Integrating Catchment Hydrology and Farm Management in a Programming Model for Policy Analysis

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Summary This paper outlines the framework of a model presently being developed for the quantitative assessment of policies directed at enhancing environmentally sustainable and financially viable agricultural land management. Specifically it is about managing water tables on a catchment scale to deal with dryland salinisation. This has become a significant resource degradation problem in Australia. A mathematical programming approach is chosen to address the problem from a resource allocation perspective and to investigate linkages between long-term resource sustainability and the financial viability of farming. The complex interactions between the hydrogeological conditions in the catchment, farming structures and land management practices, land salinisation, and economic and policy conditions are integrated within a long-term time frame.

1. INTRODUCTION

In Australia, the salinisation of soils is on the increase as a result of land use practices which have altered the hydrological balance of catchments and caused saline water tables to rise close to the soil surface. Successful management of water tables in dryland catchments requires changes in land management. Catchment-specific strategies need to take account of present and potential agricultural land use systems and hydrological processes driving the salinisation process.

Areas within a catchment contribute different rates of recharge water to the groundwater system and they are affected by the resulting water table rise to varying degrees. Depending on their location, landholders can generate and face different levels of costs from rising water tables and associated soil salinity. These costs vary depending on the agricultural productivity of the land, which is reflected in the production systems and farming structures in place. Costs which are imposed outside the boundaries of one farm on to others are classified as negative externalities.

"Fundamental to managing salinity is an understanding of the economic impact of both the problem and the solutions potentially available" [Robertson 1995].

If policies are to be developed to enhance the implementation of long-term sustainable land management systems, a holistic approach must be taken. There are two aspects to the problem. The first is to identify the physical linkages between farming practices, rising water tables, and the costs (benefits) of lost (improved) agricultural productivity. The second is to understand the economic incentive structure of existing and proposed policies which may act to impede or facilitate the catchment-wide adoption of land management practices. Farmers who export their recharge to other areas face no economic incentives to change current land use practices. Despite reductions in land productivity from increasing salinisation, farmers in the discharge areas are often reluctant to abandon hitherto profitable land use systems and practices.

An analytical framework for linking farm-level decision making and regional hydrological process description into a catchment-scale equilibrium model is presented in this paper. The model is currently under development. It draws extensively on data generated by research into soils, hydrology, and agronomy. Mathematical programming is used as a technique for assessing policy alternatives related to land use. Optimally, these policies internalise the costs associated with salinisation on a catchment wide basis. The aim is to develop strategies for encouraging landholders to participate in a catchment management strategy that will promote the environmental sustainability of agricultural production in terms of water table management as well as maintain the financial viability of farming. The methodology is applied in a case study in the Liverpool Plains catchment in New South Wales.

2. REQUIREMENTS OF CATCHMENT-SCALE MODELLING

Development of an analytical framework for water table management in a catchment context poses a range of problems. Greiner and Parton [1995] emphasise in particular the following aspects: First, it is essential to account for the fact that land use decisions are taken at the farm level. While a gross-margin analysis may provide useful scoping information, only a whole-farm budget can determine the absolute and comparative financial feasibility of land management options by taking account of capital and cash flow constraints.

Second, salinisation is characterised by time lags and spatial effects between cause and effect. The formulation of the physical mechanisms that lead to externalities associated with dryland salinisation must be an integral part of the modelling framework.

Third, land use activities are the major decision variables that influence the hydrological balance because there are different levels of recharge associated with different crops. Furthermore, salinity has a varying impact of different crops, hence returns and the economic incentives for alternative land use decisions are affected. Thus, there is a major feed back relationship inherent in the productive land use - salinisation system which is the essence of any inter-temporal analysis (Greiner 1994).

Fourth, accessions to the groundwater system are strongly influenced by sporadic recharge events which occur after prolonged and heavy rain [McDonald 1995]. Rainfall variability is a major intricacy of the salinity problem and is a major external variable to the system. Hence there is an element of risk associated with alternative management plans in that one may need to consider costs and benefits in the context of the likelihood of extreme rainfall events.

3. METHODOLOGY

3.1 Model Type

The complexity of the salinity management issue and the objective of gaining a quantitative understanding, necessitates systems analysis via modelling. There are a range of modelling techniques and the choice of technique, as well as the details of model construction, have to be case and objective orientated. The model needs to be a comprehensive, pertinent and operational representation of reality which grasps the essential elements and mechanisms of the system and allows investigation of policy questions [Braat and Lierop 1987]. The model must also reflect the perspective of stakeholders, in particular farmers, if it is to secure acceptance and implementation of the research results.

The model outlined here is aimed at investigating policies that promote the adoption of land use options for water table management. In the first stage, an optimal situation is to be identified. Once an understanding is established of (1) how natural resources are optimally distributed and utilised in the regional context and over time, and (2) what is the rate of soil salinisation associated with the optimal strategy, then scenario modelling can show how policies may influence the transition process. In defining an optimal outcome, a normative approach which maximises the region's long-term welfare from the use of its natural resources is used. Individual policy scenarios are developed separately that demonstrate the effects of the resulting optimal choice and timing of land use practices in a context of bio-physical, economic/financial, agronomic and sociological constraints that describe the system's framework.

3.2 Farm Model

Farmers are the main agents in land use decision making. Income expectations from different enterprises represent the pivotal motivation for on-farm land and financial management decisions. Emerging soil salinisation interferes with the flexibility of this framework in various ways. The range of land use options is reduced, land management becomes agronomically more difficult, and the value of land may be diminished.

The Model of the Farm Economics of Dryland Salinity (MoFEDS) was developed to investigate the implications of soil salinisation on dryland farms [Greiner 1994]. MoFEDS was applied to a situation where farmers in the salinisation zone in the Liverpool Plains catchment seek to develop an optimal path of developing on-farm land use while coping with emerging salinisation on their land [Broughton 1994].

In a multi-period context, MoFEDS investigates trade-offs between the income (after tax and debt repayments) of a model farm and the salinisation occurring on the property in scenario experiments that reflect the range of hydrological conditions applicable in the area. The results lead to an evaluation of the model farm with respect to its long-term financial viability and environmental sustainability [Greiner 1994]. MoFEDS is a multi-disciplinary model and integrates bio-physical modules into the core structure of the farm management model through a feedback structure [Greiner and Parton 1995].

A soil-hydrology and crop growth simulation model is employed as a bio-physical submodel which supplies coefficients for the optimisation model. Within the MoFEDS optimisation framework, a three dimensional water balance module simulates the implications of land use, rainfall and hydrogeological conditions on the development of the water table. The farm water balance is translated into water table movement. The calculated water table then determines the area of salt-affected land on the farm which in turn influences future soil productivity and land management decisions.

3.3 Catchment Model

MoFEDS serves as a the basis for developing a catchment model. A spatial equilibrium model is being developed for the Liverpool Plains that interconnects the activities of the farm units in the area. Whereas MoFEDS assumed hydrological conditions to be external variables to the single farm model, the catchment model includes spatial data sets which endogenously define these very conditions (Figure 1).

The spatial data are linked to a grid structure that is superimposed on the catchment map. It operates as a data base similar to a Geographic Information System (Figure 2). The most relevant information here is the distinction of areas within the catchment that have similar contribution, relevance, and disposition to the development of soil salinity. Broughton [1995] identified six hydrogeological provinces for the Liverpool Plains. The model includes best available information on the quantitative components of regional groundwater flows between these spatial units over time. A comprehensive ABARE farm survey and a special landholder survey provided data on farming structures, aspects of financial management and land use practices [Ockerby 1995, Hall *et al.* 1995].

While the hydrological properties over the catchment are relevant, land productivity in agricultural terms is equally important for developing a catchment management strategy. This aspect is captured in the soil-landscape mapping that has been completed for part of the catchment [Banks 1995]. Soil landscape mapping is currently being extended to the rest of the catchment. In combination, these two spatial data sets are used for developing unique mapping units. These areas are treated as homogeneous for the purpose of a catchment modelling exercise [Johnston *et al.* 1995].

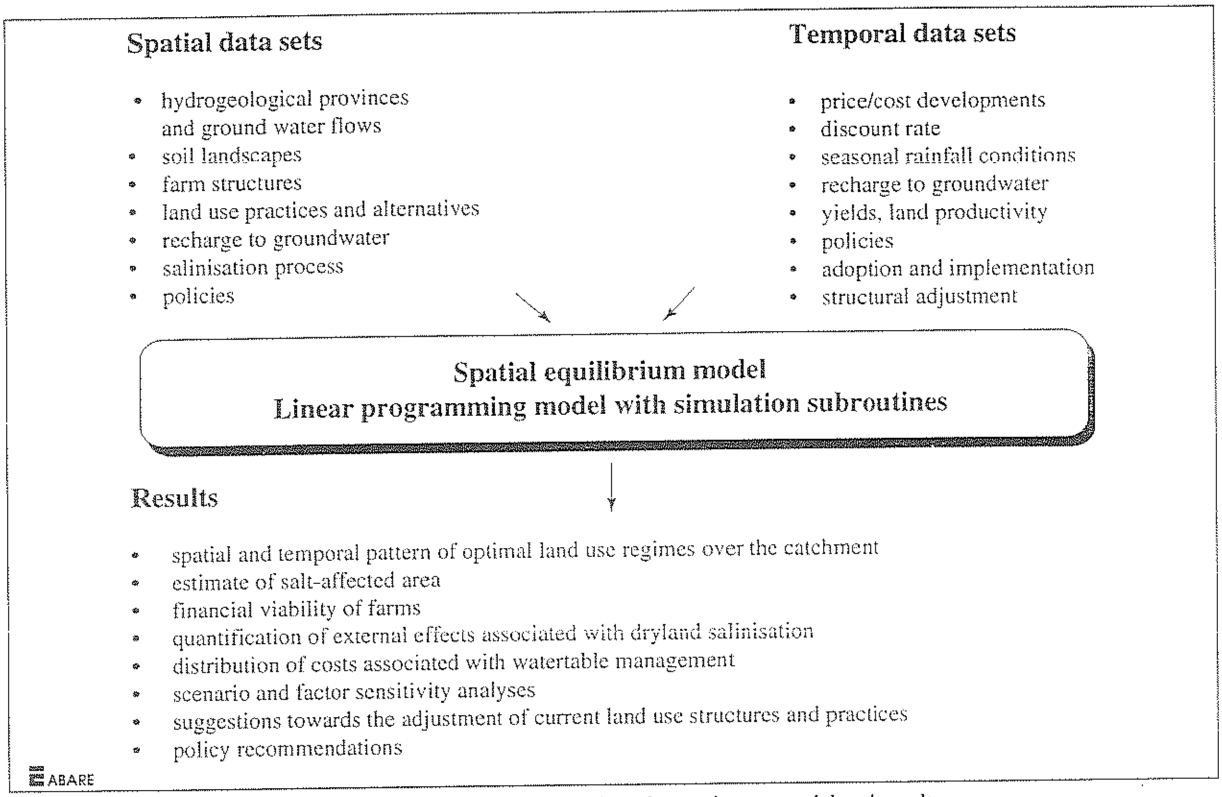

Figure 1: Integration of data sets into the catchment model and results

Different sets of land use options and production systems are feasible for the unique mapping units. A simulation modelling system is used to calculate deep percolation and soil erosion for the various land use options on these landscapes [Keating *et al.* 1995].

All data sets have a temporal dimension to account for the long-term character of the catchment management issue (Figure 1).

The essential impact of climatic variability on salinity development and farm incomes is captured in a discrete stochastic programming approach which is a constituent element of the MoFEDS model [Greiner and Parton 1995]. For winter and summer, three season types are distinguished (wet, average, dry), depending on total rainfall during the season. The rainfall conditions over the optimisation period can be randomly generated or chosen deliberately. The simulation modelling system employed to quantify land use, crop yield, and recharge relationships [Keating *et al.* 1995] is used to generate these very parameters for the specified seasonal rainfall conditions.

Other temporal data sets include policies and adoption behaviour of the farming community. Price trends for prices and costs are assumed and price elasticities for certain crops such as lucerne are accounted for to capture the regional character of their markets. A schematic overview of the elements and mechanisms that drive the catchment model is shown in Figure 3.

The spatial equilibrium model performs an optimisation of the total discounted regional income from agricultural land use in the catchment as generated by the farms [Hall *et al.* 1995]. Allowance is made for degradation of the catchment's natural resource base through soil salinisation. Salinisation reduces the regional income through the feedback relationships adopted in the model (Greiner 1994). The rationale for such an equilibrium approach is documented in

Salerian [1991] and its applicability for this research is explained in Section (1) of this paper.

3.4 Potential and Limits of the Approach

The spatial equilibrium approach can provide a useful tool for answering a range of questions. What land management strategies are optimal for the catchment? Which options constitute the optimal spatial and temporal mix? How does the optimum differ from the current situation? What is the optimal degree of soil salinisation in the catchment? Would the regional income from agriculture be increased if landholders in the recharge zones of the catchment internalised the costs associated with salinity caused by recharge from their land? What impact does climatic variability have on regional farm incomes and the incidence of salinity? Do policies enhance the adoption of recommended action for the sustainable management of water tables in the catchment?

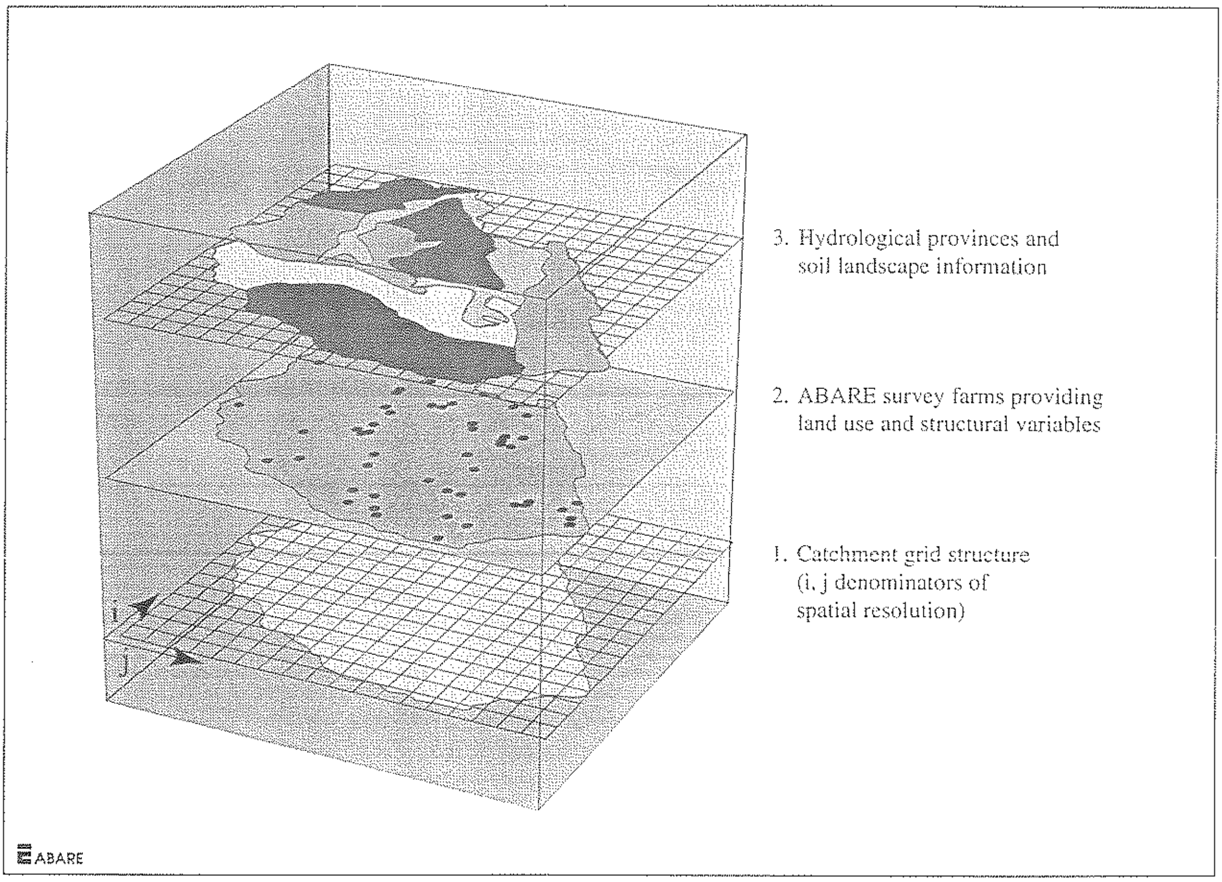

Figure 2: Integrating spatial data sets into the catchment model

The answers to these questions may help in the design of policies and programs on a state, federal and local policy level and may assist catchment management groups in assessing specific strategies.

Stakeholders in the Liverpool Plains are the source of the main proposals to be investigated. These proposals are being developed in consultation with Landcare Groups and the Liverpool Plains Land Management Committee (Dickson, K., personal communication, 18 July 1995).

Despite its potentially versatile applications, the catchment model does have limitations which are due to the methodology, to assumptions, and to the focus of the analysis. Given the long-term character of the analysis, data uncertainty increases with time, particularly with respect to economic coefficients. This reduces the predictive potential of the model but does not affect the prescriptive power when extensive sensitivity testing of economic and hydrological parameters is done.

The constrained income optimisation approach has to be interpreted as a proxy for a myriad of philosophies and paradigms [Hooper 1995]. There is sufficient evidence that profit and income generation are the major motivation for business-orientated farmers [Young *et al.* 1990]. By formulating adequate decision rules, other goals that landholders may pursue are incorporated.

In its current form, the model focuses on catchment related salinity management and declining soil productivity from salinisation. It will not assess the damage of salt exports out of the catchment neither does it account for damage to farm or community infrastructure. The model also neglects the issue that landscapes serve functions other than agriculture, such as nature conservation and recreation. Different approaches may be necessary to integrate the conservation issue [Faith 1995].

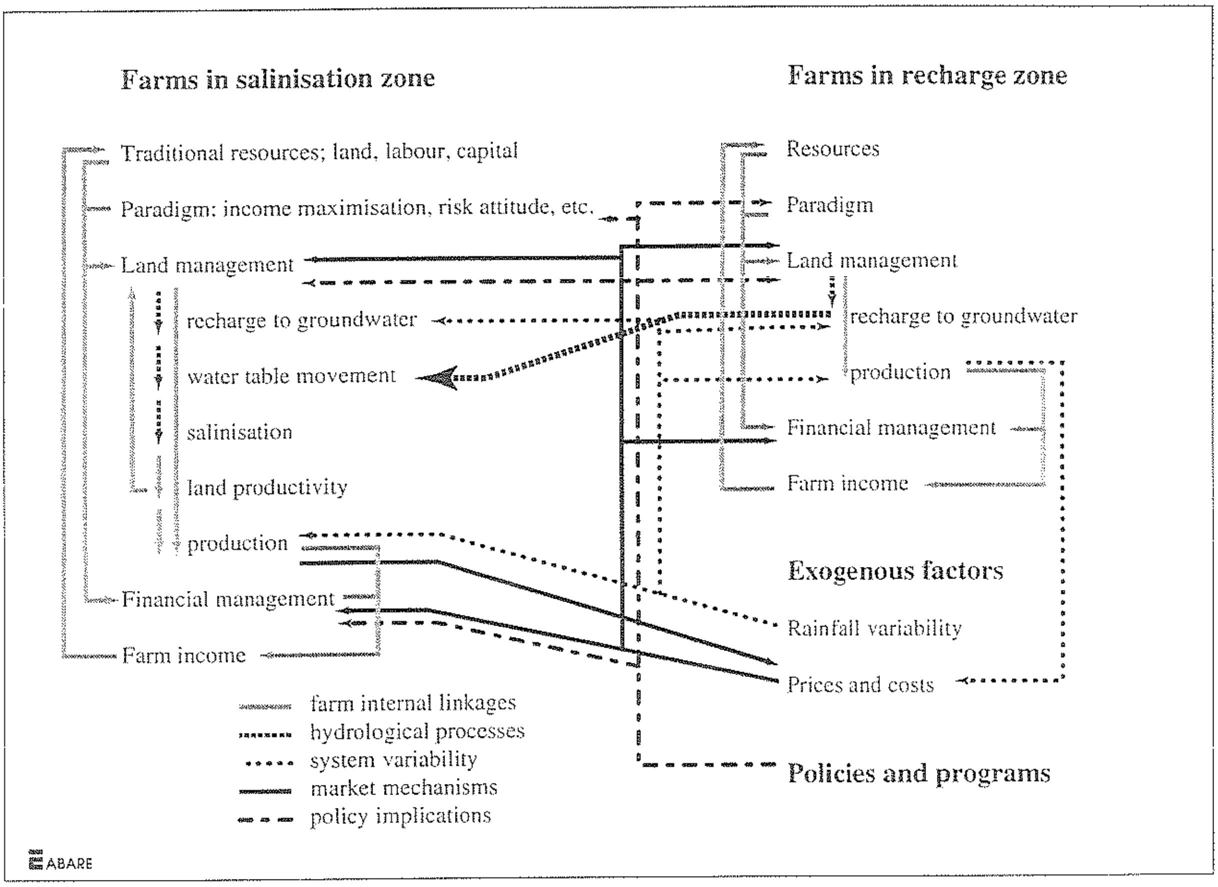

Figure 3: Essential elements, factors, and relationships considered in the catchment model

4. CONCLUSIONS

This paper introduces the concept and constituent features of a catchment model for promoting sustainable catchment management. The model integrates the bio-physical and socio-economic aspects of land use that are relevant to addressing land and water management at the catchment scale. The intention is to use it for assessing the effectiveness of land management options proposed for the management of dryland salinity, and for investigating the potential role of policies in facilitating the implementation of sustainable land use practices in a catchment context.

The spatial equilibrium approach combines two process levels. It acknowledges that land use decisions are made at a farm level, given specific economic and financial conditions, and that these decisions tend to follow economic motivations. Land management links with catchment-scale hydrological processes that drive dryland salinisation. Land use options vary in their water use efficiency which regulates accessions to the groundwater system and consequently soil salinisation. In turn, emerging salinity impacts on soil productivity and the land use options that are potentially available to farmers. The farm units within the catchment are linked spatially and temporally through hydrological and market mechanisms, so that the optimal solution internalises the costs associated with water table management. While the methodology is transportable, the model is parameterised for the specific conditions in the Liverpool Plains in northern New South Wales.

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