Land Use and Hydrological Management: ICHAM, an Integrated Model at a Regional Scale in Northeastern Thailand

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Abstract: Soil salinity is a major problem in Northeastern Thailand as a result of the interaction of groundwater flow systems with widespread deposits of rock salt. Successful salinity management would involve changing land use and water balances at a regional scale with a time scale of 30 to 50 years. The scientific issue requires multidisciplinary cooperation including hydrologists, hydrogeologists, agronomists and economic and social researchers. A major issue is the real complexity of the quantitative relationships driving salinity under different environments and the uncertainty resulting from data limitations. This requires that modelling frameworks be open and accessible to a range of disciplines as well as allowing flexibility in coefficient values. This paper reports on interdisciplinary research in progress on salinity and land use in Northeastern Thailand using a combination of bio-economic modelling to assess the socio-economic impacts of changing land uses, including the use of agroforestry to manage salinity, and groundwater modelling. Models that were derived originally to support the investigation of salinity in the Liverpool Plains of New South Wales, Australia have been redeveloped for application to Northeastern Thailand. The earlier models used the GAMS™ language but the current modelling is being developed in EXCEL™ and MODFLOW™ for ease of use. Preliminary results of the modelling indicate that the saline land area will increase under a "do nothing" scenario, from the present 13% of land area to 24% in 30 years. The optimal land use would include more rice cultivation and plantation forestry, with less cassava growing compared to present land use.

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

1. INTRODUCTION

1.1 Salinity issues

Ghassemi, Jakeman and Nix [1995] showed that soil salinisation is a land degradation process which is a major problem in Northeastern Thailand as a result of the interaction of groundwater flow systems with widespread deposits of rock salt. It has been estimated that an area of 6 million hectares, is already affected by salt and that the problem is becoming more widespread. The salinity problem in North-east Thailand is of national importance because salt affected land reduces crop and forage yields.

Arunin [1987] stated 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.

1.2 Salinity management

Successful salinity management would involve changing land use and water balances at a regional scale over 30 to 50 years as discussed by Pannell [2001]. Salinity management requires multidisciplinary cooperation including hydrologists, hydrogeologists, agronomists and economic and social researchers.

In Thailand the monsoon rain fills the soil profile in the wet season so that there is a layer of fresh water resting on saline groundwater and in some areas pressing it down. The plant roots live in the fresh water and use it up over the dry season. At the end of the dry season there will be little fresh water in the profile and rivers may well carry salty water flowing from the groundwater layer. The next monsoon rains wash the salt out of the rivers and presses the salt groundwater back into the profile allowing a further season of growth. This process is described by Lertsirivorakul and Milne-Home [2000].

Despite the differences, between Southeast Australia and Thailand there are similarities in the effects of land use change. In both countries salinity has become a problem after deforestation and increased cropping. Limited reafforestation has been proposed as a management approach.

This paper discusses modelling of salinity management through vegetation change. The research is helping the development of Thai tree planting policy and is linked with the Land Development Department's program of reforestation of recharge areas of the Northeast.

1.3 Study regions

Two regions have been the subject of modelling studies in northeast Thailand for this project. A catchment in Kalasin near Khon Kaen and one near Khorat. Both are intensively cropped with rice and cassava. Forest and treed areas are limited. Pigs, poultry, buffalo and cattle are kept. Each region approximates a catchment and is quite large (1245 sq km in Kalasin and 553 in Khorat). The regions are divided into subregions that are broadly homogeneous in terms of soils, hydrology and topography.

This paper concentrates on the Khorat model. The study region covers 553 square kilometres. The land slopes from east to west and is divided into three subregions. The Khorat region is divided, for this modelling exercise, into three subregions; the upper, middle and lower catchment. Subregion 1 is upland along the east side of the modelling area with extensive forest cover. This is a recharge area. Subregion 2, in the middle of the catchment, is predominantly rice-growing country while subregion 3 grows rice with cassava and other crops.

2. MODELLING ISSUES

2.1 Context

Quantitative analytical models are important means of testing hypotheses in relation to salinisation and its management but the complexity poses a series of methodological challenges.

Greiner and Parton [1995] describe soil salinisation and its management as a complex systems problem that is characterised by issues of geographical and temporal scale in relation to process description as well as multiple non-linearities and interdisciplinarity. This complexity poses challenges for the quantification of the system, in terms of capturing relevant factors, formalising systems relationships, accounting for risk and developing the data necessary to support the model. These challenges apply across both the socio-economic and hydro-geological domains of the system.

2.2 Normative modelling approach and operating system

Greiner [1997] developed a bio-economic model (SMAC) for the Liverpool Plains catchment in Australia, which succeeded in solving the conceptual and methodological challenges outline above. The model was based on the approach of Baumol [1977] using regional, or catchment level, optimisation that applies spatial equilibrium modelling theory. However, the model required a large amount of data, based on a vast body of other research that had been completed for that catchment.

Applying the approach to northeast Thailand meant not just re-parameterising the model. The different agronomy and hydrology and the comparative shortage of data and of pre-existing catchment research required a different description of catchment relationships.

The SMAC model was implemented in the GAMS language. GAMS is an excellent and flexible modelling language but requires skilled users and is not widely accessible in Thailand. EXCEL, in contrast, has a straightforward and comprehensible structure that is self-documenting and has a reasonably powerful solver for optimisation.

It has been found that the spreadsheet approach is a useful communication tool in taking the model and its results to a wider audience including administrators. An example of this is Last, Hall, Anuluxtipun, Lertsirivorakul, Yongvanit, Milne-Home and Luangjame [2003].

2.3 Hydrological and socio-economic data

The hydrological data used in the bio-economic model is derived from on estimation of underground water movements beneath the modelled using a MODFLOW hydrological model run on an annual time basis. MODFLOW is a widely used model system for quantifying groundwater movements described by Harbaugh [1992]. MODFLOW models have already been applied in northeast Thailand by Lertsirivorakul and Milne-Home [2000].

The MODFLOW model is not directly incorporated into the bio-economic model. Instead it is assumed that marginal changes in water movements, such as are likely to be produced by moderate land use change, will change flows between sub-areas in the model in proportion to the change in inflows to the subregion. This is an approximation; if resources had been available it would have been better to simulate a set of scenarios of changing water accessions by sub-area and derive response functions that could have been used within the bio-economic model.

The socio-economic modelling is based on farm management data collected as part of the wider project. Data was collected at a village level on crops, prices, farming costs and yields and on salinity and its effects. Data on family incomes was also collected including debt and off-farm incomes.

Both formal and informal methods of collection were used and a variety of informants were contacted in each village. Village data was collated and checked then averaged to produce survey estimates at the appropriate level of aggregation for the models.

2.4 Decision variables

Land use activities are the major decision variables that influence the hydrological balance because different land uses have different levels of recharge. As different land use options use different amounts of available water, 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. Yields of crops are reduced on saline land.

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 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. Scenario analysis makes it possible to draw out temporal and spatial trade-offs of land management and land-use change.

2.5 Model implementation

The agronomic and economic data are brought together with the outcomes of the hydrological modelling in the ICHAM bio-economic model (Isaan Catchment Hydrogeological and

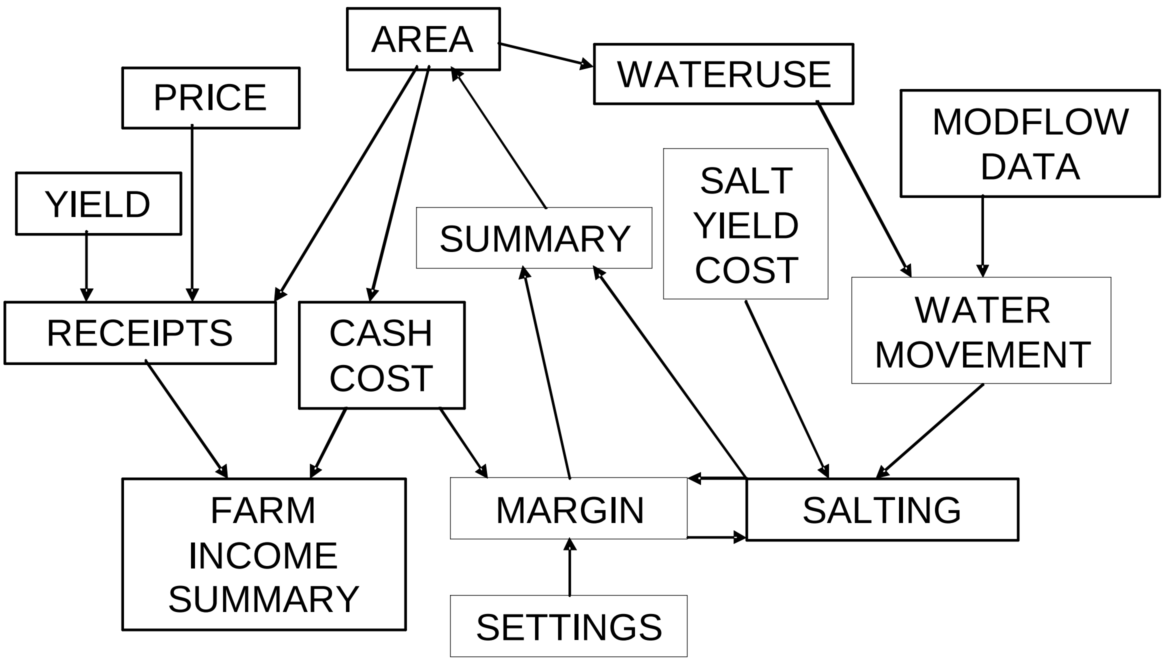

Figure 1. ICHAM flowchart

Agricultural Model). ICHAM consists of a series of interconnected worksheets, which cover different aspects of the salinity management system.

The operation of the model is described in the users manual Hall [2004]. The model is operated from the 'Summary' sheet that shows summaries of land use, incomes and salinity over 30 years. All the other worksheets depend on Summary, Settings, which holds the data, and MODFLOW, which bring in the hydrology.

The linkage from Salting, which estimates the area salted each year to Area allows the increase in salinisation in a year to affect future costs and cropping and so the net present value of the farming operations.

3. RESULTS

3.1 Salinity and economic outcomes

The results presented are for the Khorat catchment model. The analysis examines the differences between the base solution (triangles) for which current land use is projected to continue for the next 30 years and an optimal solution (squares), which maximises farm profits at a catchment level. The left hand axis measures the percent of the catchment, which is saline, while the bottom axis shows years. The optimal solution takes an objective of maximising the net present value of farm incomes, taking into account the costs of salinity.

Table 1 shows the effect of discount rate on the optimal solution. Two discount rates were used: four percent as an indicator of social time preference, and ten percent as an indicator of a commercial rate of time preference, such as that of a poor and indebted farmer

Table 1. Percentage of area saline after 30 years

	%
Current level of salinity	13.3
Base solution after 30 years	21.3
Optimal solution after 30 years	
- at 4% discount rate	15.3
- at 10% discount rate	15.7

The current saline area is 13 per cent of the catchment. The base solution results show that if current land use continued for the next 30 years then salinity would be expected to increase from the present 13 per cent to 21 per cent of the catchment. However, if the catchment were managed for maximum profit, taking account of salinity costs (optimal solution), then the area saline would be only 15 per cent at a four percent discount rate. Taking account of future salinity costs would lead to less salinity than would occur with current land use practice.

Using the higher commercial discount rate of ten percent, rather than the social discount rate of four per cent, would lead to almost 16 per cent salinisation after 30 years, a half per cent more than at the social rate. Hence, heavily indebted poor farmers may rationally decide to allow more salinisation than society considers desirable.

trees while the acacias would be planted along the bunds around rice paddies so that their deep roots dry out the profile in the dry season. Experimental plantings of eucalypts, other trees and acacias are currently underway in the catchment.

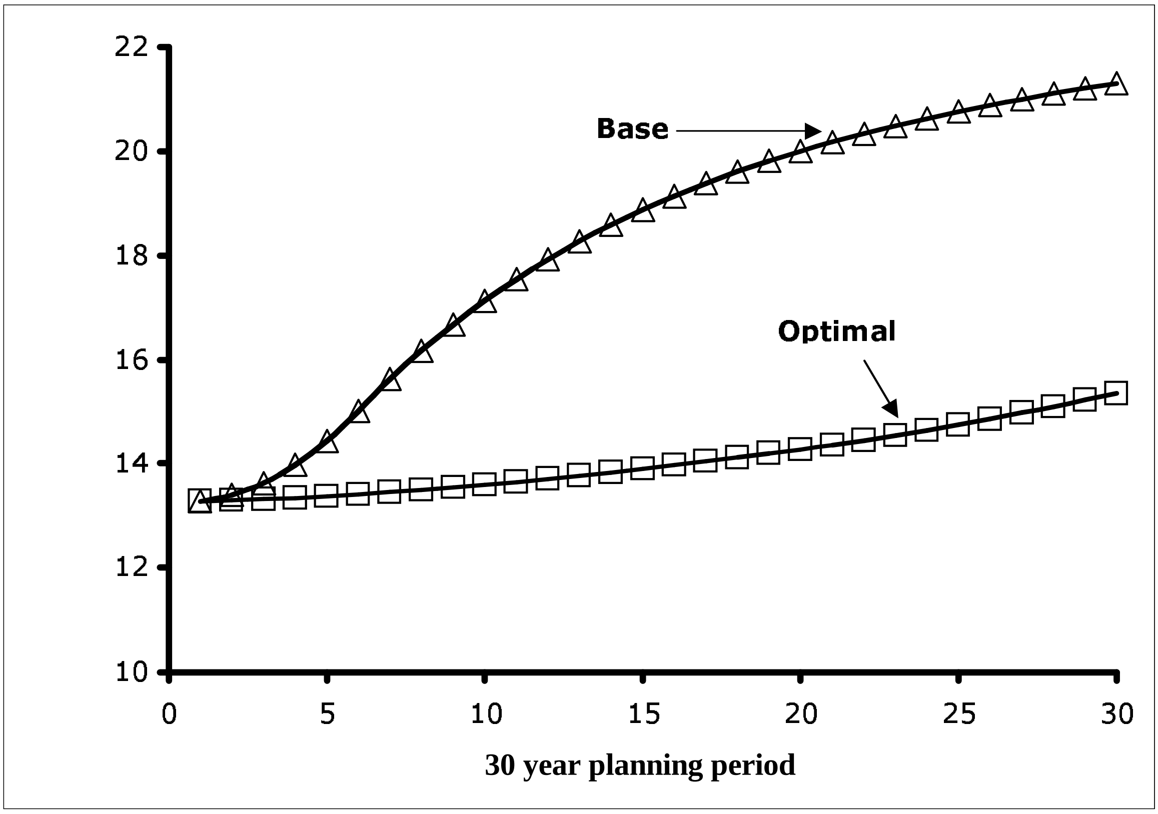

Figure 2. Area saline: base and optimal solutions

If current land use continues unchanged, the net present value of the cost of salinity over the next 30 years is estimated to be 1026 million Baht, twelve per cent of net present value of farm incomes (at a four percent discount rate). The optimal solution at the same discount rate has a net present value of salinity cost of 756 million Baht, nine per cent of net present value of farm incomes. It is significant that the optimal solution does not eliminate all saline areas.

3.2 Land use change

Table 2 shows the land use for the base and optimal solutions of ICHAM for Khorat expresses in rai. One rai is equivalent to a 40-metre square so that there are 6.25 rai to a hectare. The optimal solution has more rice, other crops, fruit trees, other trees, and acacia and less cassava.

The changes are not large as a proportion of the whole catchment, suggesting that stabilising salinity by changing land use is feasible. The trees envisaged are plantation eucalypts and native

Larger plantings of trees and acacias at the expense of food and cash crops would be needed to reduce the current levels of salinisation. These might have major consequences for the economic and social wellbeing of people farming in the catchment.

Table 2. Land use in Khorat model: base and optimal solutions at 4% discount rate

	Base	Optimal
	Rai	Rai
Rice	210336	223567
Cassava	111217	88549
Other crops	9447	10809
Fruit trees	3113	4381
Other trees	36	6843
Acacia	0	6732
Forest	2454	2454
Total	336603	336603

4. DISCUSSION AND CONCLUSIONS

ICHAM is a simplified representation of a very complex and partly unknown reality. It brings together our current knowledge of hydrogeology, agronomy and farm economics but further ground studies are needed before making confident recommendations about changing land use in particular areas.

The simulation results presented show that for a catchment in northeast Thailand, salinity will almost double in the next 30 years if current land use is maintained. The optimisation results show that it would be economically rational to implement land use changes to reduce the rate of salinisation.

The lower levels of salinity under optimisation show that there is market failure in the management of salinity on land in northeast Thailand. This is not unusual in management of salinity because changes in water balances are affected by land use in the whole catchment, while salinity normally affects only some areas. Hence there is no direct incentive for all farmers to change land use for the benefit of farmers in affected areas [Greiner and Cacho [2001]. Also, new crops such as trees are different to field crops and often need a significant wait for income. This may not be an option for farmers who rely on the rice crop to feed their families.

ICHAM shows that salinisation can be managed, the general direction to be taken and the approximate magnitude of land use change needed. Changing land use, without affecting the livelihood of farmers, requires social interactions between governments, at all levels, farmers, extension services and technical experts. This is a formidable undertaking but ICHAM shows that the cost of doing nothing will be a big increase in the area salinised and increasing losses caused by salinisation.

ICHAM has been developed through cooperative effort in Australia and Thailand between agencies and disciplines. The modelling approach has been successfully applied and a training program is under development. An extension of the modelling into the Lao People's Republic has also been discussed with Lao government agencies.

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