Modelling tools for integrated, adaptive management: a case study of New Zealand Regional Authorities

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Executive Summary

This report looks at some of the integrated computer-based modelling tools available for use by regional level government in New Zealand. These types of modelling tools have the scope to assist end-users by providing the adaptive capacity essential to accelerate the transition toward sustainability.

An assessment of eight different modelling tools gives an insight into their use by Regional Authorities (RAs) in New Zealand. As it was of interest to the researchers, the models were evaluated for their degree of integration, spatial capability, and whether they were static or dynamic. It is acknowledged that when making decisions on model use a number of additional criteria need to be considered such as: fitness for purpose, the outputs provided, input data requirements, compatibility with other tools/models, reliability and transparency, user-friendliness, time required for implementation, and times and monetary cost. This study is regarded as a starting point towards a better understanding of the integrated modelling frameworks available for use in planning and further work is anticipated.[1]

The eight tools covered in this report are: Geographic Information Systems (GIS), Mediated Modelling (MM), Spatially Dynamic Systems Support Modelling (SDSS), Computable General Equilibrium Modelling (CGE), Multi-Criteria Analysis (MCA), Agent-Based Modelling (ABM), Input-Output Modelling (IO), and Bayesian Belief Networks (BBN). These models are assessed according to the degree to which they are integrated, dynamic and spatial. These techniques can be used together assimilating data to populate specific models in order to emphasize different aspects of the questions that each model aims to answer.

Responses to a survey undertaken on current model use by RAs indicate they predominantly utilize externally provided models. These models are generally issue specific and in most cases produce a decision-making recommendation. While current model use is issue-based the need for more integrated modelling tools with the capability of demonstrating spatial and temporal change was recognized as important. The three most common barriers to the use of this type of model are: 1) an inability to assess if and how the model adds value; 2) monetary cost; 3) time cost.

A theoretical foundation to develop the methodology and tools to build adaptive capacity among stakeholders and decision-makers is provided by the Multi-scale Integrated Modelling for Sustainable Adaptive Systems (MIMSAS) (van den Belt, 2009).

[1] As this report goes to print, a proposal has been submitted to Envirolink for funding to build a web-based directory of models and Decision Support Systems to provide practical, policy-relevant examples and case studies of actual use.

CONTENTS

1. Introduction

This report starts by outlining why integrated decision-making is important in a planning context and the short-fall of expertise and tools to support integrated decision-making at the regional scale in New Zealand. The next section of the report provides an overview of the type of integrated modelling capacity available for use at Regional Authority[2] level in New Zealand. The results of a survey undertaken to get information and a base line on model use by RAs in New Zealand are then provided. The final section provides a framework for the development of integrated assessment tools for use in decision-making.

2. The development of integrated decision-making tools for use at regional scale in New Zealand

Decision-making for sustainable development requires the integration and building of the four capitals — social capital, human/cultural capital, natural capital, and built capital. Socio-economic and ecological systems are sensitive to issues of scale; add the human factor of governance (fairness of distribution and efficient allocation) and it becomes clear that humanity is facing a daunting task to curb current undesirable trends and create a more sustainable and desirable future. To address sustainability issues councils need tools that can help them better understand the complex systems in which they operate. "Sustainability presents an unstructured or 'wicked' problem characterized by: (1) multiple actors with differing, legitimate values and opinions; (2) high uncertainty; (3) aspects of irreversibility; (4) no clear solutions; (5) being fraught with contradictions; and (6) being persistent and unsolvable" (Huser *et al*., 2009, p. 2371).

Often, when one problem is addressed in isolation another problem arises, especially when a more overarching, integrated approach is lacking (Sterman, 2002). The current development of 'how to use models' is shifting from individual modelling techniques toward finding the synergies between modelling techniques and combining them, to solve real world problems (Smajgl *et al*., 2009).

Integrated Assessment (IA) allows councils to consider the 4 well-beings (social, cultural, economic and environmental) simultaneously using both, or either, quantitative or qualitative measures. Adaptive Management (AM) provides an evaluation mechanism to facilitate continuous response to change to gain improvement. Together, IA and AM provide a means for councils to move from issue-driven research toward having a clearer overview of the sustainable and desirable outcomes they would like to achieve and simultaneously evaluate the different pathways for getting there. Some

[2] Regional Authorities (RAs) as referred to in this paper include both Regional Councils and Unitary Authorities that combine Regional Council responsibilities with Territorial Authority responsibilities.

(not all) research questions then become anticipatory to policy and planning cycles and emphasize synthesis over analysis. Modelling provides a visualization (often involving much data) of the simulated pathways that, with a time lag, can be compared with monitored data, acknowledging that mandatory planning cycles already are iterative. Using an AM framework provides an opportunity to reflect on what we thought was going to happen or what we would have liked to have happen and compare this with current reality.

RAs are the level of government in New Zealand responsible for the integrated management of natural and physical resources. Included in RA statutory duties (as well as others not listed) are soil conservation, maintenance of water quality in water bodies and coastal water, avoidance or mitigation of natural hazards, pollution control, and water quantity management. These functions need to be achieved while taking into account the need for people and communities to provide for their social, economic and cultural well-being and for their health and safety Resource Management Act 1991, Part II.

The extent to which modelling techniques are used by RAs in New Zealand is not readily apparent. Relationships between councils on the one hand and universities, Crown Research Institutions (CRIs), and consulting firms on the other tend to be private. Many models and tools are proprietary and wide dissemination is fraught with intellectual property issues. While the outcome results from running a model are often made available, models and data used are less frequently made available.

Computer-based simulation models and similar technical tools are expensive and, as a rule, only a few of the larger RAs have a ‘core set of models’ to draw on to help them make informed decisions, e.g., Auckland Council (AC) has the ASP (Auckland Strategic Planning model) and the ART (Auckland Regional Transport model), which they combine to form the ‘Delta’ Model. Other RAs contract out their strategic planning modelling tasks to providers including CRIs, universities, and, mostly, consultancies, that develop, modify or use existing proprietary models they have developed to address specific issues. Alternatively, integrated modelling is not used at all, and complex decisions are made with the use of softer forms of human capital, such as ‘experience’, ‘intuition’, and ‘political nous’.

Lack of developed, in-house, integrated modelling capacity can be explained to a certain extent by the prevalent science-policy interface at government level in New Zealand.

Science-Policy Interface in New Zealand

In 2002, the Parliamentary Commissioner for the Environment (PCE) asserted that one of the greatest impediments to implementing sustainable development was “a lack of accessible information and a gap in terms of translating information that does exist into material that can be used by the community to facilitate debate and understanding”

(PCE, 2002, p. 8). This acknowledges the inability to integrate existent knowledge, and the dearth of decision support tools able to be drawn on for this purpose. This is particularly acute at the local-government scale, due to the lack of resourcing and capacity for incorporating science. A 2009 Ministry of Research, Science and Technology (MoRST) review found local government organisations did not know what research opportunities existed to help decision-making, or coordinate research sharing across local and/or central government departments. In addition, local government felt that research organisations did not understand their research requirements, and therefore research outcomes provided by research organisations were undervalued or not sufficiently targeted to meet local government needs (MoRST, 2009).

Since the restructuring of the mid-1980s, government agencies have progressively relinquished their in-house scientific capacity and either relied on Crown Research Institutions or contracted out to private companies for the provision of their science. RAs are a major user of environmental science in New Zealand and represent one of the few branches of the public sector with some form of in-house science capacity, though most authorities feel they lack adequate information to manage their region effectively (Bremer, 2009). Research has found most RAs purchase 40–50% of their science requirements (MoRST, 2004; Bremer, 2009). In 2004, owing mainly to variable rating and asset bases across the regions, only three RAs had significant in-house capacity and a good 'engagement' with the scientific system, with variable capacity across the other 13 Councils (MoRST, 2004). Central government's contestable 'public good funding' does not extend to the operational research of local government. Smaller RAs have access to the Envirolink fund, which the Foundation for Research, Science and Technology (FRST) fund up to $800,000. This fund, launched in December 2005, allows these councils to interact with the country's top Crown Research Institutes and other research providers and is a mechanism to direct science where it is needed. Since Envirolink was established more than 730 science advice projects have been funded across a range of areas such as freshwater, air quality, marine biodiversity, and natural hazards management.

Three main types of policy-relevant science are utilised by RAs: (i) resource consent science; (ii) State of the Environment science; and (iii) issue-based science (Bremer, 2009). Resource consent science is supplied by the applicant as part of consent process to use or develop a resource. The information provided needs to be sufficient to allow a RA to undertake an Assessment of Environmental Effects. The other two forms are collected or commissioned by the authorities themselves. State of the Environment reporting represents the ongoing collection and monitoring of data on a selection of critical environmental indicators, and is generally done in-house. However, up until late 2007 there was no standardised set of indicators, meaning much state-of-the-environment data is piecemeal and short-term. Issue-based science includes those scientific reports commissioned on a 'one-off' basis to inform decision-making on a specific issue or policy instrument, as it becomes politically expedient. Issue-based scientific reports usually represent the 50% of science that is commissioned from external providers given its specialised nature, and includes models (Bremer, 2009). Of the three forms, recent research found nine out of 16 RAs placed most value on issue-based science for informing policy and political mechanisms (Bremer, 2009).

Lack of Integrated Modelling

In 1999 the State Services Commission (as cited in PCE, 2003, p. 58) found that across New Zealand's public sector, "Information is typically generated in departmental silos as there are few incentives to share information and resources." A recent review of RA coastal management found only six of the 16 authorities used any form of interdisciplinary approach, with these few examples exhibiting differing degrees of sophistication (Bremer, 2009). This represents a reluctance and/or inability to cross (a) disciplinary boundaries, (b) jurisdictional boundaries and (c) the science-policy boundary. Beyond the limitations imposed by funding, there is also a lack of time, experience and willingness from individuals in both the policy and scientific fields to explore the other's terrain and bridge the boundary between the two (PCE, 2004). The past decade has brought improvements from the situation identified in 1999 as, by 2007, the PCE reported, "it appears that relationships between policy makers and science providers are becoming more robust, strategic and long term… However, the competitive model, along with capacity and resourcing issues, continues to restrict this" (p. 29). At this time new developments in integrated modelling started getting off the ground, such as the Environment Waikato led 'Creating Future project' (www.creatingfutures.org.nz) funded by the Foundation for Research, Science and Technology.

The MoRST Environmental Research Roadmap released in 2007 promoted the need for AM, predictive forecasting, and enhanced communication tools for advising decision-makers (MoRST, 2007). Scientists have responded by providing a variety of modelling tools. Focus has been on integration as this enables the replication of the real world as a complex system rather than just a number of individual components. The interlinkages and feedbacks built into models enable the impact of a policy to be measured not just for the sector at which it is aimed but also for the other sectors that are part of the system. Integrated computer modelling enables far more variables to be taken into account than is possible otherwise. "The choice for dynamic modelling has been made because important driving forces and processes change over time, and actions and developments that have taken place are very often not reversible, indicating a path-dependency of developments" (van Delden, 2009, pp. 2458–2459).

Lack of integration of the different outcomes makes it difficult to establish any kind of causality between policy measures and sustainable development 'on-the-ground'. Integrated models can be effectively used to analyse the impacts of a number of policy options such as reforestation, zoning regulations, infrastructure investment, restrictions on water extraction, and water pricing (van Delden, 2009). The outcome of the models is not to achieve an optimisation, as in reality influences change and AM needs to be incorporated to allow for this. Instead the aim is to explore the potential outcomes of decisions made now into the future so that linkages and revealed feed-back loops are understood and planned for. Modelling tools can help with integrated long-term planning by evaluating different drivers of change or different policies or strategies and answering what-if type questions (van den Belt, 2004; Huser *et al.*, 2009).

3. Integrated modelling capacity available for use by Regional Authorities

In this section we define the terms 'model' and 'systems thinking' and 'spatial explicitness' and position the models we are interested in on a continuum to indicate their integrative capacity. A brief description and example/s of use are then given for each of the following model types: Geographic Information Systems (GIS), Mediated Modelling (MM), Spatially Dynamic Systems Support Modelling (SDSS), Computable General Equilibrium Modelling (CGE), Multi-Criteria Analysis (MCA), Agent-Based Modelling (ABM), Input-Output Modelling (IO), and Bayesian Belief Networks (BBN). A brief summary of the various model characteristics is then provided.

Models are defined as abstracts of reality that allow us to expand the boundaries of our mental capacity and lengthen time-frames so that we can see patterns of behaviour, linkages, and feedback loops. Models therefore provide a tool to assist us to abstract from detail and concentrate on the larger picture and the inter-linkages. Because they are simplifications of the real world all models are wrong (Sterman, 2002), but they can play an important role in expanding the boundaries of our mental models to cross, among others, disciplinary, management, temporal, cultural and social boundaries. Regardless of whether we are conscious of it, everybody 'models' in daily life; without the capacity to 'model' people would be unable to deal with information overload. As discussed earlier, modelling capacity without computer assistance is expressed in experience and gut-feel and is extensively used in planning. However, as problems grow in complexity such decision-making becomes less dependable. Research indicates human rationality is limited or bounded, which can lead to persistent judgmental biases and errors (van den Belt, 2004). Personal positions are often static and defended on the basis of convictions and perceptions, and people select information that reinforces their initial position (Bakken *et al.*, 1994). The human mind favours linear trajectories rather than anticipates the time lags and feedback loops that occur in reality, which is where computer modelling can assist and support some rigor in thinking.

Integration promotes systems thinking (ST), which is the art of identifying and interconnecting the crucial elements of a system in a qualitative manner through causal loop diagrams (Checkland, 1981). One characteristic of ST is 'interrelatedness' within and among systems, also called 'mutualism'. Each part of a system may have its own characteristics and behaviour, but when interconnected the parts exceed the sum of the individual parts and form a system with its own behaviour. Another characteristic of a system is that any one part cannot be removed without affecting the behaviour of the system. The time span of interest is such that patterns, and the structure causing them, have a chance to emerge. ST requires that situations be explored from a long-term perspective for a particular system, with an eye to 'unintended consequences' beyond 'quick fixes' through causal feedback loops and time lags. ST is used to develop a qualitative representation of a dynamically changing situation.

In this report, we are specifically interested in computer-based simulation models and the degree to which they are integrative. Even though somewhat arbitrary, the continuum shown in Figure 1 presents a consensus among the authors of this report on the extent to which the current 'state of the art' modelling tool named can be regarded as integrative of the four well-beings. All models have the potential to be more integrative; it is a matter of tradeoffs in resources regarding precision, accuracy, time commitment and funding.

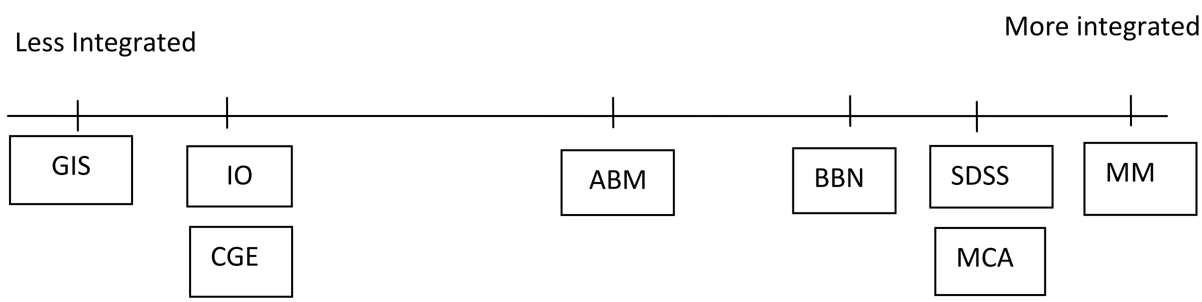

Figure 1: Continuum indicating degree of integration of models as typically used.

A brief description is presented next for each of the modelling tools on the continuum.

Geographic Information Systems Modelling (GIS)

GIS modelling presents data in map form as well as providing a tool for map-based queries and analyses. Geographic information is stored as a collection of layers and other elements in a map view. Numerical data layers can describe aspects such as climate, landforms, income levels, soils, asset and business locations, and so on.

By combining geographic data from a wide range of sources, managers can quickly assemble custom maps to expedite a range of management activities. This process of creating new GIS outputs from existing data is referred to as modelling. Such modelling converts existing datasets into new datasets by applying analytical functions. This combination of data can create a model output that helps answer questions posed with spatial relevance. Typically, this is not modelling in terms of integrated simulation modelling, though this is possible. GIS data presentation is of considerable value when spatial and visual representation is important.

Application: There is extensive use of GIS modelling by local government in New Zealand. The location of infrastructure, land-use and biophysical characteristics are recorded as GIS layers by most councils. These are regularly superimposed to answer queries on subdivision, location of sewage, water power cables and roading networks, for example. RAs also use predictive spatial models for issue-based purposes, for example, freshwater biology. These types of models provide information non-specialist staff need to process consent applications. Models such as “point click fish” enable staff to go to a map point and get predictions on the likely probability of finding fish species located there and then access information on the sort of habitat and biological requirements needed (Joy & Death 2004a, 2004b). More integrated bioassessment models developed from and linked to GIS, such as the fish index of biotic integrity are also in use (Joy, 2004, 2005).

Mediated Modelling (MM)

Since Meadows and Robinson, (1985) made a strong argument for model building in social decision-making, advances in computing capabilities have opened possibilities for facilitated, computer-assisted processes in group settings. MM is one such participatory approach and uses computer modelling as a consensus building tool. There are a host of names[3] for similar approaches that have developed in isolation of each other. A generic MM process involves:

(1) A preparation phase to establish whether MM is the correct tool to be used for the issue of concern, to identify and select between 10 to 30 representative stakeholders, and to set the general context for a MM process. Appropriate buy-in from stakeholders at the start is crucial, as MM is model building with (instead of for) stakeholders.

(2) A series of workshops, during which a qualitative model structure progresses towards a simulation model. This requires the interactive involvement of the stakeholders. The dialogue among the participants is simultaneously interpreted and reflected onto a projected computer screen. The evolving model and simulation of ‘what-if’ scenarios supports the stakeholder group while it decides on an action plan to implement shared findings developed in the workshops. This process requires about 30 to 50 workshop hours, spread over a period of time that can vary from 1 month (e.g., van den Belt *et al.*, 1998) to 5 years (e.g., van den Belt *et al.*, 2006).

(3) A follow-up phase may include a report, publications, public outreach or re-visiting the model after a period of implementation. This is a way to add to long-term AM capacity building (van den Belt, 2009).

Mediated Models tend to be spatially homogeneous and focus on high level integration of (measured or perceived) trends in socio-economic and ecological dimensions. This

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[3] These include: Mediated Modelling, Anticipatory Modelling, Collaborative Modelling, Cooperative Modelling, Participative or Group Model Building, Strategic Forum, Participatory Modelling, Participatory Scoping Modelling, Scoping Modelling and Companion Modelling.

allows for the inclusion of a broad range of perceived relevant trends rather than a focus on detailed but less available sets of data. MM supports the 'scoping' phase in an IA. The 'trust' in the resulting models is based on the collaborative learning and the transparency of the model. By the end of the process several of the end-users will have the ability to update the model and adapt it with newly gained information, which provides extended shelf-life and added value from this type of computer-based simulation model. A literature review of opportunities and barriers to the use of MM in the public sector is provided by van den Belt *et al.*, (2009).

Application: The Mediated modelling component of the Sustainable Pathways 2 (MAUX0906) project provides a process for multiple stakeholders to combine their expertise and experience to inform the development of the SDSS models being constructed for Auckland and Wellington regions. The mediated modelling scoping stage is planned to enhance the systems integration.

Mediated modelling is being implemented to bring diverse stakeholders together to generate an Action Plan to develop the adaptive capacity in resolving water quality issues for the Manawatu River as part of the Integrated Freshwater Solutions project (MAUX1002). A similar approach is underway for an ecosystem service restoration project Manaaki Taha Moana (MAUX0907), which uses MM to work with stakeholders to better understand the important drivers that will enable effective restoration activities of the Tauranga Harbour.

Spatially Dynamic Support Systems (SDSS)

SDSS have their roots in Geographical Information Systems (GIS). Emerging from geocomputing and the modelling of spatial processes (White & Engelen, 2000), they apply a variety of techniques including systems dynamics, multi-agent systems, and cellular automata to simulate the dynamics of land-use change at various spatial scales. The desire for such modelling has been driven by the need to balance environmental, social, and economic consideration in decision-making processes. Because of the complexities and enormous volumes of data required, the development of SDSS models is still very much in its infancy.

Application: The Creating Futures Project, led by Environment Waikato, is currently the only SDSS available for use in the New Zealand context. In this project existing dynamic models used by Environment Waikato (covering population, economics, land use, hydrology, biodiversity and climate change) have been integrated using the Research Institute of Knowledge Systems Geonamica® modelling platform.[4] The Creating Futures model is driven by a combination of macro-scale exogenous scenario inputs, and internal endogenous dynamics, relating to demography, economy and environment under various policy options that ultimately provide demand for various potential land-use classes. Once this macro-level demand for land has been

[4] See www.riks.nl

determined, a dynamic spatial interaction model based on a cellular automata algorithm is used to allocate land use by 200m x 20m cells across the region. In turn, information on conditions at the cellular level, such as the quantity and quality of land available to various activities and actual densities at the cellular scale, are returned to the regional macro-scale models to modify parameter values for the next time iteration. The Creating Futures SDSS has the temporal resolution of one year for all incorporated models and its horizon is set at 2050. Ecological Economics Research New Zealand (EERNZ), in collaboration with Market Economics Limited (MEL), are working on the Sustainable Pathways 2 programme to develop SDSS for Auckland and Wellington.

Computable General Equilibrium (CGE)

CGE models have become invaluable tools for analysing economic impacts of environmental policies and indeed, environmental impacts of economic policies. CGE models provide a comprehensive and detailed description of an economy that is based on microeconomic foundations and is consistent with key macroeconomic balances and principles. They may readily be extended to model resource use, emissions and other environmental pressures that are directly associated with production or consumption activities. Environmental CGE models can be used to model quantity and price-based instruments (e.g., technology or emissions standards, emissions taxes or cap-and-trade schemes) and to assess the efficiency and cost-effectiveness of environmental policies. Although CGE models most often take national economies as the unit of analysis, they are increasingly being developed for individual and multiple regions within national economies. Consequently, CGE modelling may usefully be applied to a wider range of issues. In recent years, water quantity and quality issues have been a focus of many studies (e.g., Smajgl, 2006; Seung, 2000; Dixon, 2005; Decalauwe, 1997).

Application: In New Zealand CGE modelling has been used at the national level extensively but has been slow to be taken up at the local level. The New Zealand Institute of Economic Research used CGE to assess the impact of a natural disaster on the Thames-Coromandel District (Walton *et al.*, 2004). CGE modelling is also being developed to inform regional water resource policies in Canterbury (Lennox & Diukanova, 2010), and urban infrastructure decisions in the Auckland region (Yeoman *et al.*, 2009).

A joint University of Waikato/BERL model has been constructed to assess international immigration effects on the national and regional economies (see Poot & Cochrane, 2004).

Efforts to develop multi-regional CGE models for the whole of New Zealand are also underway through Victoria University. The objective is to build a comprehensive multi-regional CGE model to facilitate the examination of economic issues and interdependences at the regional level (Robson, 2009).

Multi-Criteria Analysis (MCA)

Multi-Criteria Analysis (MCA) techniques can be used to support choices within a set of defined options, particularly when decision-makers are concerned with multiple dimensions of performance not directly commensurable. Using a spreadsheet, each decision-maker assigns weights to each of the criteria, the options are scored against the criteria, and a ranking of options is produced. In its original forms, MCA may be seen simply as a technocratic tool that is useful for structuring decision-problems and bringing transparency to the decision process. More recently, researchers have been concerned with the use of MCA techniques where there are multiple decision-makers with different values, and where uncertain and/or subjective aspects of performance are important. A prominent example is Deliberative Multi-Criteria Evaluation (DMCE) (Proctor & Dreschler, 2006), which combines MCA with the deliberative Citizens' Jury process. DMCE allows for structuring the decision-making process and facilitates interaction and deliberation amongst decision-makers. While DMCE makes use of the weighting, scoring and ranking techniques common to all MCA processes, it emphasizes increasing understanding of the issues, trade-offs and participants' points-of-view rather than simply the selection of a preferred option.

Application: In New Zealand, aspects of the DMCE process have been applied as part of a stakeholder consultation process over a proposed water storage and irrigation scheme in North Canterbury. MCA approaches have been used within a wider process of developing a regional water management strategy for Canterbury (Lennox *et al.*, 2010).

Agent-Based Modelling (ABM)

ABM reflects the likely or expected behaviour of various agents or stakeholders in a system. ABM is often spatially explicit and can be used in conjunction with role-play situations to test a model interactively in a real life context. ABM is widely used internationally in Land Use—Land Change (LULC) studies (Parker *et al.*, 2003), most notably by the Global Land Project.[5] Agents can be created in models as software entities with at least the following basic properties: autonomous behaviour; ability to sense their environment; ability to act upon their environment; and rationality (Woolridge & Jennings, 1995). ABM (also known as multi-agent simulation) is a dynamic simulation technique detailing individual agents and their interactions with each other and their environment. LULC ABM provides us with a tool that recognises diversity in decision-making and diversity in evaluating land-use options. Its main function is therefore to represent collective effects of actions taken by individual decision-makers with distinct individual sets of values, and customise evaluation criteria for land-use options to represent tradeoffs visually (Gimblet, 2005; Heckbert & Smajgl, 2005; Bolte *et al.*, 2006). LULC ABM can be used to give us a better understanding of how various land-based sectors and sets of individuals within these sectors are likely to react to various

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[5] http://www.globallandproject.org/

policy scenarios and potential policy implementation pathways, and also provide additional insight on rural landowner values and perceptions. Complexity in agent's behaviour varies considerably. For example, it can be defined by simple heuristics (Guzy *et al.*, 2008) or by complex cognitive processes based on psychological theory, such as the *consumat* approach proposed by Jager *et al.*, (2000).

Application: In 2009, Landcare Research developed two ABM models: for the 'Integrated Catchment Management' programme to articulate impacts of landscape change in Maori cultural values; and for the 'Iwi Futures' programme to explore land-use development options for Maori land owners. Landcare Research and AgResearch are developing an ABM for the 'Sustainable Land Management for Adaptation to Climate Change' programme to investigate farmer adoption of greenhouse gas mitigation policies and technology using case studies in the Manawatu and Canterbury regions.

Input-Output (IO)

Input-output analysis, developed by Wassily Leontief during the 1930s, provides a comprehensive snapshot of the structure of the inter-industry linkages in an economy. Developed nations prepare input-output tables at regular intervals. Generally speaking, an input-output table of a nation is reconcilable with its System of National Accounts (SNA). Input-output tables adopt internationally recognized systems of commodity/industry classification, which facilitates comparison across space and through time.

Input-output models divide the economy of a nation or region into economic industries (the level of disaggregation can be from 3 to 500+ industries), primary inputs (wages and salaries, imports, operating surplus, etc.) and final demands (household consumption, exports, gross fixed capital formation, etc.). Interrelationships between industries are based on purchases and sales. An input-output model may be used to trace the *direct*, *indirect* and *induced* economic impacts associated with a given change in final demand. Direct impacts refer to the flow of economic resources used by an industry to produce an output of goods and/or services, be it from a farm, factory or business service. *Indirect* impacts refer to the additional economic activity resulting from supply chain linkages with other industries. *Induced* impacts refer to the additional economic activity resulting from wages and salaries spending in those industries with direct and indirect impacts. The calculation of direct, indirect and induced impacts is typically determined through the use of input-output multipliers.

Since the 1970s input-output analysis has been the method of choice for analysing regional economic activity. Consequently, there has been a great deal of interest in methods for constructing regional input-output models. For reviews, see Round, (1983), Miller and Blair, (1985, 2009), Hewings and Jensen, (1986) and Jensen, (1990). Although input-output tables are usually presented in monetary terms, authors such as Daly, (1968), Isard, (1968), Kneese *et al*., (1970s), Leontief, (1970) and Victor, (1972a) *inter alia* have demonstrated that biophysical information on resource use and generation of residuals (i.e. waste, pollution, emissions, etc.) may also be placed in an input-output framework. More recently, analysts such as Stahmer, (1996, 1997, 1998), Gravgård, (1998) and in the New Zealand context, McDonald and Patterson, (2005), have generated Physical Input-Output Tables using mass and energy as numeraire.

Input-output tables, specifically in the form of supply-use tables, are a key ingredient in the development of Social Accounting Matrices (SAMs), which may be used to trace the distributional impacts on different groups within society associated with changes in economic activity (see, for example, Zhang *et al*., (2008)). The construction of SAMs is a necessary prerequisite for the development of Computable General Equilibrium (CGE) models.

Between late 2002 and mid-2003 Statistics New Zealand (SNZ) investigated the possibility of developing survey-based regional input-output models in New Zealand. This feasibility study assessed user requirements, reviewed existing New Zealand and international methodologies, evaluated data sources and provided recommendations for a development plan (Statistics New Zealand, 2002, 2003a, 2003b, 2003c). It was concluded that if official regional input-output tables were to be developed these would adopt the national commodity-by-industry framework, however, "limited data availability restricts any official development" (Statistics New Zealand, 2003a, p. 8).

Application: Non-survey inter-industry tables derived by mechanically reducing national level input-output coefficients to the regional level are commonly employed in the New Zealand context. This follows the predicted path of the Statistics New Zealand's, (2003a, p. 8) feasibility study that concluded that the development of regional input-output tables "would begin with a simple non-survey-based methodology and move toward more complex survey-based methods over time".

A Multi-Regional Input-Output framework has also been developed that is used by several regional councils including Auckland Regional Council (ARC, 2008, 2009) and Environment Waikato (McDonald *et al.*, 2006a). These tables have been used for studies such as assessing the economic impacts associated with major events such as the America's Cup in 1999 and 2003 and the 2011 Rugby World Cup.

McDonald and Patterson, (1995a, 1995b, 1995c) and Patterson and McDonald, (1996) have used Environmental Input Output (EIO) for a number of studies, including generating Ecological Footprints for New Zealand and all its regions. Other use of EIOs has been in assessing the tradeoffs between environment-economy under different policy options. For example, in the Waikato Region (McDonald *et al.*, 2006a; McDonald & Smith, 2008) the EIOs have been used to assess the environment-economy consequences of dairy land conversion. In the Auckland Region EIO models have been used comprehensively in the Economic Futures Project (ARC, 2008, 2009) to assess environment-economy tradeoffs under different regional growth projections including those focused on Business-As-Usual, Digital Content and Energy Efficiency scenarios. Gisborne District Council, a unitary authority with joint regional and local authority roles, has also used EIOs to assess tradeoffs under various growth pathways (Smith &

McDonald, 2008). SAMs have not been widely used in New Zealand. At the national level a quasi SAM was used to assess whether the ageing nature of New Zealand population would offset future demand by projected population growth, for various environmental resources/residuals (McDonald *et al.*, 2006b).

Non-survey development methods allow the construction of IO at various spatial scales.

Bayesian Belief Networks (BBN)

Bayesian Belief Networks (BBNs) are statistical models that calculate probabilities for use in a spatially explicit GIS environment. A BBN is a graphical structure that allows for the representation, of and reasoning about, an uncertain situation. BBNs are also known as Bayes nets or causal probabilistic networks. The nodes in a network represent a set of variables in the domain being modelled. The nodes are connected by links representing the relationship between variables. These relationships can be learned from the data if these are available or can be elicited from experts in the field. There can be many independent or predictor variables and many dependant variables. A classic example of the use of BBNs is as a diagnostic tool in medicine with the independent variables being a set of possible symptoms and the diseases as dependant variables. Thus, BBNs can answer 'how' questions by selecting a desired outcome and looking at how the independent variables are changed. 'What-if' scenarios can also be tested by changing predictor variables to states expected in the future, then observing changes in dependant variables. Any information supplied to the network will update the probabilities throughout the network immediately, and the strength of the prediction can be judged by the probability value for a given outcome. As with the connections between the variables, the probabilities can be supplied by experts (Uusitalo, 2007) or learned from the data (Cheng *et al.*, 2002), if available. Utility nodes can be added to calculate costs of different decisions. BBNs are a very flexible modelling tool with many unique features such as an ability to model multiple dependant variables, or handle missing data; they can update probabilities from only one piece of information, they can be predictive, diagnostic or classifiers, and they are intrinsically informative, given the ability to update immediately on screen when any information is provided. The ability of BBNs to model real-time, real scenarios, makes them ideal as tools for AM of environmental situations and linking directly to GIS maps allows those involved to visualise management changes immediately (Smith *et al.*, 2007).

Application: The Cawthron Institute undertook a study to address stakeholder's concerns over the effects of aquaculture developments on the Miranda Ramsar wetland in the Firth of Thames. The study involved the development of a hazard assessment, and investigating risk pathways through the use of a Bayesian network model, and a complex systems model (Gibbs, 2006).

Quinn *et al.*, (2010) have recently used BBN to work with stakeholders to identify and understand the key stresses and mitigations required to guide the management of land activities to work towards protecting and restoring water quality in the Southland, Burn Bog catchment.

Model Characteristics

All models can run different scenarios, but there is a tradeoff between the capacity for answering broad questions (where the purpose of the model is to understand an underlying system) versus narrow and specific questions (where the purpose tends to be prediction).

Figure 2 plots the previously described models on a two-dimensional graph depicting the characteristics of spatial versus non-spatial and static versus dynamic applications. This figure provides a basis for exploring synergies between the various modelling approaches. For example, MM lacks spatial explicitness, but is dynamic and inclusive from an integrative perspective and relatively easy to understand and communicate. The SDSS platform is both dynamic and spatially explicit. Other models may be spatial but are more difficult to use and update. For instance, GIS has advanced mapping capacity but requires in-house experts to maintain and run. As part of the systems dynamics MM process stakeholders learn to use and maintain the model developed themselves. For the complex SDSS models the capacity to build these still needs to be developed in New Zealand.

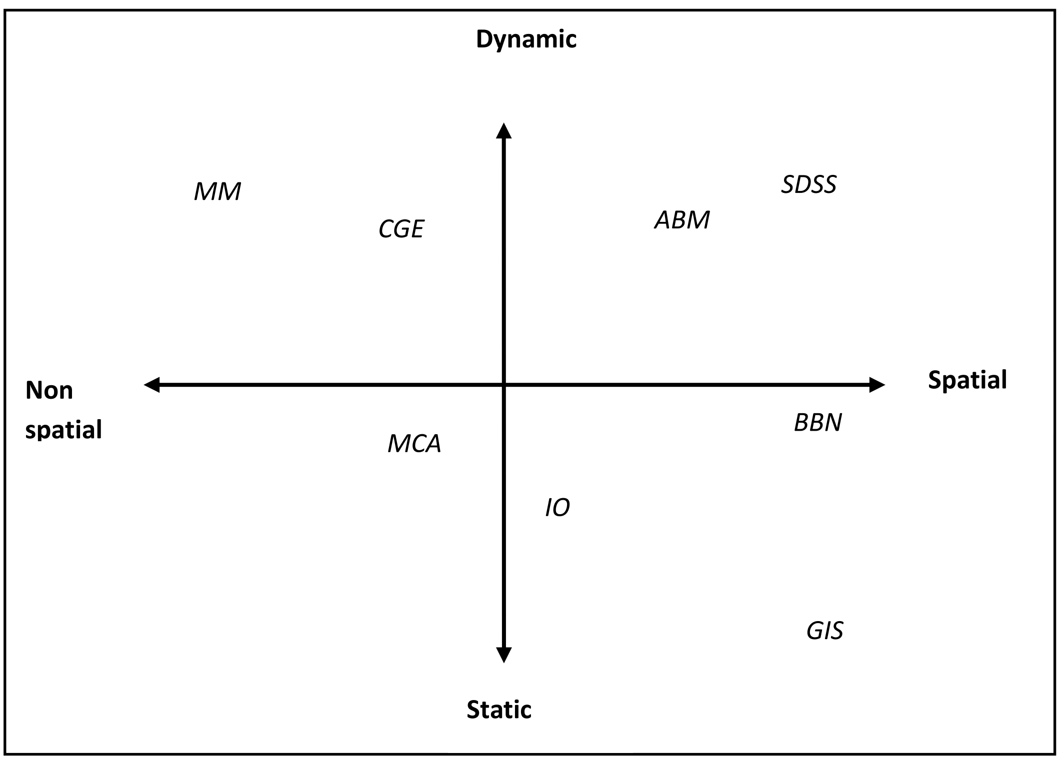

Figure 2: Two dimensional graph in terms of characteristics of spatial/non-spatial and static/dynamic.

4. Results of a survey undertaken on model use by Regional Authorities

Empirical research was undertaken as part of the Sustainable Pathways 2 (SP2) project to explore the degree to which New Zealand's 16 RAs use certain types of computer models to support strategic planning and decision-making. The research sought to establish: (1) which models are most used in RAs; (2) characteristics that are important to the councils in selecting a model; (3) the barriers the councils face in using models; (4) and finally to what degree the councils use the computer-based simulation models most central to the SP2 project. All RAs in New Zealand were surveyed by mail, phone or face-to face where practical, on the use of models within their organisation. Respondents were asked to complete the survey in consultation with other staff to add to the robustness of the results; however, in some cases the survey was completed by a single knowledgeable individual, and could potentially be biased toward their perspective. As a quasi-Likert scale was used, results are subject to the standard difficulties associated with these scales: such as whether an individual is more disposed to give high rather than more moderate scales. Largely, however, a degree of consistency was found across the authorities, lending credence to the survey outcomes.

Authorities were asked to list the computer-based models they currently use to assist decision-making. The responses indicate authorities predominantly utilise models to answer specific questions. All councils use GIS models. Other commonly used models are: (i) transport, (ii) input-output, (iii) hydrological and (iv) nutrient run-off. A number of characteristics are common across the models currently used by RAs. First, the models have a clearly demonstrable value in that they are directly linked to a specific issue providing evidential support. Second, models are generally produced externally, by consultants or crown research institutes, primarily because RAs rarely have the capacity in-house (in terms of skills or staff time) to produce such models, and potentially also to demonstrate some separation between those producing the model-based 'evidence' and the authority who makes the decision. Third, the models are constructed to use data captured for/by the model. Finally, in most cases the model produces a decision-making recommendation 'output.' Policy-makers/end-users are not expected to interact with and manipulate the model; rather they expect to turn to a summary/conclusion that will inform them of the likely outcomes of actions, which is subsequently used in mandated legislative or regulatory processes.

Linked to the discussion on models used by RAs are the preferences of authorities when deciding whether to employ a model. For this reason respondents were given a list of model characteristics and asked to rank them as 'important' or 'not important'. Responses are shown in Figure 3.

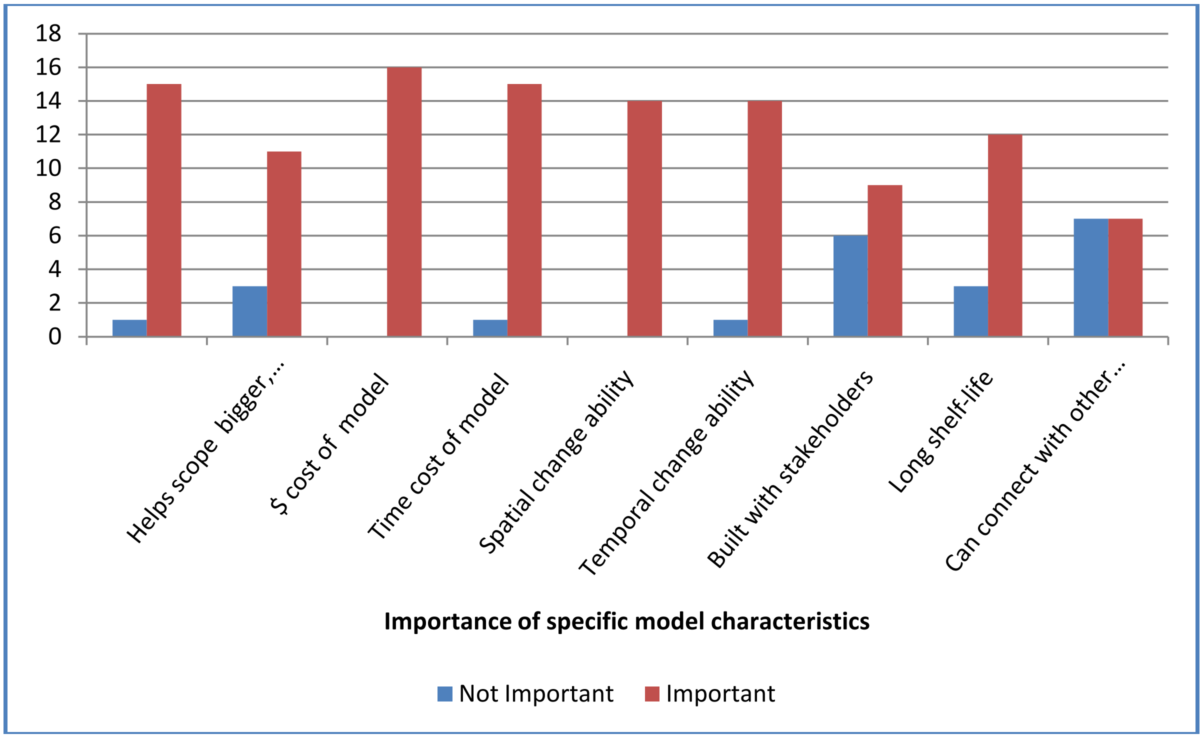

Figure 3: Importance of different model characteristics to respondents.

Respondents place considerable importance on issue-specific models, reinforcing the response already given regarding the types of models in use. Most respondents also recognised that it is important to have models that help scope the bigger strategic and integrated picture. These two preferences signal that while current practice places credence on outcomes from issue-specific models, the need for a more integrated approach is accepted. All respondents placed importance on the cost of a model (in financial terms and staff time) when selecting it. They preferred models with a long shelf-life that also relates to cost. When choosing to use a model, respondents regarded the ability to demonstrate both spatial and temporal changes as important characteristics. Nine respondents had a preference for models to be built with stakeholders, while six regarded this as unnecessary. There was no clear preference whether it was important for a model to be able to be incorporated into a broader model framework; an equal number of respondents said it was important as said it was not.

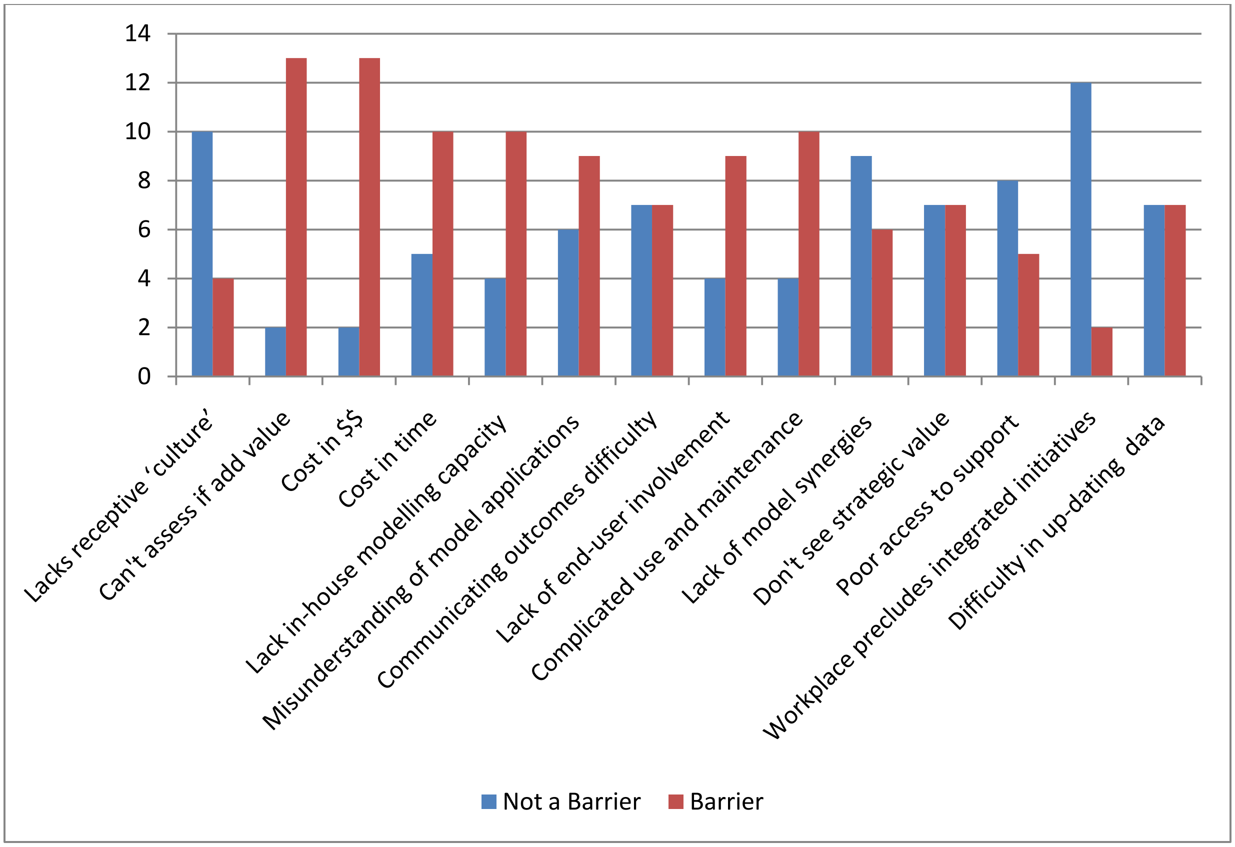

Figure 4: Factors that influence model use by RAs.

The Council respondents were provided with a list of potential barriers to model use and asked to rank these (Figure 4). The most frequently cited barriers in order of significance were:

1. Inability to assess if the model adds value. This barrier links with the current predominance of issue-specific models used by councils. Such models are designed for a specific purpose, for example, Beachwatch collates data to determine whether or not a beach should be open to the public for swimming. Their value is more easily definable than models designed for exploring the future by means of scenario modelling.

2. The cost in monetary terms. This was a major concern for councils across the user spectrum. Those that did not use models said they could not justify the expense for a small population with a low rating base, while large scale model-users were aware and concerned about the costs of model use.

3. The cost in time. Though not as much of a barrier as monetary cost, this was still a significant barrier.

4. The complicated nature and maintenance of models was seen as a barrier to use and commented on separately under ‘other’ by two respondents. Lack of follow-up and maintenance of models when new information comes in or knowledge increases as a result of running the model mean such models can quickly become ‘out-of-date’.

5. Lack of in-house capacity to work with technical models was a barrier even in councils that used models extensively.

6. Misunderstanding of the model’s application was regarded a significant barrier (though not in the very significant barrier class).

7. Lack of end-user involvement in building models. Understanding how a model works and to what applications it is suited gives end-users greater confidence in model outputs. This can best be achieved by working with end-users when the model is constructed. For large-scale integrating models that combine data from a number of sources and take into account feedback loops and lag times, this involvement from the outset is even more important.

For some of the questions there were similar numbers of respondents who regarded the issue as a barrier as did not. These included the questions on: difficulty in communicating the model outcomes; lack of clear connection with policy and management processes, i.e. the strategic value; and updating data needs. The variable capacity of RAs across New Zealand is a possible explanation for this divergence. Sound model implementation practices would help overcome difficulties in these areas. A national coordination toward making modelling applications more readily available to various RAs would help improve the dissemination and costing. This would require more transparency and emphasis on capacity building by providers of modelling capacity.

Overall, the majority of the respondents did not see lack of commitment from senior management or the current departmental structure of the organisation as factors that precluded integrated model use, though one respondent did cite ‘lack of a champion’ as a barrier. The ‘culture’ of councils is therefore less an issue than the need to know there is added value from model use. The lack of synergies between models and poor access to support were barriers to more than half the council’s though this was not uniform.

In terms of the integrated computer based simulation models described in section 3, which were of interest to the SP2 project team, the survey revealed GIS and Input-Output were used extensively, with Multi-Criteria Analysis the third most commonly used. As shown in Figure 5, with the exception of Agent-Based Modelling, respondents indicated all the model types listed in section 3 had been used by at least one RA. As part of the survey respondents were given a short description of each model and an example of its application; however, uncertainty remains as to whether these exact models were in use across all RAs, or if respondents were reporting on a similar, though different, modelling technique.

Participants were also asked which of the models from Section 3 they recognised, or were aware of. Registering that the modelling technique was in use was taken as also registering that they were aware of it. Where not used, respondents registered they either knew of the technique, or left the question blank. The responses indicated there was some knowledge of the various modelling techniques even where not actively in use.

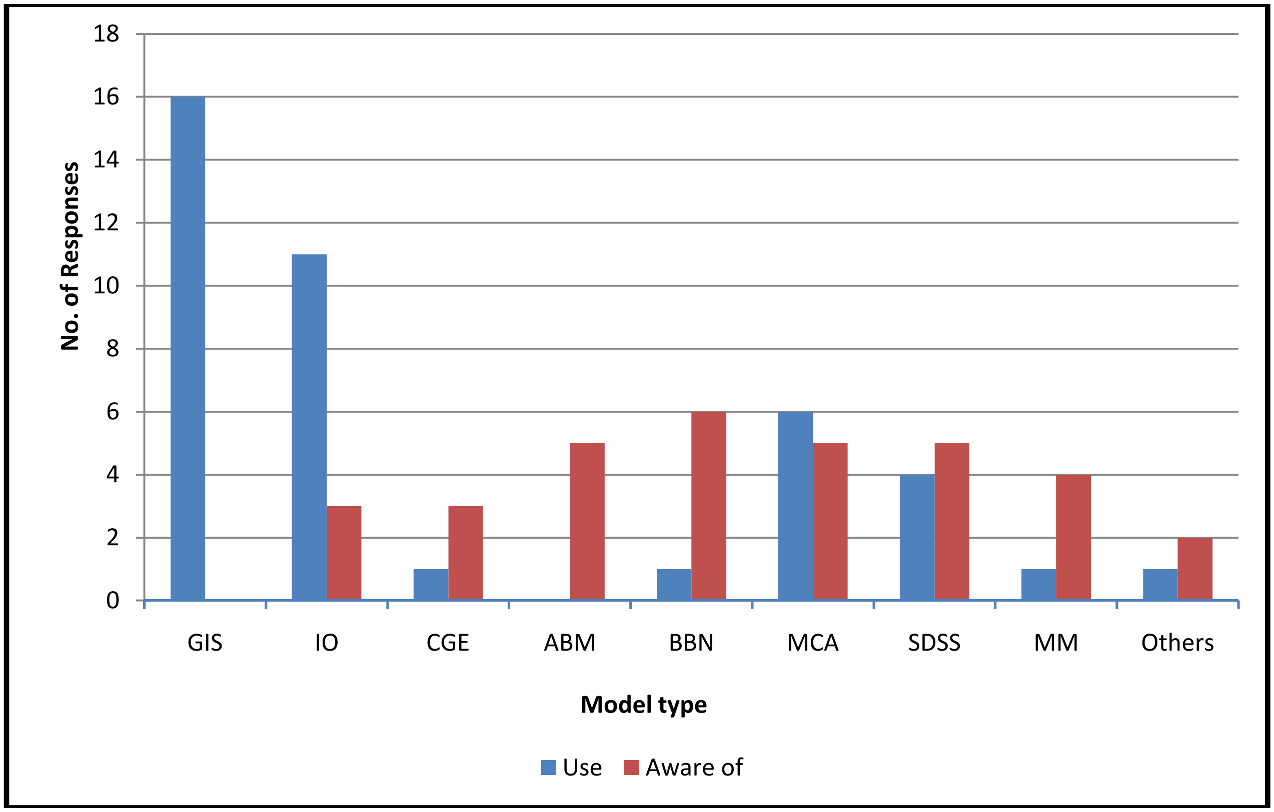

Figure 5: Use and awareness of different model types**.**

5. Use of Integrated Assessment tools in decision-making

Models are only useful to the extent they answer the questions the model sets out to answer. This tends to limit the scope of what is modelled, due to the technical complexity of models. The specific but detailed models such as CGE and IO referred to as 'research models' (Costanza & Ruth, 1998), are used frequently to answer precise issue-based questions. 'Management models' such as SDSS have broader application and are developed more to quantitatively explore a range of questions and get an understanding of how addressing one issue can impact on other areas. These models are based more on understanding linkages, time lags, and feedbacks and can involve the integration of a number of individual research models.

More than 25 years after Meadows and Robinson (1985) published "the electronic oracle: computer models and social decisions" the gap between the providers of modelling capacity and end-users persists. The "implementation gap" well known from management in the '60s (Ackoff, 1960; Churchman and Schainblatt, 1965) is still very prevalent when it comes to computer modelling (Te Brommelstroet, 2010).

Different approaches can be taken to achieve the enhancement and uptake of integrated models useful for decision support. These include:

1) Linking existing 'legacy' models and databases into a large-scale model, and

2) Integrative (scoping) assessments where models are used to assess what types of models are required and there is a transition from one model to the next based on applying AM.

Both approaches have their costs and benefits, therefore it is important to find the appropriate mix through careful evaluation and criteria to ensure that the desirable next step, relevant to the context, takes into account both the reality of 'what is' and the vision of 'what is desired'.

There can be a tendency to build management models in isolation, without flexibility, and managers are encouraged to change reality to fit the model, rather than question the underlying assumptions or adjust a management model. To bridge the gap between end-users and conventional computer-based modelling techniques, models at the 'scoping' level (such as MM) are gaining interest; the participatory process and collaborative learning aspects of model building in a group is emphasized to gain broad understanding and 'buy-in' for the recommendations based on the 'scoping' modelling process. Working with end-users from the early stages in the development of computer modelling allows them to guide development and ensure models add value.

Models are ideally constructed to aid a process of AM which can be described as "decision making as an experiment" (Riley *et al.*, 2003). AM is, in principle, the acknowledgement of a 'feedback loop and time lag' in a policy-making context. It is crucial to include targets and baseline measures to evaluate the impact of implemented policies or measures, although a lack of concrete measures should not stifle initative it should assist and contribute to continuous improvement and the collaborative learning. AM can benefit from various forms of model-based assessment and there is hypothetically a logical progression. To support decision-making with Integrated Assessment (IA) in a transition toward a more sustainable and desirable world, we propose a framework that highlights Adaptive Management (AM) and the need for reflective and collaborative learning. We focus on the IA component of an AM cycle and the use of model building to support IA (van den Belt, 2009).

Figure 6 is a schematic overview and conveys the elements of AM on outward pointing axes. These axes signify an increasing level of detail, spatial resolution and time frame that requires additional model capacity to deliver.

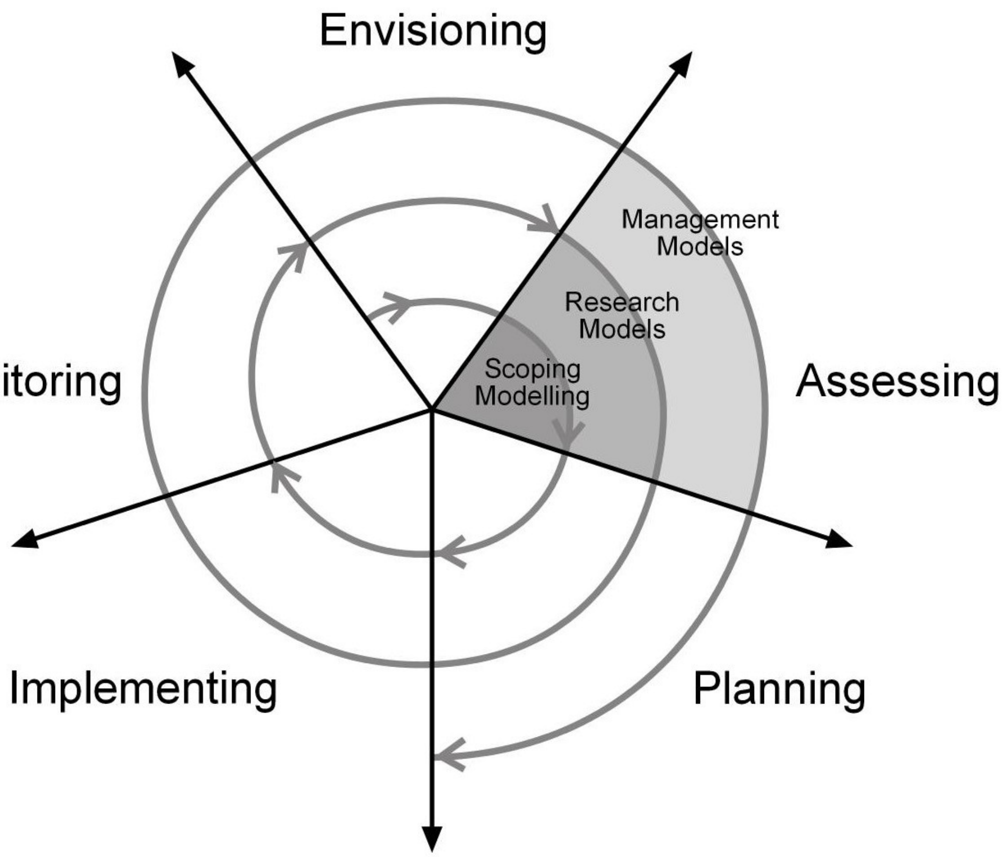

Figure 6: Multi-scale Integrated Modelling for Sustainable Adaptive Systems.

Using this worldview, an AM cycle starts with the recognition of a seeding vision (Envisioning), followed by an assessment of what information is available and/or required to develop a viable plan (Assessing). Provided the appropriate stakeholders are involved and their understanding grows, a modelling project can help build consensus during the assessment stage. A period of Planning, Implementing and Monitoring follows. Plans are developed with measurable targets and monitoring is preferably based on the indicators the stakeholders develop as part of the assessment stage.

After a full AM cycle, the scoping model is ideally revisited; its function is now to evaluate "were we right or should the model structure be updated, because we missed major feedback loops or time lags?" If we were right then what research models provide the next step. These research models are more detailed, explicitly targeted models with higher resolution, data requirements, precision and generally less transparency in narrower areas. In principle, research models are developed by experts. The goal is to develop models with a longer ‘shelf life’, i.e. models that provide a basis for learning and insights for a greater number of people/communities. The applicability of research models increases when based on appropriate questions; again, the broader the perspectives involved during the scoping phase, the higher the likelihood that the ‘right’ questions surface. ‘Right’ or robust in the adaptive context refers to ‘shelf-life’ as the assessment tools and plans are regularly up for review. A research model can be commissioned when all stakeholders involved identify a lack of information. Alternatively, emphasis on the process of joint fact-finding can be used when the question is clear (i.e. there are no hidden contextual agenda’s that skew the issue) but the answer remains polarized.

Not until the next step in planning, implementation, monitoring, and envisioning is cycled through, is the stakeholder community considered ready to construct resource-intensive management models.

Different modelling techniques fulfil different needs for end-users in the search for pathways towards a sustainable and desirable future. Not every pathway is similar or can be prescriptive/ normative, but the AM approach to model application allows input by stakeholders from the outset, which ideally should assist with buy-in and understanding if the resource intensive management models are required and implemented.

The Multi-scale Integrated Modelling for Sustainable Adaptive Systems (MIMSAS) framework presented in Box 1 is proposed as a theoretical foundation to develop the methodology and tools to build adaptive capacity among stakeholders and decision-makers. It is envisioned for use in the design of models as assessment tools, and also as a roadmap to guide the process through the various stages.

Multi-scale – refers to vertical integration of global, national, regional and local perspectives.

Integration – refers to environmental, social, economic technology, policy and political perspectives. Synchronization of expert and visionary thinking that maintains the bigger picture while going in ever greater detail.

Modelling – refers to any assessment tools at scoping, research and management level, including databases.

Sustainable – refers to socio-economic and ecological systems being able to support well-being for current and future generations.

Adaptive – refers to the capacity to manage iterative cycles of complexity and resolution while maintaining flexibility. Building the capacity to see the big picture in increasing detail without losing the overview (i.e. provided by vision, assessment, planning, implementation, monitoring). Policy-making as a deliberate “experiment”.

Systems – refers to the ability to identify linkages, interconnections and feedback loops that impact when a holistic approach is taken and time lags considered.

Box 1 – Multi-scale Integrated Modelling for Sustainable Adaptive Systems.

Conclusion

The benefits derived from the use of models for adaptive and integrated management are increasingly recognized within New Zealand's Regional Authorities, with this research revealing both the demonstrated use of models, and an awareness of the models that are available (such as those in Section 3), across all authorities. To this extent, RAs were seen to utilise GIS, Input-Output analysis and Multi-Criteria Analysis most, though all other models found some expression. Inability to assess the extent to which a model adds value and the monetary cost of building and maintaining models were the most frequently cited barriers to more widespread use by councils.

We found that RAs typically use modelling as a means to mobilise knowledge for a specific politically salient issue, where the models 'evidential' value is immediately apparent, though respondents recognised the importance of models that help scope the wider, integrated picture. Modelling tools and the synergies between them should be able to contribute integrated answers to the increasingly complex questions that authorities face. Understanding the questions a RA wants to have answered within their broader context is an important part of model development, as inappropriate definition can lead to issue-driven research and model development with a narrow focus that does not address the needs for broader IA and long-term adaptive management. This noted, any development of models as IA tools must be evaluated for ability to add value; resource intensity in terms of money; time investments; and longevity. Model providers, therefore, have to take time to ensure that the needs of the authorities are clearly understood and matched to the delivery characteristics of the various modelling techniques.

Given a demonstrated weak connectedness between science and policy in most RAs, many council officers draw on the types of modelling techniques described in this report but may be oblivious to the connection, as the techniques are embedded in models held by third parties and council officers typically only get reports giving the end results. As a consequence, the process of model building and the content remains a 'black box' to councils and their public constituencies, which can impede confidence in model use, cause misunderstanding about model application, and mask the value added by models to supporting decision-making.

Integrated assessment is usually undertaken through a multi-disciplinary approach, i.e. the bringing together of teams with specialist skills who jointly undertake the assessment. This results in models largely being provided by external consultancies. Typically, the role of council officers in these teams is more of a facilitator to council information, and ultimately as the recipient of the work, a bridge through to politicians and decision-makers.

New Zealand has the scope to increase efficiencies if RAs are considered as a 'community' actively seeking benefit transfer and learning from the RAs that have developed integrated assessment modelling capacity. When looking at it from an adaptive management perspective, the providers of models recognize there are synergies between different techniques that can reinforce each other as part of a developing tool kit. The goal is a long-term sustainable and desirable future at all levels: local, regional, national and global. Modelling tools are not ‘the goal’ but a means to an end. A National Advisory or Steering Committee toward a more coherent and synergetic use of various modelling tools and providers might increase their value from a societal perspective.

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