Integrated Modelling for Natural Resource Management: Where to Next?

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Abstract: The objective of the INSIGHT project was to develop a modelling system that could help policy makers to develop an understanding of the implications of different land uses in a catchment and how various policies would affect these outcomes over a long (20 year) time frame. The purpose of this paper is to report on current capabilities of the prototype model for the Lachlan Catchment, review the project's objectives in light of recent developments and lessons learnt, and suggest areas for future work. The paper describes a scenario evaluation, as an illustration of the prototype capabilities. The scenarios explore the connections between adjustment in farm ownership, land use and environmental and socio-economic outcomes. Merits and limitations of the present prototype are discussed, with specific reference to: a) the original project aims; b) the types of questions the model can address and its place in the policy design cycle; c) how such a prototype model can actually be used in the policy making process; and d) the level of causality in the model and how uncertainty is dealt with. It is concluded that INSIGHT complements other model-based approaches in distinct phases of the policy design cycle. Imbalance in the level of detail and causality of model components limits analysis of interactions in the system and reduces its ability to explore long term futures. This imbalance points to a disciplinary research agenda, as there is a lack of quantitative understanding of some of the many interactions and components (e.g. hydrology-salinity interactions, ecosystem services) and a lack of metamodels describing other components. We recommend that the next step be a bench and field testing phase with stakeholders in which the prototype model's potential to support policy design can be evaluated.

Keywords: Land use study; Stakeholder; Uncertainty; Causality

1. INTRODUCTION

CSIRO Sustainable Ecosystems is developing a spatially-explicit modelling system, known as INSIGHT, to explore land and water policy alternatives in the Lachlan River Catchment of New South Wales.

The objectives and philosophy of INSIGHT, and its biophysical and socio-economic components have been described by Gorddard and Walker [2001], White et al. [2001] and Gorddard [2001]. This paper illustrates results of the prototype system, discusses capabilities within the context of supporting development of policies for integrated natural resource use management (INRM) and discusses its capabilities in relation to other approaches to model-based land use analysis.

1.1 Overview of the INSIGHT Model

The prototype INSIGHT model consists of agricultural production point models linked to a spatial hydrological model simulating the implications of various land use types for stream flows and salinity. A model of farmer decision making based on household production theory allocates land to different uses (grain production, pasture and sheep production, and native vegetation). Three methods of growing grain and wool are defined. They are called standard, high input and conservation. Three different farm types are defined that differ in size, preferences and restrictions on production options. They are called lifestyle, family and agribusiness farms. The differences between farm types affect the returns to different land use types and therefore the land use choices. A model of farm adjustment driven primarily by demographics reallocates land among

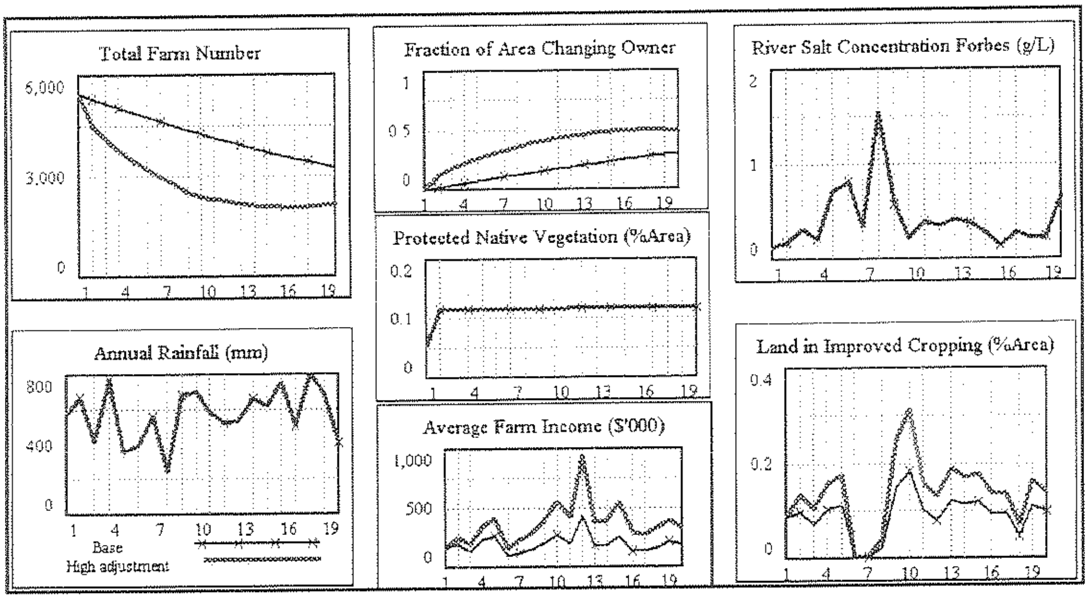

Figure 1. Results from two model scenarios exploring the systemic impacts over 20 years of an increase in the rate of farm adjustment.

the three farm types. Farm population, employment and production link farm activity to a model of regional employment and population adjustment. This integrated catchment model, illustrated in Figure 2 of Gorddard and Walker [2001] is run for 20 years replaying historical climate data.

2. REGIONAL SIMULATIONS

2.1 Scenario Definition

Two runs explore the sensitivity of key Lachlan Catchment scale variables (river water and salt loads, native vegetation, and average farm income) to the rate of adjustment in agricultural land ownership. This addresses the issue of how significant rural adjustment might be for natural resource issues, given the likely timing and extent of the changes. From an integrated policy perspective, it looks at the potential for rural adjustment policy to influence natural resource management. The runs differ in assumptions about the average age of farmer retirement and the rate of non-retirement land sales. The base model run uses historical averages for the rate of sales and average retirement age. The high adjustment scenario assumes a ten year reduction in the average retirement age, and a doubling in the rate of non-retirement land sales. Underpinning both runs are assumptions about the retirement decision, the proportions of sold land that will be bought by the three different types of farmers, and the land use possibilities and preferences of the different farm types. Given that these factors are largely unknown, they are parameterized to explore the upper bound of the potential impact of a feasible shift in farm ownership on natural resource management. It is therefore assumed that land will predominantly be bought by agribusiness farms who will invest in profitable but management intensive perennial cropping and grazing systems that are not feasible for smaller farmers.

2.2 Example of INSIGHT Output

Figure 1 indicates that the changes in land ownership produce a significant increase in average farm income, a result of declining numbers of small, relatively inefficient lifestyle farms. The change in ownership produces a significant change in the area of land used for improved (intensive) cropping. The impact of ownership changes on the area of protected native vegetation and on the river water and salt loads however are minimal.

Exploring the reason why these changes are small illustrates appropriate uses of the model. Conservation of native vegetation is not affected in this model run as the amount of conservation activity undertaken by the different farm types is assumed to be approximately the same. If this assumption is changed, the proportion of land that has changed hands is an indication of the potential for farm adjustment to affect conservation. The minimal impact on river water and salt loads is a more complex story.

The specified high intensity cropping system does not use much more water than standard technologies as it is only actively transpiring throughout the same growing period as the base cropping method. The high input grazing system has a larger amount of perennial pastures than the standard grazing option, this resulting in a significant increase in annual evapo-transpiration. The land ownership changes results in movement of land from standard grazing enterprises into both high intensity grazing and high intensity cropping. The change from grazing to cropping systems offsets some of the increased water consumption due to the improvement in grazing systems.

It is important that the model results are not seen as predictions. The value of the modelling exercise is in raising a range of potentially important issues about what the systemic effects of a policy change might be, and permitting users to identify what factors might drive these results.

3. CHARACTERISING THE INSIGHT APPROACH

We assess the INSIGHT approach according to three criteria. The first criterion is where it fits into the policy design cycle, the second is how it interfaces with the policy process, and the third is how it deals with causality and uncertainty. In our discussion we differentiate between the project specifications and the resulting model.

3.1 Relationship to the Policy Design Cycle

The process of developing policies for natural resource management (or regional development in general) requires different types of information during its various stages. This information cannot be supplied by one modelling approach as the information requirements dictate the appropriate simplifying assumptions. Figure 2 provides one possible classification of the policy cycle.

The potential uses and benefits of the proposed INSIGHT modelling system were originally identified as:

- Improved integration and targeting of policies;
- Improved sequencing of policies;
- Assessment of the likely impact of research funding strategies;
- Assessment of the collective impact of strategies and programs being implemented at the local level; and
- Evaluation of the costs of implementing regional and state-wide policies.

The place of these issues in the design cycle is open to discussion. One view of the policy cycle might hold that objectives and targets should be set with respect to the political and physical performance of and constraints on the system. According to this view it is only after the policy formulation stage that the issues of design and implementation of policies should be considered. Focussing on policy levers in the very early stages of development of INRM policies obscures biophysical and technical opportunities in the system. Extrapolation of existing systems, associated policies and their consequences and imperfections are likely to hinder open debate about future opportunities.

An implicit assumption of this view is that feasible

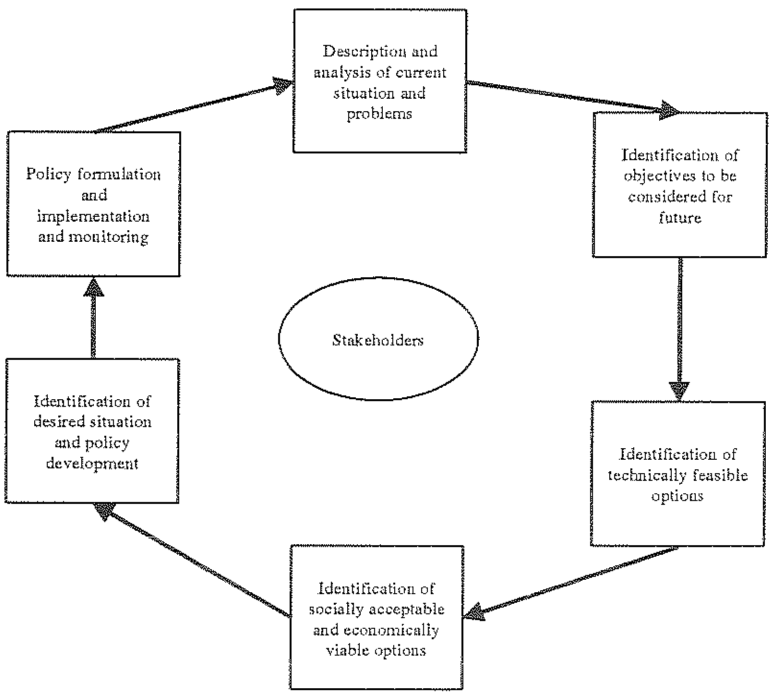

Figure 2. Development cycle of policies for natural resource management.

policy levers exist or may be developed to achieve the physically and politically achievable goals. If this is not the case, as the above list of policy questions suggests, then there is a need to consider the limited power and specificity of policy early in the policy development cycle. One objective of the INSIGHT project can be seen as providing input on policy limitations to the objectives and to this target setting process. How well does the prototype model achieve this?

The above illustration suggests that the INSIGHT prototype is capable of exploring the indirect implications of a single policy change for the various components of the system. While it cannot ensure that all possible connections are taken into account, it does provide a framework for incorporating the various effects and for indicating the timing and extent of the impacts. As such it can aid in the identification and targeting of policies to avoid adverse impacts. It can also readily be used to explore the potential implications of multiple policies.

Conversely, the focus on interactions and system effects means that the model is not suited for detailed analysis of specific issues and policies. Even for rapid assessment, the development of more issue-specific models, perhaps built with pre-existing data sets and modules, would be a preferred option.

Results of INSIGHT, and thus the assessed effectiveness of particular policies, depend on assumptions within the model about biophysical possibilities and their interactions with socio-economic dynamics. The presented illustration, for instance, uses the following assumptions:

- the agri-business farm type uses more intensive cropping and pasture systems than the smaller family and lifestyle farms;
- conservation activities do not differ between the farm types;
- the model can only choose from a limited number of land use types and technologies, with the various technologies having similar water use.

Each of these assumptions may be defended by referring to empirical data on present farming systems. They may, however, also be debatable by arguing that configurations and choices of farmers change (certainly within time frames of 20 years) when new technologies are used to their full potential or markets and policy incentives change. If this is true then the model is likely to underestimate the potential of the system.

So called explorative land use studies as developed in Wageningen (The Netherlands) focus on the optimal land use configurations of systems when prioritising objectives and targets differently [Van Ittersum et al. 1998; Roetter et al. 2000]. They aim to reveal the broadest spectrum of land use options that would optimally satisfy societal aims. Consequences of policies are taken to their logical conclusion. These approaches complement approaches such as INSIGHT by being much more detailed and explicit about optimum land use alternatives. However, while good for setting physically achievable goals, they have difficulties in linking up with development processes that require information on what issues and policy options should be changed today. In other words, the explorative approaches developed in Wageningen tend to analyse optimal destinations but do not provide information on the alternative paths that might be taken. INSIGHT explores these paths but is likely to have difficulties in defining optimal destinations. Evidently the two approaches are complementary in supporting questions and various stages of the policy design cycle. It illustrates the point that a suite of models needs to be developed [cf. Bouman et al. 2000] to support the various questions related to a policy design cycle. Future research must focus on how this complementarity can best be used.

3.2 Interface with the Policy Process

The initial consultation of stakeholders in the INSIGHT project, based on the techniques of systems thinking, has been discussed by Gorddard and Walker [2001]. Work since then has focussed on the development of the model. The trialling of the system with policy makers has not yet occurred.

Walker et al. [2001] describe how the process of operationalising sustainable development challenges the traditional structures and roles of researchers, policy makers, resource users and resource managers. Leeuwis [1999] argues that when talking about the design of natural resource systems we must think primarily about activities and processes rather than products. In his opinion the dominant processes are experiential learning and negotiation. He therefore (re-)conceptualises the 'design of natural resource management systems' as 'joint learning and negotiation about natural resource management'. The idea is that no meaningful change or innovation in systems can be brought about without some degree of effective co-ordination between inter-dependent social actors. Since tensions will inevitably emerge whenever changes are proposed to the *status quo*, such co-ordination requires a degree of shared understanding (on the basis of joint learning) and negotiated agreement. Focussing on the role of science in 'joint learning and negotiation processes', it is evident that there must be a considerable break from conventional practice in agricultural and ecological science. These differences include an intensive cooperation between researchers and stakeholders, holistic rather than reductionist forms of research, and a focus on synthesis rather than on analysis.

The INSIGHT concept had a clear focus on the policy maker as a client and user for this system. Attempting to implement this approach, however, raises several issues. The big ones are:

1) What is INSIGHT's best role - enhancing learning, increasing awareness, enhancing transparency in the societal debate or policy making process, or even influencing outcomes of societal debates, decision or policy making processes? The initial concept of how to engage policy makers was as follows: '... to trial an ongoing consultation process with stakeholders focussing on the development of a shared perception of both problems and consequences of management options', and 'to develop a computer modelling system to support this process by providing policy makers with access to integrating data sets and models, and the ability to systematically track interactions and policy consequences throughout the complete environmental and social system'. This approach to engaging in the policy process is broadly consistent with the views of Leeuwis [1999] and Walker et al. [1998, 2001] in particular, as it conceives of the model as part of a shared learning process. One of the aspects of such a learning process also refers to the stakeholders' expectations about what the model will deliver, and perhaps more importantly, what it will not deliver.

2) How should such a model interface with the policy process? Does it aim at individual learning or group learning? Is there a hard (computer-based) interface, an intermediate computer-based facilitated interface, or a purely soft interface presenting feedback to 'what-if' questions? Results and impacts of computer-based systems are generally poorly monitored and documented. Few successful attempts are known. Experiences from the Netherlands and South East Asia show that soft interfaces [e.g. Van Ittersum et al., 1998] or perhaps intermediate computer-based interfaces at a group level have potential [Roetter et al., 2000].

3) Finally how should we measure effectiveness of an approach? This probably requires a careful social evaluation process. Few, if any, evaluation processes with respect to the use of model-based approaches in supporting policy development for INRM issues are known. The approach and experience as described by Walker et al. [1998] could be helpful here.

3.3 Causality and Uncertainty

A focus of INSIGHT was to look at the long term consequences of current policy options. The reasons for this are that many current actions have effects that take a long time to emerge, such as salinity, and policies that once set in place can be difficult and expensive to change. The need to look say 20 years into the future and focus on how interactions among components of the system may determine the outcomes, means that we need to deal with a high level of uncertainty due to factors which are endogenous (e.g. relationships between geology and salinity) and exogenous (e.g. climate change, national and international policies and markets) to the system. With long time-frames and a focus on interaction between issues, extrapolation of current trends is not useful, particularly when the real questions are about the potential for policies to change the system. Hence a high level of causality in the model is required. Even then, a high level of causality within the model only allows the exploration of behaviour of the system with what-if questions; it cannot provide predictions about the future states of the system [cf. Van Ittersum et al., 1998; Walker et al., 2001]. The what-if questions capture the uncertainty in exogenous factors. For instance the significance of uncertainty in climatic conditions is explored by including a range of historic climate data that can be replayed into the future.

The focus on strategic issues and interactions requiring a highly mechanistic model conflicts with another desired INSIGHT specification, i.e. keeping the model simple and transparent. Hence causality is easily sacrificed for the sake of simplicity. For example, for its intended purpose the model should be more mechanistic in its catchment scale hydrology. This would indeed benefit the model, in that the mechanistic model would reveal added complexities, particularly at the landscape level, that could influence the behaviour of the system. However, given the complexity and large uncertainties surrounding these issues, at least given our understanding of these, there would appear to be a trade-off between a potentially misleading and complex model, and a transparent model that permits the influences in the rest of the system to be linked in a way that makes the assumptions clear.

A review of the present INSIGHT prototype model reveals that it has highly mechanistic components, particularly those related to agricultural production, purely descriptive ones, particularly those concerning conservation issues and farm dynamics, and components taking an intermediate stand, e.g. catchment hydrology. This imbalance in causality of components on the one hand is part of the assumptions that need to be considered when analysing 'what-if' questions, as answered by the model. On the other hand it points to the need for component research and the need to summarize our understanding of systems' behaviour in relatively simple models. As such, projects like INSIGHT contribute to identifying a research agenda for more disciplinary component research.

4. WHERE TO NEXT?

Catchment level decisions are not currently made on the basis of a shared understanding of where the system is headed, or the implications of different policy options for the range of assets in the catchment. The scientific challenge is to make future perspectives in terms of INRM and associated policies more transparent.

The INSIGHT concept contained a wide range of ideas. These include to develop a modelling system focussing on learning about the behaviour of a system, to model catchments as a system, to look at the interactions between spatial and temporal issues, to use modelling to add value to spatial data, to examine the systemic impacts of policy changes, and to integrate across social, economic and environmental issues. Now that a running prototype is available, bench and field testing with stakeholders is required to assess whether it meets (some of) these specifications. We conclude that such a testing project, or any future attempt at developing integrated catchment models, must consider at least three issues:

1. Balance in the level of detail and causality of modelling of various processes and components of the system, as well as their interactions. This is crucial to make the system future-oriented and capable of exploring INRM alternatives.

2. Evaluating the possible use of INSIGHT with stakeholders in development of policies for INRM, and establishing explicit criteria as to how the quality and effectiveness of model-based approaches may be assessed.

3. Different phases of the policy cycle require different scientific approaches for support. Explicit analyses of complementarity of and synergism between various approaches are required.

Finally, addressing these issues adequately is not a trivial task, and requires adequate time and resources.

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