Modelling tools for adaptive integrated assessment: a case study of New Zealand regional authorities

Marjan van den Belt[1], Vicky Forgie[1], Scott Bremer[1], Garry McDonald[2], James Lennox[3], Oscar Montes de Oca[3], Mike Joy[4]

Key words: Integrated Assessment, Adaptive Management, Modelling

Abstract

Several computer-based simulation modelling tools are available to New Zealand's Regional Authorities for strategic policy research and management. Selecting effective modelling tools is often a daunting task for Councils and other end-users. New Zealand Centre for Ecological Economics (NZCEE), Landcare Research (LCR) and Market Economics Ltd (MEL) provide several modelling tools as part of our research/advisory relationships with the Regional Authorities (RAs). This paper describes a selection of eight modelling tools and provides an overview of which RAs are using them, to our best knowledge, without attempting to be exhaustive. From a provider's perspective, this paper is a reflection both on how these tools are or are not being used and on their potential and limitations for future use.

With global biophysical systems moving towards a 'tipping point', ecosystem degradation, a financial crisis, and a global economic recession, the trans-disciplinary approach of Ecological Economics (EE) is gaining relevance. We highlight primarily the models that are used at an ecological economics interface, focusing on the use of modelling tools to provide adaptive modelling capacity among end-users to accelerate the transition toward sustainability.

Introduction

The integration of socio-economics and ecological systems is inherently complex and 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 create a sustainable and desirable future. 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, 2009a). More than 20 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.

RAs[5] are the level of local government in New Zealand required to achieve integrated management of the natural and physical resources of the region. Included in RA statutory

---

[1] New Zealand Centre for Ecological Economics (NZCEE), Private Bag 11052, Palmerston North, New Zealand. email: vandenbeltm@landcareresearch.co.nz Phone 0064 6 3534864; Fax: 0064 6 3534801

[2] Market Economics Limited (MEL)

[3] Landcare Research (LCR)

[4] Ecology, Institute of Natural Resources, Massey University

responsibilities (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 (RMA, 1991, Part II).

It is not easy to understand what models or techniques are used throughout New Zealand RAs. Relationships between councils on the one hand and universities, Crown Research Institutions (CRIs) and consulting firms on the other tend to be personal and private. Many models and tools are proprietary and their dissemination fraught with intellectual property issues. While the results from running a model are often made available, models themselves are less frequently made available, and the process of model building and the content generally remains a black box to the Councils and their public constituencies.

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 Regional Council (ARC) 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’, ‘gut feel’, and ‘politics’.

Many Council officers will draw on the types of modelling techniques we describe in this paper, but may be oblivious to the connection, as the techniques are embedded in models held by third parties and council officers typically only see end results. Council officers hardly ever have a modelling background, and while they do try to understand, their efforts are mostly directed at the political interface between the results of studies and decision-making.

This paper is intended to (1) help inform the appropriate selection and use of models for addressing the issues Councils face, and (2) explain ’black box‘ models and include more transparency by emphasizing process and learning, as part of the model building exchange between providers and end-users.

Science-Policy Interface in New Zealand

For the past decade, the role of science and community knowledge in defining environmental issues has been the centre of evaluation and debate. 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 dearth of decision support tools, models and IA at the science–policy interface. This is particularly acute at the local government scale, due to the lack of resourcing and capacity for incorporating science. A recent Ministry of Research, Science and Technology (MoRST) review found local government organisations did not know what research opportunities were available to help decision-making, or coordination and research sharing across local and/or central government departments. In addition, local government feels that research organisations do not understand their research requirements, which results in research outcomes being undervalued (MoRST, 2009). Therefore

[5] 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.

it is important to work with council staff in the development of computer modelling so they can be better informed to judge whether or not they can add value.

Since the restructuring of the mid-1980s, government agencies have progressively relinquished their in-house scientific capacity, and contracted out the purchase of their science. RAs 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 by MoRST in 2004 found that, owing mainly to variable rating and asset bases across the regions, only three RAs have significant in-house capacity and a good 'engagement' with the scientific system, with variable capacity across the other 13 Councils (MoRST, 2004). Research has found most RAs are forced to purchase 40–50% of their science requirements (MoRST, 2004; Bremer, 2009). Central government's contestable 'public good funding' does not extend to the operational research of local government so each council has its own independent system, the extent of which is determined by resource availability.

Three forms of policy-relevant science are utilised by RAs: (i) State of the Environment science; (ii) issue-based science; and (iii) resource consent science (Bremer, 2009). Resource consent science is supplied as part of applications to use or develop a resource, 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 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 mechanisms (Bremer, 2009).

Evidence for need for IA tools at RA level

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. This has been found especially true of RAs who, isolated from public good funding, are unlikely to have the resources to devote to interdisciplinary projects, such as modelling (PCE, 2003). Beyond the limitations imposed by funding capacity, there is also a lack of 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).

The MoRST Environmental Research Roadmap seeks to promote AM, predictive forecasting and enhanced communication tools for advising decision-makers (MoRST, 2007). Scientists have responded to this need 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 it is aimed at 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 reafforestation, 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 (what if type questions) (van den Belt, 2004; Huser et al., 2009).

To address sustainability issues councils need to better understand the complex systems in which they operate and the need for an AM perspective: "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).

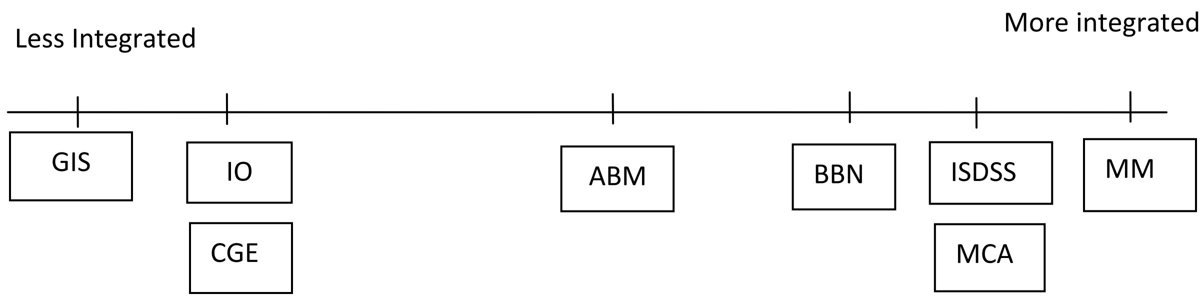
An overview of Computer Simulation Strategic Planning Models

First we define the term model and then rank by degree of integration the computer simulation strategic planning models available for use by RAs in New Zealand. We then give a brief description of the various models: Geographic Information Systems (GIS), Mediated Modeling (MM), Integrated Spatially Dynamic Systems Support Modelling (ISDSS), Input/Output Modelling (IO), Computable General Equilibrium Modelling (CGE), Agent-Based Modelling (ABM), Multi-Criteria Analysis (MCA) and Bayesian Belief Networks (BBN). A table summarizing the modelling tools at a glance is designed to present the various characteristics of the modelling approaches we deem relevant. We then discuss the current use of these models at the local government level in New Zealand to get an understanding of the extent of their application.

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 allow 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 understanding as they allow us to expand the boundaries of our mental models and to cross, among others, disciplinary, management, temporal, cultural, and social boundaries. Regardless of whether we are conscious of it or not, 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 politics. In this paper, we are specifically interested in computer-based simulations models.

Models are more or less integrative. Even though somewhat arbitrary, the continuum shown in Figure 1 presents a consensus among the authors of this paper of the current ‘state of the art’ of each modelling tool regarding integrative applications. 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



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.

Mediated Modelling

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. Currently, there are a host of names[6] for similar approaches that have developed in isolation of each other. Van den Belt et al. (2009b) provide a literature review of opportunities and barriers for use of MM in the public sector. A generic MM process involves:

(1) A preparation phase to establish whether MM is the correct tool to be used in the context, identify and select about 10–30 stakeholders, and set the general context of 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 toward a simulation model with the simultaneous and interactive involvement of the stakeholders. The

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

dialogue among the participants is simultaneously interpreted and reflected onto a projected computer screen. If successful, simulation of 'what-if' scenarios and the evolving model supports the stakeholder group in deciding on an action plan to implement the shared findings. This step requires about 30–50 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 a re-visiting of the model after a period of implementation. The latter may add to long-term AM capacity building (van den Belt, 2009a).

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 allows for the inclusion of a broad range of perceived relevant trends rather than a focus on accurate but narrowly available set of available data. MM supports the 'scoping' in an IA. The 'trust' in the resulting models is based on the collaborative learning and the transparency of the model. The ability to update the model and adapt it with newly gained information by several of the end-users provides the added value of this type of computer-based simulation model.

Integrated Spatially Dynamic Support Systems (ISDSS)

ISDSS 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 ISDSS models is still very much in its infancy.

Computable general equilibrium (CGE)

CGE models have become an invaluable tool 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 spatial and political unit of analysis, CGE models 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.

Multi-criteria analysis (MCA)

Multi-criteria analysis (MCA) techniques may be used to support choices within a set of defined options, particularly when decision-makers are concerned with multiple dimensions of performance that are 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 Multicriteria 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.

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 interactively test a model 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[7]. 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 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).

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

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

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), Gravard (1998), and in the NZ 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 distributional impacts (i.e. 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. SAMs have not been widely used in New Zealand.

Geographic Information Systems Modelling (GIS)

GIS modelling presents data in map form as well as providing a tool for map-based queries and analysis. 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 that helps answer the question you have posed. Typically this is not modelling in terms of simulation modelling, though this is possible. GIS data presentation is used when spatial and visual representation is important.

Bayesian Belief Networks (BBN)

Bayesian Belief Networks (BBNs) are statistical models, calculating probabilities that can be used 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 a 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 is the use of BBNs in medicine as a diagnostic tool with 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. Or ‘what-if’ scenarios can 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 in real-time real scenarios makes them ideal as tools for AM of environmental situations and they can be linked directly to GIS maps to visualise management changes immediately (Smith et al., 2007).

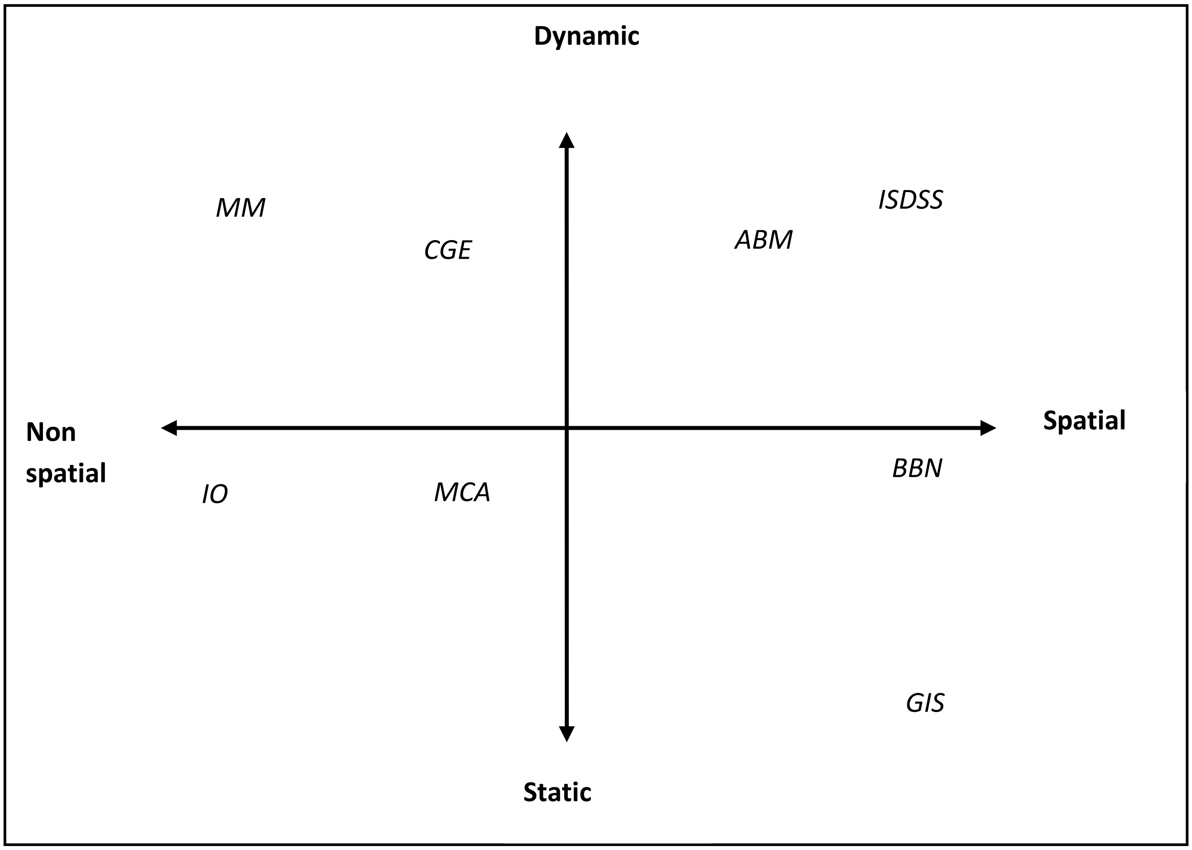
Model Characteristics

Models have different strengths and weaknesses that enable them to be used synergetically as assessment tools. Figure 2 plots these models on a two-dimensional graph in terms of the current characteristics of spatial/non-spatial and static/dynamic applications. This figure provides a basis for exploring synergies between the various modelling approaches. For example, MM lacks spatial explicitness, but is broad scoping and more transparent to end-users. If relevant dynamics are discovered and data sets or models are available, the ISDSS platform can includes those aspects in the spatially explicit management model.

Some models are easier to maintain and update than others. For example, GIS mapping capacity is generally available in all RAs and in-house experts maintain and develop many of the maps. However, the capacity to maintain ISDSS models still needs to be developed in New Zealand. MM aims to build the capacity of using and maintaining the resulting models in the model development process.

All models can run different scenarios, but there is a tradeoff between the capacity of 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: Two dimensional graph in terms of characteristics of spatial/non-spatial and static/dynamic



Modelling tools at a glance

Table 1 gives a summarized overview of the various modelling tools discussed previously following the order in which the tools appear on the integration continuum.

Table 1: Modelling characteristics of various forms of tools employed in an integrated ecological economics context

Use of computer simulation strategic planning models at the local government level in New Zealand

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.

Use of other types of computer simulation modelling has been more issue driven and specific to an individual council's requirements. The following section discusses a range of models that have been implemented or are about to be implemented at local government level in New Zealand.

The Creating Futures Project, led by Environment Waikato, is currently the only attempt at creating an ISDSS 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. 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 determined, a dynamic spatial interaction model based on a cellular automata algorithm is used to allocate land use by 200 m x 200 m 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 ISDSS has the temporal resolution of one year for all incorporated models and its horizon is set at 2050. NZCEE, in collaboration with MEL, recently received funding for Sustainable Pathways II programme to develop ISDSS for Auckland and Wellington. A mediated modelling process is envisioned to enhance the systems integration.

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 & Varghese, 2007; Lennox & Diukanova, 2008) and urban infrastructure decisions (Yeoman et al., 2009) in the Auckland region.

Two separate efforts to develop multiregional CGE models for the whole of New Zealand are currently underway through Victoria University and the University of Waikato/Business and Economic Research Limited (BERL). In the case of the former model, Robson (2009, p.1) states that:

> New Zealand has so far lacked a comprehensive multi-regional CGE model that would facilitate examination of economic issues at the regional level. Assessing the regional impact of external shocks and understanding the interdependence of our regions, and the implications of that interdependence for the national economy, are some of the applications such a model would be useful for.

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

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). Nevertheless, 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. Statistics New Zealand's (2003a, p. 8) feasibility study 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 number of non-survey regional inter-industry tables have been developed in New Zealand. 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 extensively in assessing the economic impacts associated with 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 of 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. While in the Auckland Region these 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, 2008b). 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).

In New Zealand, aspects of the DMCE process have been applied (Lennox & Proctor, in preparation) as part of a stakeholder consultation process over a proposed water storage and irrigation scheme in North Canterbury, and MCA approaches have been used within a wider process of developing a regional water management strategy for Canterbury.[8]

The Cawthorn Institute undertook a study to address stakeholder's concerns over the effects of aquaculture developments on the Miranda Ramsar wetland (MRW) 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).

The concept of using ABM for land-use change scenarios in New Zealand is new. LCR is currently developing three ABM models: for the OPNS programme to analyse water allocation policy options in North Canterbury; for the Sustainable Land Management for Adaptation to Climate Change (SLMACC) programme to investigate farmer adoption of greenhouse gas

[8] Canterburywater.org.nz

mitigation policies and technology using case studies in the Manawatu and Canterbury regions; and for the Integrated Catchment Management programme to articulate impacts of landscape change in Maori cultural values.

Table 2: Regional Authorities and their commitment to various modelling tools

Regional Authorites	**MM**	**ISDSS**	**CGE**	**MCA**	**ABM**	**IO**	**GIS**	**BBN**
Manawatu	IFS				SLMACC	P21	A	IFS
Auckland	SP2	SP2				ARDEEM	A	
Wellington	SP2	SP2					A	
Waikato		CF				WRDEEM P21	A	MRW
Nelson					ICM		A	
Canterbury			OPNS	OPNS	OPNS SLMACC	CANDEEM	A	
All other RAs							A	

Key: SP2 – Sustainable Pathways II, NZCEE; CF – Creating Futures NZCEE, Landcare Research, NIWA, Scion; IFS – Pending proposal on Integrated Freshwater Solutions; OPNS – Old Problems, New Solutions, Landcare Research; ICM – Integrated Catchment Management, Landcare Research; A – In use in some form; ARDEEM & WRDEEM – Market Economics, Ltd; MRW – Aquaculture development on the carrying capacity of shorebirds at the Miranda Ramsar wetland (Gibbs, 2006); SMLACC Catchment Modelling – Landcare Research, AGResearch and the World Resources Institute (Washington DC); ICM – Landcare Research, Cawthron, NIWA, and others; P21 – AgResearch, NIWA, Landcare Research, Waikato University; CANDEEM – Landcare Research.

Synergies between models to develop adaptive management capacity

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).

Often when one problem is addressed in isolation another problem arises, especially when a more overarching, integrated approach is lacking (Sterman, 2002). 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. Modelling provides a visualization (often based on much data) of the simulated pathways that, with a time lag, can be compared with monitored data. 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.

Models constructed to answer ONE current policy issue (issue driven research mentioned earlier in the paper) can follow the AM process, but if the problem is exogenous it is more likely there will be movement to another modelling approach, because there is a different issue to confront.

The proposed MIMSAS framework (Box 1) is a theoretical foundation to develop the methodology and tools for adaptive capacity among stakeholders and decision makers in the design process of models as assessment tools, and is also a roadmap to guide the process through the various stages.

Box 1 – Multi-scale Integrated Modelling for Sustainable Adaptive Systems (MIMSAS)

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.

There are two possible tracks towards the enhancement and uptake of integrated models useful for decision support:

1) Linking existing 'legacy' models and databases or,
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 a desirable next step, relevant to the context, takes into account both the reality of 'what is' and the vision of "what's desired".

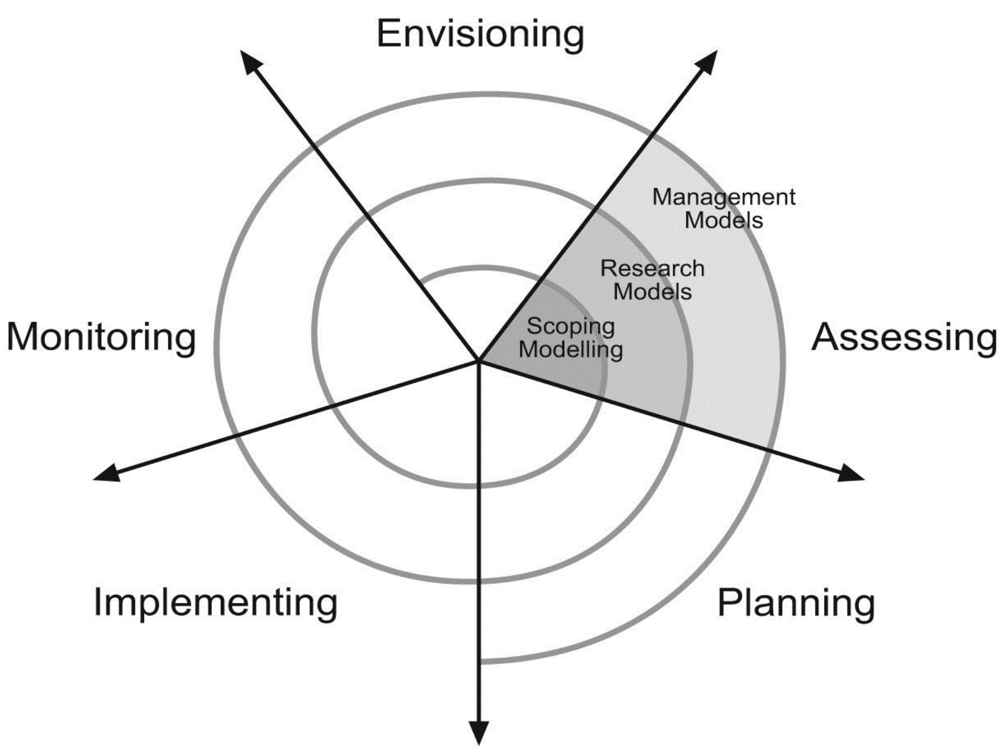
Models are only useful to the extent that they answer the questions the model sets out to answer. This tends to limit the scope of what is modelled, due to the technical complexity of models. The specific but detailed models such as CGE and I/O referred to as 'research models' (Costanza & Ruth, 1998), are used frequently to answer precise issue-based questions. 'Management models' such as ISDSS 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.

Sometimes there is 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 the 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.

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. AM can benefit from various forms of model-based assessment and there is generally (but not always) a logical progression.

Figure 3 is a schematic overview and conveys the elements of AM on outward pointing axes. These axes signify an increasing level of detail and resolution of time frame that requires additional model capacity to deliver.

Figure 3: 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 growing, a modelling project can help build consensus during the assessment process. A period of Planning, Implementing and Monitoring follows. Monitoring is preferably based on the indicators the stakeholders develop as part of the modeling process.

After a full AM cycle, the scoping model is ideally revisited; its function is now to evaluate "were we right? Should the model structure be updated, because we missed major feedback loops or time lags or are research models the next step?" Research models are more detailed, explicitly targeted models with higher resolution, data requirements, precision and generally less transparent. 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 increase 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.

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 fulfill 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 implemented.

Conclusion

The use of models as integrated assessment tools by RAs in New Zealand is gradually increasing, with the larger Authorities leading the way. Providers have to ensure that the needs of the Authorities are clearly understood and matched to the delivery characteristics of the various modelling techniques. Modelling tools and the synergies between them should contribute integrated answers to the increasingly complex questions Authorities face. Understanding the questions an RA wants to have answered 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 its resource intensity in terms of money, time investments and longevity.

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 IA modeling capacity and are developing their own capacity. IA is an essential component of AM. When looking at it from an AM 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 can never be 'the goal', but are rather a means to an end.

References

Auckland Regional Council. (2008). *Economic Futures for the Auckland Region Part 1: Knowledge Base for Scenario Development.* Auckland: Auckland Regional Council.

Auckland Regional Council. (2009). *Economic Futures for the Auckland Region Part 2: Scenarios for Economic Development.* Auckland: Auckland Regional Council.

Bolte, J.P., Hulse, D.W., Gregory, S.V., & Smoth, C. (2006). Modeling biocomplexity – actors, landscapes and alternative futures. *Environmental Modelling & Software*, *22*, 570–579.

Bremer, S. (2009). *Evaluating the state of New Zealand's coastal management: Application of integrated coastal management indicators at national and local scale.* (NZCEE Monograph 16). Palmerston North: NZCEE

Cheng, J., Greiner, R., Kelly, J., Bell, D., & Weiru, L. (2002). Learning Bayesian networks from data: An information-theory based approach. *Artificial Intelligence, 137*, 43–90.

Checkland, P. (1981). *Systems thinking, systems practices*. Chichester, UK: Wiley.

Costanza, R., & Ruth, M. (1998). Dynamic systems modeling for scoping and consensus building. *Environmental Management, 22,* 183–195.

Daly, H.E. (1968). On economics as a life science. *Journal of Political Economics, 76*. 392–406.

Decalauwé, B., Patry, A., & Savard, L, (1997). *Quand l'eau n'est plus un don du ciel: Un MEGC appliqué au Maroc*. Quebec, Canada: Département d'économique, Université de Laval.

Dixon, P.B., Schreider S.Y., & Wittwer, G. (2005). Encapsulation of water allocation into a general equilibrium model. *MODSIM05 International Congress on Modelling and Simulation, Modelling and Simulation Society of Australia & New Zealand* (pp. 999–1006). Where published and by whom?

Gibbs, M. (2006). Application of a Bayesian network model and a complex systems model to investigate risks of a proposed aquaculture development on the carrying capacity of shorebirds at the Miranda Ramsar wetland. Prepared for: Environment Waikato, Auckland Regional Council & Ministry for the Environment, Hamilton, N.Z.

Gimblet, R. (2005). *Modelling human-landscape interactions in spatially complex settings: Where are we and where are we going?* International Congress on Modelling and Simulation, Melbourne, 11–15 December 2005.

Gravgård, O. (1998). *Physical Input-output Tables for Denmark, 1990.* Extract of a forthcoming report on physical input-output tables and emissions accounts for Denmark, 1990. Copenhagen: Statistics Denmark.

Guzy, M.R., Smith, C.L., Bolte, J.P., Hulse, D.W., & Gregory, S.V. (2008), Policy research using agent-based modeling to assess future impacts of urban expansion into farmlands and forests. *Ecology and Society*, *13*(1), 37.

Heckbert, S., & Smajgl, A. (2005). A*n agent-based policy impact assessment tool for the Great Barrier Reef Region.* Presented at International Congress on Modelling and Simulation, Melbourne, 11–15 December 2005.

Hewings, G.J.D., & Jensen, R.C. (1986). Regional, interregional and multiregional input-output analysis. In P. Nijkamp (Ed.), *Handbook of regional and urban economics: Vol. 1*. Amsterdam: North Holland.

Huser, B., Rutledge, D. T., Delden, H. v., Wedderburn, M. E., Cameron, M., Elliott, S., Fenton, T., Hurkens, J., McBride, G., McDonald, G., O'Connor, M., Phyn, D., Poot, J., Price, R., Small, B., Tait, A., Vanhout, R., & Woods, R. A. (2009). *Development of an integrated spatial decision support system (isdss) for local government in New Zealand.* Presented at 18th World IMACS / MODSIM Congress Cairns, Australia, 13–17 July 2009. http://mssanz.org.au/modsim09

Isard, W. (1968). Some notes on the linkage of ecological and economic systems. *Papers, Regional Science Association, 22*, 85–96.

Jager, W., Janssen, M.A, De Vries, H.J.M., De Greef, J. &, Vlek, C.A.J. (2000). Behaviour in commons dilemmas: Homo Economicus and Homo Psychologicus in an ecological-economic model. *Ecological Economics, 35*, 357–380.

Jensen, R.C. (1990). Construction and use of regional input-output models: Progress and prospects. *International Regional Science Review, 13*, 9–25.

Kneese, A.V., Ayres, R.U., & d'Arge, R.C. (1970). *Economics and the environment – a materials balance approach*. Washington, DC: Resources for the Future.

Lennox, J., & Diukanova, O. (2008). Modelling regional general equilibrium effects of water allocation in Canterbury (submitted to Water Policy).

Lennox J., & Proctor, W. (2009). Water management in Canterbury – participation in decision-making (in preparation).

Lennox, J., & Varghese, S.K. (2007). *From input-output to computable general equilibrium modelling of water use in the Canterbury region.* International Input-Output Conference, Istanbul.

Leontief, W. (1970). Environmental repercussions and the economic structure: An input-output approach. *Review of Economics and Statistics, 52*, 262–271.

McDonald, G.W., & Patterson, M.G. (2005). A system dynamics model of global biogeochemical cycling. *Ecological Economics, 56,* 424–439.

McDonald, G.W., & Smith, N. (2008). Waikato Region Dynamic Environment-Economy Model (WRDEEM): mathematical description. Takapuna: Market Economics Ltd.

McDonald, G.W., Smith, N., & Zhang, Y. (2006a). Waikato Region Economy–Environment-Futures Model. Environmental Waikato Technical report 2006/51. Hamilton: Environmental Waikato.

McDonald, G.W., Forgie, V., & MacGregor, C. (2006b). Treading lightly: Ecofootprints of New Zealand's ageing population. *Ecological Economics, 56,* 424–439.

Meadows, D. H., & Robinson J.M. (1985). *The electronic oracle: Computer models and social decisions.* Chichester: John Wiley & Sons.

Miller, R.E., & Blair, P.D. (1985). *Input-output analysis: Foundations and extensions*. Englewood Cliffs, NJ: Prentice-Hall.

Miller, R.E. & Blair, P.D. (2009). *Input-output analysis: Foundations and extensions* (2nd rev. ed.). New York: Cambridge University Press.

Ministry of Research, Science and Technology (MoRST). (2004). *Evaluation of the environmental output class*. Wellington: MoRST.

Ministry of Research, Science and Technology (MoRST). (2007). *Roadmaps for science: Environment research.* Wellington: MoRST

Ministry of Research, Science and Technology (MoRST), (2009). *Survey of urban councils and research.* Wellington: MoRST

Parker, D.C., Manson, S.M., Janssen, M.A., Hoffmann, M.J., & Deadman, P. (2003). Multi-agent systems for the simulation of land-use and land-cover change: a review. *Annals of the Association of American Geographers*, *93,* 314–337.

Parliamentary Commissioner for the Environment. (2002). *Creating our future: Sustainable development for New Zealand*. Wellington: Parliamentary Commissioner for the Environment.

Parliamentary Commissioner for the Environment. (2003). *Illuminated or blinded by science? A discussion paper on the role of science in environmental policy and decision-making*. Wellington: Parliamentary Commissioner for the Environment.

Parliamentary Commissioner for the Environment. (2004). *Missing Links: Connecting science with environmental policy*. Wellington: Parliamentary Commissioner for the Environment.

Parliamentary Commissioner for the Environment. (2007). *Outcome evaluation: Missing links. Connecting science with environmental policy*. Wellington: Parliamentary Commissioner for the Environment.

Patterson, M.G., & McDonald, G.W. (1996). Regional level environmental accounting systems in New Zealand, using input-output methodologies. Institute of Environmental Studies (Ed.), *Tracking progress: Linking environment and economy through indicators and accounting systems* *conference papers*. Australian Academy of Science Fenner Conference on the Environment. Sydney: Institute of Environmental Studies, University of New South Wales, 30 September – 3 October 1996.

Poot, J., & Cochrane, B. (2004). Measuring the economic impact of immigration: A scoping paper. Where?: Population Studies Centre.

Proctor, W., & Dreschler, M. (2006). Deliberative multicriteria evaluation. *Environment and Planning C 24*, 169–90.

Riley, S.J., Siemer, W.F., Decker, D.J., Carpenter, L.H, Organ, J.F., & Berchielli, L.T. (2003). Adaptive impact management: an integrative approach to wildlife management. *Human Dimensions of Wildlife 8*(2), 81–95.

Robson, N. (2009). *A multi-regional computable general equilibrium model for New Zealand.* Paper Presented to the New Zealand Association of Economists Conference, 1–3 July 2009.

Round, J.I. (1983). Non-survey techniques: A critical review of the theory and evidence. *International Regional Science Review, 8*, 189–212.

Seung, C.K., Harris, T.R., Englin, J.E., & Netusil, N.R. (2000). Impacts of water reallocation: A combined computable general equilibrium and recreation demand model approach. *The Annals of Regional Science 34*, 473–87.

Smajgl, A. (2006). Quantitative evaluation of water use benefits – an integrative modelling approach for the Great Barrier Reef region. *Journal of Natural Resource Modelling, 19*(4)*,* 511–538.

Smajgl A, Morris S, Heckbert S. 2009. Water Policy Impact Assessment – Combining Modelling Techniques in the Great Barrier Reef region. Water Policy Journal. 11: 191–202.

Smith, C.S., Howes, A.L., Price, B. & McAlpine, C.A. (2007). Using a Bayesian belief network to predict suitable habitat of an endangered mammal - The Julia Creek dunnart (Sminthopsis douglasi). *Biological Conservation 139* 333–347.

Smith, N., & McDonald, G. (2008a). *Ecological footprint for the Waikato Region*. (NZCEE Research Monograph Series, No. 8). Palmerston North: New Zealand Centre of Ecological Economics.

Stahmer, C., Kuhn, M., & Braun, N. (1996). *Physical input-output tables: German experiences*. London Group Meeting on Environmental Accounting, Stockholm, Sweden, 29–31 May 1996.

Stahmer, C., Kuhn, M., & Braun, N. (1998). *Physical input-output tables for Germany, 1990.* Eurostat Working Papers, 2/1998/B/1. Brussels: European Commission.

Stahmer,C., Kuhn, M., & Braun, N. (1997). *Physische input-output tabellen 1990*. Schriftenreihe Beiträge zu den Umwelt ökonomischen Gesamtrechnungen. Wiesbaden, Statisches Bundesamt.

Statistics New Zealand. (2002). *Regional input-output study: User needs review*. Christchurch: Statistics New Zealand.

Statistics New Zealand. (2003a). *Regional input-output study*. Christchurch: Statistics New Zealand.

Statistics New Zealand. (2003b). *Regional input-output study: Data evaluation*. Christchurch: Statistics New Zealand.

Statistics New Zealand. (2003c). *Regional input-output study: Methodological review*. Christchurch: Statistics New Zealand.

Sterman, J. (2002). All models are wrong: reflections on becoming a systems scientist. Systems Dynamic Review, 18(4), 501–531.

Uusitalo, L. (2007). Advantages and challenges of Bayesian networks in environmental modelling. *Ecological Modelling, 203*, 312–318.

Van Delden, H. (2009). Integration of socio-economic and bio-physical models to support sustainable development. Presented at 18th World IMACS / MODSIM Congress, Cairns, Australia, 13–17 July 2009 http://mssanz.org.au/modsim09

van den Belt, M. (2004). Mediated modeling: A system dynamics approach to environmental consensus building. Washington, DC: Island Press.

van den Belt, M. (2009a). Multi-scale integrated modeling for sustainable and adaptive systems. Conference proceedings System Dynamics Society, Albuquerque, New Mexico, 27–31 July 2009.

van den Belt, M., Kenyan J.R., Krueger E., Maynard A., Roy, M.G., & Raphael, I. (2009b). Public Sector Administration of Ecological Economics Systems using Mediated Modeling, *Ecological Economics Reviews*, (in press).

van den Belt, M.J., Deutch, L., & Jansson, Å. (1998). A consensus-based simulation model for management in the Patagonia coastal zone. *Ecological Modeling*, *110*, 79–103.

van den Belt, M., Bianciotto, O., Costanza, R., Demers, S., Diaz, S., Ferryra, G., Koch, E., Momo, F. & Vernet, M. (2006). Mediated modeling of the impacts of Enhanced UV-B Radiationon Ecosystem Services. Special Issue of *Photochemistry and Photobiology*, *82*, 865–877.

Victor, P.A. (1972a). *Economics of pollution.* London: Macmillan.

Walton, M., Johnston, D., Leonard, G., Gray, W., Bell, R., & Paton, D. (2004). The Waikato weather bomb: Understanding the impact. Where: NZIER and NIWA.

White, R., & Engelen, G. (2000). High-resolution intergrated modelling of the spacial dynamics of urban and regional systems. Computers, Environment and Urban Systems, *24*, 383–400.

Woolridge, M., & Jennings, N.R. (1995). Intelligent agents: Theory and practice. *Knowledge Engineering Review*, 10, 115–152.

Yeoman, R., Kim, J., McDonald, G.W., & Zhang, Y. (2009). *Modelling regional general equilibrium for the Auckland Region*. (NZCEE Research Monograph, No. 9). Palmerston North: New Zealand Centre of Ecological Economics.

Zhang, Y., McDonald, G., Nixon, P., & Smith, N. (2008). *Development of a regional social accounting framework for New Zealand*. (NZCEE Research Monograph, No. 15). Palmerston North: New Zealand Centre of Ecological Economics.