A Conceptual Modelling Framework for Integrated Catchment Management of Salinity

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Abstract; Integrated Catchment Management for salinity is currently a central area of policy concern in Australia. The realisation by politicians and policy makers of the costs and importance of salinity has led to major policy initiatives and spending plans. These focus on the management of catchments as an integrated whole by Catchment Management Boards or Authorities or other bodies depending on State. In New South Wales, the Murray-Darling Basin Commission and the NSW government have initiated a project to support integrated catchment management in the Lachlan and Macquarie catchments (TARGET). This will involve cooperative work by Department of land and Water Conservation (NSW) and the Integrated Catchment Assessment and Management Centre (iCAM) at ANU. iCAM will be responsible for developing a conceptual framework for integrated catchment management involving development of producer profiles, Regional Integrated Management Information Systems and multiperiod models integrating land use, hydrology and salinity management on a land management unit basis within catchments. This paper describes possible modelling approaches to support Integrated Catchment Modelling and presents an outline of the approach planned for TARGET. Future papers will describe progress of the model through to application and regular use in the Lachlan and Macquarie catchments.

Keywords; Integrated modelling; Conceptual framework; Salinity; Integrated Catchment Management

1. INTRODUCTION

The degree of land use change required for mitigating the effects of salinity in some catchments and sub-catchments may need to be extensive. Best management land use options to ameliorate the salinity hazard include farm forestry, increased use of perennial pastures, modified cropping practices and vegetation establishment/retention for carbon trading.

Under recent legislation, the management of catchments in NSW for water and salinity issues is the responsibility of Catchment Management Boards. Some of the challenges facing these new Catchment Management Boards are those of making decisions with limited data and trying not to oversimplify complicated natural resource systems. In particular, there is very limited data on the social and economic profiles of the community.

There is a need to develop and implement innovative actions with major impact on the catchments with limited understanding of the tradeoffs involved and their acceptability to the community. Large changes in resource use are envisaged in some areas. Adoption of these massive changes needs the community and Boards to be more concrete about cost sharing arrangements, market based solutions and social constraints.

The *Tools to Achieve Landscape Redesign Giving Environmental /Economic Targets Project* (TARGET) is a cornerstone project of the NSW Salinity Management Strategy. The TARGET project will facilitate large-scale land use change in catchment areas, which have been identified as being major contributors to Basin wide salinity. These areas are the Lachlan and Macquarie catchments, and in particular, the Warrengong, Mid Talbragar, Weddin and Little River sub-catchments.

As part of the TARGET project, the aim of this project component is to analyse the financial consequences of current and proposed land use options and to better understand the economic factors affecting producer land use decisions in each of the six focus catchments. Economic impediments to land use change will be identified and the impact of a range of incentive schemes assessed.

Farm multi-period investment models will be developed and used to analyse the economic feasibility of current and possible future land use options in the Lachlan, Macquarie and associated key subcatchments. The models will be developed for key enterprises in each of the smaller scale catchments and each of the land management units of the larger catchments. The farm models can also be used to assess the policy impacts at the farm level of incentive schemes, for example, salinity and carbon credit schemes.

2. MODEL TYPES

2.1 Mathematical Programming Models

Linear programming (LP) is an optimising technique with a well-established record for modelling agricultural and other systems. For a farm modelling exercise, LP can be used to derive the most profitable combination of enterprises based on the resources required and available to each enterprise as well as prices of inputs and outputs [Makeham and Malcolm, 1998]. It has a number of advantages including the capacity to represent a major change in the way a system operates, such as the introduction of water trading into Australian irrigation systems. In addition, the components of linear programming models can be broken down into manageable segments that can be discussed and checked with industry experts. An example of such a segment is the expected yield of rice in a given region under particular conditions.

Some of the disadvantages of linear programming are the mass of data that can be needed and the difficulty of validating the modelled results. Unlike an econometric study, there is no simple measure of goodness of fit for a mathematical programming model of a system.

MIDAS models are whole-farm, profit maximising linear programming models developed by Agriculture Western Australia and the University of Western Australia. MIDAS models use detailed biological and economic relationships to analyse interactions between enterprises on farms. MIDAS has given rise to the PRISM models in NSW and Victoria and MIDAS-EP in South Australia, MIDAS has been used in salinity research in WA [Petersen, et al., 2001; Pannell, 1996].

SMAC is a multi-period linear programming model developed as a strategic research tool for the Liverpool Plains of NSW by Romy Greiner. SMAC makes allowances for seasonal variability, feedback between landuse and water tables and productivity [Greiner and Cacho, 2001].

2.2 Spreadsheet Based Models

The development of spreadsheets such as Excel has made it relatively easy to develop models capable of calculating or solving a wide range variety of financial and statistical functions.

A further advantage of spreadsheets is that their workings are relatively easy to understand and allow relatively quick construction of models. These attributes can be helpful for extension work or where the model is to be used for practical catchment planning. A simple spreadsheet model can facilitate communication and open up discussion that would otherwise be inhibited by more technically sophisticated modelling approaches.

However, because spreadsheet models are relatively easy to build they often have a relatively short operational life. This can be for reasons such as being built for a short-term specific purpose and a lack of program staff continuity. Models which may have been state-of-the-art a few short years ago are now more often than not obsolete. An example is the FARMULA model. Developed in Western Australia and used in a number of salinity analyses [Morrissey, et al., 1996], this model has not been redeveloped since 1996.

Examples of spreadsheet based models included in the West Australian modelling database [WADA, 1997] are:

- SALTPLAN, a catchment or farm scale model developed and used by Agriculture Western Australia;
- FARMTREE, developed by Agriculture Victoria, evaluates the costs and benefits of trees on farms;
- AGROFORESTRY CALCULATOR, developed by Agriculture Western Australia, is another investment analysis model used to evaluate the economics of agroforestry options.
- The Carbon Farmer Model, recently developed by Hassall and Associates for RIRDC, is an example of a similar model developed for carbon management [RIRDC, 2000].

2.3 Simulation Models

Simulation models attempt to reproduce the structure of decisions and feedback in farming and natural systems and are usually based on a specific simulation language. Researchers with a natural science background often prefer simulation models because they allow relative freedom to represent environmental processes in reasonable detail. In general, simulation models take better account of biological and hydrological feedbacks than either mathematical programming or spreadsheet models.

The major disadvantage is that simulation models can become very complex and require specific programming skills to construct and interpret. There may be an element of the black box syndrome for unskilled users that in turn may deter widespread use of the model and reduce the value of simulation as a discussion tool.

The Australian Bureau of Agricultural and Resource Economics (ABARE), in cooperation with the MDBC and CSIRO, have developed a simulation modelling framework that incorporates the relationships between land use, vegetation cover, surface and ground water hydrology and agricultural returns [Bell and Heaney, 2000].

Another example of a simulation model developed for salinity management is INSIGHT, a catchment model still under development by the CSIRO division of Sustainable Ecosystems. This is a highly complex simulation model attempting to take account of social, economic and biophysical issues in catchment management.

3. MODELLING ISSUES

3.1 Model Levels

Modelling of systems can be carried out at a variety of levels or scales. In the farm and natural resource modelling context, the key levels are paddock, farm and catchment. A regional level is sometimes used instead of a specific catchment.

A paddock is usually the smallest management unit of land and is often used for biological or hydrological modelling. Small paddocks or plots allow for accurate measurement of parameters and subsequent modelling based on well-defined responses and feedbacks.

The farm is the common management unit for agricultural land use. It is mostly at this level that economic and social variables are included in models. Variables such as income, taxation and family structure as well as the farmers' interests and skills, all affect the way that land is used on a farm and the way that the system responds. Farm management modelling and modelling focused on the managers role has to be focussed at farm level.

Catchment level modelling is particularly important for assessing the broader scale implications of hydrological processes. In the TARGET project, there are two relatively small sub-catchments (Warrengong and Mid-Talbragar) and two medium sub-catchments (Weddin and Little River). These four sub-catchments are among many others that in turn make up the Lachlan and Macquarie catchments.

The TARGET project modelling needs are at three main scales or levels—farm level, small/medium catchment level and large catchment level. Different models may be appropriate at different levels. In particular, the two large catchments may require a different approach than that for the farm and the small/medium sub-catchments.

3.2 Time Span

The time span of models is the number of years that they represent. Some models represent only a single period while others simulate large numbers of periods. Some models define different periods for different systems, for example, hydrological data may be daily and income data annual.

Single period models may represent an actual single period such as one year, in which case they are referred to as short-term models. Alternatively, they can represent a long run steady-state situation that abstracts from year to year variation and the lags between management decisions and outcomes. This approach allows comparison of the end state of the system under different scenarios to be made with the minimum size of model. However, where the lags periods are long the time to a steady state may be too long for sensible analysis. In addition, steady state analysis does not give any insight into the path of adjustment. Nevertheless, steady state models can be an economical approach when the time path is not important.

Farm management models often have a within year component reflecting pasture productivity and the limited availability of labour and machinery at key times. This may be combined with single or multi-year farm financial modelling.

Multi-year farm management models typically are run over 20 to 30 years to allow them to come to a steady state. This is important for long-term investments such as tree crops and to take account of gradual changes to watertables and salinity levels. Both spreadsheet and programming models can be operated as multi-period models.

Hydrological models are usually run in periods of days rather than years. When hydrogeological models are combined with farm management models the result will be two separate (but nested) systems of multi-periodicity. This can be complex to model and have heavy data needs if for example, daily rainfall over a period of years is to be included.

3.3 Focus

A model is a tool for investigating a particular problem. Although it appears to reproduce the actual system, it is only a numerical representation of ideas and hypotheses about how that system works. The system itself can be approached from different disciplinary perspectives but no single discipline can fully describe the whole system.

A major issue in multi-disciplinary models is lack of "evenness" of modelling. Thus, for example, economists can model the economic system in detail but need assistance to model the hydrology. A team of hydrologists, in the same way, may build a good hydrological model but require assistance from economists and agronomists to produce a balanced model of all three aspects of the system.

These weaknesses are inherent in a system of specialised disciplines and require purposeful interaction between disciplines to ensure that all the important aspects for the model are adequately covered. This interaction must involve all the processes of model design and development so that the model is based on an integrated understanding of the whole system rather than being a series of single discipline models welded together in the final stages.

3.4 Financial Objective

Models may be focussed on farm incomes and cash flow rather than biophysical criteria. These income measures are key inputs to an understanding of the socioeconomic position of farmers. Income and cash flow modelling emphasises short-term economic and financial issues and is most appropriate for changes in prices or marketing systems. It will not readily accommodate an analysis that involves long lags in responses.

A discounted cash flow criterion such as Net Present Value (NPV) is a long-term measure of economic performance that calculates financial outcomes over a period of years. NPV is particularly suitable for comparing the returns to investments such as timber where costs are incurred during the initial years of the project while returns occur years in the future. Multi-period models normally present NPV as the main economic indicator that can be used to compare scenarios.

Although NPV is a valuable indicator of long-term performance, individual farms have limits to their borrowing capacity and a need for consumption each year. This constrains their capacity to take on investments that provide no income for a long period. It is normal to build such constraints into multi-period models since otherwise NPV may give a misleading picture of which are the most profitable investment options.

3.5 Hydrology

Salinity management depends on a good understanding of the hydrology of the system modelled. In some models, this is built into the simulation system as a feedback mechanism. In others, feedback may be limited to estimation of accessions to the groundwater under each scenario modelled without attempting to estimate the impact of the accessions on salinisation within the model. The decision on this issue will have major effect on the complexity and usefulness of the model.

3.6 Other Environment Processes

Hydrology and salinity are not the only hydrological processes, other environmental issues can be modelled as well such as soil erosion and soil acidity. Each environmental process has a different causal mechanism and therefore taking account of several land degradation processes will necessarily increase the complexity of any model. Conversely, the fewer environmental processes taken into account the less complex the model. However, a model that focuses on one process only, for example salinity, may lead to neglect of any interrelationships between a number of processes and inadvertently lead to the promotion of solutions that could reduce the impact of one problem while at the same time making another worse.

3.7 Integration and Feedback

Models can differ in the degree to which consequences of decisions are modelled. In the simplest models, only the direct impacts will be modelled. In more sophisticated models, there will be very complex pathways linking for example, land use changes to groundwater accessions, future salinisation and yield impacts and their financial consequences. Different model types handle these feedback loops differently.

The effectiveness of modelling feedback depends not only on the model but also on how good the understanding of the feedback loop may be. If there is little data in a catchment to model groundwater movements and salt mobilisation, then sophisticated modelling of the presumed feedback loops may not be very productive. However, even poor modelling based on limited data may still highlight potential problems with one or more management options.

Models vary in the degrees to which they integrate economic and biophysical systems. Some models attempt to encompass the whole of the relevant systems in a single system that can generate “answers” to a full range of issues, including economics, agronomy and hydrogeology. The problem with this integrated approach is the complexity of the resulting model.

The different spatial and temporal scales that the different disciplines normally use increase the complexity. In addition, the process of integration is likely to require compromises in the representation of particular systems to fit the whole system. Such compromises are needed for any numerical model but deciding on the degree of simplification is made harder when several disciplines are involved.

A simpler approach is to model some aspects independently. For example, economics and agronomy could be modelled together but the hydrogeology could be modelled independently. Where this approach is adopted however, care needs to be taken to incorporate the relevant outputs and feedbacks between the various models.

4. CONCLUSIONS

This paper reports on the preliminary stages of a project to model the impacts of changing land management on farm income, production and salinity. Selection and development of a suitable model and initial analyses are planned for the second half of 2001. This will allow some preliminary results to be presented at MODSIM2001.

The modelling is a key part, but only a part, of a large integrated research and implementation process. TARGET aims both to implement significant change in land use in selected catchments and to simultaneously develop research. The research strategy is to support implementation by predicting and monitoring outcomes and to influence the choice of landscape changes by assessing their impacts and comparing the costs and benefits for social, environmental and economic sustainability.

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