Modelling Salinity Management at Farm and Catchment Scales in NSW and Thailand

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Abstract: The Spatial optimisation Model for Analysing Catchment Management (SMAC) has been developed to examine the relationship between groundwater accessions from agricultural land, land salinisation and its medium-term economic effects. This mathematical programming model represents the farm and catchment-scale aspects of land management. The model quantifies the relevant inter-relationships between socio-economic conditions, including the economic and policy environment affecting farms, and the biophysical condition of the catchment, including agronomy, hydrogeology and soil salinisation. The SMAC model was chosen as the catchment-modelling tool in an ACIAR project on salinisation to be carried out by a research team headed by the University of Technology, Sydney and, in Thailand, the project will involve Khon Kaen University, The Royal Forest Department and the Land Development Department of the Ministry of Agriculture and Cooperatives. SMAC will be applied for hydrological, economic and social modelling, at catchment and other scales to evaluate the impact of revegetation in Thailand (Lam Pao and Khorat and Australia (Liverpool Plains and Upper Macquarie Valley). This paper describes the SMAC model and discusses the methodological and other challenges of applying it in other regions with different land-use systems, economic conditions and hydrology, and a data-sparse environment.

Keywords: Integrated modelling; Agroforestry; Salinity; Integrated Catchment Management

1. BACKGROUND

ACIAR is funding a research and development project entitled 'Salinity Management in South-Eastern Australia, North-Eastern Thailand and Lao PDR[1]. This project is focussed on the management of dryland salinity, its manifestations and socio-economic effects in three broad regions: South-eastern Australia (New South Wales), North-eastern Thailand (Lam Pao and Khorat) and Lao PDR (Vientiane and Suvannakhet).

The main socio-economic research aims are to develop and apply hydrogeological, economic and social models, at catchment and other scales to evaluate the impact of revegetation in Thailand (Lam Pao and Khorat) and Australia (Liverpool Plains and Upper Macquarie Valley) and advise on revegetation strategies for each project site.

The key outcome of the project is expected to be the development of soundly based procedures for assessing the economic and social benefits of the remediation of land affected by salinisation in the three study regions. In Thailand, immediate application of the research results is expected by involvement of the Land Development Department, which is already undertaking replanting of trees near Khorat. In addition the results will be used in relation to the selection of the locations for revegetation, and type of revegetation of upland (recharge) areas in Lam Pao and other areas of North-east Thailand. In Lao PDR, the Department of Irrigation is involved in the project. The immediate application of the research is aimed at informing decision-makers of the possible implications of ongoing logging of forest resources and the expansion of irrigation areas.

The economic analysis within the project is primarily aimed at providing information for

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decision making by governments and government agencies within the three countries. It is at this level where far-reaching decisions are taken. Project proposals in Lao PDR and Thailand such as broad-scale logging of rainforest (Lao PDR) and the introduction or expansion of irrigation schemes (both countries) are assessed and approved. Extension services and concepts are developed. Policies can be developed which protect natural resources and enforce measures to ensure their long-term sustainable use.

2. SALINITY

Salinisation of land and water resources has developed into a global problem with major implications for a long list of countries in arid and semi-arid regions, but also in moderate and humid climates. [Ghassemi, et al., 1995] presents the most recent and comprehensive account of salinisation and its effects in Australia, Thailand and other countries.

Dryland salinisation in North-east Thailand is a problem of major proportion and great economic significance. It is estimated that an area of 6 million hectares, or 34 per cent of arable land, is already affected by salt [Ghassemi, et al., 1995]. Indications are that the problem is getting more widespread. In Lao PDR salinity is currently of minor significance, but has the potential of becoming as serious as in Thailand if land-use change continues along the current trajectory.

The analysis and management of soil salinisation are complicated by the multi-dimensionality of the problem. The human activities and hydrogeological causalities leading to secondary soil salinisation are complex and involve spatial effects and time lags. Human activities have to be viewed in the context of economic conditions and institutional arrangement in a country at a given point in time.

Soil salinisation is a textbook externality problem. Externalities exist when the people who cause a problem by clearing and/or irrigating their land, thus causing increased groundwater accessions, do not face the full environmental costs of these activities because salinisation and associated costs emerge further downstream and therefore on other people's land. In principle, an appropriate property right system could internalise all the costs but such a system is not apparently in place and difficult to achieve [Greiner and Cacho, 2001].

2.1 Salinity in Australia

Quantification of the economic effects of salinity and rising water tables both, on-farm and off-farm, has become more precise in recent years following a series of research projects by agencies including CSIRO and ABARE. Relevant literature includes, for example, [Oliver, et al., 1996; Stauffacher, et al., 1997; White, et al., 1998]. The National Land and Water Resources Audit has provided a general picture of the salinity situation in Australia.

Selected catchments have been used as case study areas for developing methodologies to analyse and assess dryland salinity and address the problem through adequate management. One of these has been the Liverpool Plains region, which falls within the highly productive black-soil-plains landscape of the Namoi Valley of Northern New South Wales. Shallow groundwater levels are rising generally throughout the catchment in response to accessions to groundwater from recharge.

Another area of New South Wales that is severely affected by dryland salinity and contributes to the salt load of streamflow in the Murray-Darling Basin is the Upper Macquarie Valley, [Kazemi and Milne-Home, 1997; Williamson, et al., 1997; Kazemi, 1999].

The Australian part of the ACIAR project adds value to the studies undertaken in these two catchments. The Little River Catchment is the principal focus area with addition work planned on forestry in the Liverpool Plains.

2.2 Salinity in Thailand

The scale of the dryland salinity problem in North-east Thailand is similar to that of South-eastern Australia. The problem is of national importance because about 17% of the land area of the North-east is salt affected to some degree. This results in significant reductions of crop and forages yields. For example, yields of rice and economic returns are about one third when grown in salinised soil compared with nearby unaffected areas.

Arunin [Arunin, 1987] has shown that the reason for the spread of salinisation is primarily the removal of forest cover leading to increased groundwater recharge. This factor has been exacerbated by anthropogenic activities including dam construction, low technology salt extraction and irrigation. The source of the salt is primarily the dissolution of rock salt in the Mahasarakham Formation which underlies most of the Khorat Plateau in North-east Thailand and parts of the Lao PDR. Groundwater recharge on deforested uplands allows deep groundwater flow systems to dissolve and transport the salt towards lowland discharge areas. Another source of salt is the shallow interflow in the regolith forming local flow systems.

Salinity is a major agricultural, economic and social problem in Thailand and it is appropriate to validate and help optimise the tree planting policy. The results of the new project will be directly linked with the Land Development Department's program of reforestation of recharge areas in the uplands of salinised areas of the North-east.

In Thailand, the project has the potential to improve the rural living standards by providing the principles for recovering degraded salinised land in discharge areas and increased yields of cattle and rice production. Short term applications of the research outputs include providing guidance to the Thai government on replanting activities at Khorat and to provide the basis for decision making regarding development proposals around Suvannakhet. In the longer term important outcomes will involve information, tools, techniques and technology transfer (training) that will assist with land use planning and minimise the impact of salinity on land resources, agricultural production and the communities in those regions.

The overall economic benefit is to likely improve annual household incomes by a factor of 2. This would offset the relatively modest, in discounted present value terms, gains from improvement of the discharge salinised areas. In any event, these gains would take some time to become effective due to the very long response time of these systems to applied change.

2.3 Salinity Management

In principle, there are three approaches to salinity management. Firstly, one can deal with the problem as it arises through a change of land-use on affected areas. Secondly, one may consider technical approaches such as groundwater pumping where this is an effective and efficient option to address the symptoms of rising groundwater tables. Thirdly, the fundamental causes of the problem can be addressed by re-vegetating the landscape, with deep-rooted perennial plants.

Studies have proved that the establishment of plantations of salt-tolerant, commercial tree species will result in increased evapotranspiration and contribute to the management of groundwater accessions [for example, Salama, et al., 1994; Feikema, et al., 1997]. To provide a viable land-use option for farmers, trees need to contribute to farm income in addition to providing environmental benefits. Farm forestry, defined as multi-objective commercial tree growing on farms, thus forming a subset of agroforestry [Robins, et al., 1996] overcomes some of the impediments associated with full-scale agro-forestry. The results of a model analysis for the Liverpool Plains indicate that farm forestry options may indeed contribute towards salinity management on the Liverpool Plains as well as being profitable for landholders [Cacho, et al., 2001].

3. MODELLING SALINITY

3.1 Models for the Liverpool Plains

A model to examine the relationship between groundwater accessions, dryland salinisation and its farm-scale economic effects on land management was developed by Greiner [Greiner, 1994]. The model of farm economics of dryland salinity (MoFEDS) sought to identify and quantify the relevant interrelationships between the socio-economic conditions, agronomy, hydrogeology, soil salinisation and economic and policy environment affecting the farm. Scenario modelling identified optimal land management strategies for farms in the Liverpool Plains. MoFEDS was extended subsequently for application to the entire Liverpool Plains catchment.

The catchment model is termed SMAC (Spatial optimisation Model for Analysing Catchment Management), [Greiner, 1998]. It investigates the relationship between land use, groundwater table and salinity. SMAC integrates the biophysical and economic aspects of land use that are relevant to addressing land and water management at the catchment scale. The model encompasses the spatial variation across the catchment by differentiating areas that are distinct in their land use and hydrogeological characteristics.

SMAC was chosen to provide the foundation for the salinity investigations of the ACIAR project. The subsequent sections describe SMAC and discuss how this model can be modified to suit the various requirements in the two quantitative study areas.

3.2 Methodology and Generic Model Description

The approach of regional, or catchment level, optimisation applies spatial equilibrium modelling theory [Lambert, 1985 and Baumol, 1977]. Land use activities are the major decision variables that influence the hydrological balance because different land uses have different levels of recharge. Rainfall variability is a major driver of the salinity system. Land management is linked with the catchment scale hydrogeological processes that drive dryland salinisation. As different land use options will use available water to different extents, their impact on accessions to the groundwater system and on soil salinisation will differ. In turn, emerging salinity affects soil productivity and the land use options that are potentially available to farmers.

SMAC differentiates four areas within the Liverpool Plains catchment that can be thought of as land management units. These four areas were deemed sufficiently homogeneous based on land-use patterns, farm structures and soil-hydrological conditions that were reflected in the corresponding representative farms. The number of areas was determined by the specific conditions in that catchment.

Representative farms embody the characteristics of each area. Each farm has land use options associated with yields, recharge and runoff, and flows of ground and surface water. The four farms within the catchment are linked (1) through the surface and groundwater flows between the areas, which they represent, and (2) through market mechanisms. This configuration means that the model objective can be set to internalise the costs resulting from salinity and those associated with groundwater management within the catchment.

The model's functional logic and its suite of economic, agronomic and hydrological parameters are explained in detail by Greiner [Greiner, 1998]. It is important to mention that neither the soil hydrological nor the catchment hydrological parameters are empirically based. The latter are outputs of simulations by the APSIM model, a soil hydrology and a crop growth model [Keating, et al., 1995]. The catchment hydrological connections were based on expert understanding of hydrological system function.

In terms of its objective function, SMAC maximises the total net present value of agricultural land use in the catchment over 30 years plus terminal land values. 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 and reduces the closing land value.

The long-term catchment-scale optimisation ensures that externalities, that is costs and benefits that arise from land-use in one part of the catchment can be tracked through time and across the landscape. Scenarios analysis makes it possible to draw out temporal and spatial trade-offs of land management and land-use change.

Land use variables are the key decision variables in the catchment model. The selection of land use options applicable in the model is based on discussions with farmers and agronomists and covers current land use practices and some potential alternatives. On cropping land, the model accounts for both winter and summer crops.

Perennial land use options include natural and planted pasture, lucerne, saltbush pasture and trees at various densities. The model parameters assume that perennial plants can, to various degrees, extract water out of the groundwater system and help reduce salinity.

The amount of rain received, its distribution over the year and its variability, are major external variables to water management in a catchment. Model parameters account for seasonal rainfall variability with implications on crop yields and recharge rates to the groundwater system.

The model can be run assuming average rainfall or generating 30-year seasonal rainfall scenarios. The first setting is sufficient when investigating generic questions about salinity management, land use and relationships between areas with the catchment. The second, variable rainfall, setting can help explore the implications of extended periods of above or below-average rainfall or be used for exploring climate change options.

4. USING SMAC IN THE ACIAR PROJECT

The ACIAR project involves developing versions of the SMAC model for the Little River Catchment and for two regions in northern Thailand as well as developing a better representation of agro-forestry in the Liverpool Plains.

4.1 Investigation of Farm Forestry in the Liverpool Plains

In order to examine farm forestry options, feasible options need to be specified for the four areas within the catchment and production and hydrological parameters attached. The length of planning period of currently 30 years will need to be extended so that the income function can fully capture the benefits of tree establishment.

Agroforestry options include eucalyptus woodlot and oil plantations for which base parameters are available [Cacho, et al., 2001] but need to be refined. Other tree-based land-use options will be developed in collaboration with NSW Agriculture and forestry experts.

The functional relationships used to describe the hydrological connections between land management units in the catchment will be reviewed and, if possible, improved based on the empirical hydrological work undertaken in the catchment over the past years [Dawes, et al., 1997].

4.2 Application to the Little River Catchment

The Liverpool Plains is a catchment with summer-dominant rainfall that is extensively cropped with both summer and winter cropping possible. In contrast, the Little River Catchment, although not very distant, is a winter rainfall area dominated by livestock enterprises.

The challenge in adopting SMAC to this area lies in the following areas, none of which is trivial.

A new set of land management units needs to be developed to represent the given farming structures, land use practices and options, and hydrogeological conditions.

A different set of land-use options has to be developed and parameterised in terms of agricultural production as well as accessions to groundwater. This also applies to the definition of a set of farm forestry options.

The hydrological connections between the land management units have to be characterised and quantified and salinisation function(s) established for the discharge area(s).

4.3 Application to Thailand

The two Thai regions are monsoonal rice growing areas and differ greatly from the Liverpool Plains in both the biophysical and economic setting. This can be dealt with similarly to the Little River catchment.

The other, more significant, difference is that we are dealing with an environment, which is much sparser in terms of data. Built for application in a comparatively data-rich environment, the challenge, here lies in translating the fundamental logic of SMAC into this environment. This will require a fundamental simplification and reduction of model complexity. While this will result in a reduction of resolution of issue complexity, this is not necessarily a problem as long as the problem definition adequately reflects the fundamental characteristics of the issue.

In this context, SMAC will provide a valuable guide for (1) asking the relevant questions in defining the issue at hand and (2) collating existing data as well as guiding the design of empirical and analytical research to generate relevant data.

The initial stages of the work will involve consultation with experts on the farming systems involved and the nature of salinity in each area. The University of Technology in Sydney, their Australian collaborators, the University of Khon Kaen and the Department of Land Development in Thailand will provide their expertise.

5. CONCLUSIONS

This paper elaborates on a project that is only just commencing. The aim of the project is to generate knowledge on how soil salinisation can be (better) managed through changes in land management.

An existing catchment model is to be applied in three very different environments in Australia and Thailand. The existing catchment model was developed for one of these catchments.

The paper explains the fundamental thinking behind the model approach and outlines the challenges that lie ahead in expanding its application. These challenges include, in order of increasing difficulty:

- Expanding the range of land-use options and parameterising them,

- Re-defining the hydrological connections between land-management units,
- Replicating the creation of land management units and representative farms for different catchments and generating a new set of land use options that can be supported by data, and
- Moving the methodology into a data-sparse environment with completely different environmental, economic and institutional variables.

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