Understanding the Practice of Land Use Modelling

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Abstract

Some problems are too complex to be addressed with all the detail with which they are encountered in reality. Addressing these kinds of problems requires the use of a simplified representation of reality: a model. In the context of water quality, land-use models are used to help anticipate and diagnose problems, estimate the cost of meeting environmental targets, and simulate different policy options to explore their likely impacts.

Among scientists, the formal and frequent use of models is so well established that it is accepted without requiring explanation. However, to those outside the scientific community models can seem like black boxes, and the variety of available models can cause confusion.

This report discusses the practice and usefulness of land-use modelling for an audience that is unfamiliar with it. It focuses on modelling that addresses the choice of rural land use, land-use intensity and land-use practices in response to economic, regulatory and environmental conditions. We provide brief descriptions of some of the key land-use models that are relevant in a New Zealand context, and discuss the key differences among them.

Keywords

Intensity, land management, land use, land-use change, model, rural

Contents

1. Introduction

Some problems are too complex to be addressed with all the detail with which they are encountered in reality. Addressing these kinds of problems requires the use of a simplified representation of reality: a model. In the context of water quality, land-use models (combined with water-quality models – the subject of a companion paper, Anastasiadis and Kerr, 2013) are used to help anticipate problems, diagnose the sources of pollutants, estimate the cost of meeting environmental targets and simulate different policy options to explore their likely impacts on people, production, land use and the environment. By capturing the key agents, elements, processes and decisions, models enable complex systems and situations to be understood and complex problems to be solved.

"Everyone is a modeller" (Meadows et al., 1972). When any person needs to make a decision in the face of a complex situation they select certain key details, make assumptions about details they have ignored, and apply intuition and judgement, to inform their decisions. Scientists make these models more explicit.

Among scientists (including economists), the formal and frequent use of models is so well established that it is accepted without requiring explanation. However, to those outside the scientific community the reasons and methods used for modelling can be unclear, models can seem like black boxes, and the variety of available models often results in confusion.

This report discusses the practice and benefits of land-use modelling for an audience that is unfamiliar with it. It focuses on modelling that addresses the choice of rural land use, land-use intensity and land-use practices in response to economic, regulatory and environmental conditions. We provide brief descriptions of some of the key land-use models that are relevant in a New Zealand context, and discuss the key differences between them.

Models are used to understand land use because the social, economic and geographic factors that determine the choice and impact of land use are complex (Rindfuss et al., 2008; Lambin et al., 2001). In this paper we define land use to include variations in the type and intensity of rural, land-based activities. Models provide a structured way to think about land use and a methodology for investigating land-use change.

Land-use models are often developed to inform government, community and industry stakeholders decision making by highlighting probable future outcomes, issues and opportunities. Models also inform the direction of research, provide tools to answer research questions, and express results in a repeatable and robust way that helps promote, but does not guarantee, better understanding of land-use change. While they can be subject to deliberate misuse, models are an important part of doing good science. In general, the quality of a model and the robustness of its conclusions are tested within the scientific community before model results are made available to the wider society. This helps ensure that modelling, and scientific activity in general, upholds the standards of rigor that are expected by the scientific community.

Land-use models aim to deepen understanding of how people decide where and how to make use of land. Some land-use models consider land use only in aggregate: how much of different types of land use (for example: dairy, forestry, residential) occur in a given area. Other land-use models consider also the specific locations and configurations of different land uses and land use intensities, and how they change over time.

There is a variety of land-use models because different models are required to answer different questions, to model different situations and to work at different levels of detail. These models make different assumptions, use different data and methodologies. As land-use change is too complex for any one model to capture fully, using multiple models in combination can provide a more complete and robust understanding. In addition, cross model comparisons can be used to help validate the different models. Hence, when used appropriately, the variety of available models should be seen as a strength rather than as a weakness.

Relative to models based in natural science, land-use modelling has several distinctive features. First, humans behave in different and complex ways. Their behaviour is not necessarily constant over time, they form groups and networks, and they can behave strategically and (sometimes) illogically. This means that predictions of changes within human systems are inherently uncertain. Land-use models, to a greater or lesser degree, consider this variability in how humans behave. These models all have underpinning assumptions about human behaviour or directly incorporate different drivers of human behaviour. Providing predictions of future outcomes is an appropriate use of land-use models. These models can provide plausible projections, can exclude unlikely outcomes and can often predict the direction or nature of a response to changes in external conditions.

Second, within New Zealand, land-use modelling is a relatively new research activity. This means that the databases required for robust modelling (for example, maps of land use) are still developing, the fundamental science (empirical evidence) behind some key relationships is weak or missing, models and documentation are still evolving, and for some models there has been little time for peer review or model comparisons.

Third, the institutional and funding environment in which most land-use modelling is developing is different from that for the more geophysical models. Because land-use models directly involve humans and their results are directly used in policy processes, the context for developing models, commissioning applied studies and interpreting results is inevitably more political. Although public good funding has supported basic model development in recent years, most model applications are done for specific end users (e.g. Regional Councils or Government Departments), for clearly defined policy scenarios and under tight timeframes. Such research is not always publicly released and is rarely openly peer-reviewed. As the field evolves, these issues are being addressed with more publications and critical review in conferences and other venues

The remainder of this report is set out as follows. The first four sections answer the questions "what is a model?", "why are models used?", "how are models developed" and "how are models used?" respectively. The last three sections provide an overview of some of the current water-quality models in New Zealand, answer the question "why are there different models?", and conclude.

2. What is a model?

A model is a simplified representation of reality that focuses on the key factors and (cause-and-effect) relationships of a phenomenon. Models describe how these factors are related, and the strengths of the different relationships.

Constructing a model requires a scientist to explicitly specify their assumptions, identify the phenomena they are concerned with, and explain their methodology. This benefits the individual scientist by imposing on them a high standard of scientific rigour. It also benefits the users of the research who can better understand how any research question has been framed, the context in which a study has been conducted, and its strengths and limitations.

We think of models in two broad categories: Theoretical or conceptual models and numerical or computer models. Theoretical or conceptual models provide a representation of reality that emphasizes how the different parts of a system interact without seeking to quantify the magnitude of any interactions. Flow diagrams and systems of algebraic equations are examples of theoretical or conceptual models. These types of models are often used in situations where numeric data is not available.

Numerical and computer models provide representations of reality that both describe how the different parts of a system interact and quantify the magnitude of the different interactions. Numerical models are frequently constructed inside the context of a more general theoretical model. Weather forecasts and economic forecasts are frequently outputs from numerical computer models. These types of models are almost always informed by other research activities where data has been collected and analysed. In this respect numerical models summarize and embody existing science.

3. Why are models used to understand land-use change?

Models are used to understand land use because the factors and decisions that determine land use and land-use change are complex. This complexity arises from the decision process made by the land owner when determining land use, intensity and management practices, and from geographic variability, economic uncertainty and interactions between land owners.

Land owners combine social, personal, economic, geographic and regulatory information together in ways that are only partially understood. In addition, the values, attitudes and behaviours that guide how land owners make decisions about how to use their land differ among people. This includes what purpose they have for using the land, what information they consider relevant, what emphasis they place on different types of information, and the way they think about the future.

In the face of such complexity, a scientist must exercise professional judgement as to how they will model land owners' decisions. For example: to what extent do land owners respond to commodity prices, interest rates, or their neighbours' decisions? Are land owners primarily profit seeking, revenue seeking, cost minimizing or risk avoiding? Do they have preferences for lifestyle or aesthetics? Do they have a sense of stewardship for the land? Scientists must also use judgement in their choice of methodology. For example: will they attempt to explicitly model individual land owners' decisions? Will their model solve for an 'optimal' outcome? Will they use a statistical approach and assume that future behaviour will be similar to behaviour observed in the past? Will they model land owners' aggregate decisions or use representative land owners?

Models are used because they require the scientist to write down and formalize their judgements. The use of a model helps clarify what is within the scope of the research; how it will be treated, and also what lies outside the scope of the research; what is assumed or ignored. As a result their work becomes visible to, and subject to critique from, other scientists. This transparency enables the quality of the model to be tested and helps ensure that any results produced by it are robust and are interpreted in the context of the decisions, judgements and assumptions that were made during its development.

Land-use models are used in response to questions that are difficult to answer in any other way. These questions often arise in a policy context where it is desirable to quantify the potential consequences of a particular course of action, to explore alternative courses of action, or to anticipate issues that may arise in the future.

The use of surveys (for example, the harvest intention surveys by the Ministry for Primary Industries (Lane and Geard, 2005; Manley, 2013) could be used in place of a model that attempts to predict deforestation) is sometimes suggested as an alternative to the use of models. However, while surveys are useful, they complement but do not replace the use of models.

The use of survey responses for estimating future land use assumes that land owners' stated intentions are indicative of their actual future courses of action. This may not be the case, especially where land owners have incentives to misrepresent their intentions (for example: land owners may over-state their intentions to adopt environmentally friendly practices so that regulation to protect the environment seems less important), the land owner has not yet considered the situation of interest, or the land changes ownership. There are also issues surrounding the privacy of survey data that limits how the results can be used. We are often interested in producing land-use maps but maps produced from survey data could breach privacy requirements if individual properties can be identified. In contrast land-use models can make use of data that is less sensitive to manipulation and, as much of this data is publicly available, there are seldom privacy concerns.

Models can inform the design of surveys. While it is straightforward to survey land owners as to their past land uses or their intentions under a given scenario, such an approach is simplistic, expensive and of limited use (for example: a survey must ask the same questions for each scenario of interest). When surveys are designed using a conceptual model of land owners' decision making processes, they can capture not just land owners' intentions but the factors that contribute to their decisions. These more detailed results are valuable as they can be combined with modelling to generalize these intentions to other scenarios.

While models are sometimes criticized for containing errors, it is important to recognize that this does not prevent models from generating new insights that can both inform decision makers and extend scientific understanding. Just as good scientific practice includes accounting for the error in any information used, so also it includes developing models from data and accounting for the uncertainty any errors introduce to the results.

4. How are models developed?

Models are developed from a range of knowledge sources, both formal and informal, and new knowledge is often created to support the development of a model where weakness in the existing science is identified. Models may be developed to guide the initial direction of research, as the focus point or key tool for research, or as the intended outcome from research. In general, the development of a model occurs according to the following process:

1. The purpose of the model is defined.
2. The existing scientific knowledge is examined. This stage includes conducting reviews of the published literature and consulting with recognised experts in the field. The goal of this examination is to identify the key factors and relationships that are of interest.
3. The scope of the model is defined, specifying what factors and relationships will be included in the model and in how much detail. For example: Does the model need to consider the process by which land-use changes or just its final land use? Are we interested in the location of land-use change or just the amount of land converting between land uses? The answers to these questions are driven by the intended purpose of the model.
4. The data that is needed for the model is collected. This may entail collecting new data. Where the ideal data cannot be observed or collected, appropriate alternative sources of data are identified (for example, we may not be able to consistently observe the profitability of dairy farms, but can use data on the price of milk solids as an alternative). As part of this stage, the reliability of the data is assessed (considering the nature and magnitude of any errors with the data).
5. Supporting and constituent research is completed and documented. If the model cannot be constructed from existing scientific knowledge, new research is necessary. This research may require the development of sub-models that act as inputs to the original model.
6. The model is realized as a computer program. This computer program is often talked about as "the model" and is frequently given its own name.
7. The model is documented. This documentation describes the scope of the model, how it has been constructed, the datasets that it draws on and the uses it can be put to. In addition, the documentation describes the judgements and assumptions that

were necessary during the construction of the model, why they were made and their likely impact on the model results.

8. The model is tested by the scientists involved in its development. The focus of this in-house testing is often checking the model results for consistency with observations and intuition. This may lead to models being calibrated so they better match reality.
9. Where possible the model is validated. Traditionally, this involves comparing the model results against data that has not been used to build or calibrate the model. This is difficult for land-use models because they are often used to project land-use patterns under various counter-factual scenarios (which cannot be observed). For land-use models, validation is often limited to selected model components (such as the baseline map or simulation methodology) and cross model comparisons. These help quantify any uncertainty associated with the model.
10. The model is exposed to the wider scientific community who have opportunity to comment and critique (most often this occurs in the context of journal articles, working papers and conferences). This process is often called "peer review" and encompasses not just the model results but also its methodology and underlying assumptions. This is a standard part of the scientific process, having the goal to enhance and clarify the new work. Where critical issues are identified with the model the developing scientists may return to stages 3 and 4.
11. The model is made available for applications for stakeholders and those outside the scientific community who have an interest in it. The model results are assessed by stakeholders outside the scientific community.

While we have presented these stages sequentially, it is important to acknowledge that these stages frequently overlap. Furthermore, scientists often return to earlier stages during the development of a model in order complete the later stages. For larger and more complex models these stages may be followed for different sub-parts (or sub-models) of the model.

The peer review process imposes upon scientists a requirement for rigor. Rigor gives credibility to models, their results, and the conclusions that are drawn from them. While situations arise where an organization funding the application of a model applies pressure to bias the results, such results are unlikely to pass scrutiny of the rest of the science community. Users and funders of models can therefore have confidence in models and results that have undergone peer review, and should request it of those models and results that have not.

It should also be recognized that a completed model is not a static thing. Models are never perfect because scientific understanding is never perfect and continues to evolve.

Developing and maintaining models is an ongoing process. As models are critiqued and as scientific knowledge increases components of the model may be enhanced or require revision. The Land Use in Rural New Zealand model (LURNZ) is an excellent example of this process, with an early version completed in 2006, and the most recent version released in 2013.

To those outside the scientific community, the process by which models are improved has, on occasion, been misinterpreted as an indication that models are unreliable. However, improvements to models, whether in response to feedback or to take account of new science, almost always take place to extend a model's capabilities and reduce the uncertainty associated with its results.

5. How are models used?

Land-use models are put to a variety of uses. Because land-use decisions have environmental, economic and social consequences, we wish to understand the drivers that affect it and the consequences of policies that are developed to influence it.

1. Models are used to predict the possible consequences of specific policy. For example: What is the likely impact of including pastoral agriculture in the New Zealand Emissions Trading Scheme? What impact is this likely to have on water quality? And who will be most affected?
2. Models are used to inform the design of policy by exploring alternative courses of action. For example: How does the effectiveness and cost of nutrient regulation vary under different regional policies? And how will the speed with which an intervention is introduced affect land owners' ability to adjust to it?
3. Models are used to diagnose the potential for issues to arise in the future. For example: What are the impacts of external pressures (for example, climate change or demographic shifts) on land use and land-use change? Which locations are likely to face increasing environmental stress? And what patterns of land use might be encouraged to mitigate these stresses?

Outside a policy context, models are used by scientists to identify areas where new knowledge is needed and to evaluate existing knowledge. This includes identifying the features that modelling results are sensitive to (for example: price projections, assumptions about new technologies) and cross checking land-use models against each other. Because land use is determined by many complex factors, comparing models against each other helps assess the validity of the models (as an application of the existing knowledge) and highlights where both models could be extended (by the development and application of new knowledge).

Land-use models are developed by scientists but their results are often interpreted and used by government (local and national), industry and community stakeholders. This distinction between developers and end users can hinder the appropriate use of models. While scientists are aware of the limitations and uncertainty inherent in any model they develop, these limitations and uncertainty are not always communicated to, or understood by, end users. Consequently, models have been applied to contexts where they are not suited and model results have been misinterpreted. It is therefore important that models are interpreted in the context they were developed.

There is an ongoing hazard with land-use models that users outside the scientific community interpret model results as predictions of where land-use change is going to occur and who is going to carry out this change. None of the models covered in this report claim to predict future outcomes with such accuracy; this is not an appropriate way to assess the credibility of land-use models. Instead land-use models aim to identify the type of land where land-use change is likely to occur and the type of land owners who are likely to carry out this change.

One of the key limitations of land-use modelling is the poor availability of land-use data. Map data is available for only selected years and land-use categories: The Land Cover Database provides maps for 1996, 2002 and 2008 (Landcare Research, dataset, 2012); and the only empirical map that differentiates between different pastoral activities, such as dairy and dry stock farming, is dated 2002 (AsureQuality, dataset, 2008). This is due to land-use modelling being a relatively new area of scientific study in New Zealand, and also the cost to collect, prepare and validate new land-use data. A more detailed discussion of the data and resources available for land-use modelling in New Zealand is given by Rutledge et al. (2009), Price et al. (2010), Morgan et al. (2010) and Rutledge et al. (2013).

Some of the other criticisms that have been directed at land-use modelling include models have not been satisfactorily calibrated or validated, combining datasets can compound errors, and models consider only a small range of the possible land uses (and management practices). In addition, there is a lack of detailed data to inform those models that attempt to incorporate farmers' individual decisions and this data is difficult to collect. Despite these criticisms and the need for better data, it is important to recognize that models can still generate new insights that can both inform decision makers and extend scientific understanding.

6. What are the key land-use models?

In this section we provide a short list of some of the key models used for investigating land use and land-use change in New Zealand. Our focus in providing this list is to highlight the differences between each model, their relative strengths, and when / why you would use a particular model.

We limit the scope of this list to socio-economic models currently in use for modelling rural land use, land-use intensity and land-use change. Hence we deliberately exclude models that focus only on urban expansion, natural scrub reversion or on-farm management practices (for example: Smeaton et al, 2011; Bryant et al, 2010; Beukes et al, 2009). We also exclude time series or computable general equilibrium models, such as PSRM (Gardiner and Su, 2003; Ministry of Agriculture and Forestry, 2008; Dake and Manderson, 2010), several New Zealand-only Computable General Equilibrium models (Stroombergen, 2010; NZIER and Infometrics, 2011; Lennox and van Nieuwkoop, 2010) and three global models (GTAP: Rae and Strutt, 2011, CliMAT-DGE: Lennox et al., 2012 and the model by Saunders and Cagatay, 2004). In response to scenarios with different economic conditions, these models predict variations in agricultural production and livestock numbers from which changes in land use could be inferred.

Other studies and websites have compiled lists with different scopes and also illustrate the interactions between models. An interested reader might investigate: Samarasinghe and Greenhalgh, (2012), Arbuckle, (2013), https://teamwork.niwa.co.nz/display/IFM/IFS, and http://tools.envirolink.govt.nz/.

Figure 1: Classification of land-use models

Model methodology	Area covered: Catchment	Area covered: Region	Area covered: National
Individual decision makers	ARLUNZ Waikato M.A.	Rural Futures	
Optimization / Best option	NZ-FARM NManager	LUMASS	
Statistical / Amalgamated preferences		WISE	LURNZ

Figure 1 classifies the land-use models based on the area they cover and the central methodology used. Those models that use an individual decision maker method model the learning and preferences of individual farmers. In these models, farmers' decisions may differ from those of their neighbours (and may not be ideal from a policy making perspective) and the final outcome arises as a result of many decentralized decisions. Those models that use an optimization method model decision makers (whether individual or collective) as always making the ideal decision. In these models, profit or revenue is maximized given that the environmental or regulatory targets must be met. Those models that use a statistical or amalgamated preferences method are based on statistical relationships, identified in historical data, between land use, land-use change and economic variables. In these models, the statistical relationships capture the combined decisions of many farmers at a regional or national level. We list the following land-use models alphabetically.

ARLUNZ

ARLUNZ (Agent-based Rural Land Use New Zealand model) is a catchment scale, spatial model for considering the response of land owners to different agricultural policies. It extends the modelling of NZ-FARM to allow for the individual decisions made by farmers who differ in their attributes, preferences, behaviour and response to policies over time. ARLUNZ considers the following land uses: arable, dairy, sheep/beef, indigenous vegetation, plantation forest and scrub. It produces estimates of changes in catchment profitability, greenhouse gas emissions, nutrient loss, management practices and land use over time. The model inputs include data on initial land use, land quality, commodity prices and commodity demand by land use and land management, in addition to definitions of farmers' characteristics and social networks.

ARLUNZ has been developed by Landcare Research. Using Landcare capability funds it has been used to investigate how the Hurunui-Waiau catchment would respond to various carbon prices under the New Zealand ETS. The intention of ARLUNZ was to expand the ability of NZ-FARM to consider other drivers of farmer decision-making beyond just profit seeking behaviour. It's primary purpose is to access how the impact of agricultural policies, resources constraints and other external pressures might differ across farms (Daigneault and Morgan, 2012).

ARLUNZ addresses questions such as:

- How might individual farmers respond to changes in commodity prices, carbon prices and resource constraints?
- How do these individual responses and the overall response vary over time?

Land Allocation Simulator

The Land Allocation Simulator is a modelling framework for assessing the possible impacts of agricultural and environmental policy. A feature of this framework is that it provides a robust means of calibration. The model inputs can include data on farm systems, hydrology, forestry and urban land, and Overseer results. The model can both investigate long-run outcomes as well as dynamic interactions.

The Land Allocation Simulator has been used to analyse alternative allocation systems, different load reduction targets, and alternative irrigation futures in the Selwyn-Te Waihora catchment in Canterbury, and also to guide policy formulation in the Lake Taupo catchment. In response to the National Objectives Framework, the model is currently being used to identify the implications of policy and dairy conversions on future water quality in the Upper Waikato catchment. The model has also been applied throughout Australia (Doole and Paragahawewa, 2012; Doole et al., 2013; Howard et al., 2013).

The Land Allocation Simulator addresses questions such as:

- How do the long-run outcomes for a catchment differ under a range of policies?

LUMASS

LUMASS (the Land-Use Management Support System) is a spatial scale model that optimises the allocation of land uses across a landscape subject to multiple and possibly conflicting objectives and constraints. The land uses it considers are dairy, sheep, beef, sheep/beef and forestry. LUMASS generates an optimal land-use configuration (map) subject to the specified objectives and constraints. Different optimisation scenarios can be used to represent different stakeholder preferences and different planning scenarios. These objectives could include maintaining or improving catchment level nutrient leaching, erosion, production (milk, meat, wood and wood), or revenue. The model inputs include maps of initial land use, soil type, land quality and property boundaries, from which maps of potential nutrient loss, erosion, water regulation and provision, and production by land-use type can be constructed.

LUMASS has been developed by Landcare Research to support spatial planning and policy development by regional councils. It helps explore environmental and economic limits of a landscape (such as a catchment) and helps identify its future development potential. LUMASS has been used in a number of case studies in Germany and New Zealand. The New Zealand case studies include Waitaki and the Manawatu. (Herzig, 2008; Ausseil et al., 2012).

LUMASS addresses questions such as:

- What distribution of land uses would reduce nutrient loss while maintaining current levels of production or revenue?
- Where should regional councils encourage land-use change to occur in order to meet their social and environmental objectives?

LURNZ

LURNZ (Land Use in Rural New Zealand) is a nation scale, spatial model for considering the implications of environmental policies on future land use, production and greenhouse gas emissions. [1] The land uses it considers are dairy, sheep/beef, plantation forestry and scrub. LURNZ spatially allocates national level changes in land use and produces maps of land use, production and greenhouse gas emissions at a fine spatial scale. It does not model landowner decisions explicitly, but instead is based on empirical estimates of relationships, over time, between aggregate land uses and commodity prices (Kerr and Olssen, 2012); and also relationships, over space, between land use and land characteristics (Timar, 2011). The model

[1] www.motu.org.nz/research/group/land_use_in_rural_new_zealand_model

inputs include initial land use, measures of suitability for different land uses (slope, LUC, ownership, and distance to ports and towns), and forecasts of commodity prices.

LURNZ has been developed by Motu Economic and Public Policy Research to assess the impact of greenhouse gas policies, both regionally and nationally, on land use, native forest reversion, emissions and the distribution of costs (Hendy et al., 2006; Kerr et al., 2009a; Kerr et al., 2009b; Kerr et al., 2012). It has also been used to produce maps of historic and future land uses to understand potential impacts of climate change on pasture productivity (Baisden et al., 2010) and to explore the potential for biofuel production (Todd et al., 2009).

LURNZ addresses questions such as:

- How does land use change in response to changes in commodity prices and greenhouse gas regulation?
- Where is land-use change likely to occur across the country?

NManager

NManager is a catchment scale model for considering the effectiveness of different designs of nitrogen regulation. The land uses it considers are dairy, sheep/beef and plantation forestry. NManager models land-use change as a result of farmers nitrogen mitigation decisions, and gives non-spatial results including the share of land in each land use along with costs of mitigation. The model inputs include land use, nitrogen transport and the design of regulation.

NManager has been developed by Motu Economic and Public Policy Research to assess the possible gains from regulation that accounts for the hydrological complexity of the Lake Rotorua catchment. It has been used to inform both local (Bay of Plenty Regional Council) and national (Ministry for Primary Industries) level government on issues including relative costs of different lake quality targets (stringency and timing), allocation of costs, likely land-use change, and interactions with greenhouse gas regulation. (Anastasiadis et al., 2011; Cox et al., 2011; Daigneault and McDonald, 2012; Yeo et al., 2012).

NManager addresses questions such as:

- How do different nitrogen leaching policies affect land use and land-use intensity?
- How does the cost of obtaining a nitrogen leaching target vary with the complexity of nitrogen trading regulation?

NZ-FARM

NZ-FARM (New Zealand Forest and Agricultural Regional Model) is a catchment scale, spatial model for considering the impact of different policies, resource constraints and prices. The land uses it considers are: arable, horticulture, dairy, sheep/beef, pigs, deer, native forest, plantation forest and scrub. NZ-FARM calculates optimal land use and production under a given policy, in addition to estimates of nutrient leaching and greenhouse gas emissions. The model inputs include maps of initial land use, land-use capability class (LUC) and soil type, as well as data on input prices, input use by land use and land management, and output prices.

NZ-FARM has been developed by Landcare Research to inform decision-makers on the probable economic impacts of different policies relating to irrigation, water quality and greenhouse gas emissions. The model has been applied to case-studies in the Manawatu, Hurunui and Waiau, Selwyn-Waihora, and Hinds catchments. Developed to inform and evaluate policies for regional councils and central government (both MPI and MfE), the model has also been used by MPI to highlight how a policy that targets one environmental indicator could improve or worsen other indicators (for example policies imposing a cost on greenhouse gas emissions may in some cases encourage higher nutrient leaching) , (Daigneault et al., 2011; Daigneault et al., 2012; Daigneault and McDonald, 2012).

NZ-FARM addresses questions such as:

- How might land use respond to local irrigation and water quality policies? Or to national greenhouse gas policies?
- How could policies designed to target nitrogen leaching interact with greenhouse emissions, and vice-versa?

Rural Futures MAS Model

Rural Futures MAS Model is a, regional scale, spatial, simulation model for considering the implications of farmers' demographics and decision preferences, agricultural policies, as well as trends and shocks in prices and technologies on rural communities. The Rural Futures MAS Model allows for individual decision making by farmers who differ in their avoidance of risk, objectives and peer networks. The land uses it considers are different intensities of dairy, sheep/beef and forestry. The Rural Futures MAS Model calculates the share of land in each land use on an annual time step, and estimates probable strategic decisions by farmers in response to changes in their operating environment. Given these responses it also calculates regional wealth creation, social and environmental outcomes. The model inputs include maps of land use and parcel boundaries, data on farm inputs, outputs, prices, overhead costs and externalities.

The Rural Futures MAS Model has been developed by AgResearch and NZIER as part of the Rural Futures Innovation Platform. It was designed to engage rural stakeholders with the issues affecting their communities (including irrigation, nutrient leaching) and possible approaches to addressing these (including regulatory responses). The model is intended to be customized for each region where it is used in order to focus on the issues of interest. The Rural Futures MAS Model has been used in Hawke's Bay, Taupo and Southland. (Schilling et al., 2012; NZIER, 2013).

Rural Futures MAS Model addresses questions such as:

- How might individual farmers respond to nutrient leaching and irrigation issues affecting their communities?
- How do these responses vary between individuals and over time?

Waikato Multiple Agent Model

The Waikato Multiple Agent Model is a regional model for considering the impact of policy design on the dairy industry. It considers only dairy farms, but allows the farms to vary according to their own unique characteristics. The model inputs include farm area, milk production, stocking rate, distance from waterways and soil types. Model outputs include grazing rotation across the year, feed allocation and sources (pasture, silages, concentrates, and crops), herd size and structure, fertiliser use and abatement practices.

The Waikato Multiple Agent Model was developed solely to inform the design of nitrate policy. It has been used to investigate the use of uniform reductions and the trading of entitlements for restrictions levied at stocking rate, nitrogen fertiliser, and nitrogen leaching. The model has been used exclusively in the Waipa, Otorohanga and South Waikato areas (Doole, 2010; Doole et al., 2011; Doole, 2012; Doole and Pannell, 2012; Doole et al., 2012).

Waikato Multiple Agent Model addresses questions such as:

- How do different regulations designed to reduce nitrogen loss impact land use and land-use intensity?
- How might dairy farms change management practices in response to different regulations?

WISE

WISE (Waikato Integrated Scenario Explorer) is an integrated model that links land use, demography, economics, climate, hydrology, water quality and biodiversity. We focus on its land-use sub-model. The WISE land-use sub-model considers changes among 25 different categories of land use including dairy, dry stock, forestry, indigenous vegetation, horticulture, commercial, manufacturing and three types of residential use. Land-use change is determined based on transition potentials calculated from four factors: 1) the suitability of the land, 2) land uses on neighbouring land, 3) ease-of-access, and 4) zoning restrictions.

WISE determines land-use change by allocating land to the locations with the highest transition potential according to an externally provided demand. In WISE the external demand for land is provided by the economic sub-model.

WISE produces annual maps of land use along with indicators of the potential for each piece of land to change use. The sub-model inputs include maps of current land use, accessibility, zoning and other land-use restrictions, and the suitability of land for different uses in addition to industry and residential demands for land.

WISE was developed to support and facilitate long-run integrated planning by the Waikato Regional Council. The land-use sub-model is based on a model originally developed by (White and Engelen, 1997) and implemented by the Research Institute for Knowledge Systems (RIKS) in the Netherlands. WISE has been used exclusively in the Waikato region for which it was designed. Similar land-use models are currently under development for use in Auckland and Wellington regions. (Rutledge et al., 2011).

WISE addresses questions such as:

- How might land use in the Waikato region evolve under different climate, policy, price or demographic scenarios?
- How could the Waikato Regional Council respond to potential changes in land use and water quality?

7. Why are there different models?

The range of models used in New Zealand are in response to the range of questions that models are expected to answer, and the range of contexts in which models are used. This helps ensure that the model process and results are relevant to the end users of each specific model.

The variety of available models also represents a range of different modelling approaches. Given that land use and land-use change decisions are not well understood, a range of alternative approaches to modelling them have been developed. Models like ARLUNZ and the Rural Futures MAS Model attempt to model the learning and expand on the assumption of profit seeking behaviour of individual farmers. Models like WISE acknowledge that identifying the land that will change use is impossible, but identifying land that is more or less likely to change use is possible. These models update the probabilities of land changing uses according to observed prices or pressures and then use random numbers to simulate which land changes. Models like LURNZ and PSRM assume that land-use decisions are determined, in some way, by economic variables (such as commodity prices and interest rates). These models identify statistical relationships in historical data between land-use shares and economic variables to capture land owners' aggregate decision making. They can then use predictions of future economic variables with these relationships to predict future land use.

Different models are calibrated for different locations. This can be seen with the Rural Futures MAS Model and NZ-FARM: Both models have been customized for the catchments in which they have previously been used. Calibrating each model enables it to reflect the specific details of the location where it is used. For example: the climate of the catchment, the land uses that are feasible in the catchment, whether and how the catchment is irrigated.

Different models are required to answer different questions. For example: ARLUNZ and LUMASS both estimate land use according to some optimization process. However, the focus of ARLUNZ is how farmers respond differently to regulation over time and the decisions they make on their own land, while LUMASS determines the distribution of land use over the entire catchment that attains multiple objectives. It follows that ARLUNZ can answer questions as to how land use changes in response to land owners' management decisions, and LUMASS can answer questions as to what distribution of land uses might be ideal.

Models are designed as tools. When making use of a model, it is important to ensure that it is 'fit for purpose'. Each model can answer a range of questions (between some models, these ranges overlap) and should be used only for those questions that it can answer.

Different models are required to work at different levels of detail and scope. These details may be spatial or temporal in scale. With respect to spatial scope consider LURNZ and WISE: While WISE is focused on a single region and LURNZ considers land use across the entire country. With respect to temporal scope consider ARLUNZ and NZ-FARM: While ARLUNZ considers land-use change on an annual basis, NZ-FARM estimates only the long run distribution of land uses (the outcome in some future year once all land owners have adjusted to the new modelled environment).

It is important to recognize that models with less detail or a smaller scope are not inferior to models with more detail or a broader scope. There are tradeoffs between resolution, scope, data requirements, and computer processing time. For example, models with finer resolutions and models with broader scopes (area or length of time covered) require more data and computer processing time. To reduce the cost of collecting data and to provide timely results, scientists tend to limit the resolution or scope of their models. Furthermore, providing results at a coarser spatial or temporal resolution is appropriate where the available scientific knowledge and data does not enable scientists to be confident providing a finer resolution. This represents good scientific practice.

For some applications, complex and detailed models are necessary as they allow for dynamic responses that vary among decision makers. For other applications, less complex models are preferred as their simplicity makes it easier to determine how their results are being generated.

The variety of available models should be viewed as a strength of the research community. Given the complexity of land-use decisions, different models and modelling approaches can be desirable. If each model captures some of the underlying complexity, then together different land-use models will provide a more complete understanding of land use, land-use intensity and land-use change decisions.

The different models represent different areas of ongoing research into land use and these different areas feed back into each other. So insights and knowledge generated from one model in one context, inform the research and design of future models in many other contexts. For example, land-use suitability indicators constructed for LURNZ have been provided to Landcare for comparison against LUMASS.

The existence of a range of catchment scale land-use models does not necessarily indicate competition between the designers of these models. The land-use modelling community in New Zealand has fostered a collaborative culture. Competition arises almost exclusively from the funding process for science.

This encourages scientists to compete against consultants and against each other, and has raised concerns that policy makers and industry could use the funding process to discourage models that produce results that do not support their agendas. This would slow the critique and development of models, and would diminish the value of land-use modelling.

Given the range of available models, it can be difficult for policy makers, industry and community stakeholders to select the appropriate model to answer their questions. It is often preferable to choose a model based on where it has been previously used in order to minimize setup and calibration costs rather than to investigate whether there are alternative models available. There is an open question as to how best to communicate to decision makers which models are available and suitable for their needs.

8. Conclusion

This report has discussed the use of models for understanding land-use change. The practice of modelling is well established among scientists as it provides an effective way to think about and understand complex social and economic phenomena. Models provide structure to guide new research by combining existing knowledge and identifying areas where new knowledge is needed.

Land-use models are used by government (local and national), industry and community stakeholders to make informed decisions. Land-use models are used to quantify the consequences of a particular course of action, to explore alternative courses of action, and to anticipate and respond to issues that may arise in the future.

Models are developed, used and refined in the context of a wider scientific community. This community should both inform the design of models and test the validity of their results. This is an integral part of the accepted processes by which scientific understanding improves.

In this context, the range of models that are used is a strength of the scientific community. Results from separate models are compared against each other to identify strengths and areas for improvement in the models. The use of different models for different contexts, questions and data helps ensure that the model results are relevant to the end users of their results.

There is always a challenge when communicating scientific results to stakeholders outside the scientific community. The scientist is aware of the knowledge and the process of peer review that has informed the model, while the stakeholder is aware only that the conclusions have been generated according to a model. The challenge to scientists is to communicate not just the results of their model, but also to provide stakeholders with a glimpse into the science behind the model as part of emphasizing the credibility of this work. The challenge to stakeholders is to ask for this understanding of how the model has been developed, and to understand the definitions and concepts used by the scientist in order to interpret results appropriately and understand the implications of their limitations.

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