Biophysical Component of an Integrated Water Resources Assessment Project in the Upper Chao Phraya Headwaters, Northern Thailand

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Abstract This paper describes the biophysical research component of a collaborative project, which is developing and applying an integrated approach to water resources assessment and management in the 40,000 km^2 Ping Basin in the Northern Highlands of Thailand. The project is a collaboration between the Royal Project Foundation of Thailand and the School of Resource Management and Environmental Science, The Australian National University, and is being partly funded by the Australian Centre for International Agricultural Research. The biophysical component simulates the effect of climate and land cover/use on erosion and off-site water quantity and quality.

1. INTRODUCTION

Due to mounting and conflicting human pressures, stakeholders in the Ping Basin are facing a crucial policy problem typical of many basins in Asia, namely how to plan for the sustainable and rational utilisation, protection, conservation and management of land and water resources. The central objective of the proposed project is to develop participatory and analytical approaches to assist the government and other stakeholders to identify and assess options for highland resource use, which will better provide for the sustainability of the inhabitants' natural and human resources. To achieve this objective, the project will examine, through the development of a decision support system (see Mackey *et al.*, 1997) and participatory decision making framework (see Ross *et al.*, 1997), the economic, environmental and socio-cultural implications of different levels and patterns of cultivation and other water use in two widely representative catchments within the Ping Basin.

The type of human activities taking place within catchments in the highlands of Northern Thailand have substantial and profound socio-cultural, environmental and economic impacts, both on-site and off-site (downstream). An important issue of concern is the extent to which changes in land use in the highlands can contribute to downstream flood damage, sedimentation and the patterns of dry season flows. We hypothesise that alternate scenarios of pattern and intensity of land use may be identified which may provide for more sustainable development, by better promoting the inhabitants' socioeconomic and cultural welfare, and minimising impacts such as soil loss, flooding, drought and downstream water pollution.

To achieve this objective, the project will examine, through the development of a decision support system and participatory decision making framework, the economic, environmental and socio-cultural implications of different levels and patterns of cultivation and other land and water use in one or two case study catchments within the Ping Basin.

The biophysical research component of this project will simulate the effects (and the uncertainty bounds) of current and proposed water and land use options and climate on soil loss, agricultural productivity, stream quantity and quality, to provide inputs to the economic component (see Mallawaarachchi *et al.*, 1997) for assessing the management options arising from the socio-cultural stakeholder process (Ross *et al.* 1997).

2. THE BIOPHYSICAL ENVIRONMENT OF THE PING BASIN

The 40 000 km^2 Ping Basin, along with the Wang, Yom and Nan watersheds, is one of the headwaters of the Chao Phraya River. Like most basins in the north of Thailand, the Ping basin faces mounting human pressures on natural resources on the one hand, and several constraints to improving productivity and resource use efficiency on the other.

Rainfall in Northern Thailand follows a bimodal pattern, with two pronounced cropping seasons. The wet season, associated with the Northwestern monsoon, starts during May and finishes around mid October. From November to February is the winter dry season, associated with a Northeastern monsoon bringing in cold fronts from Mainland China. The dry season continues during March and April, the premonsoonal months, but is associated with very high temperatures and thus represents the summer dry season. Superimposed on the seasonal rainfall pattern is an interannual drought and flood cycle. The patterns of cultivation in the region are heavily influenced by this climatic regime.

Despite these natural constraints, over the past two decades, the system of agricultural production and other land and water uses in the Ping Basin have undergone a dramatic transformation. Greater competition over the highland resources, an increase in state protected areas (watershed areas, wildlife sanctuaries, national parks) within the highlands and altered perceptions of living standards and motivation for income improvement have resulted in an increasing scarcity of arable land, and increasing pressure for expanding agricultural output. As the feasibility of agricultural expansion has diminished, agricultural intensification has become widespread throughout the highlands as a means of increasing income and providing continued food security. In particular, there has been a marked diversification of crops. In most areas cropping frequency has increased, resulting in shortened fallow periods, and intercropping (of maize with legumes and temperate fruit trees with vegetables) has become common (TDRI, 1994). Accompanying the agricultural intensification has been a greater reliance on fertilisers and pesticides, and increased water use with low-cost gravity-fed sprinkler irrigation systems becoming widespread (TDRI, 1994).

While intensification of highland agriculture "can effectively reduce land requirement, by raising land productivity, thus allowing degraded forests to regenerate" (TDRI, 1994, p128), it has also been associated with a range of adverse environmental effects. Reducing fallow periods and cultivation of marginal land may exacerbate onsite soil erosion. In turn, increased soil erosion may contribute to increased turbidity and sedimentation downstream. Pesticide and fertiliser use may be washed off and hence affect the toxicity levels of the soils and the nutrient loading of streams, further restricting the potential uses of already polluted waters of the Northern streams.

Soil degradation and sedimentation of river systems is a major problem in the North for which remedies will be sought during the course of this research. In Thailand, soil erosion has been classified under five classes; from very slight to very severe. Moderate to very severe soil loss has occurred on approximately 107 million rai (1 rai = 0.16ha), particularly on the upland and highland areas. These losses are particularly high over bare slopes (up to 25 t/ha/year) and under shifting cultivation (around 16/t/ha/yr) (TDRI, 1989). Research suggests that these erosion levels can be substantially reduced through improved agronomic practices.

3. RESEARCH OBJECTIVES

The broad objective of this research is improved understanding of the spatial and temporal distribution of catchment resources, particularly quantification of the sensitivity of the water and land resources to land use changes, management and climatic variability. Specific aims are to:

- assess the contribution of upland activities, including reduction in forest cover, to water availability, increased flooding, stream bank erosion and deteriorating water quality.
- simulate the effects of current and hypothesised land and water use and climate on erosion, soil loss, agricultural and forest productivity, stream quantity (including flooding) and quality at key points in the catchment network including the Chiang Mai aquifer.
- develop and apply models of the relationships between land and water use, landscape attributes, climate, flooding, channel bank erosion, turbidity and streamflow.

4. SCALES OF ANALYSIS

The research methodology for this project has been designed using two nested scales of analysis: regional (the Ping Basin) and local (representative subcatchments).

Examining the regional context ensures that the broader picture of water demand and the extreme downstream implications of highland resource use are considered. Ultimate assessment at basin scale is intended to be undertaken in a follow-up project. Basin scale simulation is required in order to address at a more regional level the cascading and intersectoral nature of the impacts of water and associated land resource utilization. The assessment of management options is feasible at this scale, with development of the tools in this project's representative case studies, where useful data or information already exists. Subsequent extrapolation to the other catchments in the basin can be undertaken using appropriate models and spatio-temporal (GIS) databases.

The biophysical team are selecting about 15 focal catchments of size 50 - 1000 km^2 , including three which have been shortlisted by the sociocultural and economic teams as candidates for the two focal case studies (Figure 1). Climate and discharge data are available for these but turbidity data will need to be collected. This number of focal catchments is required so that landscape attributes can be adequately related to catchment response dynamics, estimated from rainfall-flow-suspended sediment time series. The relationships obtained will allow the generation of streamflow and water quality time series (from climate and land use options) at smaller scales than are measured in the two representative subcatchments, as well as allow generation of such information in other parts of the Ping Basin in the follow-up project. The catchments have been selected on the basis of their representativeness of the major landscape types throughout the basin. For example, some are totally forested, most contain a mosaic of land cover types and major geological types, and the predominant range of slopes in the highlands are represented among the fifteen selected.

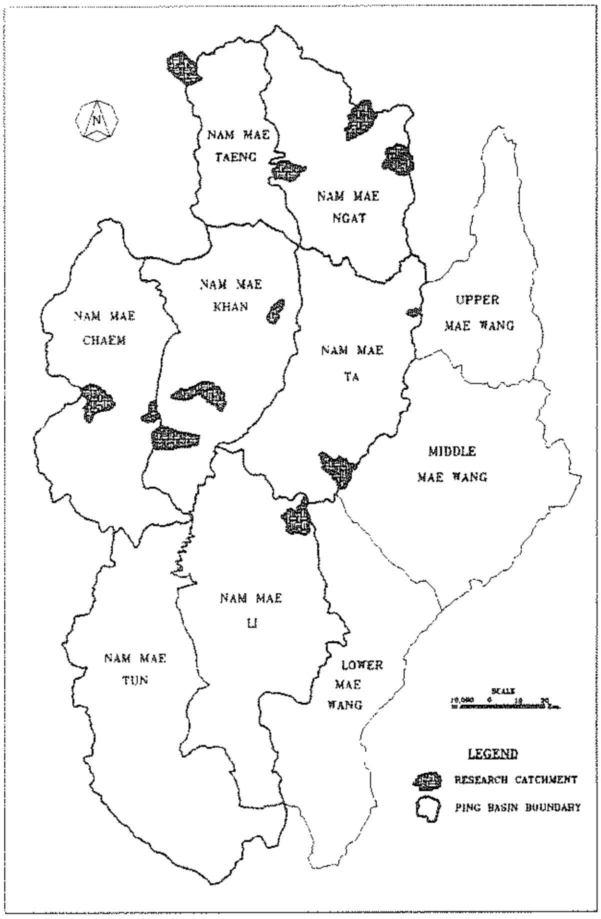

Figure 1: Small catchments shortlisted for focal analysis.

5. RESEARCH METHOD

Towards meeting the research aims, an integrated biophysical modelling system will be developed to assess the hydrologic impacts under different land use, rainfall and temperature scenarios. The system will have the capacity to simulate the instream water quantity and quality response from a dynamic precipitation-runoff-quality model, whose parameters will be related to landscape attributes. Pollutant washoff and export fluxes will also be calculated. In order to construct the simulation model, the following submodels are needed:

(a) a small catchment model IHACRES (Jakeman *et al.*, 1990; Jakeman and Hornberger, 1993) which takes daily climate variables (precipitation, temperature etc.), relevant landscape attributes, and land use/management/technology in order to calculate daily stream discharge (and hence flood events), turbidity and sediment loss. The scale of such catchments will be approximately 10-50 km^2 as this is the smallest scale at which stream discharge is currently measured throughout the Ping Basin. However, soil erodibility factors will be developed for Thai conditions at large scale and soil loss outputs will be integrated with the aid of a GIS and the small catchment model. Instrumentation to measure turbidity will be installed at some of the small catchment outlets. Most of this instrumentation will be in the two representative catchments.

Figure 2 shows a fit of the IHACRES model to streamflow in the Nam Mae Ngat at Ban Teen That catchment. This is the most successful rainfall-streamflow relationship we have obtained so far. Obtaining similar success in other catchments requires development of a protocol to identify poor periods of record and the installation of rainfall gauges in some catchments where rainfall is not presently measured.

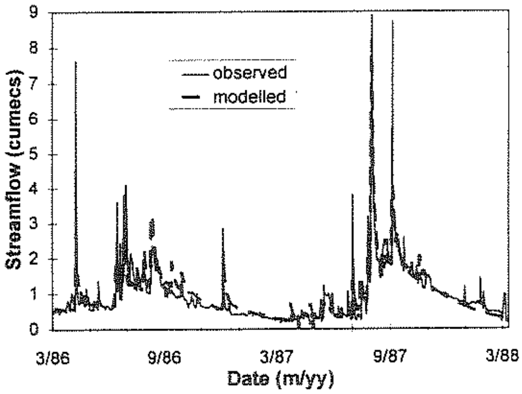

Figure 2: Fit of the rainfall-runoff model to daily discharge in the Nam Mae Ngat at Ban Teen That catchment.

The parameters of IHACRES quantify the lumped dynamic response of a catchment in terms of a few simple quantities including quickflow and slowflow recession rates, proportion of base flow, and peak flow response. These parameters in turn have been shown to be related to turbidity levels and to landscape attributes (Post, 1996). For example, quickflow recession rate is well correlated with drainage density for catchments in Australia (Post and Jakeman, 1996) and the United Kingdom of size up to a few hundred square kilometres. By building such relationships using the focal catchments, it will be possible to use landscape attributes and climatic inputs to predict the flow and turbidity in other small catchments in the Ping Basin under existing and hypothesized land cover/use scenarios.

(b) an in-stream network routing model (Dietrich and Jakeman, 1997) which takes daily upstream discharge and turbidity from the small catchment model outputs and routes these to required downstream locations, taking into account in-stream processes such as abstractions (irrigation), storage (dams) and stream bank and bed erosion and particle settling.

The model will quantify the sources and sinks of sediment in each major reach of the representative catchments. Sources and sinks will vary spatially and temporally with flow rate and this variation can be quantified. Monitoring of erosion along different sections of the river system representing a range of processes and riverine land use will aid identification of hot spots for management of stream bank erosion.

Promising results have been obtained with the in-stream model. Since 1986, it has been shown to route stream flows and salinity very well (Jakeman *et al.*, 1989). Recently it has been extended to allow suspended sediment routing. Successful calibration of the model on several reaches of the Murray and Murrumbidgee Rivers (Dietrich and Jakeman, 1997) in Australia illustrated that the model will be of the appropriate structure for Northern Thailand.

(c) a groundwater flow model, which will be built primarily for the Chiang Mai aquifer. This model will be capable of simulating the impacts of different land use (rural and industrial) on the quantity and quality of groundwater resources in the region. It will quantify various components of groundwater balance such as recharge, lateral inflow and outflow, and extraction for domestic and agricultural usages. The model will be used to investigate interactions between the aquifers and the river systems and to simulate the impacts of land use changes, extractions and climate changes (in terms of rainfall pattern and temperature) on the aquifer. A solute transport model will also be developed for the areas affected by leachate from waste disposal sites or other sources of contamination.

(d) empirical agricultural (crops, pasture, orchards) and forest productivity relationships will be adapted to provide the driving links with climate, soil fertility and depth information.

(e) erosion models will compute spatial indices of erosion hazard based upon precipitation, slope, vegetation and other landscape attributes. These will be ground-truthed in our representative catchments and by comparison with sediment yield data at the catchment outlets.

Much of the data required for these models is already being collected as part of the project. Most rainfall and streamflow data are available from existing gauging station records. Land–use and topography data are being derived from aerial photographic interpretation and satellite imagery. Development of Digital Elevation Models (DEMs) for the study regions is a major data development activity in the project. These data development activities are being undertaken in the decision support research component (Mackey *et al.*, 1997).

6. INTEGRATION WITH OTHER RESEARCH COMPONENTS

Figure 3 depicts how the biophysical component relates to the other project components.

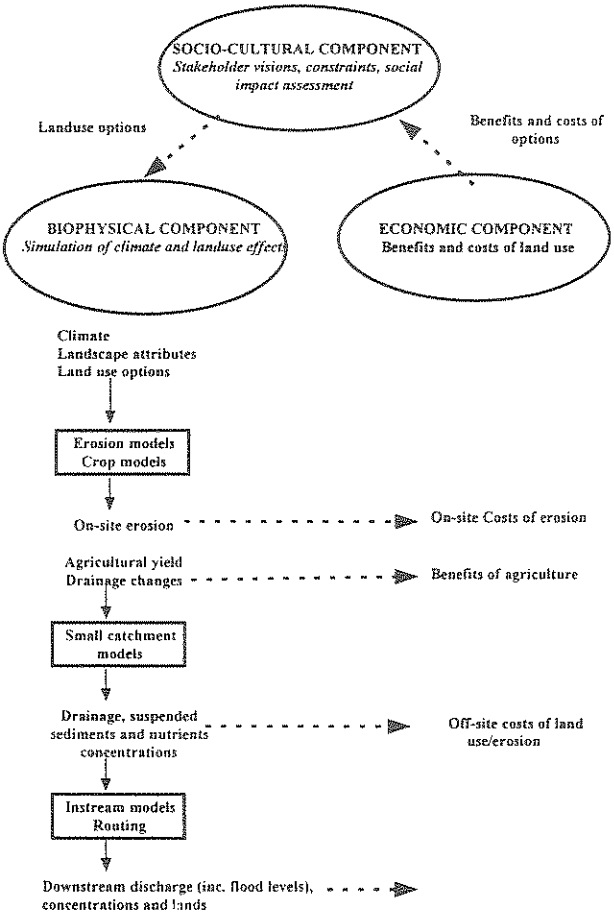

Figure 3: Interaction between the biophysical and economic and socio-cultural components

Scenarios or management options generated by the regional and local stakeholders and local participation processes undertaken in the socio-cultural component (Ross *et al.*, 1997) will be used as inputs to the biophysical land-use management simulations. This will ensure that management options being modelled are 'real' and perceived as desirable by the different stakeholders. Information from the biophysical component and the economic component (Mallawaarachchi *et al.* 1997) on agricultural benefits will also be fed into the stakeholder process to provide feedback to the stakeholders on the benefits and costs of different visions and options for land use management. Information from the biophysical component on flood stage height, water quality, and dam siltation will be fed into the economic component for calculation of off-site costs and benefits. Also, crop yields calculated in the biophysical component will allow on-site benefits of yields, and costs of and losses in land productivity to be calculated in the economic component. Finally, the biophysical models and data systems developed during the project will be integrated into the decision support system (Mackey *et al.*, 1997).

7. CONCLUSION

A key output of this biophysical research component is the development of models of the relationships between climate inputs and small catchment response (discharge, including flood events, soil loss/turbidity) in terms of landscape attributes. These models contain an understanding of how climate, land management and landscape attributes affect water quantity (including flood levels) and quality. Models of flow and suspended sediment for major reaches of streams will allow quantification of water supply availability and sources and sinks of suspended sediment in relation to climate, flow levels and stream morphology - riverine land use. Empirical relationships between climate, land use capability information and crop and forest growth will provide productivity information which will allow the subsequent calculation of the benefits of crops and forest land use at sites where these are vegetation options. A model of groundwater flow and quality in the major Chiang Mai aquifer will be developed which will permit calculation of the effects of rainfall, irrigation, rural, urban and industrial pollution on the aquifer so that it can be managed to achieve desirable water levels and quality criteria. Erosion hazard indices and models based on landscape and climate information are also being developed which will allow identification of hot spots for erosion and sediment delivery.

8. ACKNOWLEDGEMENT

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