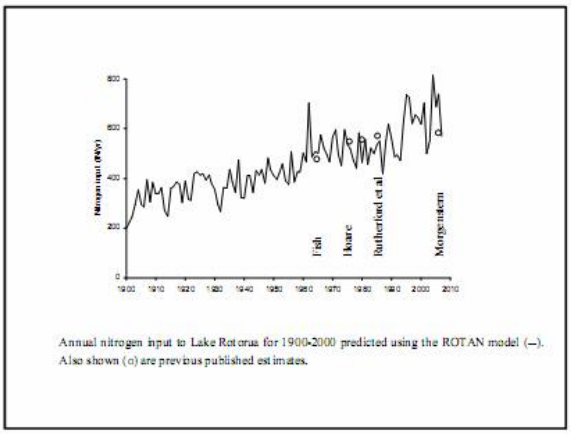

aquifers
catchments




TN predictions
Ngongotaha


Puarenga
RLTS
Waiohewa
geothermal





Annual nitrogen input to Lake Rotorua for 1900-2000 predicted using the ROTAN model (—). Also shown (o) are previous published estimates.

Does	Does not
Daily timestep Rain events	Daily rainfall patterns right
Landuse change	Model N leaching Uses Overseer for generation
Aquifers Groundwater lags	Define aquifer boundaries
Attenuation Riparian buffers, Streams Aquifers	Very little at Rotoua >50% at Taupo
	Phosphorus
Climate change	

Case Study 3b ROTAN – End User Presentation – Andy Bruere, Environment Bay of Plenty

Lake Rotorua Catchment Modelling

Prepared By Andy Bruere,
Lake Operations Manager

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An **Environment Bay of Plenty, Rotorua District Council** and **Te Arawa Lakes Trust** joint project

1

The Rotorua Lakes Programme

- 12 lakes
- Varying trophic state
- 4 E
- 4 M
- 4 O
- Varying sizes 35 Ha to 80 km^2
- Catchments 350 Ha to 65,000Ha.

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The problem

- 4 Eutrophic
- Algal blooms
- Unacceptable to the community
- Undesirable effects
  - Recreation
  - Tourism
  - Aesthetic
  - Odour
  - Health
  - Fisheries

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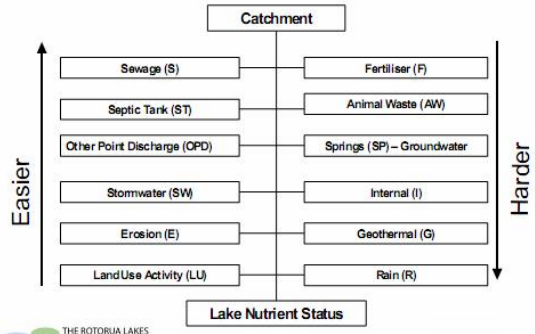
The Cause – too much nutrient



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4 Eutrophic Lakes

- Rotoiti, main inputs from Rotorua
- Rotoehu, 800 Ha, 2 main land owners and shorter GW age,
- Okaro, 35 Ha lake, 350 Ha catchment…

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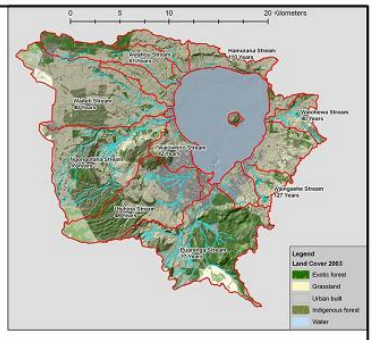
Rotorua

- 80km^2
- 65,000Ha catchment,
- Variable GW age, 60 years av,
- Dependent on sub-catchments
- 15 to >170 yrs



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Current nitrogen reduction targets

- Whole catchment 250 T/year
- In lake/in-stream interventions 80T/Yr
- Land use change 170 T/yr

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Community expectations and time scale

- Rotorua $100M project
- Community expects return in their lifetime
- Need to meet 2 objectives
  - Improvement in their lifetime, and
  - Leave a legacy of improvement
- Identify projects that have a short pay back

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ROTAN MODEL

- Catchment scale model
- NIWA project Kit Rutherford
- Nitrogen predictions from land use
- No P predictions
- Predict sub catchment outputs with changing land use
- Model only recently completed

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EBOP expectations

Run a range of scenarios to identify
- Effect of changing land use in each catchment
- Best land use combinations
- Identify extreme scenarios to test if targets feasible
- Identify time scale round LUC c.f. leaching
- Output linking to other models

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Linkages with other Modeling

- Feed into lake model
- Interact with other lake interventions
- Identify best options for lake
- Identify timing for options
- Identify time scale between LUC and GW impact

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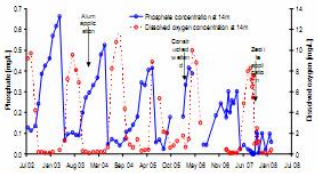
Decision making

- ROTAN only part of link in determining lake restoration
- Only recently completed
- Next steps
  - Intervention selection
    - Best options, and
    - Value for cost
  - Timing
  - Optimisation
  - Policy direction



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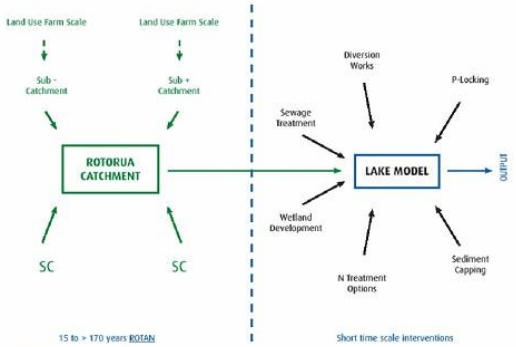

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