Policy Options for Dryland Salinity Management: An Agent-Based Model for Catchment Level Analysis

Keywords:

Technology adoption, landholder heterogeneity, interdependencies, policy analysis, agent-based model, spatial model

Shamsuzzaman Bhuiyan
School of Agricultural and Resource Economics
University of Western Australia
CRAWLEY WA 6009
AUSTRALIA

Tel: +61 8 6488 2536
Fax: +61 8 6488 1098

Abstract

Dryland salinity management requires the integration of hydrologic, economic, social and policy aspects into an interactive method that decision makers can use to evaluate the economic and environmental consequences of alternative land use/management practices as well as various policy choices. This requires that modelling frameworks be open and accessible to a range of disciplines as well as allowing flexibility in exploration in learning or adapting. This interactive method will present the development of a new integrated hydrologic-economic model in the context of a catchment in which land use change is the dominant factor and salinity emergence due to land use and land cover change presents a major land and water degradation problem. This model will reflect the interactions between biophysical processes and socioeconomic processes as well as to explore both economic and environmental consequences of different policy options. All model components will be incorporated into a single consistent model, which will be solved in its entirety by an agent based modelling (ABM) approach. Agent-based Modelling (ABM) will allow to incorporate features that are necessary for a realistic representation of economic behaviour and interactions among resource managers.

Introduction

Dryland salinity, a consequence of land use and cover changes (LUCC) is a growing problem in Australia because of threat to agriculture through the loss of productive land; to roads, houses and infrastructure through salt damage; to drinking water through increasing salt levels; and to biodiversity through the loss of native vegetation and salinisation of wetland areas (WASI 2003). The problem can be alleviated by introducing land use options such as plant based solutions, engineering choices, and/or adaptation to saline conditions. Implementation of dryland salinity management options by different farmers and on different farms results in differentiated water table responses due to heterogeneous landscapes. However, the likelihood that many of the treatment options being adopted is low because they are economically unattractive. The costs and impacts vary among locations. In economic terms, salinity is a problem of market failure due to externalities from one farmer to another and from the farm sector to the non-farm sector (e.g. Pannell, 2001). A farmer's uncertainty about the performance of all alternative approaches makes adoption of improved practices slow and limited (Pannell, 2001). Delaying adoption may lead to yet higher costs through the spread of salinity.

Management of dryland salinity in a heterogeneous landscape depends upon the characteristics of individual farmers and the way they interact with each other and with the environment. Farmers differ in awareness, aspiration, resources, spatial location and attitudes. Landholder specifics and interactions impact on human decisions about land use (Curtis et al. 2000). However, heterogeneity in both biophysical and socioeconomic factors, and interdependencies among the human decision makers acting on the landscape, make a difference: outcomes can be very different compared to homogeneous conditions.

To date, there have been no studies on dryland salinity management options for catchments where heterogeneity and interactions among farms are taken into account. The proposed study aims to address this major gap in the current literature and provide a tool for evaluating policy options for salinity management under more realistic settings. This study will employ a spatially explicit catchment level agent-based model. Agent-based modelling (ABM) is a promising new alternative to more traditional economic analysis.

Agent-based modelling (ABM) involves the construction of an artificial society representing the actors in the real system under study (Epstein and Axtell 1996). It is akin to conducting experiments *in silico* (Tesfatsion. 2002). An agent-based model consists of a population of artificial agents representing the real economic agents as well as the physical and institutional environments within which these agents interact. Spatial and behavioural heterogeneity, interaction among agents as well as physical space can be easily incorporated within the ABM framework.

Modeling of human decision making with heterogeneous biophysical processes for assessing dryland salinity over time and throughout space requires a spatially explicit and integrated hydrologic-economic model. While decision support tools for spatially explicit modelling that appropriately recognize biophysical heterogeneity are now commonly used in hydrology and other scientific research, economic modelling remains non-spatial and heavily dependent on models that are not capable of incorporating the heterogeneity of farmers. The approach proposed in this research provides for a more accurate evaluation of the performance of different policy instruments by incorporating the spatial and social elements that impact on their effectiveness.

Objectives

The management and planning of a dryland catchment requires an interactive method that decision makers can use the knowledge about the spatial and temporal interactions between economic and environmental processes and how these interactions are altered by changing land uses at the catchment scale, to evaluate the performance of dryland salinity management options. Knowledge and information from socioeconomic and biophysical processes in a dryland catchment are integrated into an interdisciplinary hydrologic-economic model. A graphical user interface enables decision makers to generate scenarios, change farming systems, run the models, and view results.

The main objectives of this investigation are to

- provide the context for establishing an interdisciplinary approach to problem solving in natural resource management, and

- discuss the functionality of each component of the Hydrologic-Economic Model and how it contributes to the decision support tool.

The specific objectives of this research include:

- Developing an ABM (Agent-Based Modelling) model of a catchment capable of simulating the dynamic interactions between policy instruments, land use practices and hydrologic processes. This will consist of two separate modelling systems: a hydrologic model with a paddock-level resolution and an economic model with a farm-level resolution.

- Evaluating the performance of alternative policies using the ABM model. The criteria for policy evaluation will include salinity targets, economic efficiency and equity relating to the distribution of benefits and costs across the catchment; and

- Providing useful guidelines for the classification of catchments, as well as insights into the design of innovative policy approaches to dryland salinity management.

Literature Review

The aim of this section is to introduce the key issues in salinity modeling at catchment level to develop alternative management options that lessen the economic, environmental and social impacts of dryland salinity.

Policy Options and Dryland Salinity

This review is conducted to focus on policies that might enhance the adoption of best practices for dryland salinity management. These best practices include agro/farm forestry; deep open drains, replacing annual pastures with introduced perennial pastures; better management of native grasslands; retention and management of remnant native vegetation (RNV); revegetation of cleared areas with native species (MacKay et al. 2000); and planting of salt tolerant species such as saltbush and bluebush, aquaculture and other commercial uses of salt water that are also of interest to some farmers (Kingwell et al. 2003)

Tree planting in a catchment can significantly affect the spreading of spread of salinised land, reduce productivity losses and salt loads in rivers (Heaney et al. 2001; Herron et al. 2001; Walpole and Lockwood, 1999; and Hill, 1997). However, the impacts of widespread reforestation have been reported elsewhere and indicate it may not be a cost effective mitigation option given average characteristics of a catchment (Heaney, et al. 2000). According to Hajkowicz et al. (2001) effective solutions may require changes to land use practices and production activities over whole catchments or drainage basins. In economic terms, salinity as consequences of land use and land cover change is a problem of market failure due to externalities from one farmer to another and from the farm sector to the non-farm sector (Pannell, 2001a). There is therefore a role for Government to play in reducing environmental problems in agriculture, although the existence of market failure does not automatically require Government action. Such action should only occur where the social benefits of taking action outweigh the costs of doing so. Market approaches such as tradable permits have the ability to place a monetary value on activities responsible for environmental degradation, and can create markets to balance the consumption and production of a resource (AGO 1999). The VCG (2000) recommended that markets would be desirable for the management of dryland salinity, and suggested incentives such as salinity credits for salt load reductions and recharge credits.

Kuginis and Daly (2001) have reviewed the technical impact of plant based options on dryland salinity and addressed the question as to whether trees and other types of perennial vegetation can save catchments from salinity. They have mentioned that the impact of vegetation management depends on the relevant constraints: hydrological setting, amount of catchment revegetated, location within the landscape, depth and salinity of the water table, planting density and age of vegetation, soil type and climate.

A number of dryland salinity management options are in use around Australia. However, their adoption has been primarily based on their production and profit advantages compared to alternative systems. Their contribution to management of the water table may have been considered, but in most cases as a secondary factor. As reported by Bell and Heaney (2000), the costs and benefits of salinity management will vary between catchments due to differing climate, geo-morphology, soil characteristics, land cover and land management options. Consequently the most appropriate policy instrument and degree of landscape intervention required to meet salinity targets will vary between catchments. An assessment of the likely impact of intervention strategies will need to be considered taking into account downstream benefits and costs. This requires the use of models to evaluate the complex interactions and multiple outcomes arising from landscape intervention.

Agent Based Modelling (ABM) Studies in Natural Resource Management

The use of modelling based on multi-agent systems (MAS) for tackling natural resources and environmental management issues has been steadily growing steadily (Bousquet 1999). Publications relating to its use have appeared in scientific journals such as JASSS (Journal of Artificial Societies and Social Simulation) as well as in workshops and seminars, MABS (Multi-Agent Based Simulation) (Sichman 1998) and SMAGET (Multi-Agent Models and Systems applied to the Management of the Environment and the Territories in English) (Ferrand 1999). Simulation models are increasingly used as decision support tools. In the case of natural resource management, a decision is seldom the result of one hypothetical decision-maker; it is rather a matter of interactions between several stakeholders (Weber 1995).

Simulation models have been used to evaluate the impacts of a variety of land-use policy instruments. Each of them represents the land-use state at each location and the variables and processes that determine that state. An important next step in the evolution of land-use models, and improving their usefulness for policy scenarios, is directly representing the heterogeneous set of actors in the land-use change process (Page, 1999), their decision making processes, and the physical manifestation of those changes on the landscape. Agent-based models (ABMs) serve as tools for this purpose. Otter et al. (2001) presented an ABM of land development that includes a reasonable representation of the different types of agents and that makes an initial contribution on which further developments in this area might build. Furthermore, experimentation with this kind of model can improve our understanding of how the interaction between landscape characteristics and the preferences and behaviors of agents might influence ecological functions and diversity.

Agent Based Modelling (ABM) techniques explicitly incorporates human processes by addressing the complexity of time, space, human decision-making found in the real world situations, because of their uncertainty behaviour in land-use/land-cover change. ABMs are computer representations of systems that are comprised of multiple, interacting actors (i.e., agents). In a land-use/cover change (LUCC) context, agents can include land owners, farmers, collectives, migrants, management agencies, and/or policy making bodies, all of whom make decisions or take actions that affect land-use patterns and processes. By simulating the individual actions of many diverse actors, and measuring the resulting system behavior and outcomes over time (e.g. the changes in patterns of land cover), ABMs can be useful tools for studying the effects on land-use/cover

ABM simulation models are increasingly used as tools in aiding policy makers, concerned with the management of water tables and catchments, to project short-term land use and land cover change (LUCC) (Manson et al. 2000). It determines the effects of different types of controls (Berger, 2001) and also generates data used in communicating with relevant stakeholders. (Feuillette et. al. 2003). Agent based modelling in LUCC is also used to understand the complexity of heterogeneous human behaviours in an ever-changing environment that is characterized by interdependencies, heterogeneity, and nested hierarchies among both agents and their environment (Arthur, Durlauf and Lane 1997; Holland 1998; Epstein 1999; Kohler 2000; LeBaron 2001; Manson 2001 in Parker et al. 2002). More traditional simulation models, such as game theory or linear programming, fall significantly short of any realistic representation of reality (Berger, 2001). An ABM allows the creation of a more realistic simulation that represents the human dimension more accurately than conventional modelling methods. The ABM depends upon the influence of interaction between agents to affect the behaviour of each agent differently, given that an agent can represent factors such as weather, markets and other non human scenario components as much as they can represent people

McKinney et al. (1999) has recommended the development of integrated economic - hydrologic models (Rosegrant et al. 2000) for water resource management. Decisions on natural resource use are usually taken by individual resource users (Berger et al. 2002) Multiple –agent models that represent farmers' decision-making processes and direct interactions have been used in the neighbouring field of agricultural economics to analyze technical and structural change (Balmann, 1997; Berger, 2000). Berger et al. (2002) has suggested to combine these two approaches within a multiple scale – multiple agent framework that will generate valuable information for policy development as it captures more fully temporal and spatial scales of human-environment interactions. This framework will provide a way to address interrelated water and land use issues; and allow the inclusion of policy responses from farmers' and other resource users' points of view.

In all ABM models for Natural Resource Management, in all models, the common conceptual model consists of agents choosing where to locate activities based on preferences for minimising distance to services and maximising socioeconomic factors of the chosen location. The same basic mechanism of agent-based models will be used to evaluate the policy responses for dryland salinity management. It will also be used to demonstrate the flexibility of the ABM framework by relaxing assumptions and extending the representation of dryland salinity management systems to include: (1) a two-dimensional landscape and (2) an effect of land use management practices on the socioeconomic factors of the nearby environment.

Study Area

Blackwood Catchment has been divided into nine zones based on biophysical and social boundaries for managing the natural resources of the Catchment as a whole. Katanning Zone (Blackwood Zone 6) locates in the south-east of the Blackwood Catchment in the south-west of Western Australia. The Katanning Zone covers almost 307,000 hectares and retains 10% of its original vegetation. The towns of Katanning, Nyabing and Broomehill are within the zone, which includes portions of the Kent, Katanning, Broomehill, Gnowangerup and Woodanilling Shires. The major road and railway infrastructure includes the Great Southern Highway, Chester Pass Road, Tieline Road, Katanning-Nyabing Road, the Great Southern Railway and the Katanning-Nyabing railway (see Map 1).

The study area is affected by relatively low rainfall (400 – 480 mm). The soils are dominated by deep and shallow sandy duplexes, with saline wet soils, alkaline grey shallow sandy duplexes and duplex sandy gravels also common. Eleven land management units have been identified. The two most widespread are poorly drained sandy duplex and sandy duplex. About 6% or more than 18,000 ha are currently at risk of salinity according to Land Monitor estimates, and this could rise to more than 91,000 ha or 31%. Land degradation is also being caused by soil acidity (43% at risk); water logging (41% at risk); and wind erosion (23%). In the main township of

Katanning, 26% of the town area is at risk of rising water tables, with 17% of Nyabing and 10% of Broomehill. About 104 km of sealed roads (27%) and 237 km of unsealed roads (26%) are at risk of rising water tables. Current approximate annual infrastructure costs (roads and townsites) total $300,000 which is estimated to rise to $591,000 per year for towns and $450,000 for roads at groundwater equilibrium (i.e. catchment water balance). The approximate loss to gross annual agricultural production at groundwater equilibrium is estimated at $8.4 m at current prices.

Map 1: location of The Katanning Zone (Source: Resource Management Technical Report 232, Dept. of Agriculture, Government of WA) (Lat. 33 40.983S Long. 117 36.726E

Katanning faces a rising groundwater table and increased water logging, salinity problems have grown. Salinity and water logging may have negative impacts on agricultural production systems at local scale, offsite at landscape level, which may make some production systems an unviable proposition in the long term. In order to understand and manage salinity, an integrated hydrologic-economic model will be developed together with social development, climate and policy to determine the effect of land-use on the dynamic and spatial variations of groundwater levels and gross margins from agricultural production as well as to identify the relationships between onsite management (action) and catchment level impacts, to investigate the trade-offs that are likely to be incurred and the possible on-ground response. The scale of information reported above is presented elsewhere (RMTR, 2001; 2002).

Model Structure

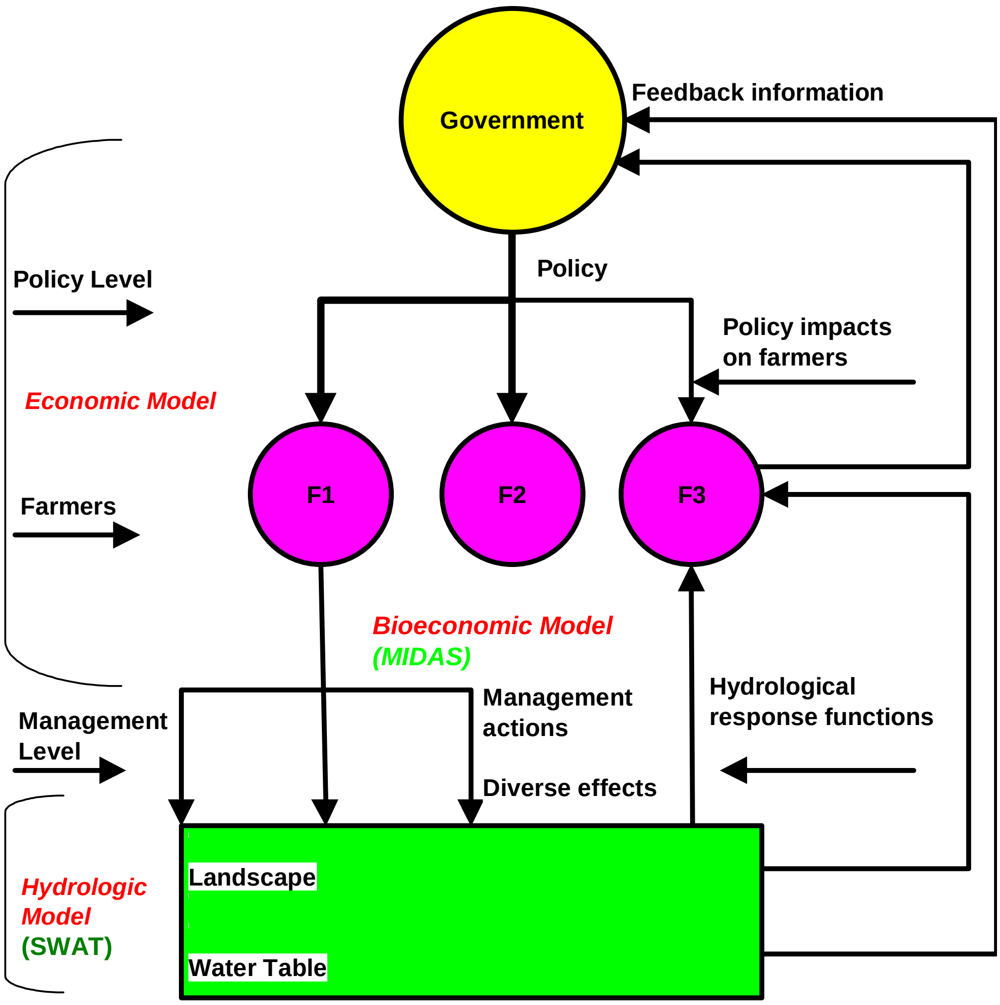
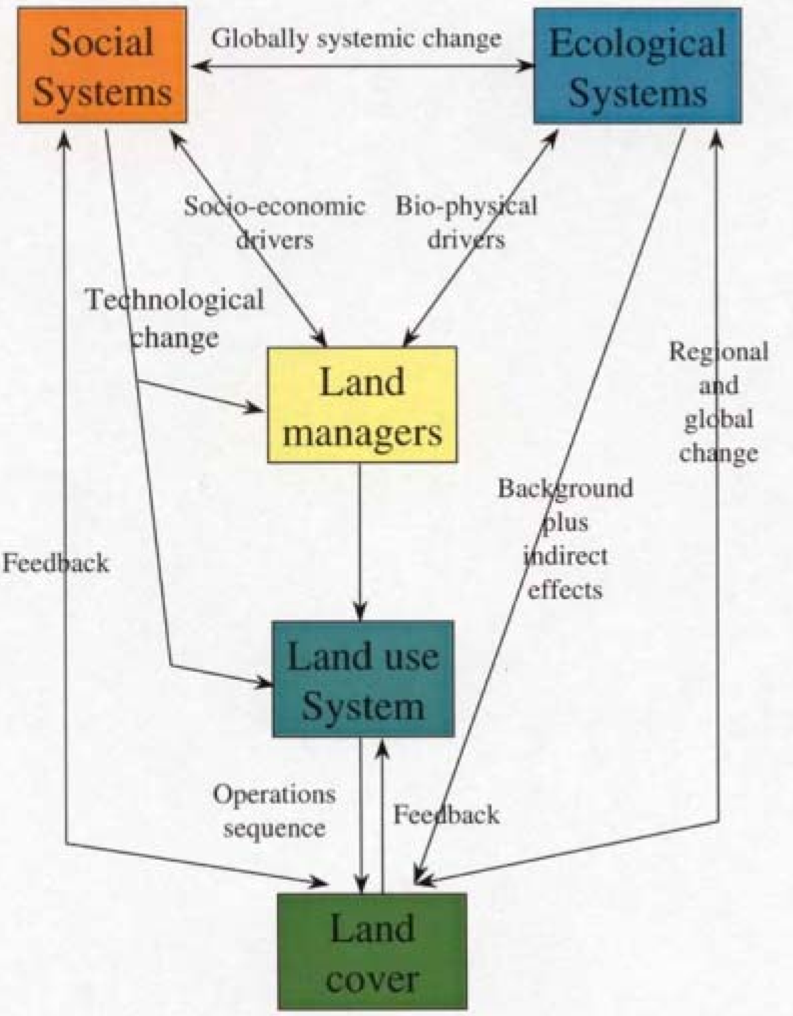


Figure 1: Schematic Representation of the Dryland Salinity Management System



The relationship between bio-physical and socio-economic drivers and other components of the land use-cover system

Source: Adapted from Turner *et al.* (1995)

Figure 2: The Relationship Between Biophysical and Socio-Economic Drivers and Other Components of the Land Use Cover System

Overview

In order to evaluate the environmental and economic consequences of existing dryland salinity management options, it is important to understand the dynamics of land use changes that have important implications for future changes in the Earth's climate and, consequently, implications for subsequent land-use change. (Agarwal et al. 2002). In addition, land use changes may result in land cover changes which, then, feed back on land use decisions causing perhaps new rounds of land use change. Human actions, "or macroforces are those fundamental societal forces that in a causal sense link humans to nature and which bring about global environmental changes" (Moser 1996, 244).

Human actions on land use are characterised by biophysical and socioeconomic processes. The biophysical attributes include climate, land use, soil type, topography and available water content of the natural environment. The socioeconomic attributes comprise social, economic, policy, institutional and technological change, and markets. The relationship between bio-physical and socio-economic drivers and other components of the land use-cover system are summarily depicted in Figure 2.

Successful dryland salinity management requires explicit consideration of the response of individual land managers to financial incentives and constraints created by alternative policies. These issues have a significant bearing on model design and are discussed further in Bell and Beare (2000) and Bell, Mues and Beare (2000).

From a biophysical perspective, alternative land use options determine the effect of any change in water balance, and in turn, on soil and stream salinity levels, that are dictated by the characteristics of the ground water system.

Optimal economic use of land resources over time requires an evaluation of the current value of alternative land use practices. Increased stream salinity and dryland salinisation may reduce the productive capacity, and hence economic returns, of land in particular uses in later years.

No economic model will be able to manage a salt affected catchment accurately without incorporating the necessary hydrological functional relationships. This requires an integrated hydrological-economic model that takes into account both the dynamic and spatial characteristics of dryland, and determines the optimal combination of land use into different farming systems that will maximize returns or profits both in the long run and in the present. Such a study then, would contribute greatly to an understanding of integrated hydrologic-economic catchment management. In this study, the model will develop to incorporate this feedback loop of land use and salinity and is represented in figure 1.

Concept of Modelling Framework

A farmer manages a portion of land in the catchment and influences groundwater fluctuations by land use and land cover change. The effects of groundwater fluctuations leading to dryland salinity have alerted many land managers, who currently express great enthusiasm to arrest the problem. Dryland salinity emergence is site specific and depends on climate, topography, land use, soil type, and available water content. Correct diagnosis of both the cause and the nature of site specific determine the likely success of its management. The problem that commonly delays the implementation of land management is the confidence of a land manager in understanding both the cause and the nature of site specific features. Salinity is often considered in isolation of other social and economic pressures on landholders, the most immediate impact of salinity on landholders being a fall in production. The farmer seeks to optimize production or maximize profit in the long run by adapting dryland salinity management options. Land uses are the result of human actions and decisions. Human actions arising from a multiplicity of social objectives are considered the immediate source of land cover change (Schimel et al. 1991; Hobbs et al; Turner 1989 in Turner 1993). To understand these social objectives one must analyse the underlying drivers that motivate and constrain human actions. There are also biophysical drivers and shocks (e.g. geomorphic processes, global and local climate changes and variability) responsible for changes in land cover, and ultimately land use (Turner et al., 1995). Each of these interacting drivers operates over a range of scales in space and time. The term *scale* refers to the spatial and temporal dimensions used to measure and study objects and processes. For each process a range of scales may be defined over which it has a significant influence on the land use pattern (Meentemeyer 1989; Dovers 1995 in Verburg 2003 et al.). Knowledge of the biophysical processes will contribute to understanding the potential social and economic impacts of salinity and salinity control and will also provide a context for policy intervention in farming communities.

In order to make decisions on how to manage dryland salinity appropriately at the catchment level, one requires a spatially explicit and integrated hydrologic-economic model. This model will be used to evaluate the economic and environmental consequences of alternative land use/management practices subject to policy options for dryland salinity management. Within the modeling framework, economic decisions to optimise land use will be integrated with biophysical processes (as shown in Figure 1).

The individual model components are as follows:

- **Hydrological Model: SWAT (Soil and Water Assessment Tool):** The role of hydrologic modelling is to provide robust and defensible information about the likely impact of landscape intervention for salinity management. It determines the optimal land use into different farming systems.

- **Economic Model: MIDAS (Model of Integrated Dryland Agricultural Systems):** Economic and policy analysis requires an explicit representation of farming systems and the capacity to assess the off-site impacts of land management decisions in a catchment context. As such, information is required across a range of spatial and temporal scales. It determines the behaviour of decision makers.

Hydrological Model: SWAT (Soil and Water Assessment Tool)

The hydrological model used in this study is SWAT (Soil and Water Assessment Tool), developed by the USDA Agricultural Research Service. It is designed to predict the impact of land management practices on water balance and water quality in catchment with varying soils, land use management conditions over long period of time (Neitsch *et al.*, 2001). SWAT operates on daily time steps and requires specific information about climate, soil properties, vegetation and land management practices occurring in the catchment (Neitsch *et al.*, 2001).

The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, etc. are directly modeled by SWAT using the input data. Model inputs include management inputs: *crop rotations, tillage operations, planting and harvest dates, irrigation, fertilizer use, and pesticide application rates, as* well as the physical characteristics of the catchment and its sub-basins: *precipitation, temperature, soil type, land slope and slope length, width and slope, Manning's n values and USLE K factors.* Either simulated or measured precipitation and temperature values may be used in SWAT. Measured stream flow and sediment concentrations can be statistically compared with model predictions.

SWAT allows a number of different physical processes to be simulated in a catchment. Using a routing command language the SWAT model can simulate a catchment subdivided into sub-basins based on topography. The subdivision of the catchment reflects differences in evapotranspiration for various crops and soils. The sub-basin components of SWAT include hydrology, weather, sediment yield, nutrients, pesticides, soil temperature, crop growth, tillage and residue and agricultural management practices (Arnold et al. 1995). The hydrology component is based on water balance equation (Equation No. 1), which takes into account processes such as precipitation, evapotranspiration, surface runoff, return flow and soil water storage. The basic requirement of any catchment model is the capability to estimate surface runoff. Surface runoff volume is computed from daily rainfall using a modification of the Soil Conservation Service (SCS) curve number method (USDA-SCS, 1972).

$$SW_t = SW + \sum_{i=1}^{t}\left(Rd_{ay} - Q_i - E_a - P_i - QR_i\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

where SW_t is the final soil water content (mm), SW is the soil water content available for plant uptake, defined as the initial soil water content minus the permanent wilting point water content (mm), t is the time (day), R_{day} is the amount of precipitation (mm), Q_i is the amount of surface runoff (mm), E_a is the amount of evapotranspiration (mm), P_i is the amount of percolation (mm), and QR_i is the amount of return flow (mm).

The water balance is categorized into four storage volumes: precipitation, soil profile (0 – 2 m) consisting of 10 layers, shallow aquifer (2 – 20 m) and deep aquifer (> 20 m). The Soil Conservation Service (SCS) curve number technique is used to estimate surface runoff volume because of its wide use in the USA, easily available input requirements and it also allows linkages among soil type, land use and management practices. Estimation of percolation is conducted by using a storage routing technique based on assumption that percolation occurs when field capacity of the soil is exceeded and if the layer below is unsaturated in combination with a crack flow model. The contribution of groundwater to stream flow is simulated by creating shallow aquifer storage. The model assumes that percolation beyond the root zone recharges the shallow aquifer. Estimation of potential evapotraspiration is conducted using one of the three methods; Hargreaves (Hargreaves and Samani, 1985), Priestley-Taylor (Priestley and Taylor, 1972), and Penman-Monteith (Monteith, 1965).

The SWAT (Soil and Water Assessment Tool; Arnold *et al.*, 1998) model, whose input parameters have a physical interpretation and explicit representation of spatial variability (Abbott et al. 1986), has been widely used in the USA and other countries for land use studies. SWAT has not been widely adopted in Australia yet, but a number of direct application of the model in different regions across the country have been reported very recently (Connolly, 2002; Rattray et al. 2002; Beverley et al. 2003; Dougall et al. 2003) for various purposes, such as crop yield and water quality assessment. This is a strong indication that SWAT is now beginning to be recognized and accepted as a model with very good potential for modeling the water balance and water quality of catchments in Australia.Due to the intrinsic spatio-temporal variability of catchments, GIS technology is an essential and efficient method of collecting, storing and retrieving input data required for simulation models. GIS can elucidate landscape characteristics (e.g. topography, soil, climate, land cover and management) and effects of agricultural activities overlaying intrinsic hydrological attributes. The SWAT-ArcView interface is a tight coupling between a model and GIS (Burrough, 1995).

The AVSWAT-2000 (version 1.0) (Di Luzio *et al.*, 2002) is an ArcView extension and a graphical user interface for the SWAT (Soil and Water Assessment Tool) model (Arnold *et al.*, 1998). AVSWAT2000 is daily time-step model while AVSWAT2000 uses hydrologic response units (HRUs) based on the soil land cover types within the sub-basins. A HRU is a fundamental spatial unit upon which SWAT simulates the water balance. For a detailed description of **SWAT**, see *Soil and Water Assessment Tool Theoretical Documentation* and *User's Manual, Version 2000* (Neitsch *et al.*, 2001a; 2001b), published by the Agricultural Research Service and the Texas Agricultural Experiment Station, in Temple, Texas.

Economic Model: MIDAS (Model of Integrated Dryland Agricultural Systems)

Model of Integrated Dryland Agricultural Systems (MIDAS) is a whole-farm bio-economic linear programming model that describes the physical, technical, biological and managerial aspects of the farming systems. It also provides a vehicle for understanding important issues and decisions facing farmers and policy makers. MIDAS will be used to determine the optimal combination of land use practices that will maximise the return to agriculture in the current period as well as to keep track of the changes taking place at the paddock level or land management unit. MIDAS has been described in detail elsewhere (e.g. Morrison et al., 1986; Kingwell and Pannell, 1987).

The socio-economic modelling is based on farm management data. Data will be collected at firm level on farm size, crop yields and prices, livestock, land value, constraints, technology, **DSS**, interests and market and on salinity and its effects.

Application of Agent-Based Modelling to Study Area

The two basic agents in the model are farmers and government. They consider the economic potential of agricultural yields and the perceived risk from neighbours. Each agent has a separate objective function and individual resource constraints and updates its expectations for prices and water availability. Each agent communicates each other and with environment.

Both hydrologic and economic models will interact through a uniform grid of cells in the heterogeneous landscape representing the catchment and will have feedback loops, to determine the new course of action by the agent at the next time step. Each cell is described by attributes that affect agent behaviour. The attributes are biophysical and socioeconomic characteristics. The decision making process of the agent is autonomous in deciding the next course of action based on the information about biophysical conditions of the land and economic conditions available to the agent at a particular point in time and space. The biophysical characteristics are the climate (rain, temperature and solar radiation), soil type, topography, land use and available water content. The economic attributes are farm size, crops yield and price, livestock, land value, constraints, technology, **DSS**, interests and market. The non-spatial, statistical data as exogenous to the model will be considered at the paddock or land management unit to build the economic structure in the model. The model simulations will be validated by comparing and adjusting the data.

Once the economic and hydrological components will be designed and calibrated for a particular catchment, simulations will be conducted to evaluate the biophysical and economic outcomes of different policy instruments, including subsidies, sharing risks with farmers and payment for environmental services.

Data Requirements

The multidisciplinary nature of dryland salinity management involves changes in land use and water balances at a regional scale over 30 to 50 years as discussed by Pannell (2001), and is characterized by biophysical, social, economic, temporal and spatial scale dimensions (Parker et al. 2000). To capture the heterogeneity among various biophysical and socioeconomic parameters, when modelling salinity at catchment level in a distributed manner, it is required that catchment systems be represented with a set of streams and a set of drainage areas (called sub-basins) in which each stream can be associated with a sub-basin. The use of sub-basins in a simulation is particularly beneficial when different areas of the catchment are dominated by land uses or soils different enough in properties to impact hydrology. Sub-basins can further be subdivided into hydrological response units (HRU), each of which represents a particular combination of soil and land-cover within the sub-basin. An HRU is a fundamental unit upon which SWAT, as a physically based distributed parameter model, simulates water balance over a period of long time. The socio-economic modelling is based on farm management data. Data required may have to be obtained from different sources.

Various catchment processes and data requirements for the model are summarized below:

Level	Description	Source
Climate	Rainfall, temperature and solar radiation (mm)	SILO
Topography: DEM	GIS Map in ArcInfo Grid Format	CSIRO
Stream	GIS Map in ArcInfo Grid Format	CSIRO
Soil Type	GIS Map in ArcInfo Grid Format	Agricultural Department, WA
Land Use	GIS Map in ArcInfo Grid Format	Agricultural Department, WA
Salinity Pattern	GIS Map	CSIRO
Socio-economic data	Farm size, crops yield and price, livestock, land value, constraints, technology, DSS, interests and market	Various reports published

Data Preparation

An effort is to be made in data manipulation, if the available data is insufficient to satisfy all model requirements. Data processing includes:

- Merging Digital Elevation Model (DEM) covering the entire catchment
- Merging Stream maps covering the area for the creation of a single sub-basin map covering the entire catchment
- Merging Land Use maps covering the area for the creation of a single Land Use map covering the entire catchment
- Merging Soil Type maps for the area for the creation of a single Soil Type map covering the entire catchment
- Overlaying the Land use maps and Soil Type maps for the creation of a single hydrologic response unit (HRU) covering the entire catchment.
- Creation of soil type data base compatible with SWAT. Assumptions as to the number of soil layers and saturated conductivity for individual soil types will be made in the construction of the soil type database.
- Creation of the land use reclassification file compatible with SWAT. SWAT has a detailed Land Cover/Plant Growth database. The reclassification file relates the observed land cover type to the SWAT land cover type
- Creation of weather database files. These include rainfall, maximum and minimum temperature, relative humidity, and wind speed files on a daily basis.

In order to analyze changes in land use management practices at the catchment scale, a baseline database on socio-economic information will be established for the catchment. The baseline consists of a given set of land use management practices that serve as the foundation for generating scenarios in decision making processes. Five GIS layers will be used to generate the required input parameters for the ABM Economic model, the catchment boundary, stream, sub-basins based on topography, and hydrologic response units based on soil and land use combination, and water balance optimization.

Policy Analysis

Government traditionally manages natural resources and environmental problems through direct policy approaches such as "command and control", regulation, and education or suasion. Policy as a means of government action can be targeted and concentrated on the major areas of the external problems (i.e. neighbourhood effects) and where the highest net social benefits can be obtained through planning and targeting producers. Policy responses can provide positive or negative incentives for environmental practice. Whatever the policy mix selected, one vital requirement is for governments to make the individual and collective environmental responsibilities of farmers abundantly clear. Negative incentives may include a salt levy or charge, charging farmers for water contributions to groundwater recharge. A range of policy options is available to influence land use. In the context of dryland salinity management, this focuses on three criteria approaches: subsidies, sharing risks with farmers and payment for environmental services. The effectiveness of a given intervention will depend on a range of factors, including the costs of switching into an alternative land use, the benefits of reduced recharge rates and the costs of any reductions in usable surface runoff. The distribution of such costs and benefits is also likely to be complex, depending on factors such as climate, land use, soil type, topography, available water content and location of the farm enterprise.

Subsidies: The way land is managed can determine whether it will be affected by salinity. Subsidies with the purpose of achieving a given level of recharge and salinity control may include fixed upfront payment for planting trees, perennial pastures, groundwater pumping and drains. Such a price increase is likely to be most important in areas where the return from farming is strongly influenced by the dryland salinity as consequences of land use and land cover change. One important possible benefit of subsidies to farmers based on adoption of improved farming practices is to reduce the threat of salinity on their own and neighbouring properties. It may also increase the price of agricultural land affected by salinity. With subsidies environmental groups and others may enter the market to provide their own public good services. It is unlikely therefore that any agricultural land would become more valuable, in this event.

Sharing risks with farmers: Each farm has land use options associated with yields, recharge and runoff, and flows of ground and surface water. Quantification of the factors causing salinisation in terms of the areas of landscape contributing rising salinity and the points of discharge into stream or river will result in more efficient and more effective management. The objectives of the policy for natural resource management should include long-term, intergenerational conservation of soil, water, vegetation and biodiversity resources and natural heritage generally. In order to achieve these objectives landholder investment in dryland salinity management will be required. Working to prevent salinity requires providing insurance or guaranteeing through policy reform, cooperation for low yields, prices or death of trees as a result of fire, disease etc. and perennial pastures.

Payment for environmental services: In the medium to long-term, dryland salinity has the potential to significantly impact on the livelihood of primary producers and rural and regional communities. The severity of the impact will vary significantly from property to property and across regions. A proactive investment is required to assist adjustment and redevelopment and thereby avoid significant social costs, minimise social hardship and reduce the impacts of market failure. The environmental benefits of growing trees on firms are universally recognized for addressing problems of salinity and water logging (RIRD, 2000). Market based instruments are policy approaches designed to encourage behavioural change by specifying the amount of new rights and obligations through payment for standing trees because changes in water balances are affected by land use in the whole catchment, while salinity normally affects only some areas, and by adoption of improved land use practices.

Policy Evaluation**:** Policy options which have direct effects on model variables such as prices or credit schemes will be evaluated using the following conditions:

- effect on land in terms of water table rise, water logging, saline area, yield reduction
- land at risk of salinity

Conclusions

The study of policy options aimed at promoting land use and vegetation change for the management of dryland salinity requires the use of integrative tools for spatially explicit and dynamic modelling of economic and biophysical processes. Non-spatial and heavily simplified economic models are not capable of incorporating the heterogeneity and interdependencies among the human decision makers acting on the landscape. Agent-Based Modelling (ABM) allows the inclusion of landholder heterogeneity as well as heterogeneous landscape that are necessary for a realistic representation of economic behaviour and interactions. An ABM involves experimentation with a society of artificial autonomous decision-making entities (agents) representing real economic agents, their institutions and environments. This study aims to develop a catchment level ABM tool for studying the salinity management benefits of alternative policy instruments

The new knowledge contributions of this study will include:

- A better or more accurate understanding of the potential effectiveness from alternative incentive-based policy instruments that are currently being suggested or recommended to tackle salinity

- An understanding of the implications of social and economic heterogeneity to the performance of market-based solutions to resource management problems. These are issues that traditional economic models have not been able to address.

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