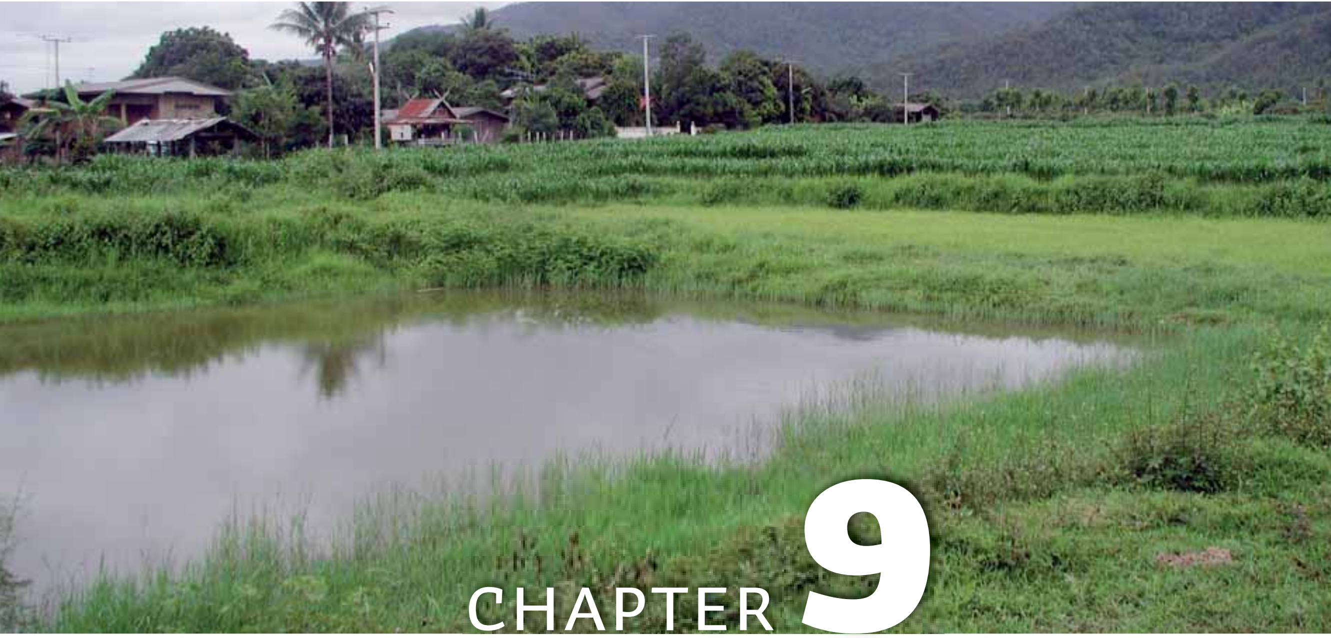


Supporting management decisions

Implementation of the Integrated Water Resource Assessment and Management project decision support system

Susan Cuddy, Rebecca Letcher, Kamron Saifuk and Parisa Saguantham

Summary

The likely success of any decision support system (DSS) depends strongly on the design process used to develop the system. Design usually depends on the types of scenarios and management options to be considered, budget and other resource constraints, client and stakeholder preferences and the desired re-usability and flexibility of the approach. This chapter describes the three DSS that were built during the Integrated Water Resource Assessment and Management project to underpin the scenario-modelling approach to integrated assessment. It is structured so that the key elements of the scenario-modelling framework are described for each DSS. The chapter concludes with a brief discussion of the software development life cycle, emphasising the importance of post-delivery planning.

Introduction

The decision support system (DSS) that was constructed as part of the Integrated Water Resource Assessment and Management (IWRAM) project went through several developments. These developments reflected the changing balance between needs (driven by assessment imperatives) and reality (driven by resources and purpose). Phase I of the project included a significant investment in building the DSS that provided scope for increasing complexity to support assessment of a wider range of issues. Phase II was a hand-over phase where the emphasis was not on the DSS per se, but on using the DSS to build and transfer capability in integrated assessment (IA) using an integrated scenario modelling (ISM) approach.

Three variants of the IWRAM DSS are described here:

- integrated modelling toolbox
- IWRAM DSS
- IWRAM XL (eXtension Layer).

The integrated modelling toolbox comprises a biophysical toolbox linked to socioeconomic models. This is a quite complex software application using a node-link framework. It was developed and coded by the Australian team during phase I of the project.

IWRAM DSS is a Thai version of IWRAM built during phase II. It is a much simpler software application and provides assessments within, but not between, catchments.

IWRAM XL (EXtension Layer) was built during Phase II to support training in IA and ISM concepts. It served as a prototype for the development of IWRAM DSS.

From a software development perspective, the progression of ideas and their implementation in the various DSS clearly demonstrate the importance of taking the time to understand the issues, and respect local knowledge and expertise when building decision support systems.

While the first two variants were developed as land use planning tools, the last was developed primarily as an educational tool. The following sections contain a discussion of the components of the framework and how they have been implemented, before going on to describe the (three) implementations, in terms of:

- issues
- design imperatives
- stakeholders
- study area representation
- models and their selection
- the integrating engine
- uses and assessment.

The chapter also contains a general discussion of other important elements of DSS implementation; namely data integration, deployment, maintenance and training.

Scenarios

While the IWRAM DSS supports the creation of many scenarios, three key methods identified by the natural resource management agencies were incorporated, being scenarios based on:

- existing land use, i.e. the base case
- 'biophysical selection only', which uses erosion as the main criterion for ranking scenarios
- 'economically optimal selection', which incorporates socioeconomic values into both the design and assessment of scenarios.

Existing land use

For this class of scenario, land-management units (LMUs) are based on the current land use map. The IWRAM DSS is run to analyse whether erosion thresholds are maintained. If not, then the user would be expected to run either a new 'biophysical' or 'socioeconomic' scenario.

'Biophysical selection only'

Scenarios in this class are based on a trial-and-error approach to modifying crop and management options to determine whether or not these can be used to reduce erosion below the nominated thresholds. The IWRAM DSS provided various interfaces to allow the description of these scenarios, always resulting in the production of a new LMU map as input to the models.

'Economically optimal selection'

For scenarios in this class, the new LMU map is created, not by trial and error but by the use of a farmer decision-making model to create new land use maps and constraints, based on economic and social drivers (see Chapter 5). The effect of these crop choices on biophysical and socioeconomic indicators is then assessed.

Regionalisation

The IWRAM models operate at a number of spatial and temporal scales. Consider, for example, the Mae Uam sub-catchment (see Figure 9.1). It is an upland sub-catchment with a large proportion of steeply sloping lands as well as paddy areas, which are located close to the stream network. In paddy fields, the dominant issue is crop water-use, whereas in upland fields the susceptibility of agricultural fields to elevated erosion rates also becomes important.

In the first phase of the project, the conceptualisation relied upon the idea of land holding of paddy or upland. The primary unit of analysis was the resource-management unit (RMU), a classification of households on the basis of access to paddy and/or upland fields (see Chapter 5). Thus, the RMUs were not unique in soil characteristics and land qualities, such that different RMUs had the same soil type. The crop and erosion models operated on a land-unit basis defined by soil type and topography, with no consideration of internal spatial variation. The crop model operated on a 10-day time step and the erosion model was an annual model—although it could be applied by season. The hydrology model, on the other hand, yielded lumped catchment estimates of daily discharge. In the case of the Mae Uam catchment, these estimates were provided at two ungauged points (nodes) in the sub-catchment, so that the crop and hydrologic models could be linked.

The spatial scale of the socioeconomic modelling was at the level of the household (Chapter 5). This scale was chosen as it was considered that the household was the main driver of agricultural production decisions in northern Thailand. The IWRAM framework, however, was sufficiently generic to allow applications at different scales (e.g. the regional or village scale).

In phase II, the conceptualisation moved to a more usual mapping approach whereby the unit of analysis was formed from the intersection of land units (described in Chapter 4) with land use. These formed a new LMU map. This approach defines the given yield of a crop for a particular land unit (or land suitability class) based on the FAO land-evaluation procedures (FAO 1976). A single land unit reflects a combination of soil class and topography. While the land-unit map is static (and provided by a government department), the land use map (and thus the LMU map) usually changes with the different scenarios under investigation.

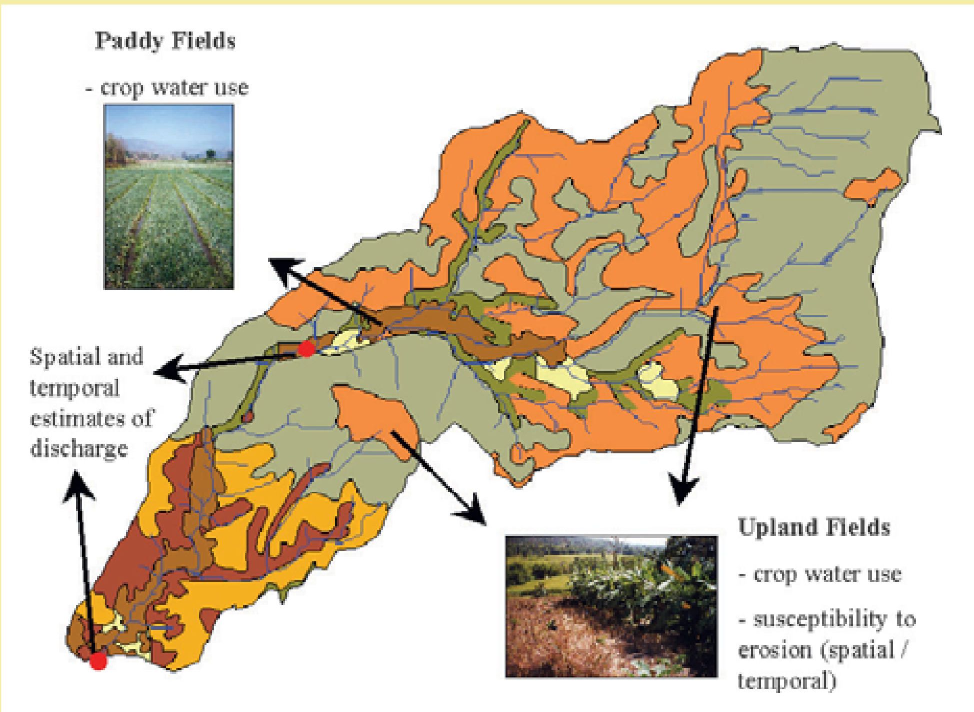


Figure 9.1 The Mae Uam catchment, northern Thailand, showing the nodal structure implemented within the Integrated Water Resource Assessment and Management project decision support system.

Integrated Water Resource Assessment and Management project decision support system implementations

The integrated modelling toolbox

Issues

The toolbox was designed to explore the spatio-temporal interactions between water supply, erosion, rice deficit and farm income. Input drivers are climate, commodity prices, technological improvements, government regulations and investments. A purpose of the DSS was to assist the Land Development Department (LDD) in its land use planning activities.

Design imperatives

The choice of the household as the decision-making unit, and the need to look at downstream impacts of land use activities, were major design drivers. The former determined the spatial aggregation and the style of economic model. The latter resulted in the adoption of a nodal-network structure. The focus of the design was then to develop an integrative framework to support prediction at each node in the network.

As with most DSS development, the design was heavily influenced by budgets (time and resources) and biased the developers to adopt approaches and model styles with which they were familiar.

Scale and study-area representation

The models in the integrated toolbox are based on a spatially lumped representation of processes. Spatial scales of the biophysical models vary from nodes, to land units to sub-land-unit scales. Time steps of the models range from daily to 10 days, while outputs may be aggregated up to seasonal, annual and higher depending on the length of simulation. The spatial scale of the economic modelling in the initial project is at the level of the household where activities are optimised with respect to income and constraints subject to the land and water resources available and external drivers mentioned previously. The temporal scales of the economic modelling are seasonal (wet, dry) and annual.

A unifying spatial scale for the modelling is the node. Nodes are identified through the stream network as distinct zones of activity in catchments between which trade-off of indicators is required. Thus, the time clocks of the various models are synchronised at these nodes.

The toolbox uses a nodal structure to represent the stream network. This supports modelling of trade-offs between upstream and downstream users. Household decisions in a catchment upstream of a node are aggregated and modelled as occurring from a specific point along the river. Households in an area are grouped into a number of representative resource-management units (RMUs) and household decisions aggregated by summing up the decision of each RMU type present at the node. The rainfall–run-off model provides estimates of stream discharge at each node.

The land-unit classification system is used to describe the soil and topographic characteristics of the RMUs. A land unit is an area with homogeneous land qualities influencing crop performance, and with the same management and practices. As an example, the Mae Uam sub-catchment contains large areas of land units 88 and 99—low-sloping clay soils suitable for paddy agriculture. This system is described in Chapter 2.

Model selection

The toolbox contains socioeconomic decision-making models, a biophysical modelling toolbox, and a socioeconomic impact simulation model. The biophysical toolbox contains a crop model, a hydrological model, a water-allocation model, and a soil-loss model (USLE).

The crop model was developed to support dynamic simulation of crop yields, without requiring large amounts of highly specific soil data. The CATCHCROP model (see Chapter 7) predicts crop yield, actual evapotranspiration, surface run-off, deep drainage and crop water-demand.

The hydrological model was based on the IHACRES rainfall–run-off model (see Chapter 6). This model was favoured by the Australian team as it performs well yet requires only rainfall and temperature (or pan evaporation) data for input, and stream-discharge data for calibration. IHACRES can also be regionalised to predict flows at ungauged nodes.

The soil-loss model to estimate gross erosion is based on the universal soil loss equation (USLE) modified to suit conditions in northern Thailand (see Chapter 8).

The integrated modelling toolbox models household-scale decisions on land and water use.

The socioeconomic decision-making model uses a linear program to solve a constrained optimisation. Constraints can range from social constraints, such as the preference to grow rice as a subsistence crop during the wet season, to 'typical' economic constraints of maximising profit or minimising risk (see Chapter 5).

The socioeconomic impact model then calculates the impact of actual yield and water availability on household income and total rice deficits.

Despite the apparent availability of model component candidates from the literature, much innovation was required in the modelling. All of the models integrated into the toolkit and DSS required some development to take into account data inadequacies, either in the form of inputs and parameters to drive the models or as outputs to assist in the calibration of models. Least modification was required for the erosion model, where the inputs (rainfall erosivity factor and topographic factor) were adjusted for the higher rainfall and steeper slopes of Thailand compared with the original areas in the USA where the USLE was developed. The crop model required simplification of the detail, in infiltration, run-off and percolation processes to circumvent the lack of comprehensive field measurements in the study catchments. The simulation of discharge provided perhaps the greatest challenge because of the need to predict flows at nodal sites that were ungauged, and to predict nodal flows under changes in land-cover conditions. This required a regionalisation approach to relate the ratio of parameters of the IHACRES model (from gauged calibrated nodes to ungauged and/or land-cover-modified nodes) to the ratios of either run-off, deep drainage or run-off plus deep drainage inferred by the crop model (see Chapter 6).

Model integration

The toolbox underwent a number of design and platform changes. The final product is a collection of programs (Matlab, Fortran, Java) that can be run separately or in combination, with clearly defined execution sequences and data flows. The integrative framework is graphically represented in Figure 9.2.

Land use decisions, based on expected returns and water availability, are simulated within the socioeconomic decision model. These decisions are passed to the biophysical toolbox, which simulates the impact of climate on crop yields, water use, water availability and erosion. Actual yields and water use are then transferred from the biophysical toolbox to the socioeconomic impact model, where the impact of actual yields on a series of socioeconomic indicators is calculated.

Uses

This selection of models suits the types of scenarios identified in phase I. A large number of scenarios (climate, crop selection, land use change, land-management practices, price shocks, forest encroachment, migration) have been developed and run through the biophysical and integrated toolboxes. In hindsight, perhaps the most important use of the toolboxes was their role in building a local multidisciplinary team that can promote IWRAM principles and practices.

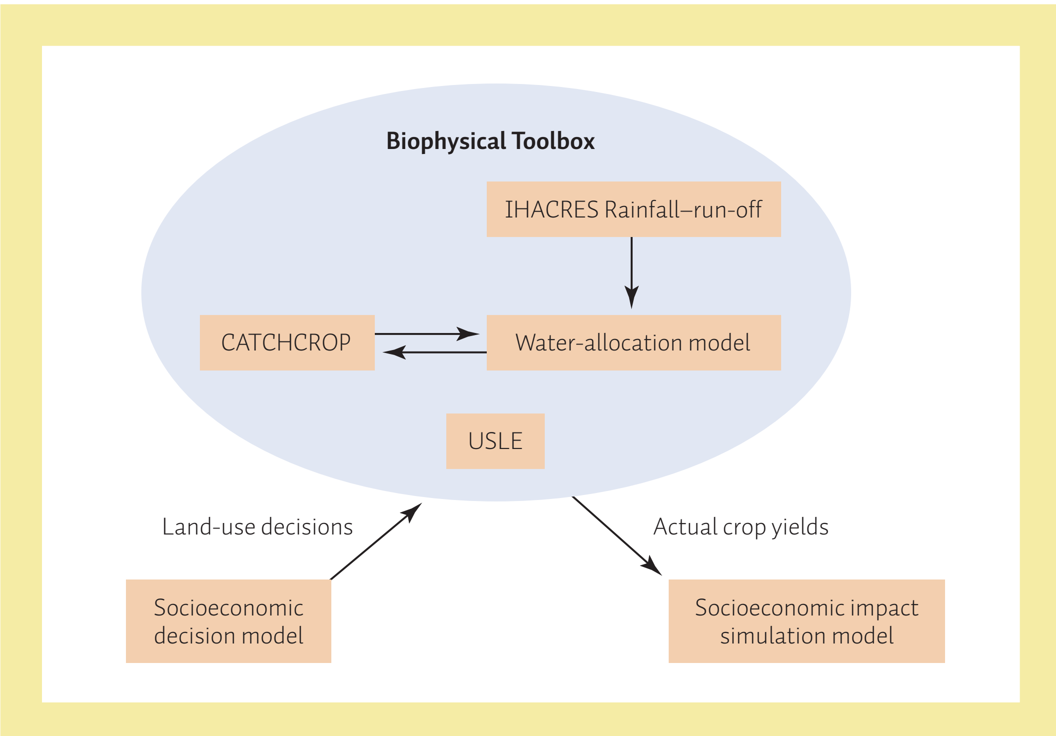


Figure 9.2 The integrative structure of the integrated toolbox used in the Integrated Water Resource Assessment and Management project, showing the main models and their linkages

Assessment

From a technical perspective, the toolboxes have been successful, as evidenced by the fact that they continue to support refinement of IWRAM principles. In retrospect, the emphasis on the development and delivery of the DSS compromised joint and mutual learning. At the end of the project, the Thai team identified conceptual and technical problems that hampered their application and adoption of the DSS. These problems related mainly to the choice of land classification and the selection of models.

Of greater consequence, the development of the toolboxes informed a real understanding of the meaning of integrated catchment management in the Thai context. Natural resource management in Thailand is fragmented and spread across many government agencies. The IWRAM project provided an opportunity for agency staff to work together, learn from each other, and develop a shared vision for natural resource management that would work across government agencies. A locally developed DSS was a key part of this, and their IWRAM DSS is described below.

Integrated Water Resource and Assessment and Management decision support system

Issues

The benefit of shared experience clarified the approach that the Thai team wished to follow. The initial toolbox developments taught the Thai and Australian teams a great deal about integration of models and scenario development. The second phase of the project focused on putting this knowledge into practice, with the Thai team taking greater ownership of the component models, DSS and the integrative framework, while the Australian team moved to playing more of a support role. In addition, other initiatives were undertaken to support the uptake and delivery of IWRAM, including extensive fieldwork, an information website at <http://www.iwram.org>, development of training materials, and extension of the IWRAM program into neighbouring regions.

IWRAM DSS design has the benefit of strong formulation of preferred scenarios for investigation developed by Saifuk and Ongsomwang (2003). These are described in later sections.

Design imperatives

The first imperative was to select a land-classification scheme that conformed to the Thai land use planning system. Land modelling units were devised, as described in Chapter 4.

The second design imperative was to couple the DSS with a geographic information system (GIS) to provide high-resolution mapping capability. This would be possible with the revised land-classification scheme.

The third design imperative was to replace the linear programming approach used in the socioeconomic model. This was driven by three factors: (1) the processing within linear programming algorithms is not obvious (i.e. 'black box') and does not engender interdisciplinary learning; (2) the optimisation paradigm does not sit comfortably with the world view of the biophysical modellers; and (3) the need to disaggregate results beyond the 'representative' decision-maker (as used in a linear-programming approach).

Study-area representation

The RMUs of the toolbox have been replaced by LMUs. These are intersections of land units and 'current' land use as demonstrated in Figure 9.3. The land-unit map does not change, but the land use map may (and usually will) change according to land use scenarios. A LMU is homogeneous in land qualities (attributes of the land unit) and land use. The use of LMUs is the fundamental key to support a GIS interface and spatial data analysis.

To use this scheme for all the models requires that survey and other biophysical and socioeconomic field data can be mapped to the same units.

Model selection

A decision-tree approach was selected to replace the linear program in the *socioeconomic decision model*, as described in Chapter 5. The revised model is a crop-choice model whose structure (a decision tree) has been generated using a data-mining algorithm. It simulates farmers' decisions on crop choice (based on decision rules). Important variables determining crop choice include land-unit class, season, water use, size of land, labour, capital, costs and profits; outputs are wet- and dry-season crops, keyed to LMU. A land use map can be generated for use by other component models.

The economic-impact model is simply a calculation of the gross margin (the economic indicator) for the designed land use pattern. This uses the simulated yield from the crop model.

The erosion model is a re-implementation of the USLE model developed for the toolbox.

This phase of the development had the benefit of a Thai crop modeller as a team member (not available in phase I). The crop model is a modified FAO crop-production model based on thermo-radiation and water-use efficiency (see Chapter 7).

The hydrology model is very different to that in the toolboxes, using the US Soil Conservation Service's curve-number approach to estimate direct run-off from rainfall events. This has been implemented in a prototype version of the model (see Chapter 6).

Model integration

IWRAM DSS has two development paths—a GIS-coupled application and an Excel/VBA application (a consequence of the IWRAM XL development described in later sections). It is anticipated that the two paths will merge with the add-in of GIS functionality to the VBA application (via Arc-Objects).

In the GIS version, the GIS itself provides the integrative functionality (see Figure 9.4). This approach has the benefit of direct linkage to agency databases (thus avoiding the complications that come with data acquisition and transfer).

The Excel version is stand-alone and, most importantly, is very portable, being easily installed on most personal computers. It operates via a set of workbooks, and worksheets within those workbooks. Model selection and execution is controlled by the interface. Figure 9.5 is a screen grab of the main worksheet and exemplifies its open and transparent style. The user can select a component model, or go to another worksheet to build LMU scenarios.

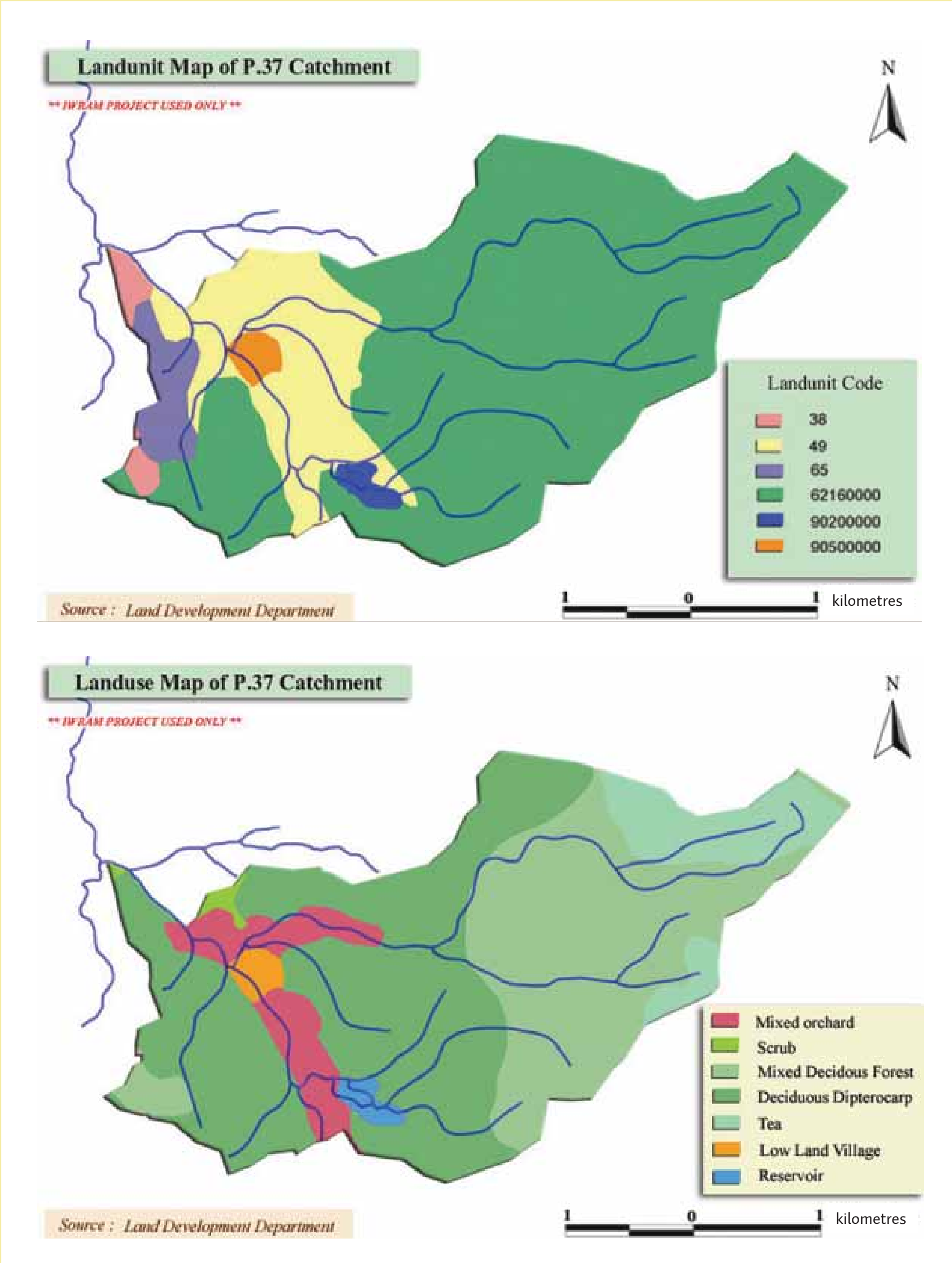


Figure 9.3 Land units and land use maps for P37 catchment of the phase II study area in the Integrated Water Resource Assessment and Management project. These maps are intersected to produce a land-modelling unit map.

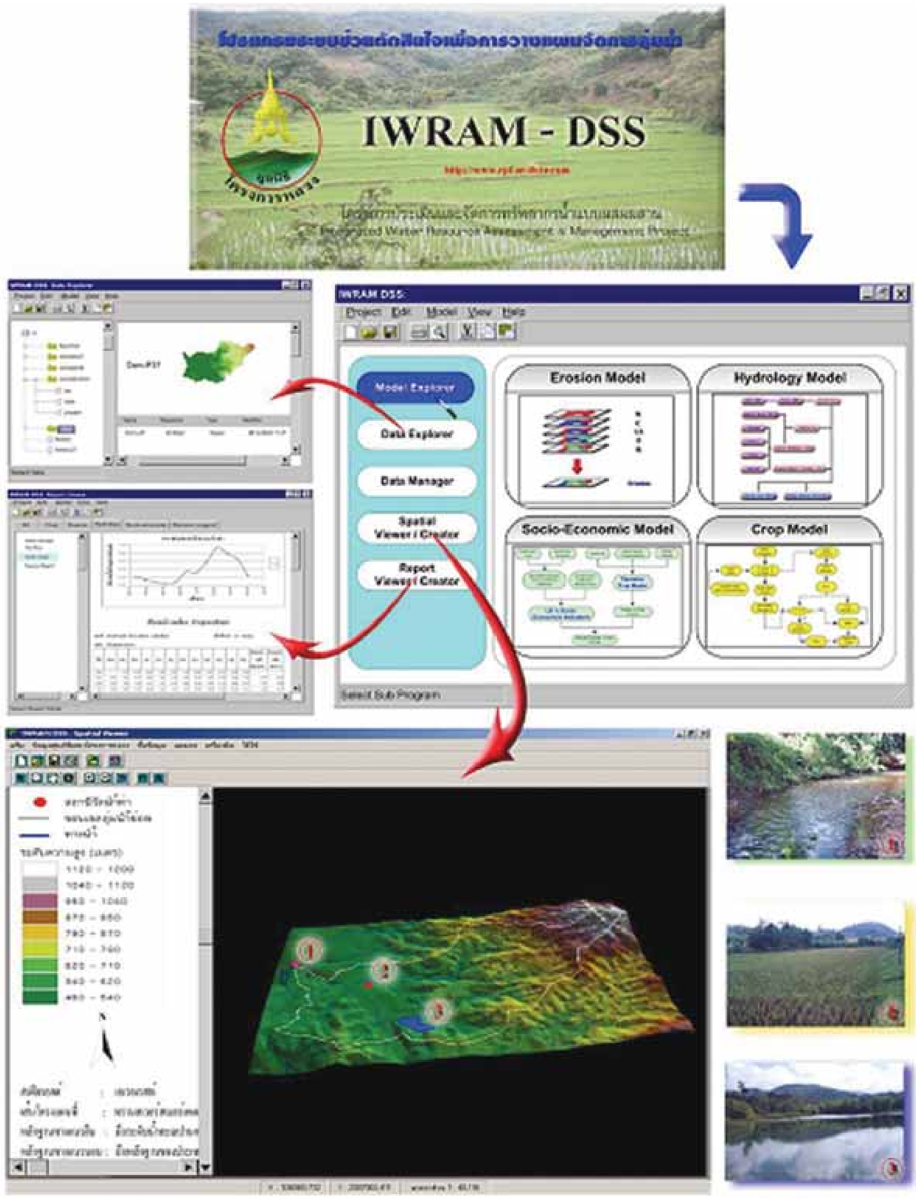


Figure 9.4 Integrated Water Resource Assessment and Management project decision support system GIS framework

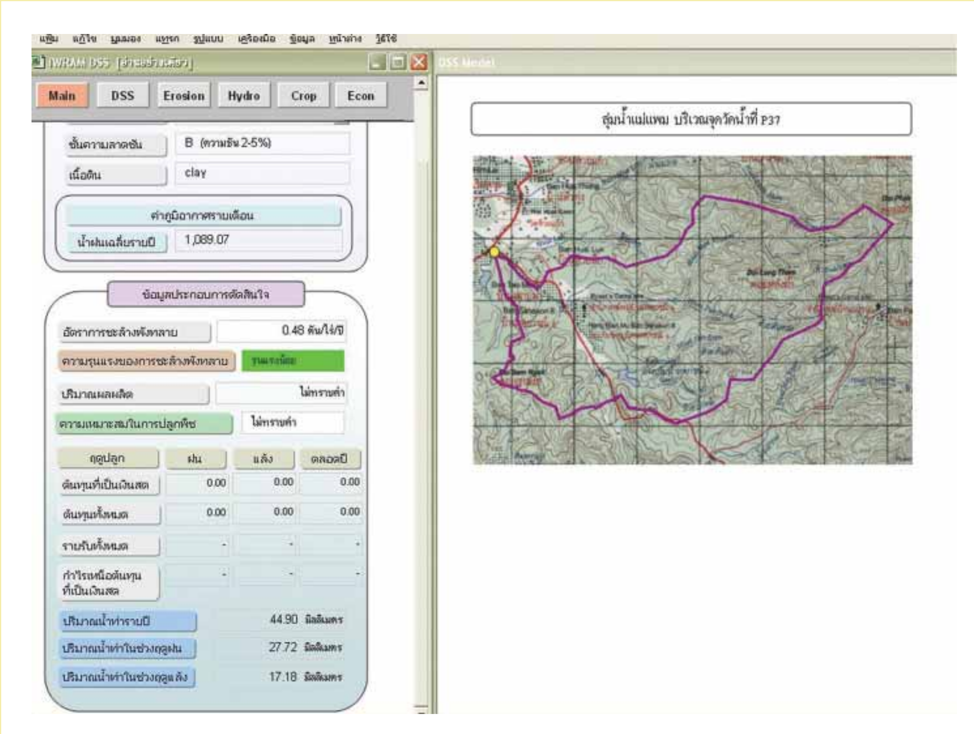


Figure 9.5 Integrated Water Resource Assessment and Management project decision support system main window, showing tools for selecting land-modelling unit and crop type. Results are then displayed under the right-hand map.

Uses

Just as it should be, IWRAM DSS is a system under continuing development. The model-building teams are developing scenarios to demonstrate the capacity of the system. These revolve around the three scenario conditions formulated by Saifuk and Ongsomwang (2003), namely:

- existing land uses—this 'base' scenario is the benchmark for further land use improvements, in both utilisation and management
- 'ideal' biophysical land uses—these scenarios are based on a trial-and-error approach to modifying crop and management options to determine whether or not these can be used to reduce erosion below the nominated thresholds
- 'economically optimum' land uses—these scenarios incorporate socioeconomic values into both their design and assessment. These are scenarios that achieve sustained yields and income with minimum environmental impact.

The socioeconomic team is using the crop-choice model to evaluate the influence of government policies on farmers' crop choices. In the first instance, this has been limited to the role of credit availability in farmer decision-making.

Assessment

As with much DSS development, time and resource pressures force the disciplinary experts to build their models independently, resulting in mismatched interfaces and delivery timetables. The threat of this approach is that the focus, by default, shifts from the integration to the component parts. Careful planning and project management are required to ensure that the models serve the needs of the DSS, not the other way around.

Having said that, the principles of integrated assessment, and the development of DSSs to support it, have been well learnt and continue to inspire the team.

Integrated Water Resource Assessment and Management XL (EXtension Layer)

Issues

IWRAM XL was originally conceived as a prototype to advance debate on the form of the IWRAM DSS. However, it proved very useful as a pilot for teaching IWRAM principles and was successfully trialled in an IWRAM training workshop in Thailand in mid 2004.

Design imperatives

The first design imperative was to demonstrate that a powerful integrative framework can be built using simple tools (such as Microsoft® Excel).

The second design imperative was to demonstrate that the overall framework is the hub of a DSS. Model selection is then to serve the purpose of the DSS, not the other way around. In fact, few new models were built for this version of the IWRAM DSS.

The third design imperative was to demonstrate the usefulness of centralised databases to rationalise and synchronise information. For example, the economists, the crop modeller and the land use planner used three different crop lists. Was it possible to construct one crop database that satisfied all members of the team, and the needs of the scenarios and analyses?

Study-area representation

A small sub-catchment (called P37) of the Mae Kuang watershed (a tributary of the Ping River) was chosen for the development of IWRAM XL, mainly because of the existence of good hydrological and socioeconomic data. Working with only one sub-catchment avoided the need to consider the complexity of spatial relationships such as on-site and off-site impacts, water transfers etc. This is appropriate for a training and educational tool (but not for a production DSS).

Within IWRAM XL, only one 'map' is stored—the LMU map—and the spreadsheet cells are used to represent a map grid.

Scenarios

Once again, with a very simple suite of models, IWRAM XL supports exploration of a range of scenarios. These include: climate change (different rainfall patterns); changes in type and extent of land use, especially crop type (revised land use map); changes in crop prices; and changes in cultivation practice.

Model selection

As IWRAM XL is a teaching tool only, it does not have a complete suite of fully functional models. The hydrology, crop and socioeconomic models are those of the integrated toolbox and are not resident within IWRAM XL.

The soil-erosion model is an Excel implementation of the USLE approach and has been complemented with an 'erosion explorer' module to explicitly investigate the likely impact of alternative crops and practices on soil erosion.

A new component was developed to construct LMU maps (by converting current land uses and/or changing management practices). This component is called the LMU maker. It allows the user to develop sets of land use change rules or manually edit the existing land uses to 'make' new LMU maps for assessment.

Design of, and technical specifications for, a socioeconomic LMU maker to construct a new LMU map based on socioeconomic decisions were written, and later implemented in IWRAM DSS. As such they were never implemented in IWRAM XL.

Model integration

IWRAM XL consists of three main components: LMU maker, model engine, and output display and export module—linked as shown in Figure 9.6.

Figure 9.7 shows the data flows between the component models and the integrating module. The input data are the LMU map, climate data, erosion factors, management practices, economic data and soil properties; the output data are erosion, economic returns, streamflow, water use (extraction) and crop yield.

The Excel workbook has a series of worksheets for storing and manipulating data, for look-up tables and maps, and for model execution. The key input is the LMU map. This is first assessed against erosion thresholds. If the LMU map exceeds these thresholds, then the user is expected to create an alternative biophysical or socioeconomic scenario.

The 'economically optimal selection' scenario would use the socioeconomic LMU maker to create broad land use maps and constraints. Crop choices are then modified from this to determine a modified land use that meets erosion thresholds.

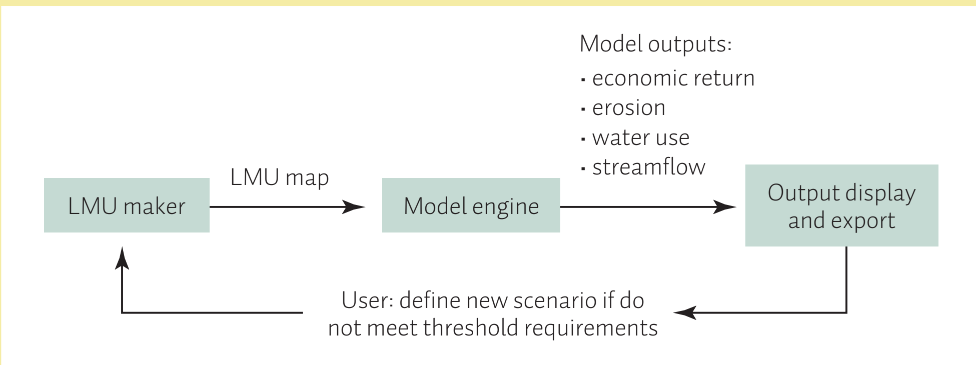


Figure 9.6 Integrated Water Resource Assessment and Management project XL (EXtension Layer) components

Uses

IWRAM XL has been, and will continue to be, used for training in IWRAM concepts. Its value as a training tool is that it has sufficient content to provide training in the individual components as well as in their integration. Its value as a prototype for IWRAM DSS is that it provides a testing ground for analysis of model simplifications and assumptions, and supports staged development and implementation of the component models.

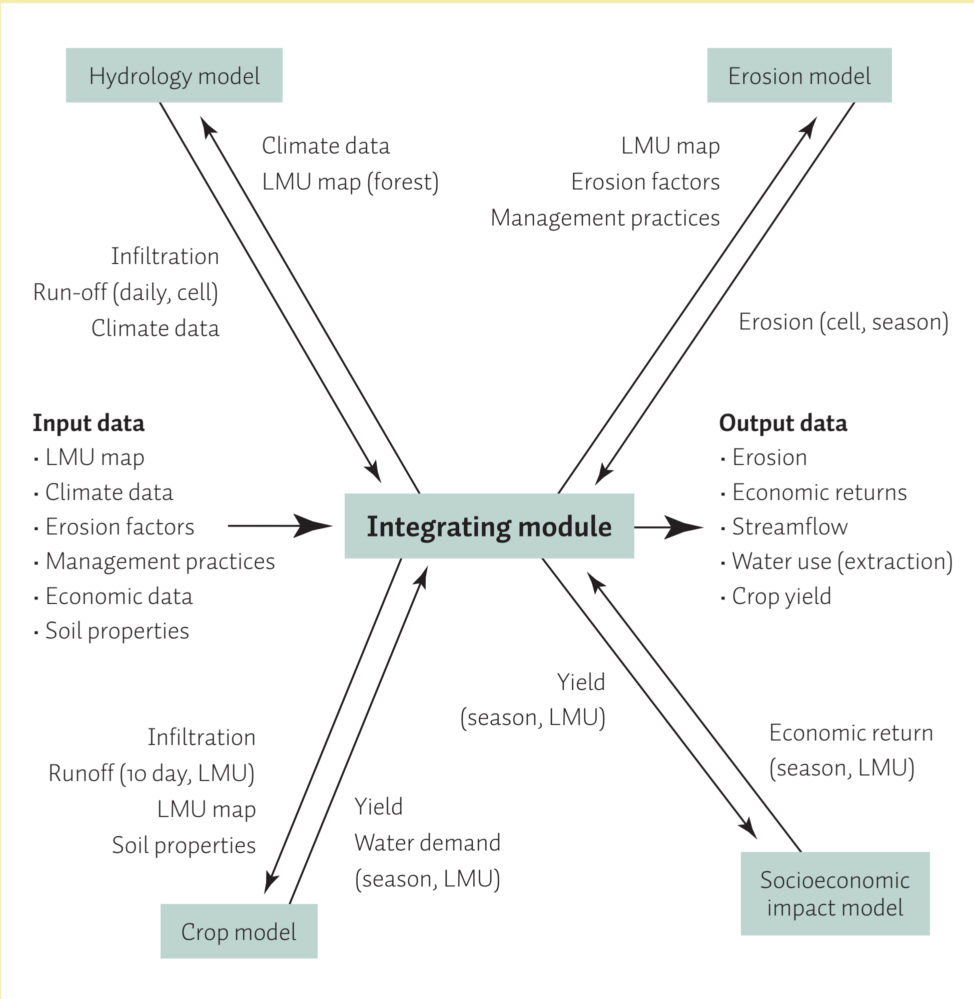


Figure 9.7 Integrated Water Resource Assessment and Management project XL (EXtension Layer) modules and data flows

Assessment

This approach to DSS development is very different to its predecessors, in that it is very ‘low-tech’. While still requiring programmer assistance (to code the minimal VBA routines in Excel), it demystified the DSS development process for the scientists.

It is very much a work-in-progress that would benefit from additional investment so that it could serve as a general training tool in IWRAM principles throughout Australia and the Asia–Pacific region.

Data integration

An important component of developing integrated assessment tools is to tackle the issue of integration of input data-sets. While Thailand has a standard land-unit mapping scheme (developed by the Land Development Branch of LDD) that has been adopted by other agencies, this is not always the case. In fact, it is more normal that different agencies use different land disaggregation schemes, and different soil classifications (because the scheme that is appropriate for, say, erosion-risk mapping, is not particularly useful for crop-suitability mapping).

The degree of integration of these data into ‘common’ data-sets depends on many issues, including determining the need for commonality, how the common set will be maintained if changes are made to the parent sets etc.

The IWRAM experience identified the crops data-set as the most difficult to standardise. The crop modeller had a very detailed list of crops, with a large number of attributes differentiating (or not) each crop. The soil conservationist had a smaller set, classified by their cultivation practices. The economists had another set, classified by price structure. And these classifications were widely used within those disciplines. In fact, the development of a common data-set was an important part of the educative process about integrated assessment, and contributed to a shared understanding of the different approaches and needs. An example of an integrated common set is shown in Figure 9.8.

Pre- and post-development

Pre and post-development issues have not been mentioned elsewhere in this book. While they are not core to the IWRAM approach, they are a very important part of DSS development and should influence the design of the DSS in terms of the functionality, and transferability of the implementation.

Design approach

Is the DSS one-off or re-useable? Serious questions such as this must be confronted early in the design phase. These questions may be difficult to resolve at this time because it is often the case that the appropriateness and usefulness of the DSS for other study areas is not recognised until after construction is near completion. A prototyping approach may be all that is required in the first instance to allow for an assessment about further application to be made later on.

An early decision that the DSS should have general applicability has enormous overheads that must be identified and costed. These include the need to have robust and efficient data formatting and import functionality, ability to describe a very wide range of scenarios across multiple issues, good and considerable documentation, development of

Database (standard table)

Crop data	Climatic data Decade data	Land characteristics	Socioeconomic data
Crop cycle	Tmin	Soil type or series	Capital resource
LAI	Tmax	Soil structure	Labour and human resource
KLAI	RHmin	Soil fertility	Land capability
Max height	RHmax	Soil chemistry	Production value
Max root depth	U	Soil water storage	Management cost
Crop group	Sunshine H	Topology and slope	Market and transport
Harvesting index		Soil drainage	

Figure 9.8 Example of centralised data-sets created to support model coupling in the Integrated Water Resource Assessment and Management project

sample applications for training purposes, and a great deal more effort and time spent on all phases of the software life cycle—especially design, specifications, coding and testing. In particular, coding style is affected, as it must ensure total separation of the interface from model execution from the data. There can be no assumptions about the format of data; e.g. the number of land use classes, the duration of time series data, the number of sub-catchments.

At the other end of the scale is the rapid development of applications that do the job, and nothing more. These require little investment in formal software engineering and may be all that is required.

Of course, awareness of the computer resources of potential users—both in terms of hardware and literacy—is crucial to making sensible design decisions. While government departments may be able to upgrade their computers or purchase particular software if required, this is rarely the case with extension officers and local agency offices.

Data management

Data and its management need careful consideration. Will the data be updated by multiple users? If so, do you want to maintain quality of data editing and track changes? Do you want users to be able to share scenarios and results? Being able to provide this functionality will consume considerable programming resources before you have even started on the purpose of the exercise, which is to build an integrated assessment tool.

A design ethos, which seems to fit well with the case-study approach recommended for IWRAM, and which has been adopted in the development of the IWRAM DSSs, is to build one-off, stand-alone applications, that store only the latest 'state' of the data (and possibly a default state for re-setting). Changes to the data (such as new crop classes or revised model coefficients) are permanent. In our experience, this is a sensible approach, as it puts the focus on the process and the integration, not the product.

Adoption and deployment

The DSS has to be portable and distributable. How is this to be done? Do the data need to be distributed separately from the software because their distribution is restricted? Can the DSS run with no data anyway? Does the DSS require specialised software and high-end computers, or can it run on standard desktop computers? Should the DSS and/or the data be covered by a licence agreement?

The answers to such questions depend on their expected use. If the DSS is to be used by many agencies within the same study area, then it could be shipped as one package combining software and data. If it is to be used in different catchments, then it may be shipped without data, or with a small sample data-set to help with training.

Maintenance

DSS are often developed and delivered with scant attention to maintenance. This can be an unfortunate consequence of fixed-term projects that focus on delivery of the DSS. Some issues that must be considered are:

- who will 'own' the DSS?
- who will maintain the DSS code and data?
- who will provide user support?
- what training materials are required, who writes them, and who delivers them?
- is there an upgrade program (even if just for bug fixes)?
- who will manage licences and to whom is the DSS distributed?
- what is the life span of the DSS?

Training

Training is an important part of IWRAM and integrated assessment, and includes building capability and capacity in the ability to:

- inform others (often senior departmental staff) of the benefits and uses of the DSS
- instruct colleagues in the principles of integrated assessment and how they are implemented in the DSS
- train in the use of the DSS (building scenarios, running, analysing and interpreting results)
- teach others to train.

These all rely on the preparation of appropriate training and instruction material. In our experience, putting resources during the life of the project into preparation of train-the-trainer, rather than training, material is important. Integrated assessment, by definition, is across disciplines—so trainers need to be capable of giving instruction in each component model (i.e. the crop model, the hydrology model etc.) and their integration. Trainers, at least in the first instance, are usually members of the in-country project team. While they have become familiar with the other DSS component models during the course of the project, it is still challenging to be asked to instruct in an area outside your expertise (e.g. a hydrologist needs to know what 'rice deficit' means if that is one of the indicators available in the DSS).

This emphasis is particularly appropriate when dealing with different language and cultural groups, where it is important that the trainers are not from out-of-country. The train-the-trainer packages should provide resource material that describes the theory and the science (and how that science is represented in the models in the DSS), how to build scenarios, how to run the DSS, and how to extract and analyse results. It could also cover how to format, import and export data, and how to source the data.

This material is then tailored, at the direction of the trainers, for different audiences. This may require translation.

During the IWRAM project, most training was conducted as workshops, as these could be co-ordinated with project meetings. These workshops included in-country team members and invited colleagues from their respective government agencies. While the out-of-country team members were the initial trainers, the final workshop (June 2004) was a truly collaborative effort with the in-country team providing instruction, and most of the workshop being in Thai. The first Thai-only workshop was held in January 2005 with material prepared by Thai team members. This workshop covered training in the component models by their developers, and hands-on use of the IWRAM DSS. While very successful, it did rely on the model developers being present. The next step is for the trainers to develop confidence in training in all aspects of the DSS and its use, without the full IWRAM team. This will be a true indication of successful adoption of the IWRAM approach.

Conclusions

The development of the DSS was to 'support sustainable use of Thailand rural catchments, specifically in relation to their land and water management, while maintaining a robust local economy' (Royal Project Foundation 2003). The DSS used a scenario-modelling approach to formulate and provide assessment tools to evaluate a range of scenarios based on their likely effects on the natural environment and the livelihoods of the local people.

The range of approaches to scenario development, model and indicator selection, and choice of integrating engine described above, demonstrate the flexibility of the IWRAM approach, which is neither prescriptive nor dogmatic.

In the short term, the primary role of the IWRAM DSS is to promote more-sustainable outcomes and educate. The best investment is in people, not products. In the words of the Thai team (Royal Project Foundation, 2003):

> The project team has developed expertise in IWRAM principles and has developed its own decision support software that predicts likely effects of a range of alternate crops and cropping practices on soil erosion, water availability and consumption, and economic return to local farmers.

References

Royal Project Foundation 2003. Integrated Water Resource Assessment and Management Project website. Chiang Mai, Thailand, Royal Project Foundation. At <http://www.iwram.org> [accessed 30 November 2004].

Saifuk, K. and Ongsomwang, S. 2003. A decision support framework for catchment based natural resource management. In: Post, D., ed., Proceedings of the international congress on modelling and simulation (MODSIM2003), 1645–1648. Available online via <http://mssanz.org.au/modsim03/Media/menu.pdf> [accessed 18 October 2004].

Using the IWRAM decision support system to understand trade-offs and improve decision-making

Wendy Merritt, Rebecca Letcher, Barry Croke and Kamron Saifuk

Summary

The Integrated Water Resource Assessment and Management project decision support system (IWRAM DSS) is a computer-based tool that links a set of biophysical and socioeconomic models to facilitate integrated assessment of land and water resource use options. Basically, it uses a scenario-indicator approach, allowing investigation of the spatio-temporal effects of postulated scenarios (model drivers or inputs) on indicators (model outputs) of catchment health. Previous chapters have described the individual models, as well as the integrating framework that connects each of these models within the DSS. The aim of this chapter is to demonstrate how the IWRAM DSS can assist with the planning of integrated land and water management, by presenting a set of case studies for the Mae Uam

sub-catchment in northern Thailand. The first set of case studies applies only the biophysical models to a set of scenarios that consider forest conversion, land management, and changes in climate. These case studies demonstrate the potential of the IWRAM DSS to explore the environmental effects of various land- and water-management options. In the second set of case studies, the full set of biophysical and socioeconomic models within the IWRAM DSS is employed to assess both the socioeconomic and environmental trade-offs associated with increasing the area of land available for agricultural production (and hence decreasing forest cover).

Introduction

The Integrated Water Resource Assessment and Management project decision support system (IWRAM DSS) is a computer-based tool comprised of a set of biophysical and socioeconomic models. The biophysical models include a crop, hydrologic and erosion model. These are linked to a set of socioeconomic models that can be used to explore economic trade-offs and impacts of the various scenarios being tested, as well as the capacity for households to adjust their behaviour to a change in government policy, prices or resource constraints.

Scenarios may be developed around agricultural or conservation policies, demographic change, potential climate variability, or changes in the world market for exported goods. The complementary and competitive nature of particular policies or paths of development can then be explored by stakeholders.

It is important to note that the IWRAM DSS does not make decisions. Instead, it supports good decision-making by helping users to explore key relationships relevant to the various environmental and socioeconomic trade-offs in catchment management, using a 'what if' scenario-based approach. Similarly, the DSS does not provide an 'optimal' outcome, as this is dependent on the perspective and objectives of the DSS user and its clients. By offering a transparent and repeatable process, it helps users to explore some of the expected and unexpected impacts of various scenarios.

The first half of this chapter tests the biophysical models within the IWRAM DSS by running a series of climate, deforestation, and other land use scenarios—see also Merritt et al. (2004). The results demonstrate not only the types of scenarios and land use planning issues that can be evaluated, but also the plausibility of the model behaviour. The results will provide, in addition, a basis for future developers and model users to question the behaviour of the models and make improvements.

The second half of the chapter combines the biophysical models with the socioeconomic models to assess the socioeconomic trade-offs of a development scenario in which the total area of agricultural land is increased. Instead of the user defining the land use scenarios (as in the stand-alone application of the biophysical models presented above), the land use is passed on to the biophysical models from an economic decision model. This decision model simulates the choice of crops to be grown in a particular season, and on a particular land unit, in response to expected constraints on land, water and labour availability. The subsequent results from the biophysical models are then fed back into another socioeconomic model that estimates 'socioeconomic performance' for that particular scenario.

The DSS implements a scenario-indicator approach whereby users can test a number of scenarios and compare outputs of the models by looking at changes between the indicator sets. The DSS incorporates a nodal structure, where nodes represent the locations at which indicators are computed. The common spatial scale of the indicators is the sub-catchment upstream of a selected node in the river network. Figure 10.1 shows the locations of two nodes selected for calculation of indicators and evaluation of upstream–downstream impacts in the Mae Uam sub-catchment. Note that if a selected node (e.g. node 2 in Figure 10.1) has an upstream sub-catchment (e.g. node 1 in Figure 10.1) nested within it, then the area of the smaller upstream sub-catchment is subtracted from the larger downstream sub-catchment to provide the 'residual' sub-catchment area at the lower node (node 2 in Figure 10.1).

Biophysical models—scenario runs

To illustrate the capacity of the biophysical models to assist decision-making, simulations based on a set of scenarios considering changes in annual rainfall, and changes in forest cover and cultivation area, were performed for the two nodes in the Mae Uam sub-catchment of the Mae Chaem catchment (Figure 10.1). A set of different land-management scenarios was also simulated. Cropping details for each land unit in the wet season (April–November) and dry season (December–March) are provided in Table 10.1. The base forest cover used in the scenario runs is presented in Table 10.2. The base scenario corresponds to the 1990 forest cover provided by the National Research Council of Thailand.

The indicators evaluated by the biophysical models within the DSS can be summarised as: crop yield (t/ha), crop water-demand (mm), irrigation (mm), streamflow (ML), residual streamflow (ML), gross erosion loads (t), and erosion rates for land units and crops (t/ha). The crop water-demand is the total water over the growing season required to reach the potential evapotranspiration for a given crop. The irrigation indicator is the total irrigation (in mm) applied to a crop throughout the season. If the crop water-demand does not exceed the amount of water available within the stream, then irrigation is the same as crop water-demand. For this work, only surface water sources were used to irrigate crops. Other sources, such as shallow groundwater, were not considered. The streamflow indicator is the streamflow before irrigation abstractions. The residual streamflow indicator is the streamflow following abstractions for crop irrigations, assuming 100% irrigation efficiency.

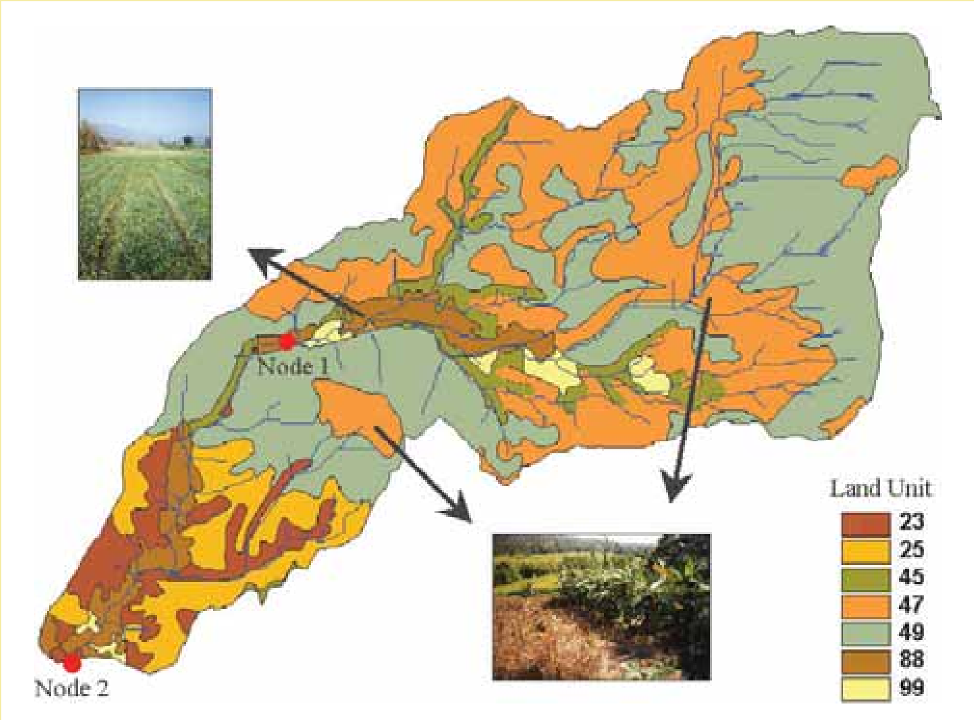


Figure 10.1 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: the sub-catchment, showing the location of nodes, the land unit types present and typical agricultural landscapes

In order to indicate some general features of the output, Figure 10.2 illustrates the erosion, yield, and water demand for the 1990–1991 hydrological year for four crops. In the wet season, agricultural fields are prone to elevated rates of erosion. In the dry season, there is very little rainfall (and hence negligible surface run-off) and so erosion rates are very low. Of concern in the dry season, however, is the availability of water for irrigation of crops. Note that, in the dry season, soybean and maize grain were irrigated. Hence, water demand by these crops is not as high as the non-irrigated fallow because, at each time-step, the crop is irrigated (thus reducing the initial crop water-demand for the next time-step to zero, while the fallow vegetation is increasingly water-stressed).

Climate scenarios

Three climate scenarios were simulated, corresponding to the 1990–91 hydrological year (1250 mm of rainfall), the 1988–89 year (1322 mm of rainfall), and the 1993–94 year (1026 mm of rainfall). Due to the short period of daily records available in the catchment, these scenarios do not

Table 10.1 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: proportion of agricultural area cropped on different land units

	Paddy fields (Land Unit nos 88 and 99)	**Upland fields** (land unit nos 23, 25, 45, 47 and 49)
Wet season	100% paddy rice Crops are fully irrigated on bunded plots, with medium fertiliser levels and no extra management.	23: 50% maize 25: 50% soybean 45: 50% soybean 47: 50% maize 49: 15% soybean Non-irrigated crops; medium and low fertiliser levels for maize and soybean, respectively; plots on land units 23 and 25 are contour cultivated; no management practices are employed on land unit 45; arable land terraces are used on land unit 47; land unit 49 has strip cropping around contour plot.
Dry season	88: 25% soybean 99: 25% maize Both crops are fully irrigated on bunded plots, with low fertiliser levels for soybean and medium fertiliser levels for maize	23: 10% maize 25: 10% soybean 45: 10% soybean 47: 10% maize 49: no cropping Irrigated crops; medium and low fertiliser levels for maize and soybean, respectively; plots on land units 23 and 25 are contour cultivated; arable land terraces are used on land units 45 and 49.

reflect the true variability of climate. Despite this, these three climate scenarios show considerable variability (Figure 10.3). For instance, only 10 mm of rain fell in the 1990–91 dry season, compared with 102 mm in the 1993–94 dry season. Three forest-cover scenarios were considered: 1990 forest cover; a 30% decrease in the 1990 forest cover across all land units; and a 50% decrease across all land units.

Table 10.3 illustrates the effect of climate on catchment streamflow and residual streamflow (streamflow after irrigation abstractions), as well as the total crop water-demand at the downstream node (node 2). An increase in annual water demand from the agricultural area of approximately 70 ML is seen when simulating the 1993–94 scenario compared with the 1988–89 scenario. The difference in annual rainfall between these two scenarios is 296 mm. The crop water-demand in Table 10.3 includes demand from fallow land. This land is not irrigated and this is why the residual streamflow and demand do not add up to the total streamflow. The total crop water-demand in the 1993–94 hydrological year is higher than the 1990–91 hydrological year despite higher annual rainfall, due to the timing of the rainfall.

Table 10.2 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: land-unit area (km²) and 1990 forested area (km²) for land units within nodes 1 and 2

Land unit no.	Description	Slope class[a]	Node 1 area (km²)		Node 2 area (km²)	
			Forest	Land unit	Forest	Land unit
23	Deep loam soils	A or B	0.00	0.00	1.76	2.40
25	Deep loam soils	C	0.00	0.00	3.01	3.39
45	Deep clay soils	A or B	1.70	2.01	0.20	0.24
47	Deep clay soils	C	12.30	12.78	0.94	1.05
49	Deep clay soils	D or E	15.95	16.22	3.78	4.01
88	Deep clay irrigated paddy soils	A or B	0.54	1.01	0.39	1.46
99	Deep clay paddy soils	A or B	0.37	0.66	0.06	0.13
Total	–	–	30.86	32.68	10.14	12.68

[a] A: 0–8%, B: 8–16%, C: 16–35%, D: 35–60%, E: > 60%

Table 10.3 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: summary of impacts of climate scenarios upon the volumes (ML) of catchment streamflow, crop water-demand at node 2, and streamflow following abstractions for the wet and dry seasons

Forest decrease	Streamflow (ML)			Residual streamflow (ML)			Crop water-demand (ML)			Rainfall (mm)
	Base	30%	50%	Base	30%	50%	Base	30%	50%	
Wet season										
1988–89	12,579	13,957	15,114	12,028	13,341	14,445	841	1,597	2,114	1,231
1990–91	14,563	15,436	15,346	16,127	14,043	15,505	646	1,087	1,390	1,240
1993–94	9,871	10,854	11,592	9,405	10,351	11,059	819	1,678	2,263	925
Dry season										
1988–89	6,797	6,045	5,347	6,723	5,933	5,210	433	773	1,001	92
1990–91	3,955	3,258	2,662	3,864	3,122	2,495	524	940	1,220	10
1993–94	2,670	2,476	2,269	2,579	2,338	2,101	526	948	1,231	102

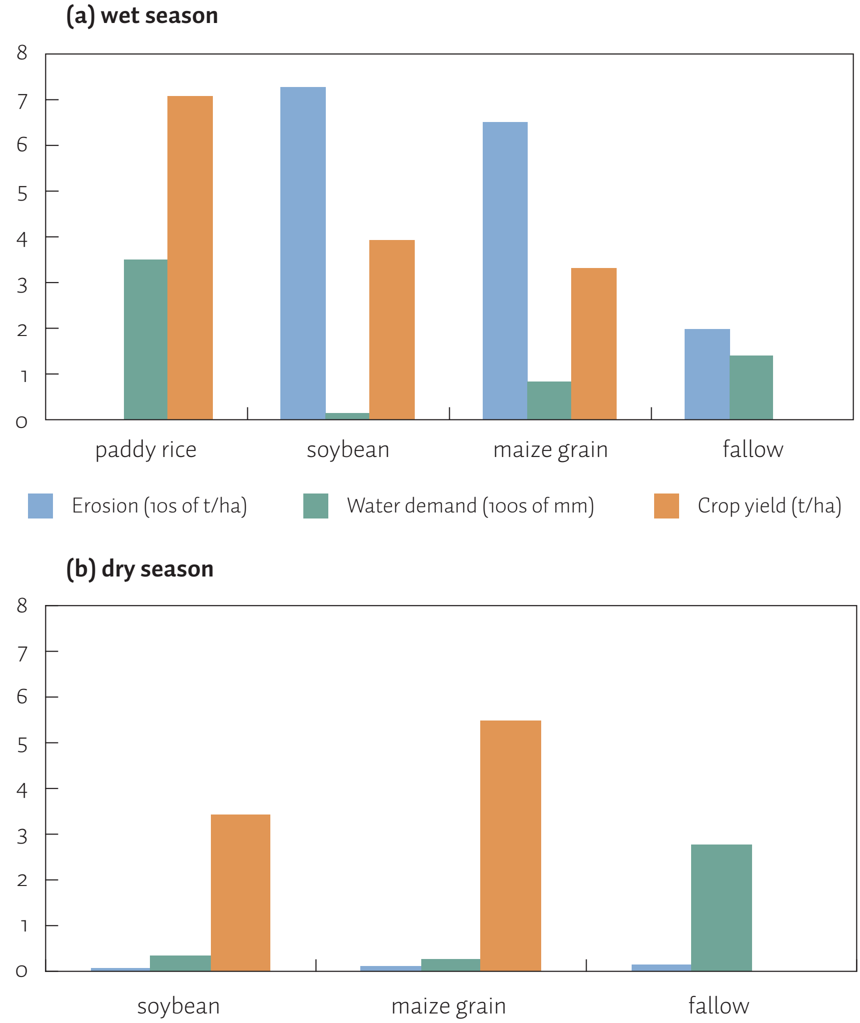


Figure 10.2 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: changes in yield, erosion rates, and water demand in the (a) wet and (b) dry seasons of the 1990–1991 hydrological year

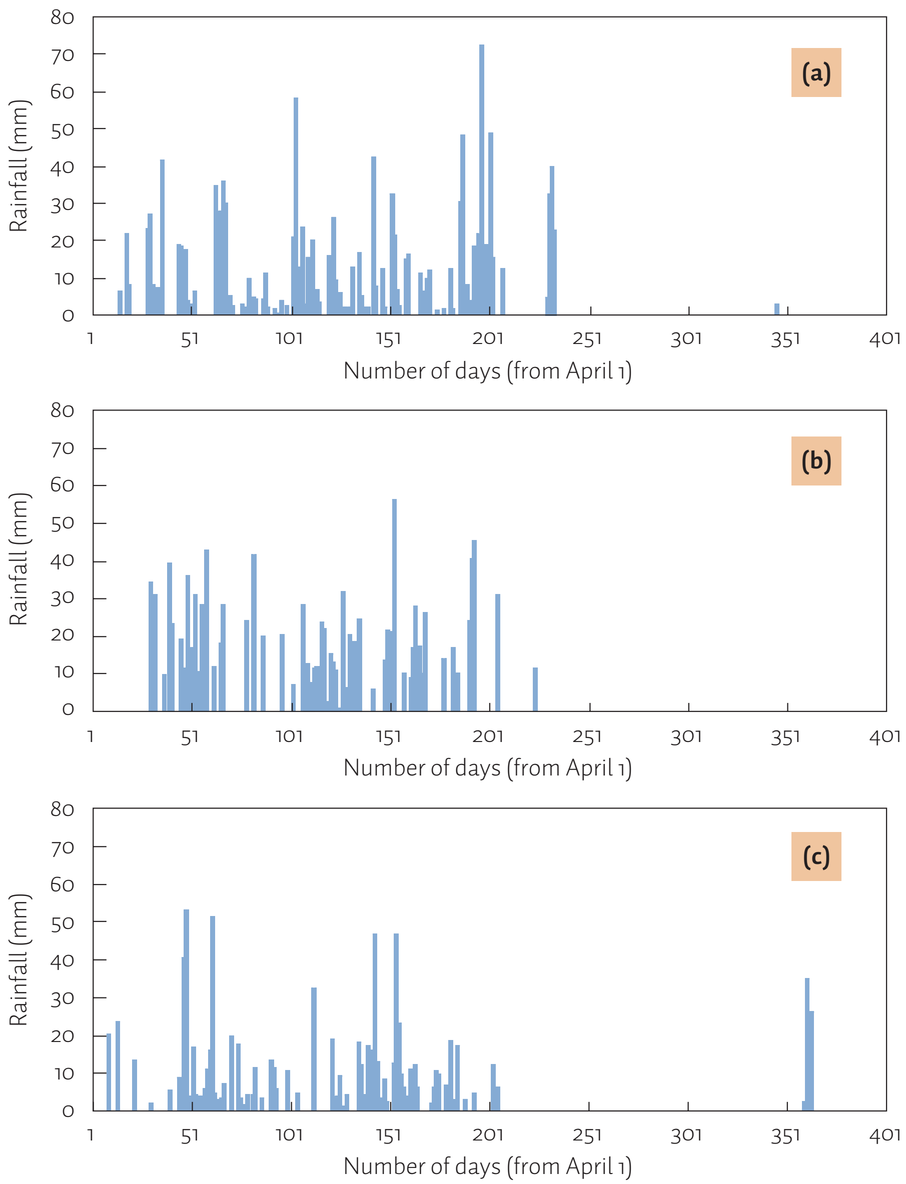


Figure 10.3 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: daily rainfall for the climate scenarios: (a) 1988–89, (b) 1990–91 and (c) 1993–94

Figure 10.4 illustrates the predicted wet- and dry-season erosion loads from the agricultural area in the upstream node of Mae Uam (node 1). The same three forest-cover-change scenarios are considered. Total erosion yields increase linearly with a change in forest cover. The wet seasons of the 1988–89 and 1990–91 years are similar in terms of precipitation, and this is reflected in similar erosion-load estimates.

The similarity between wet-season precipitation in the 1988–89 and 1990–91 hydrological years is further illustrated in Table 10.4. Here, the impact of climate scenarios on the mean erosion rates (t/ha) and average crop yields (t/ha) is shown. (Cropping patterns and land-management practices for each land unit are detailed in Table 10.1.) Table 10.4 illustrates the susceptibility of the upland land units (45, 47 and 49) to elevated levels

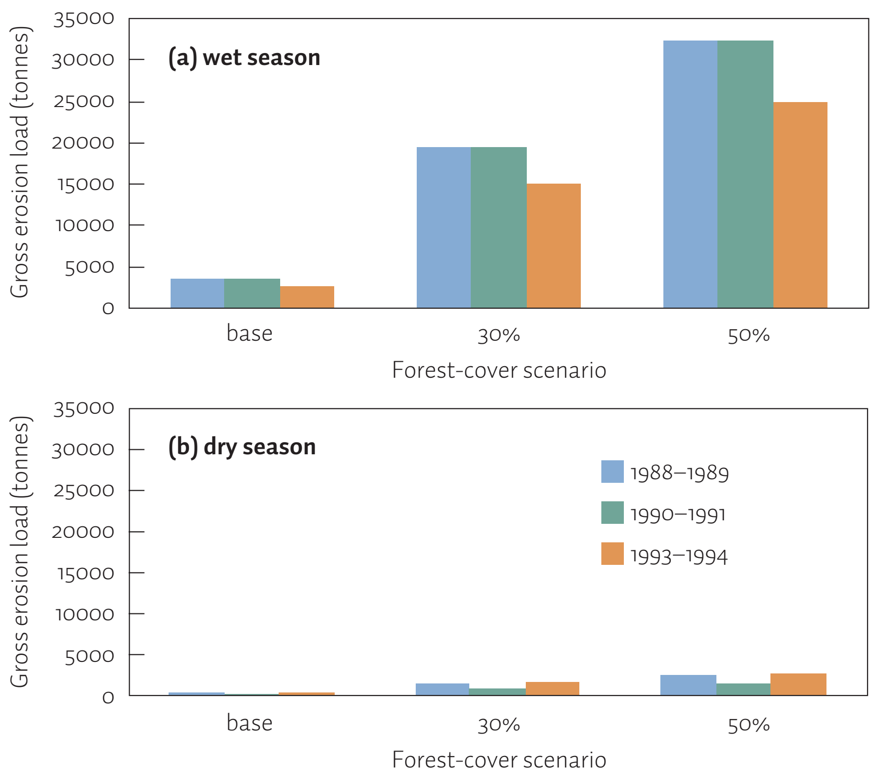


Figure 10.4 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: gross erosion loads (for wet and dry seasons) from agricultural land in node 1 under the 1988–89, 1990–91, and 1993–94 climate scenarios and 1990 forest cover (base), and 30% and 50% reduction in forest cover

of erosion under agricultural activities. On most of the land units, the only exception being land units 88 and 99, erosion rates are higher under most crops than under forest. For comparison, predicted erosion rates for forest with no bunds or land-management practices in the 1990–91 hydrological year are detailed in Table 10.4. The Land Development Department (LDD) uses a threshold of 5 tonnes per rai (31.25 t/ha) as an acceptable level under crops. This raises the possibility that many combinations of crops and management practices are likely to exceed this threshold. In particular, land unit 45—where soybean was grown with no management practices in place to mitigate soil erosion—is particularly prone to erosion. While the steep land unit 49 is highly susceptible to erosion, the management practice selected was strip cropping around contours—a practice that the model outputs suggest is sufficient to ensure that erosion rates are within the 'acceptable' rates of soil loss.

Deforestation scenarios

Scenarios of forest conversion that were tested ranged from the extreme cases of 30–50% deforestation across all land units, and removal of forest from steeply sloping land (on land unit 49), to the more-probable scenarios of removal of forest from the more-accessible land suitable for agriculture (e.g. land units 88 and 99). These scenarios are shown in Table 10.5. The absolute values for the erosion load, streamflow, residual streamflow, and crop water-demand indicators for the base forest-cover scenario are shown in Table 10.6. While node 1 land (upland) is more prone to erosion than the lower elevation land (node 2), only a small proportion of the steeper land units is cropped. This, combined with improved erosion mitigation factors on the steeper land units (e.g. bench terracing), explains the greater rates of erosion predicted for node 2.

Table 10.4 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: impacts of climate scenarios upon mean annual erosion rates (t/ha) and average yields for crops (t/ha) in node l (w = wet season, d = dry season)

Land unit no.	Erosion (t/ha) for forest (1990–91)	Erosion (t/ha)			Crop yields (t/ha)		
		1993–94	1988–89	1990–91	1993–94	1988–89	1990–91
45	0.203	37.3	48.4	48.3	2.0 (w) 1.7 (d)	2.0 (w) 1.7 (d)	2.0 (w) 1.9 (d)
47	0.253	33.2	43.0	43.0	3.1 (w) 2.0 (d)	3.3 (w) 2.0 (d)	3.0 (w) 2.4 (d)
49	0.253	19.1	24.8	24.8	1.9 (w) –	1.9 (w) –	1.9 (w) –
88	0.164	0.01	0.02	0.02	3.6 (w) 1.7 (d)	3.5 (w) 1.7 (d)	3.4 (w) 1.9 (d)
99	0.149	0.01	0.01	0.01	3.6 (w) 3.7 (d)	3.5 (w) 3.5 (d)	3.4 (w) 3.5 (d)

Figures 10.5–10.8 show the results for each of the deforestation scenarios, as a percentage of the base scenario for node 1.

With deforestation across all land units (Table 10.5) we see some extreme increases in the model's estimated gross annual erosion load. Node 1 has a high potential for erosion due to the high proportion of upland units, especially land unit 49, within its catchment area. While the results in Table 10.4 suggest that this land could be utilised with acceptable levels of erosion, it is highly dependent on the use of costly land-management practices. For this reason, it has been recommended that these areas should remain as natural forest. Despite more-intensive agriculture being assigned to other land units (see Table 10.1), their lower slopes counteract this effect. Hence, these other land units are less prone to erosion than land unit 49. Thus, fully utilising land units 88 and 99, which commonly support paddy agriculture, did not dramatically increase erosion because of their low areal extent and their flat topography (scenario 9 in Table 10.5 and Figures 10.5–10.8).

For all deforestation scenarios, there is a slight increase—up to 7.5% for scenario 5 (Figure 10.6)—in annual and wet-season streamflow at node 1 compared with the base forest-cover scenario. This reflects the structure of the hydrological model described in Chapter 6, where it is assumed that forests evaporate at a greater rate than non-forest vegetation. More importantly, there is a marked decrease in dry-season streamflow of up to 15–20% (Figure 10.6). This is in response to the increase in rapid surface run-off during the wet season (quick flow) and reduction in deep percolation (slow flow) predicted under non-forest vegetation covers compared with forested land. For the more extreme deforestation scenarios (on the land units dominant in node 1), the large crop water-demand greatly increases the irrigation extractions, thus reducing the residual discharge (Figures 10.7 and 10.8).

Land-management scenarios

The biophysical models can be used to assist with land use planning activities. The models can provide estimates for key indicators for each land-unit type and relate these back to thresholds to identify whether or not a crop or particular land use is suitable. This section looks at the changes in indicators under different crop and land-management combinations.

Table 10.5 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: forest conversion scenarios

Code	Description
sc1	Base 1990 forest conditions
sc2	30% decrease in forest cover on low sloping land units
sc3	30% decrease on low to mid sloping land units
sc4	30% decrease on steeply sloping land units
sc5	30% decrease across all land units
sc6	50% decrease in forest cover on low sloping land units
sc7	50% decrease on low to mid sloping land units
sc8	50% decrease on steeply sloping land units
sc9	0% forest on low sloping land units

Table 10.6 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: key biophysical indicators under the base forest-cover scenario and 1990 climate

	Erosion (t/ha)	Total streamflow (ML)	Residual streamflow (ML)	Crop water-demand (ML)
Node 1				
Wet season	43	10,725	10,378	589
Dry season	2.1	2,732	2,671	339
Annual	45	13,457	13,049	928
Node 2				
Wet season	74	14,563	14,043	646
Dry season	4	3,955	3,864	524
Annual	78	18,518	17,907	1,170

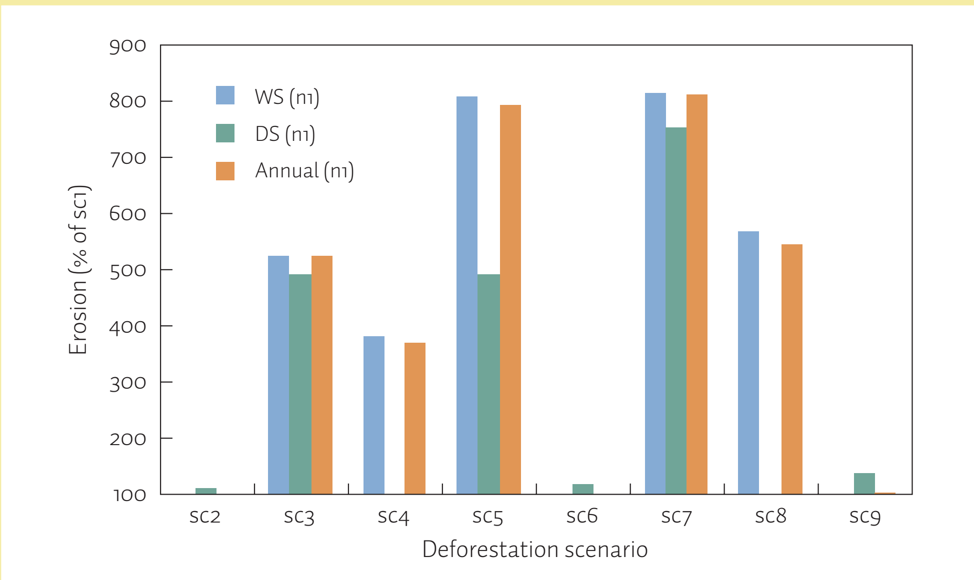


Figure 10.5 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: changes in erosion at node 1 for deforestation scenarios as a percentage of the base scenario (WS = wet season, DS = dry season)

The models were run for a range of combinations of land units, crops and land-management combinations (Table 10.7). The land-management options included fertility level, irrigation status and whether or not the plot is surrounded by bunds.

Crop yield

Figure 10.9 shows a plot of crop yields (in t/ha) for onion under the management combinations detailed in Table 10.7. Outputs are provided for the 1990–91 hydrological year. The fertility level of the plot has a greater impact on the model outputs than whether or not the crop is rainfed or bunded. When the fertility of a plot is low, the crop model predicts yields of about 15 t/ha, increasing to 20–22 t/ha for most combinations of medium fertility and 23–28 t/ha for high-fertility crops. The model outputs suggest that vegetable crops like onion are more suited to the low sloping and more clayey soils of land units 88, 99 and 45 than they are to the steeper land units (land units 47 and 49) if the crops are not irrigated. In this manner, the predicted response is plausible, as these land units will retain more moisture and allow the crop to meet more of its water requirements. If the crop's water requirements are met, then there is little difference between the yield on upland and lowland sites. This reflects the similarity in soil types of different land units (shallow loamy clays) and the parameterisation of the CATCHCROP model (see Chapter 7).

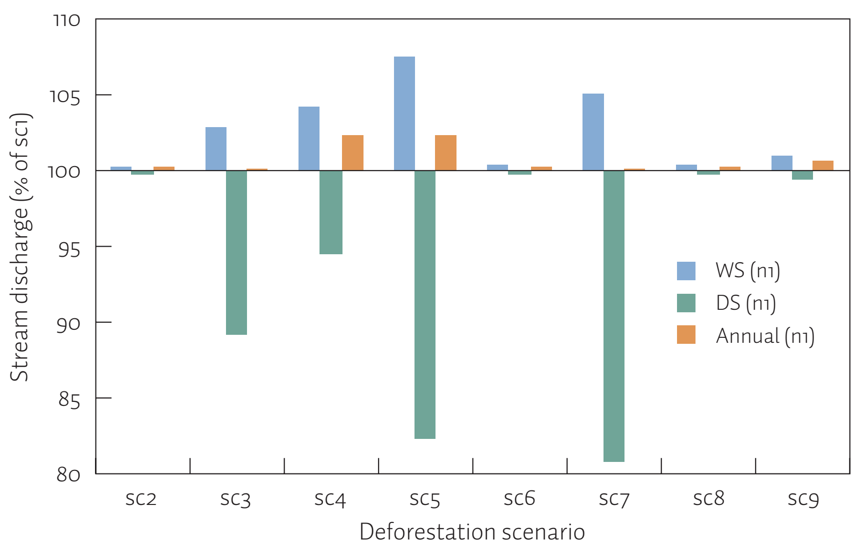


Figure 10.6 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: changes in streamflow at node 1 for deforestation scenarios as a percentage of the base scenario (WS = wet season, DS = dry season)

Erosion rates

Erosion predictions depend on both the cropping factor (*C*) and management factor (*P*) within the universal soil loss equation (USLE; see Chapter 8). For crops that were grown in paddy fields with bunding, the *C* and *P* factors were greatly reduced. The flat surface of bunded plots ensures that there is negligible erosion on such lands, and the raised banks mean that little sediment leaves the plot. Erosion rates on bunded plots are thus low, regardless of the land-unit type, ranging from 0.015 t/ha on land units 88 and 99 to 0.023 t/ha in upland land units.

Figures 10.10 and 10.11 show plots of erosion rates under different crops and land covers for the wet season of 1990–91 for land unit 88 and land units 47 and 49. For most crops and management types on land units 88 and 99, the model suggests that erosion rates are not extreme. Estimates of erosion rates for paddy rice, maize, fruit trees, fallow and forest are generally within the LDD-prescribed threshold for erosion of 31.25 t/ha. In upland fields, most crops are prone to high rates of erosion. Only maize, fallow and forest cover-types yield less than the 'acceptable' level of erosion. Land units 47 and 49, in particular, have a high erosion potential. Under current government policy, land unit 49 is designated for

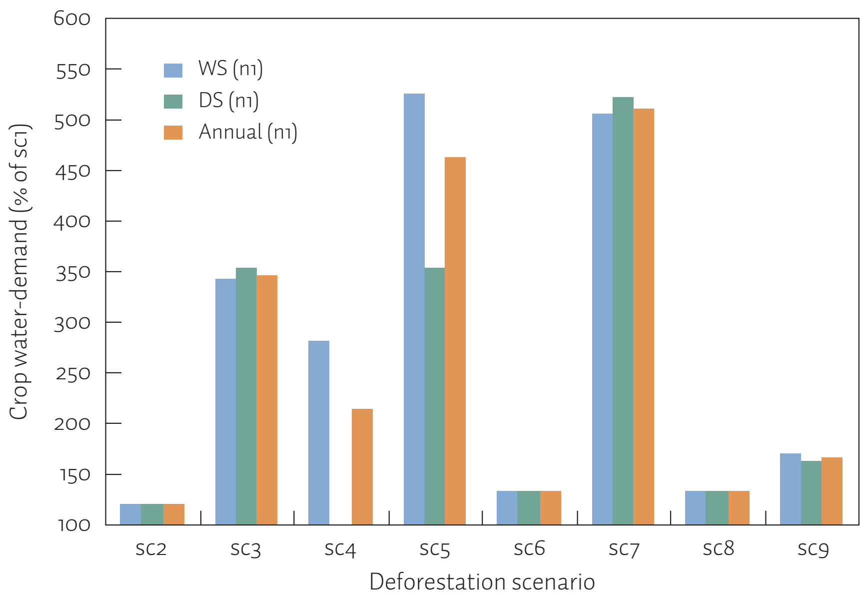


Figure 10.7 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: changes in crop water-demand at node 1 for deforestation scenarios as a percentage of the base scenario (WS = wet season, DS = dry season)

forest cover only. No differences in erosion rates are distinguished between land units 47 and 49, despite land unit 49 being generally much steeper, as the land units fall into the same slope category for defining the *P* factors for the USLE. In reality, it would be expected that considerably more erosion would occur on land unit 49 than on land unit 47.

Water balance and crop water-demand

Table 10.8 shows water-balance components and crop water-demand under paddy rice on land unit 88 in both the wet and dry seasons of the 1990–1991 hydrological year, under the land-management combinations shown in Table 10.7.

Actual evapotranspiration (ETA) is maximised under high-fertility, irrigated conditions. Under high-fertility conditions, crop water-demand is not sensitive to whether or not the plot is bunded. However, crops grown on low-fertility plots that are not bunded have a much higher water-demand than on equivalent bunded plots. The main difference between irrigated and non-irrigated crops is the deep drainage and the crop water-demand (DEM). Rainfed crops generally have a higher DEM than irrigated crops over the cropping season. In the CATCHCROP model, DEM is defined as the difference between ETA and the potential evapotranspiration (ETC) of a crop. For irrigated plots, the soil reservoir is

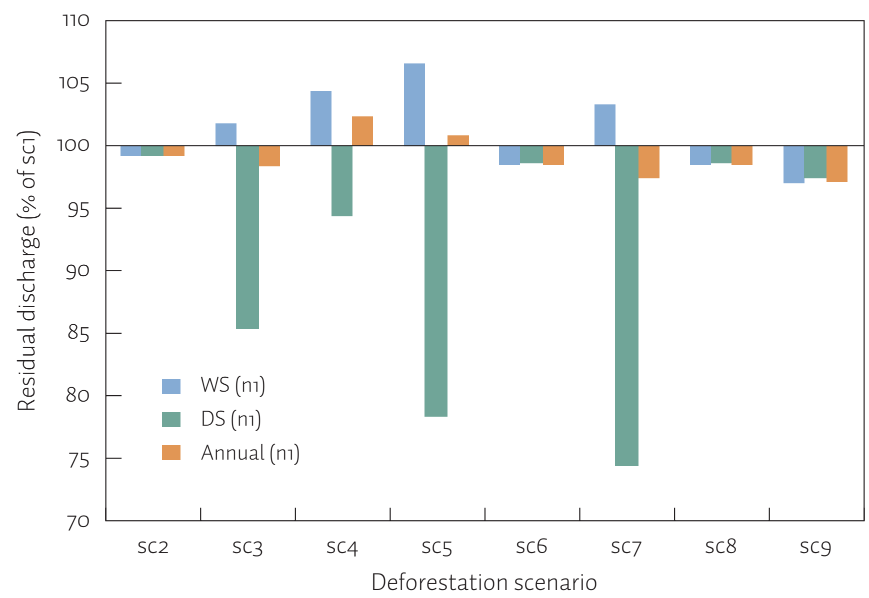


Figure 10.8 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: changes in residual streamflow at node 1 for deforestation scenarios as a percentage of the base scenario (WS = wet season, DS = dry season)

replenished at each time step, allowing ETA to approach ETC and reduce the DEM for that time step. Over the cropping season, this shows up as the difference between rainfed and irrigated crops. In the wet season, rainfall is sufficient to ensure that the crop can get most of the water it requires, such that ETA is not greatly reduced. Similar trends occur across all land units, although between crops there is a great deal of variation. Actual evapotranspiration is extremely low in rainfed crops, as crops are unable to get sufficient water to transpire, unlike crops under high-fertility, irrigated conditions. As with the wet season, under high-fertility (irrigated) conditions, crop water-demand is not as sensitive to whether or not the plot is bunded. Deep drainage is minimal, as most of the water that infiltrates into the soil is taken by the plants. Similar trends occur across all land units.

Table 10.7 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: combinations of land-management practices. The code refers to the land-management combinations in Figures 10.9 to 10.11.

Code	Fertility level	Irrigation status	Bunded
s1	low	Rainfed	no
s2	medium	Rainfed	no
s3	low	Rainfed	yes
s4	low	Irrigated	yes
s5	medium	Rainfed	yes
s6	medium	Irrigated	yes
s7	high	Rainfed	no
s8	high	Rainfed	yes
s9	high	Irrigated	yes

Discussion of biophysical case studies

The scenario runs for the Mae Uam sub-catchment highlight some of the trade-offs among indicators and raise questions about perceived impacts. For example, they suggest that while substantial conversions of forest to agricultural land do not impact greatly on the amount of water remaining in the stream, the potential erosion increases are extreme. Even though the USLE methodology applied in the toolbox provides only coarse estimates of gross erosion, it is reasonable to expect that the elevated rates of erosion would translate to increased sedimentation in the catchment's water resources.

Reported water shortages within the lowland regions of catchments in northern Thailand have been attributed to increased agricultural activities in the upland areas. This extreme case was not shown in the model outputs for the scenarios performed in this analysis. The deforestation scenarios applied to node 1 of the Mae Uam catchment, where the forest is replaced by crops in the same proportion as used in the base scenario, did not increase crop water-demand to an extent that threatened water availability to agricultural areas in node 2. This is the result even when the agricultural area, and hence crop water-demand, is increased within node 2. However, not all the land that was converted from forest was utilised in either the wet or dry seasons. Only 10% of the agricultural area of land units 23, 25, 45, and 47 was cropped in the dry season, while on land unit 49 no land was cropped. Likewise, 25% of the agricultural area of land units 23, 25, 45 and 47 and 15% of land unit 49 was cropped. Utilising a larger proportion of agricultural land in the upland land units would substantially increase abstractions during the dry season and may place water resources under further pressure.

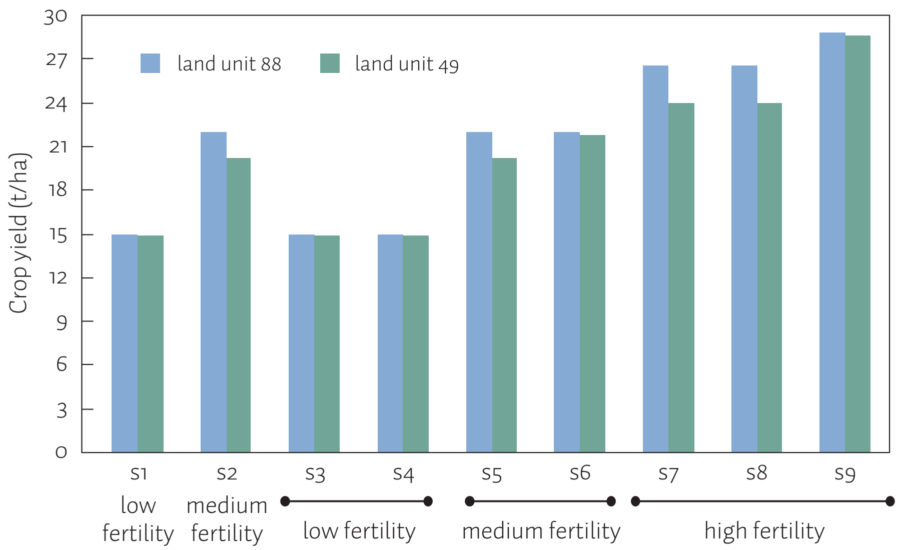


Figure 10.9 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: plot of crop yields (t/ha) for onion under varying land-management combinations. All model parameters are kept constant.

It is expected that application of the toolbox in more-intensively used catchments with greater competition and demand for water resources would produce effects like those reported in the lowland areas of this region. In such regions, where more land suitable for intensive agriculture is available, increased cropping and hence demand for water may place water resources at risk. In the Mae Uam sub-catchment, the amount of land suitable for cropping is restricted by topography. Much of the land suitable for paddy has already been utilised, and much of the remaining catchment is nominally protected as it has been designated as watershed classification 1A.

Running all combinations of land-management options provides an understanding of the model responses to changes in inputs, particularly with respect to the outputs of the CATCHCROP model. The model outputs suggest that, in the wet season, the fertility of the plot influences yield more strongly than whether or not the plot is irrigated or bunded. In the dry season, irrigation becomes significant. Most crops fail completely and produce no yields unless they are irrigated. In the field, many plots during the dry season are not utilised because transporting water to them is not practical.

Erosion rates were shown to be particularly high for upland rice and vegetable crops compared with other vegetation or cover types. The outputs suggest that forest and fallow covers fall within the LDD-defined threshold of 31.25 t/ha on all land units, while covers like maize and fruit trees tend to fall within 'acceptable' soil loss under most management types. Upland rice and vegetable crops are generally suitable under the more-advanced management practices such as bench terracing on low-sloping land, although are susceptible to 'unacceptable' erosion rates on steeply sloping lands, unless highly effective erosion-mitigation practices are implemented.

Although considerable effort has been made to keep the biophysical models relatively simple in terms of the structure and number of model parameters, the biophysical framework as a whole is reasonably complex and the interactions between the models—particularly the crop and hydrology model—can be quite non-linear. Merritt et al. (2005) assess the sensitivities of model outputs to perturbations in parameter values and the underlying assumptions.

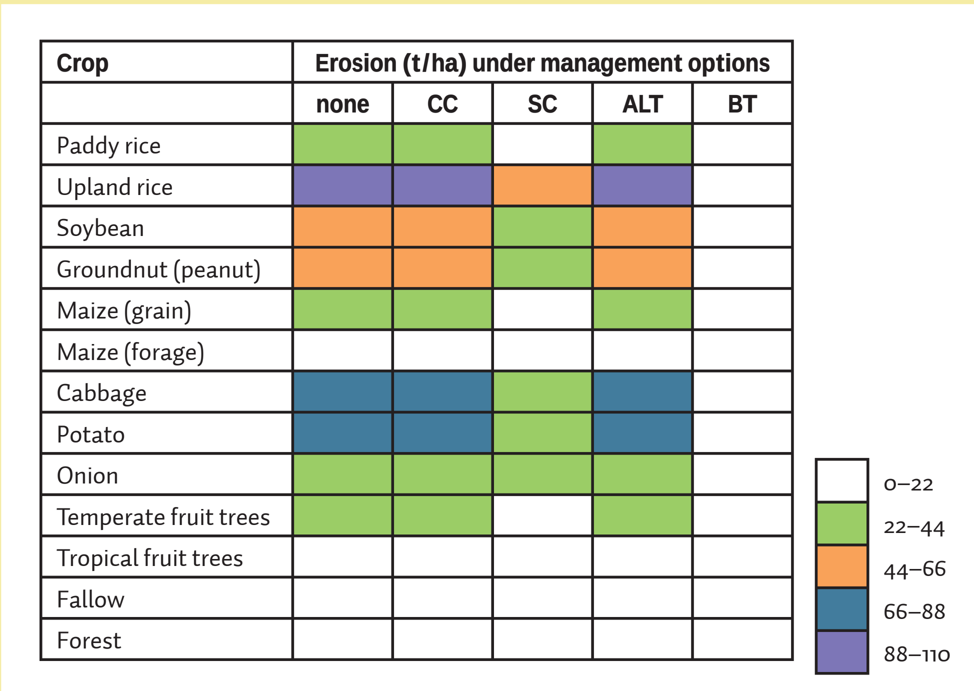


Figure 10.10 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: erosion rates (t/ha) on land unit 88 under available management options for 13 crop or land cover types on low-sloping land units suitable for paddy agriculture (BT = bench terrace, ALT = 'arable' land terrace, SC = strip cropping around contours, CC = contour cultivation)

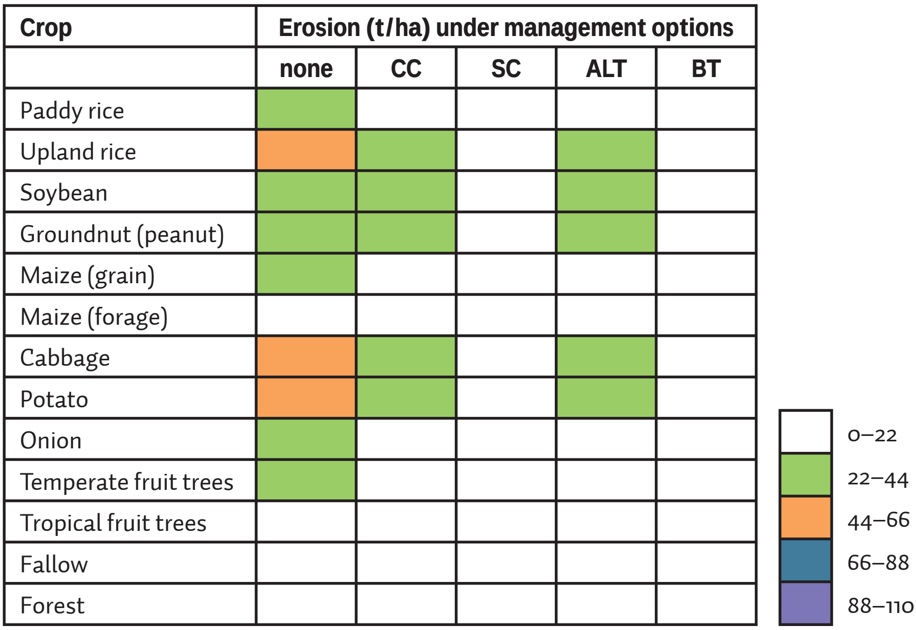


Figure 10.11 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: erosion rates (t/ha) on land units 47 and 49 under available management options for 13 crop or land-cover types on low-sloping land units suitable for paddy agriculture (BT = bench terrace, ALT = 'arable' land terrace, SC = strip cropping around contours, CC = contour cultivation)

Integrating the biophysical and socioeconomic models

The IWRAM DSS can also be employed to assess the socioeconomic trade-offs of a wide range of management and development scenarios. Instead of the user defining the land use scenarios (as in the stand-alone application of the biophysical models presented above), the land use is passed on to the biophysical models from an economic decision model. This decision model simulates the choice of crops to be grown in a particular season, and on a particular land unit, in response to expected constraints on land, water and labour availability as well as to changes in prices, costs and expected yields. The subsequent results from the biophysical models are then fed back into another socio-economic model that estimates 'socioeconomic performance' for that particular scenario. This framework, depicted in Figure 9.2, provides an integrated assessment of the biophysical and socioeconomic impacts of a particular scenario.

The socioeconomic models currently incorporated in the IWRAM DSS include a household decision model, a decision disaggregation model (DDM), and a socioeconomic impact simulation model (SISM), all of which are described in Chapter 5.

It is assumed that agricultural production (or crop choice) decisions take place at the household scale. These household decisions, including remaining forest cover, are then aggregated for each land unit within a node along the river and passed as an input to the biophysical models. The hydrologic model calculates the pre-extraction flow at each river node on a daily time step for the year, given the rainfall and temperature. This flow is sensitive to changes in forest cover. The crop model then runs for each land unit and crop combination defined by the land use decisions for the node. The water demand is calculated by the crop model on a seven-day time step. A water-allocation model, containing a crop prioritisation list defined by catchment stakeholders, is used to determine the order in which crops are able to access the available water for irrigation. Crop demands are sequentially compared with the remaining quantity of water available for extraction. Yield penalties occur for crops that do not receive sufficient water.

The erosion model is also run to calculate wet- and dry-season erosion, given the crop choice and climatic conditions. The actual water available is then calculated and is used to update households' expectations of water availability for the next year in the household decision models. Actual yields are passed to SISM to consider the impact of actual water

Table 10.8 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: wet- and dry-season crop water-demand (DEM), irrigation (IR), actual evapotranspiration (ETA), deep drainage (DD) and crop yields for paddy rice on land unit 88 for the 1990 hydrological year

Crop	DEM (mm)	IR (mm)	ETA (mm)	DD (mm)	Yield (t/ha)
Wet season					
s1	443	0	397	0	1.80
s2	707	0	471	0	2.34
s3	308	0	472	530	2.17
s4	286	286	489	799	2.29
s5	510	0	623	378	3.28
s6	456	456	658	799	3.54
s7	698	0	729	272	4.06
s8	698	0	729	272	4.06
s9	617	617	820	799	4.73
Dry season					
s1	834	0	34	0	0.00
s2	862	0	34	0	0.00
s3	834	0	34	0	0.00
s4	328	328	294	0	1.99
s5	862	0	34	0	0.00
s6	472	472	438	0	3.46
s7	870	0	34	0	0.00
s8	870	0	34	0	0.00
s9	606	606	572	0	4.82

availability on household performance and, in particular, on total rice production per person, which is considered to be a social indicator of the impact of a scenario option.

The socioeconomic indicators are given by RMU (resource management unit—see Chapter 5 for a description) and by node. They allow changes in the social and economic 'performance' of a household, due to different climatic and upstream land use-choice scenarios, to be investigated and potentially traded-off. Where a multi-year scenario is run, a time-series chart of the output is provided. Tables of values are also given for all scenario runs. The procedure yields the following socioeconomic indicators:

1. Cash per household (baht). This indicator describes the 'economic performance' of households of each RMU type.
2. Total household income from agriculture (baht). This indicator describes the agricultural income from their land use choices.
3. Off-farm (household) income (baht). This indicator shows the reliance of different households on off-farm income.
4. Hire cost (baht). This indicator shows the total wages paid per household to hired labour in each year. It shows the extent to which production relies on hired labour.
5. Rice production per person (kg). It is assumed that each person in a household requires 300 kg of rice per year to survive. This indicator shows how close households come to meeting their subsistence requirements. Most households strongly prefer to produce their own rice.
6. Cost of rice deficit (baht). This indicator shows the cost to the household of purchasing unmet rice requirements.

Socioeconomic case studies

This section provides a brief description of two scenarios for which the socioeconomic models of the IWRAM DSS are used. They demonstrate the types of environmental and socioeconomic trade-offs that can be calculated. The scenarios (for the Mae Uam sub-catchment) show the effects of agricultural expansion (and hence clearing of forest) leading to increases in the land available to individual households as summarised in Table 10.9. The model was run over five years using climate data from 1989 to 1993. Results for nodes 1 (upstream) and 2 (downstream) are shown.

Results for nodes 1 and 2 from the two scenarios are shown in Figures 10.12–10.15.

These figures demonstrate the trade-offs associated with increasing the amount of land available to households. Households of RMU2 receive a very small benefit (i.e. increase in household cash) from this increase in available land. These households are more constrained by their restricted access to other resources (water and labour) than to land and so are not able to receive large benefits from this increase in the area available. Households of both RMU3 and RMU8 have access to rainfed fields and benefit to a much greater extent than those of RMU2. In some years, the household income within these RMUs more than doubles under these scenarios. Also, these households have a small rice deficit under the base-case assumptions. Increases in land lead to the removal of this rice deficit. This means that increasing the land area available to these households helps them meet their subsistence requirements and increases their cash wealth.

Table 10.9 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: scenario input assumptions by three types of resource-management unit (RMU) (areas in hectares)

	Base case		Scenario 1		Scenario 2	
	Paddy	Upland	Paddy	Upland	Paddy	Upland
Node 1						
RMU 2	0.4	0	0.496	0	0.592	0
RMU 3	0	0.336	0	1.6	0	2.864
RMU 8	0.432	0.208	0.544	0.992	0.64	1.776
Node 2						
RMU 2	0.496	0	0.56	0	0.624	0
RMU 3	0	0.4	0	0.912	0	1.424
RMU 8	0.368	0.192	0.416	0.432	0.464	0.688

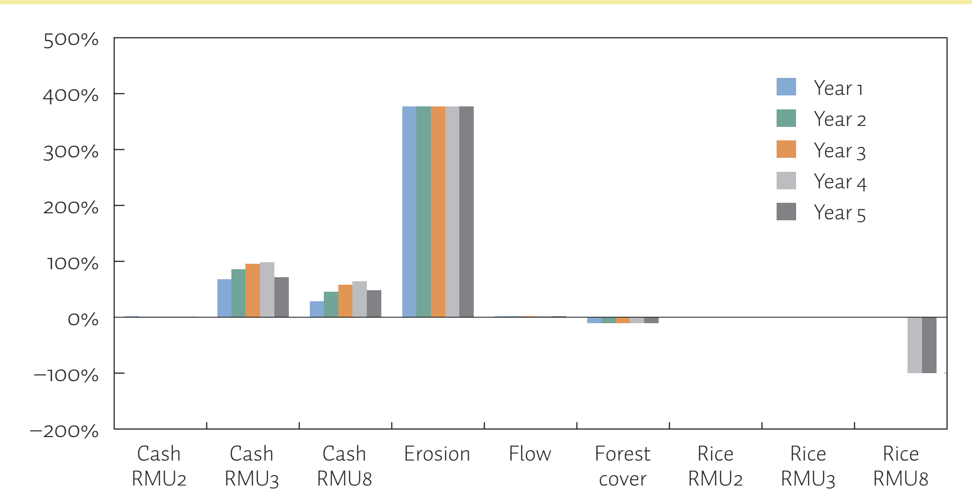


Figure 10.12 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: change in indicator values from base case, scenario 1, node 1

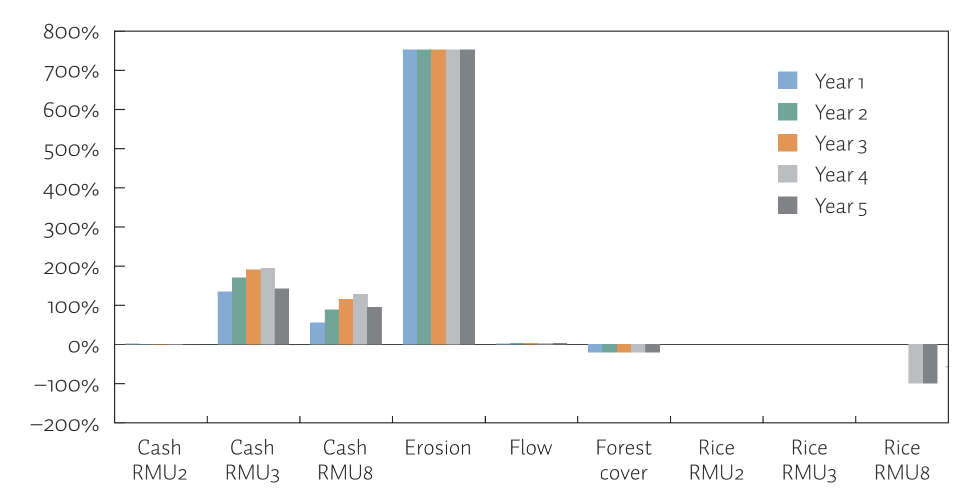


Figure 10.13 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: change in indicator values from base case, scenario 2, node 1

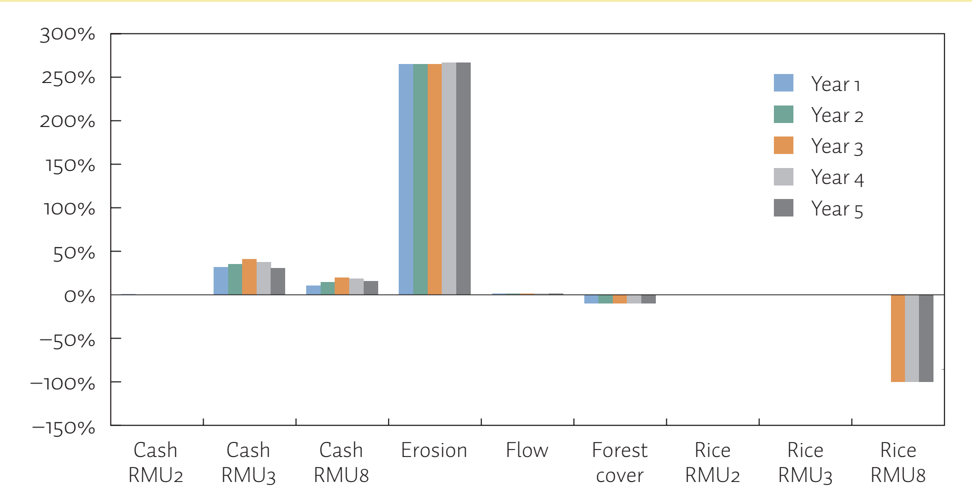


Figure 10.14 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: change in indicator values from base case, scenario 1, node 2

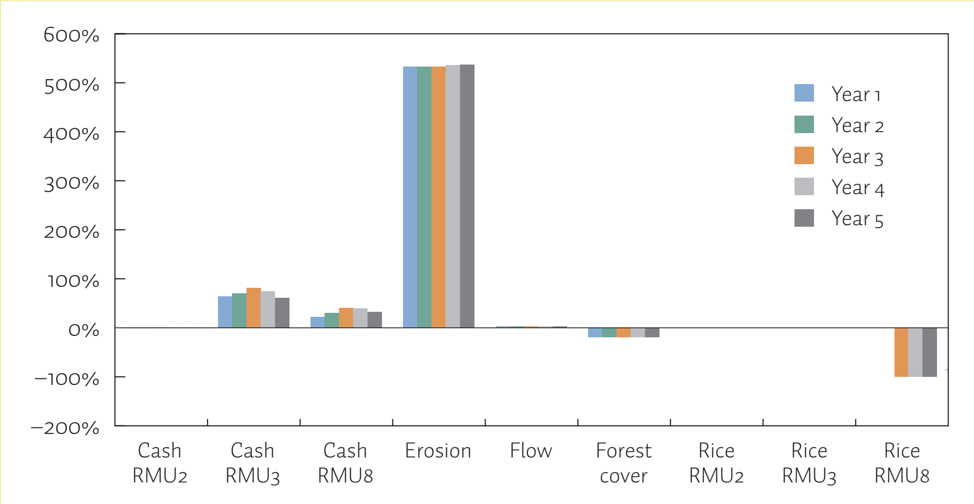


Figure 10.15 Application of the Integrated Water Resource and Management (IWRAM) decision support system in case studies in the Mae Uam sub-catchment of the Mae Chaem catchment, northern Thailand: change in indicator values from base case, scenario 2, node 2

Nevertheless, as can be seen in Figures 10.12–10.15, these economic and social benefits are at the expense of higher environmental impacts. Relatively small increases in flow are experienced at both nodes. This implies that the increase in flow resulting from a decrease in the area of forest cover is greater than the additional extraction occurring across the year. This relates to the way in which changes in forest cover can affect flow: a decrease in forest cover increases wet-season flows, increasing overall annual flows, but decreases dry-season flows which are used for irrigation. Thus, flow increases annually but less water is available for extraction in the periods when it is most required. Agricultural expansion also leads to large increases in erosion, and to substantial areas of the remaining forest cover being lost.

As would be expected, both costs and benefits are greater when larger areas of agricultural expansion occur. But the relative impacts are not proportional to the level of change in forest area in all cases. The change—from the base case—in household cash at RMU2 is less than proportional to the change in forest cover. This is the case at both nodes, but the effect is more pronounced at node 1, possibly because flows are smaller at this upstream node. The increase in flows is also less than proportional to the change in forest cover in most years for both nodes. The change in household cash is more than proportional to the change in forest cover. The relative impacts of both scenarios are the same across all years, and show the same pattern for both nodes.

Discussion of socioeconomic case studies

The case studies presented here illustrate the types of scenarios and trade-offs that can be considered by the IWRAM DSS. While the application presented is specific to the Mae Uam sub-catchment in northern Thailand, the modelling approach is more generally applicable.

A key difference between this approach and previously developed integrated models is the use of uncertain expectations as the basis for household decision-making. The socioeconomic models within the IWRAM DSS assume rather naive expectations; that is, that farmers expect this year's water availability to be the same as that of last year. However, the model framework means that it is relatively simple to assume different forms of, or complexity in, expectations, so the effects of these assumptions could be tested in future work.

A related issue is the treatment of household cash as temporally independent; that is, the assumption that cash does not carry over between years, or affect the decisions of households in future years. This assumption relates to the short-run nature of decision-making, and is of less importance given that 'longer-term' crop-planting decisions, such as horticultural crops or decisions not returning income in the current year, are not currently considered by the socioeconomic models. Modification of the approach to consider the constraints presented by available cash or credit, and longer-term planting or investment decisions would be an interesting and relevant future development path for the model.

Another key issue when considering the robustness of the approach used in the IWRAM DSS, is the sensitivity of the 'qualitative result' or recommendation to climate and uncertainty in parameter values. The scenarios demonstrated in this chapter give a similar pattern of impacts, with the direction and approximate magnitude of change of indicators being consistent across nodes and scenarios. Further testing of the model's sensitivity to changes in parameter values has been undertaken by Letcher et al. (2005). Overall, the model appears to provide consistent recommendations, regardless of climate or small levels of uncertainty in parameter values.

Finally, the integrated model developed is balanced in terms of the complexity of each of the disciplinary components represented. Each component model runs on an appropriate 'lumped' or disaggregated spatial scale. Temporal scales vary between models, but essentially correspond to the largest temporal scale appropriate. For example, household decisions and erosion are simulated seasonally (twice yearly), while crop and flow models run over smaller time scales to allow meaningful comparison of water availability and demand. The style and detail of process representation for each of the components are also similar.

Conclusions

This chapter has demonstrated how the IWRAM DSS can assist with the planning of integrated land and water management, by presenting a set of case studies for the Mae Uam sub-catchment (within the Mae Chaem catchment) in northern Thailand.

The first set of case studies applied the biophysical models to a set of scenarios that considered forest conversion, land management and changes in climate. These case studies demonstrated the potential of the IWRAM DSS to explore the environmental effects of various land- and water-management options. In the second set of case studies, the full set of biophysical and socioeconomic models within the IWRAM DSS was employed to assess both the socioeconomic and environmental trade-offs associated with increasing the area of land available for agricultural production (and hence reduced forest cover).

Currently, the IWRAM DSS includes model components that address the key issues at play within catchments in northern Thailand. Future work will need to extend the applicability of the tool in other catchments across Thailand and globally. Inclusion of models that address additional issues within the catchment are foreseen, including groundwater extraction, water extraction for urban and industrial use, more-intensive land use for agricultural production, and stream regulation.

Although considerable effort has been made to keep the models within the IWRAM DSS relatively simple in terms of the structure and number of model parameters, the integrated framework as a whole is still reasonably complex and the interactions between the models can be quite non-linear.

The aim with integrated models of this type should not be to provide absolutely accurate estimates, a task rendered too difficult by the inherent complexity of natural systems and the scant data often available. The focus should be on being able to discriminate between, and be confident about, the relative changes in indicator output sets. The analysis reported in this chapter is a step in this direction. Ultimately, a methodology is needed which will also provide the level of confidence in the results.

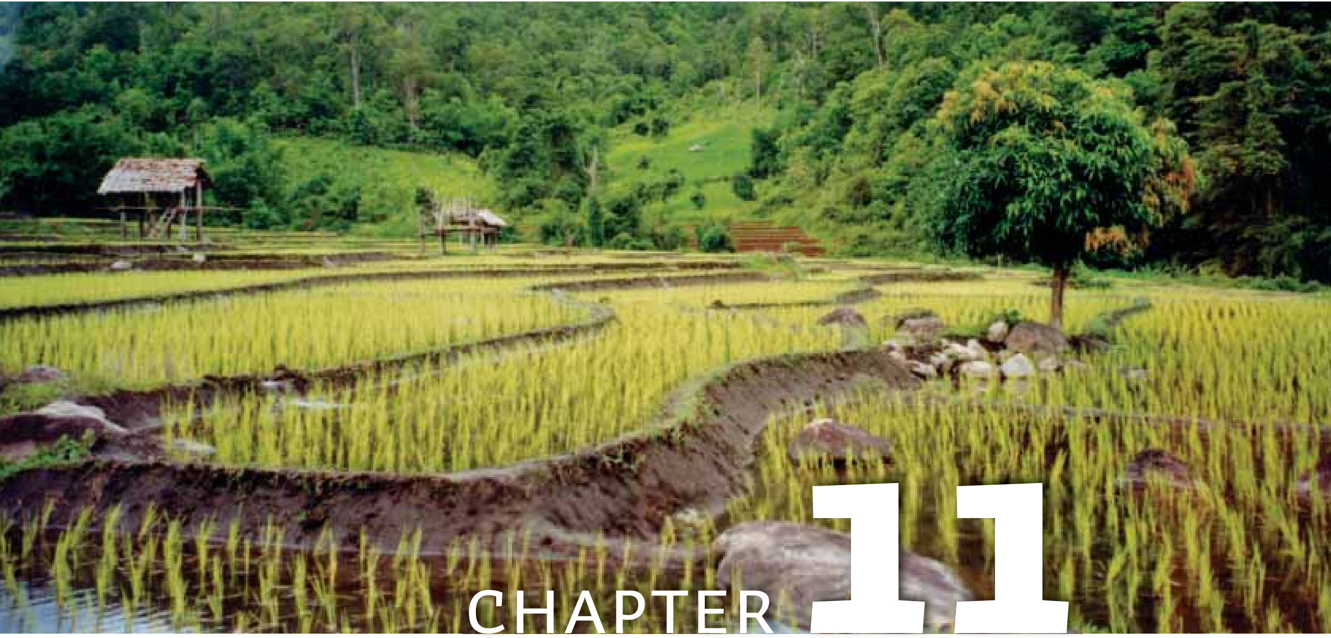
References

Letcher, R.A., Merritt, W.S., Jakeman, A.J. and Croke, B.F. 2005. An integrated modelling toolbox for water resources assessment and management in highland catchments in Northern Thailand: model description, Agricultural Systems, in press.

Merritt, W.S., Croke, B.F.W. and Jakeman, A.J. 2005. Sensitivity testing of a model for exploring water resources utilisation and management options. Environmental Modelling and Software, 20, 1013–1030.

Merritt, W.S., Croke, B.F.W., Jakeman, A.J., Letcher, R.A. and Perez, P. 2004. A biophysical toolbox for assessment and management of land and water resources in rural catchments in northern Thailand. Ecological Modelling, 171, 279–300.

Scoccimarro, M., Walker, A., Dietrich, C., Schreider, S. Yu., Jakeman, A.J. and Ross, H. 1999. A framework for integrated catchment assessment in northern Thailand. Environmental Modelling and Software, 14, 567–577.



Improving integrated assessment approaches

Lessons from the Integrated Water Resources Assessment and Management project experience

Anthony Jakeman, Santhad Roganasoonthon, Rebecca Letcher and Anthony Scott

Summary

The Integrated Water Resources and Management (IWRAM) project was an innovative attempt to use an integrated-assessment approach to understand the trade-offs involved with managing river systems in northern Thailand. When the project commenced, the science of integrated assessment was in its infancy, with new methods and approaches being developed by diverse groups internationally and little formal structure or method to fall back on. In particular, the challenges of working across the Thai and Australian cultures, in a developing country setting, had not been faced or documented previously. The IWRAM project therefore needed to develop its own approach to dealing with

the complex management and communication issues involved in working across a broad river-basin management setting in the north of Thailand. The experience of the IWRAM partnership in managing these issues, and the difficulties faced by the team in implementing such a challenging approach to science in this setting, provide a valuable lesson for future research and management exercises in Thailand and elsewhere. This chapter outlines the lessons learnt through the IWRAM project and outlines the likely future directions of the project and approaches developed.

Introduction

With rapid intensification of agricultural catchments in northern Thailand, a suite of environmental issues has surfaced. These include upstream–downstream conflicts over water availability, increased erosion and contamination of waterways, and an increase in the production of cash crops changing the pattern of cropping and fallows. In addition, there is a need for poverty alleviation. The Integrated Water Resources and Management (IWRAM) project was instigated in response to these issues. The project developed a decision support system (DSS) for the exploration of biophysical and socioeconomic trade-offs of water- and land-resource use and management options. Initially, the focus of the project was on the development of an integrative framework that was captured in the form of a DSS. This was followed by the development of the various biophysical and socioeconomic models and their verification. The final stage of the project involved the application of the DSS to demonstrate its utility. This product of the IWRAM partnership is now being adopted more widely throughout Thailand to evaluate land- and water-use options and support related decisions.

Inevitably, as with any emerging technology, there were many unforeseen problems that had to be solved during the course of the project, and the need to add or modify model components, and/or general approaches, to ensure that the integrated package met the needs of the users.

There were many lessons learnt during this project and the aim of this chapter is to present the key lessons, in the hope that these will assist similar projects in the future. This follows the principles of adaptive management, which aim to 'increase our understanding of systems through active participation and learning, evolving experimentation, reviewing and responding' (Lee 1999).

The second part of this chapter will provide some insights into the future of the IWRAM project methods, and also the future of integrated water resources assessment in general.

Technical lessons

Lack of field data

In catchment- or regional-scale studies, the issue of data availability becomes of utmost importance. Problems of data availability are exacerbated in developing countries, where detailed information for supporting complex models is less-often collected. Although Thailand is comparatively well supplied in environmental and agricultural data, they are seldom sufficient to cover the complex sets of variables demanded by many of the existing models of biophysical and agricultural processes. Many of the data needed to run these models are very specific and might only be collected at a few experimental sites, but are generally not collected during land surveys.

Finding out what data exist, and gaining access to the data (especially in digital form), proved highly time-consuming and required that considerable effort be invested in building relationships with the organisations that hold the information. For integrated catchment management, there was the additional requirement that biophysical, economic and social data be available for the same places, at least for the development of the models. When developed, they may often be extrapolated to places where data are less complete. In choosing the Mae Chaem and a set of its sub-catchments for study, the original members of the Thai research team took into account access to existing biophysical and socioeconomic data. They recognised that most sub-catchments lacked streamflow gauges, making the hydrological modelling task difficult. Similar problems existed for the crop and erosion models.

In the socioeconomic field, published data were highly aggregated, providing information such as the total area under each crop, or the populations of villages. Although useful, these data did not provide a picture of individual households, how they lived or the constraints they faced in making decisions. There were also very few data on household activities such as the gathering of forest products, which the literature and qualitative information have shown to make important contributions to the livelihoods of some communities. Aggregated data do not provide sufficient basis for assessing current, let alone potential, resource-use behaviour. While we were able to conduct our own surveys, albeit with some logistical difficulties, the need for primary socioeconomic data will continue to be a significant requirement when extending our DSS to other catchments. Integrated water resources management (IWRM) will ultimately need alternatives to such powerful socioeconomic models that are less reliant on detailed primary data, so that ‘scaling up’ to large basins such as the Chao Phraya or Mekong can be successfully achieved. There is also scope for the creative use of existing data and, over the long term, tailoring government and academic data collection to serve IWRM needs more effectively. Finally, it is important to link socioeconomic data with biophysical data. One simple but effective method is to take global positioning system readings at all sites where any type of data is collected.

Robust, simple models

One implication of the lack of suitable data-sets is that the models we, or other teams, develop need to be robust and relatively simple. In many cases, it will not be possible, or desirable, to develop complex mechanistic models that require large amounts of field data for calibration and validation. However, it should not be assumed that the use of less-complex models will necessarily reduce the accuracy or usefulness of predictions. For example, many of the simpler catchment models perform as well as, or at least are not substantially outperformed by, more complex models (Loague and Freeze 1985). Jakeman and Hornberger (1993) confirm this result for different levels of complexity in conceptual hydrologic models, as have many other authors, including Kokkonen and Jakeman (2001) and Perrin et al. (2001). Perrin et al. (2001) note that:

> …simple catchment models that lump catchment heterogeneities and represent the transformation of precipitation into streamflow, conceptually or empirically, are generally easy to use tools with low data requirements. In spite of the crude approximations resulting from their lumped and simple structure, such models have proved efficient in many studies.

They concluded this from an assessment of 19 daily lumped rainfall–run-off models of 429 catchments in France, the United States, Australia, the Ivory Coast and Brazil. If only limited catchment data are available, such as lumped daily rainfall and evaporation, then it seems unnecessary to develop spatially explicit and complex model structures (Wooldridge et al. 2001).

It is also not worth spending large amounts of time on one particular model, particularly if another model within the integrated framework is highly simplified or considerably less advanced. The overall results can only be as good as the weakest link (or model) of the integrated system. It is more important to get the overall framework and key linkages between models correct. More detailed models can then be developed and incorporated over time.

Issues of scale

Natural systems, from plot to catchment scale, tend to show a great deal of variation, both temporally and spatially. Selection of scales for the different models and model components of an integrated assessment (IA) problem is one of the key considerations at the beginning of any new project. The scale selected should be fine enough to capture the required level of variability of system response but not finer than is warranted by the availability and quality of corresponding input data and other model calibration data—a trade-off between model sensitivity to inputs and model parameter uncertainty.

There can also be vast differences in the scale at which different biophysical or socioeconomic models operate. Batchelor et al. (1998) identify potential social and biophysical forces that drive a hydrologic system, which range in scale dependency from a few hectares (farm water use, soil type, vegetation distribution) to the regional or national scale (e.g. commodity prices, infrastructure development, government policies).

Whenever possible, it is advisable to choose scales that are complementary. This becomes even more important when the outputs of one model are used as inputs to another. For instance, it may not be necessary to run an erosion model at the plot scale if the associated hydrologic model operates at only the catchment level.

The issues and problems associated with scale are clearly demonstrated by considering the modelling of agricultural systems at a catchment scale. Easterling (1996) states that it is unlikely that crop models will ever be capable of accurately simulating crop growth at a resolution of hundreds of kilometres because they are designed to simulate growth processes of a single plant or across a hectare. Other scaled-related issues that need to be overcome before successfully modelling agricultural systems for an entire catchment or region, can be summarised as follows:

- the large number of crops that are grown within a catchment, often in small paddocks owned by individual farmers
- the wide variations in biophysical properties across the catchment, such as soil types, soil moisture, and slope, all of which affect the type of crop grown in a particular paddock
- the different types of cropping systems within the catchment
- distribution of water within the catchment and the amount available for irrigation of crops.

The diversity of the cropping systems and the average plot area are two of the key constraints for modelling crop productivity and water use in many catchments. For instance, a survey undertaken in small sub-catchments of the Mae Chaem has recorded approximately 60 crops grown (IWRAM project survey undertaken in 1997). Realistically, it would not be possible to model every crop. Some simplification of the system was necessary. Three options exist for predicting broad-scale crop yield in such a situation:

- consider only the major crops and use a specific crop model for each
- combine similar crops into a representative simulated crop
- use a conceptual, generic crop model.

Ultimately, the selection of model type and scale will depend on the type of model outputs required by catchment managers and policymakers, whether it be farm-level or catchment-wide data. This is true also for the temporal scale. There might be no need for a complex hydrologic model with daily time steps, if a simpler lumped parameter model with monthly time steps provides the necessary outputs required by other models (such as the crop model and erosion model) and by decision-makers.

Integration between models

As the name suggests, IA requires a number of joint biophysical and socioeconomic disciplinary assessments. The development of integrated models requires that feedbacks and linkages between models be accurately portrayed. This can be very complex. Many existing biophysical models have not been developed with this in mind. There can be conflicting structures and flow paths between disciplines, particularly when attempting to link biophysical models to socioeconomic models. For instance, the IWRAM biophysical models required inputs describing land use and water use in the catchment. These are partly determined by the decisions and outputs stemming from the socioeconomic module. Consequently, this required a conscious effort to ensure compatibility with socioeconomic factors during the development of the biophysical modules.

Parson (1996) recommends that IA should highlight broad links, and suggests that, to achieve this, simple representations should be implemented over more-detailed—and possibly more physically correct—representations. In summary, it is critical to keep the level of integration of issues and disciplines at a manageable level. It should also be noted that the main function of IA modelling is to discriminate between different scenarios by providing the relative changes in key outputs, and not necessarily provide absolutely accurate values.

Propagation of model uncertainty and errors

The variation and complexity of natural systems, a lack of high-quality field data and the simplifying assumptions of both the mathematical models and their linkages, all tend to create a relatively high degree of uncertainty in the results of IA modelling. Uncertainty also tends to accumulate as simulations progress sequentially—as outputs of one model are used as inputs to another.

There is very little technology that has been directed towards assessing uncertainty of integrated models and their outputs. If reliable conclusions are to be drawn from complex models, a key task is to assess the sensitivity of outputs to uncertainty in input data, calibrated model parameters and the model structure and assumptions. A new approach (Norton et al. 2003) currently being investigated by the Australian National University entails use of a sensitivity analysis to explore the feasible set of parameter values, input data and model structures, so as to provide a specified range of output behaviour. The output behaviour is defined as a set characterised by a collection of constraints on realistic, acceptable behaviour or the boundaries of behaviour leading to a given qualitative solution. The focus on sets removes the need to assume linearity between cause and effect, continuity of the output or a quantification of the output. The new approach will be adaptive, combining searches, Monte Carlo trials and feature extraction by descriptive multivariate analysis.

Modelling the long leads and lags of environmental systems

A challenge for the future is to develop models that sufficiently represent the long lag times associated with some aspects of environmental systems. A simple example would be the planting of trees within a catchment where the benefits (and impacts) might not be felt for many decades. Very few models accurately represent these lag times, and this poses a challenge for future modellers.

Specialists must be flexible

The ultimate success and lessons leant through an IA modelling project will depend critically on the personalities and aims of those involved in the project. One key requirement is that the parties involved are able to respect and acknowledge the contribution from other disciplinary components. During some of our early experiences in the IWRAM project, we found that different disciplinary teams were often too tied to their own software or modelling concepts, and ended up developing their own independent modelling systems which displayed their prior ideas largely without change. In these cases, many of the participants did not want to compromise or to use the knowledge of the other teams so that a truly interdisciplinary framework could be developed. Where these problems can be overcome, the project value can be much greater than the sum of its parts. Integration is not just about linking different components models. It should also enhance participants' understanding of the interactions between system components, and increase awareness of how the impacts and effects stemming from each disciplinary model can affect the overall outcome.

Lessons about communication and adoption

Different modelling approaches for different purposes

During the IWRAM project, three different DSS were developed. Although the three DSS had the same basic framework, they each had a different level of complexity and were aimed at different audiences and applications. The different approaches also reflected the adaptive nature of the project. The phase 1 DSS was developed by the Australian researchers and had a relatively high level of complexity. This DSS was more suitable for research work, specifically for developing integrative frameworks and understanding the requirements of the problem, rather than for catchment planning at a local or regional level. There were also ownership issues where the Australian models and framework were readily accepted by the Australian researchers but not by the Thai project team. This problem was resolved when the Thai project team used the same framework to build their own DSS. The third version was a simplified DSS developed in Microsoft® Excel for training purposes. This version was very easy to use, and allowed training in the underlying principles of each model and how they interacted with each other within the integrated framework.

Although it might seem inefficient to develop three DSS, each had a different purpose and all of them played key roles during the development of the project. Most importantly, the DSS developed by the Thai project team has reinforced a strong feeling of ownership, and this has paved the way for increasing adoption of IA principles in Thailand.

Constraints with inter-agency communication and decision-making processes

Our experiences in promoting integrative environmental analysis, and our Thai team's experience in coordinating a diverse set of academic and public-service contributors, has given some insights into the demands on current institutional processes in adopting an integrated management approach. We were well aware before commencing the IWRAM study of constraints on inter-agency decision-making processes in Thailand, despite much goodwill to overcome communication and co-ordination problems. The structure of district offices, in which representatives of a number of departments are co-located and serve under a district officer, helps co-ordination at the local level. District officers also have a systematic and regular method of communication with village headmen. At the regional level (the north) departmental activities require hierarchical (and mostly 'top-down') communication between local officials and their Bangkok offices, which inhibits lateral inter-departmental communication except where special projects or committees are formed. Even staff in different divisions of the same department may not have close communication, since authority devolves from Bangkok. Despite constraints inherent in the structure of government, there is nevertheless a good base for integrating government agencies' aims in the highlands, where policies and strategies to deter opium production, ensure national security and protect the environment, all through agricultural and social development, are already well-integrated. Specific development projects such as Sam Mun and the Thai–German Highland Development Project, and the initiatives of the Royal Project Foundation, have contributed markedly to integration.

Practice in communication with local people varies a great deal both within and between Thai Government departments, with much depending on the character and inclinations of the local staff. Communication issues go far beyond willingness to talk and listen: they may involve quite fundamental differences in assumptions. For instance, the adoption of government agricultural advice has often foundered because of prescriptions which run counter to indigenous and local knowledge guiding conservation and agricultural management practices, or reliance on inputs which the people cannot afford. Although the formal system of government remains 'top-down', there are numerous examples of participatory land-development projects in which government departments have encouraged local inputs and initiatives. Meanwhile, the policy environment has recently become much more conducive to participatory approaches in resource management, with the new constitution, the Eighth National Plan, and a proposed Community Forestry Bill all mandating greater community or local-government participation in (or responsibility for) resource management. These provide an imperative to change communication processes between government and other stakeholders, opening up future potential for institutional arrangements.

Stakeholder participation

There is a general convention in Western approaches to stakeholder participation that stakeholders should be invited to participate in any planning or management process on an 'equal' basis, which is usually interpreted to include contacting them at the same time and involving them to the same degree. Our project evolved differently, with sequential incorporation of government stakeholders, which continued throughout the life of the project. By the end of the project, all key government departments, and two Thai universities were directly or indirectly involved. Some departments took an active role in the project while others seemed more content to simply stay informed through attendance at meetings and workshops. We found this to be a useful approach to increasing the adoption and utility of the DSS.

In most cases, people needed to see a prototype of the application to understand the concepts and power behind an IA approach before they felt comfortable in committing time and resources to the project. At this point they were also often in a better position to advise on the ways in which the current framework and structure did not meet their needs and to help develop the approach to overcome these problems. Staged involvement and continued development of the IWRAM approach allowed for a compromise between early inclusion, to ensure adoption and a broad system perspective, and allowing for enough development to take place for stakeholders to grasp the potential of the approach for their management problem before committing to the project.

An important factor in the success of the project, and the active involvement of the various government departments, was the coordinating role of the Thai project manager (or national coordinator) who was based within the Royal Project Foundation. This appears to have been far more preferable to having the project officer based within one of the government departments (which might have caused a bias in priorities or alienated other departments) or a project officer based in Australia. This person has a good understanding of how the government departments and hierarchy operates, and valuable knowledge of how to make things happen.

It was also important to involve and consult regularly with high-level government decision-makers in project strategic issues, so that they could reflect on project progress and outcomes. High-level decision-makers also have the influence to make things happen! Involvement of key decision-makers throughout the project life can also provide good guidance and resolve issues before they become problems.

Although some communication and coordination problems still occurred, the project facilitated an increased level of communication and understanding between officers from different government departments and also opened up links with Australian and Thai universities.

Adapting to limits on resources and finances

In 1997, many countries in Southeast Asia, including Thailand, suffered a financial crisis. This had impacts on the availability of both staff and resources from Thailand's government departments during the first few years of the project, causing some delays in progress. During this crisis, the project lost some of its key research people, while other members of the Thai team continued to assist the project, but were forced to work in their own time. These problems reinforced our view that participatory processes must be attuned to the current issues or constraints being faced by departmental staff, and the time and resources they have available. These management issues have provided a useful 'reality check' and remind us that IA must expect and adapt to such limitations.

Communication is time-consuming but essential

The communication required within the research team and between researchers and stakeholders is extremely time- and energy-consuming. A significant component of any IA project is communication between these groups. This becomes even more important when team members are spread across universities and government departments of two countries with different cultural and professional outlooks.

Capacity-building and collaboration take a long time but are ultimately worth the investment. They can ensure that ideas and methods are taken up in the long term and can also develop long-term relationships for cooperation. Without this, the ideas and frameworks will not be adopted and will almost certainly collapse when the project finishes. They also ensure that methods and understanding are able to evolve over the life of the project. A project that claims to be participatory but that does not allow appropriate time and resources for building trust between the different team members and stakeholders, risks alienating, as well as disenfranchising, some members, and making future management efforts more difficult.

The value of study tours

Study tours (or field trips) proved very effective in generating dialogue within the project team. The study tours allowed all participants to gain first-hand experience of issues related to land use, water resources, agriculture and the livelihoods of the local people. Study tours should be planned well in advance and should visit typical farms at a number of different sites within the catchment. Ideally, study tours should also occur at different times of the year, for instance the wet and dry seasons, when conditions might be quite different.

Case studies are essential

Case studies were found to be a very efficient way of testing both the integrated framework and the models (both biophysical and socio-economic) and ensuring that the models were practical and useable. They also highlighted practical issues such as the availability of field data, the complexity of the biophysical landscape, and the difficulties of obtaining good socioeconomic data. Case studies were also used as a basic approach to capacity-building, i.e. training should deal with reality, not theoretical situations.

Adoption of DSS and software

The end users needed to be directly involved with software development so that they had ownership. Without this involvement and a strong sense of ownership, there is a much lower chance of long-term adoption. Ownership can also be enhanced through the use of local case studies, and by conducting training workshops.

Project life

A three-year project was found to be too short to meet the overall objectives and successfully develop the IWRAM approach in partnership in a new region or country. Project development, and the development of communication and trust, both take time. The project inevitably hits hurdles and must adapt to new circumstances. This all takes time. These types of projects tend to evolve as they progress. A project life of 5–6 years increases the chances of adoption and application of the IWRAM approach.

Our final advice: Give it a go! Be prepared to make mistakes and learn from them.

Future of the IWRAM approach in Thailand and surrounding countries

Further training and adoption

The IWRAM approach to date has been focused firstly on establishing a framework for integrated water resources assessment in Thailand, on integrating the modules into the DSS, and on verification of both the models and the DSS. Emphasis may now be given to making use of the DSS toolkit routine, institutional strengthening and adoption through further training, which are all likely to occur through the need to apply it to other catchments. Inevitably, as with any emerging technology, there will be teething troubles to be addressed and the need to add or modify components to ensure that the integrated package continues to meet the needs of the users.

The project team has supported capacity-building within Thailand, so that the IWRAM approach can be implemented and extended throughout the country. The future of the IWRAM approach, both in Thailand and in surrounding countries, will include the following developments:

(1) The Thai team has re-implemented the underlying models to suit the level of expertise available within government departments and agencies. The models will continue to be refined and calibrated using new field data.

(2) The Thai team is actively engaged in extension of IWRAM to the rest of Thailand and neighbouring regions through national research projects, with support from the Australian team.

(3) Customisation and implementation of the DSS to different agricultural, water regulation, social and vegetation systems is being undertaken.

(4) New modules are being developed to address other issues such as water storage and allocation, water quality, groundwater systems, in-stream habitat quality, other sources of erosion such as landslips and from roads, sediment transport, and incorporation of ecological indicators.

(5) Links between GIS spatial data and the DSS modules are being improved.

(6) Development of the IWRAM website as a communications tool for team members and the public is being continued. This provides updates on progress and links to other users or sites and ongoing technical support.

(7) There is continuing development of reference materials and training manuals.

The Royal Project Foundation will remain the co-ordinating agency in Thailand and a 'users group' comprising the Royal Forestry Department, the Land Development Department, the Royal Irrigation Department, the Department of Agriculture, National Parks, Wildlife and Plants Conservation Department, and the Depertment of Water Resources will be the priority client group.

The building of an integrated approach to water resources assessment has necessarily drawn together researchers and practitioners from many disciplines and agencies, and has aligned well with a national initiative to implement integrated catchment management. The project has provided for strong linkages to be built between government departments responsible for natural resource management and socioeconomic research being undertaken in universities.

As in all countries, planning is nothing without adoption. Farmers are the principal custodians of land in most countries. It is difficult to convince them to adopt sustainable management practices when they are desperately striving to provide food and an income stream for their families. Planning for sustainable water management must therefore consider not only environmental outcomes and constraints but also local capacity to bring about change and poverty alleviation. In many cases, win–win situations may be available that both increase quality of life and are sustainable. Local capacity may need to be developed to identify and enable these types of changes.

The future of integrated water resources management

As the research effort builds in the field of integrated water resources management (IWRM), old challenges are replaced with new ones. Much relevant research is currently under way, among other things, in terms of developing integrated frameworks, modelling techniques, software platforms and tools, and creating productive links between science, management and the general public. There are, however, some pressing issues that need to be addressed. A discussion of these follows.

New modelling tools for integrated water resources management

Decision support systems can be a useful ally in connecting the interface between science and policy. Such tools must find the correct balance between the need for simplicity and ease-of-use for stakeholders on the one hand, and the implementation of rigorous scientific approaches on the other. Certainly, transparency of DSS, where model limitations and assumptions are clearly acknowledged, is essential if trust, engagement and final agreement and adoption of recommendations are to be realised. Moreover, in the future, developers of DSS should be less focused on developing 'one-off' visualisation and interface tools for specific applications, and more focused on extracting generic features that are common to many applications. As far as possible, development of DSS should be an investment in learning what is frequently useful, not in generating software that has little capacity for re-use.

Quality assurance and uncertainty management for credible models and data

To enhance the credibility and utility of scientific approaches, quality assurance must become mainstream. Quality assurance relates to the development of standards and protocols for model and data reporting and distribution—see, for example, Rykiel (1995) and STARS (2004). These standards and protocols are required because environmental and natural resource data and models are used to make management decisions, but they often have very large uncertainties or underlying assumptions associated with them (e.g. Anderson and Bates 2001). In order to ensure models and data are used in an appropriate way, and that decision-makers have access to information about the limitations of these models and data-sets, reporting standards for model testing, assumptions, appropriate scales and inherent uncertainties must be developed and used. The new models should devote special attention to the management and communication of uncertainty. Although some standard procedures for quantifying uncertainties in model outputs are available (e.g. Heuvelink 1998), these have not yet been implemented in modelling tools that are used for decision-making, although some first steps have been taken (e.g. HarmoniRib 2004; Karssenberg and de Jong 2005).

The key message is that model credibility can be enhanced by a serious two-way modeller–manager dialogue, appropriately rigorous model-evaluation tests, sensitivity and uncertainty assessments, and peer reviews of models at their various stages of development (Refsgaard et al. 2005).

Integrating disciplines and knowledge

It is a fundamental challenge that IA calls for a new breed of researchers who are much more interdisciplinary and interested in spending much of their time understanding other points of view and communicating widely. Typically, paradigms and methods are different between the biophysical sciences, economics and the social sciences. Ways must therefore be found to encourage scientists to be more open-minded towards a broader range of knowledge from different disciplines and stakeholders, while continuing to maintain proper critical standards.

There is also a clear need for the disciplinary focuses of scientists to be sharpened by management questions. This is a serious but simpler challenge that implies closer and more continuous dialogue between discipline specialists and their clients in natural resource management, so that the nature and scale of disciplinary enquiry is more relevant. The research community, as a result, should co-operate with decision-makers and jointly develop new application tools framed within the changing needs of the evolving policies.

Knowledge acquisition and knowledge generation for IWRM can be accelerated by more-systematic testing and comparison of theoretical approaches and methods in case studies. This can be facilitated by more-collaborative and strategic science, funded to bring groups together internationally and to execute comparative studies.

More research is needed to manage the wealth of heterogeneous information types (soft, hard, qualitative, quantitative, beliefs, knowledge, expert, non-expert) that is acquired and generated during the course of carrying out IWRM, involving as it does different disciplines, as well as scientists, practitioners and the broad public. Such research needs to include the development of better data-mining and navigation techniques for heterogeneous information retrieval to aid quick and efficient access to gathered information, the development of a common approach to quality assurance (see above) for these different information types, and the development of guidelines as to how and when different types should be used in decision-making.

Approaches supporting integrated water resources managements—adaptive management

Adaptive management (Holling 1978) and active adaptive management (e.g. Allan and Curtis 2003) are principles with the potential to improve our management of the environment through a process of continuous learning. In essence, adaptive management is about developing management-revision principles, experiment designs, outcome indicators, and monitoring practices to achieve sustainable management in evolving environments (e.g. STARS 2004). This must include the monitoring and evaluation of active and passive experiments to see what does and does not work and where there are gaps. Examples are improved tools to capture and express qualitative knowledge and approaches to screening and testing a broad range of alternative policies.

Public participation: methods, techniques and institutional setting

In terms of participatory methods, more effort needs to be placed on developing meaningful techniques for evaluating participatory processes. This is needed not only to provide evidence to scientists on whether or not their methods have been successful, but also to help improve participatory approaches in a rigorous way. Assessment of this nature is also useful in convincing future participants to take part in new processes or to keep current participants actively involved.

Simply introducing new regulations calling for public participation will not be enough. Experience has shown that participation does not always translate into meaningful new inputs into the traditional management decision-making process. Poor participatory methods are one cause of such problems but, crucially, unless there are transparent management procedures in place that can guarantee and illustrate that the inputs from public participation are influencing actual decision-making, then both decision-makers and citizens may end up perceiving public participation simply as a new form of bureaucratic burden without real benefits for the community (Mostert 2005).

Integrated water resources management by doing

We conclude by saying that we have no doubt that good progress is being made in the science of IWRM. There is a basic understanding and acceptance of the challenges. As this book shows, the scientific community has been developing many useful methods and models for achieving more sustainable outcomes. There is, however, a general need to accelerate the development of integration methods by learning from practical applications and sharing these experiences widely. Only by doing and showing, will we handle the complexity and difficulties of integration.

Conclusions

For the researchers involved with this project, the major impact has been the development of new skills and tools that can play a pivotal role in regional sustainability.

Within the natural resource management sphere, the major impact has been at the 'middle' level, i.e. agency professionals. This group is crucial in convincing policy-makers to legislate for, and farmers to implement, sustainable land use and natural resources management. The researchers play a key role in informing extension officers on the suitability of crops and management practices.

A major aim of the Royal Project Foundation through the activities of this project has been to identify crops and cropping practices that raise the standard of living for local farmers, especially hill tribes, while conserving the environment and anticipating future demands on water supply. The extensive catchment activities associated with the project (field trips, surveys) have provided strong positive signals to the local communities that they are valued by the Royal Project Foundation and the government.

At the regional scale, the development of expertise in whole-of-catchment assessment, using a range of social, economic and biophysical indicators, gives the Thai team the ability to play a key role in the region in the development of bilateral and trans-boundary water- and land-management issues. They intend to use this expertise to work with their regional neighbours to develop sustainable use of their watersheds.

The impact of the IWRAM project cannot be judged in the short term. In the complex world of integrated water resource management, it provides a robust framework to consider and incorporate economic, social and biophysical condition and values within national and regional planning and management agendas. Adoption of the IWRAM approach has occurred at a high level in government departments and they are now incorporating the principles into routine practices within their agencies. This will ultimately see the IWRAM approach extended throughout Thailand.

At the national level, the project has indeed been influential. The IWRAM approach has been adopted as the framework for a major initiative of the National Research Council, which will see Thailand work with neighbouring countries in the greater Mekong sub-region to implement IWRAM.

Through the project, the Royal Project Foundation has played a key facilitation role in focusing government-agency support in the northern catchments. There has been a significant investment by the foundation and government agencies in understanding the environmental, social and economic impact of changes in water use and management practices in the catchment, with the key word being 'sustainable.' This is strong emphasis on ensuring economic return to the local farmers in exchange for modifying agricultural practices.

The impact of the project is very evident in the continued partnership and collegiate nature of relationships within and between the Thai and Australian members of the project team. The impact and influence of goodwill and mutual respect cannot be underestimated.

At the local scale, the development of the IWRAM DSS means that researchers will be providing extension officers and farmers with farming 'solutions' that are better for the environment without compromising economic return.

We see several ways to achieve greater progress in future assessment of sustainability outcomes. Some lie predominantly in the hands of politicians and policy advisors, others with the scientists and social scientists. To avoid policy compartmentalisation and instil system learning, the processes of adaptive management (Holling 1978) and active adaptive management (e.g. Allan and Curtis 2003) of our 'environment' must be institutionalised and adopted across all relevant sectors. This must include the monitoring and evaluation of active and passive experiments to see what does and doesn't work and where there are gaps. Systematic representation of our knowledge and how it changes and accrues is vital to ensure that we have a platform on which to build and test. IA and modelling in general have a role here. One of the challenges is not to disenfranchise catchment communities, and perhaps politicians also, by increasing the uncertainty in their eyes through unsystematic representation of accrued knowledge.

Given the complexities and uncertainties of integrated modelling, it should be accepted that its broad objective is to increase understanding of the directions and magnitudes of change under different options. Typically, it cannot be about accepting or treating simulation outputs as accurate predictions. A key advance required is for IA modelling to allow differentiation between outcomes, at least with qualitative confidence; for example, a particular set of outcomes or indicator values might be categorised as overall better than, worse than or no different from another set (for instance a do-nothing, current situation) with high, reasonable or low confidence. This is enough to facilitate a decision as to the worth of adopting a policy or controllable change. IA must be able to differentiate between policies and specify what knowledge or data will provide leverage to improve the differentiation. Ideally, predictions would be produced with a quantitative confidence level but in most situations this is impracticable at present. Currently, methods for quantifying uncertainties have limitations; Norton et al. (2003) and Jakeman and Letcher (2003) discuss new research required to address this glaring deficiency.

We know some of the important information that needs to be gathered to progress the management of sustainability through IA. The social sciences can offer insight and information into decision-making and adoption processes previously ignored in many scenario-based models. In particular, social survey data linking information about decision-making and adoption to biophysical and socioeconomic characteristics of farmers, industries or households is key to developing more sophisticated IA and other policy analyses. Very little of this type of data exists for most catchment situations. In addition, biophysical scientists are often not in a position to extract and understand the implications of such data. Further use and development of participatory methods (e.g. Haslam et al. 2003) for model-building is one way of extracting and using such information. These techniques have the bonus of allowing stakeholders inside the model-development phase, to ensure they have a better understanding of, and opportunity to feed into, the assumptions underlying these types of models.

IA takes time. This needs to be recognised by all parties involved in sustainability and related projects. The time scales necessary for IA to take place mean that the nature of the management problem and stakeholders views will change throughout the life of the project. Problem definition needs to be sharp enough to allow for useful interaction between researchers and stakeholders, but also flexible enough for the tools and understanding being developed to be useful at the end of the IA project. While success of IA projects will breed interest from decision-makers, the latter group needs to allow sufficient time for assessments and policy implementation, thereby reducing the current piecemeal approach to sustainability.

While improved sustainability is a principal aim of any IA project, it is important to recognise that the most useful outcome may be in the learning experience of researchers and stakeholder groups. In other words, it may be over-optimistic to assume that any single research project will, on its own, greatly improve the sustainability of the system. We argue that in many cases the concept of sustainability is not fixed and that improved understanding of the integrated nature of sustainability attained by participants in the project is also an outcome worth achieving.

References

Allan, C. and Curtis, A. 2003. Learning to implement adaptive management. Natural Resource Management, 6, 23–28.

Anderson, M.G. and Bates, P.D., ed. 2001. Model validation: perspectives in hydrological science. Chichester, UK, John Wiley & Sons Ltd.

Batchelor, C., Cain, J., Farquharson, F. and Roberts, J. 1998. Improving water utilization from a catchment perspective. International Water Management Institute, SWIM Paper 4.

Easterling, W.E. 1996. Spatial resolution of crop models in the estimation of regional agroecological effects of climate change: how fine is fine enough? In: Proceedings of 3rd International Conference on Integrating GIS and Environmental Modelling, Santa Fe, New Mexico, 263–273.

HarmoniRib 2004. Info at <http://www.harmonirib.com/>.

Haslam, S.A., Eggins, R.A. and Reynolds, K.J. 2003. The ASPIRe model: actualising social and personal identity resources to enhance organisational outcomes. Journal of Occupational and Organisational Psychology, 76, 83–113.

Heuvelink, G.B.M. 1998. Error propagation in environmental modeling with GIS. London, Taylor & Francis.

Holling, C.S., ed. 1978. Adaptive environmental management and assessment. Chichester, UK, John Wiley & Sons Ltd.

Jakeman, A.J. and Hornberger, G.M. 1993. How much complexity is warranted in a rainfall–runoff model? Water Resources Research, 29, 2637–2649.

Jakeman, A.J. and Letcher, R.A. 2003. Integrated assessment and modelling: features, principles and examples for catchment management. Environmental Modelling and Software, 18, 491–501.

Karssenberg, D. and de Jong, K. 2005. Dynamic environmental modelling in GIS: 2. Error propagation modelling. International Journal of Geographical Information Science, in press.

Kokkonen, T.S. and Jakeman, A.J. 2001. A comparison of metric and conceptual approaches in rainfall–runoff modeling and its implications. Water Resources Research, 37, 2345–2352.

Lee, K.N. 1999. Appraising adaptive management. Conservation Ecology 3(2), 3. Online at <http://www.consecol.org/vol3/iss2/art3/>.

Loague, K. and Freeze, R. 1985. A comparison of rainfall–runoff modelling techniques on small upland catchments. Water Resources Research, 21, 229–248.

Mostert, E. 2005. Participation for sustainable water manager. In: Giupponi, C. et al., ed., Sustainable management of water resources: an integrated approach. Edward Elgar Publishing, in press.

Norton, J.P., Nathan, R., Podger, G. and Vertessy, R. 2003. Sensitivity assessment needs of complex simulation models for integrated catchment management. In: Post, D.A., ed., Proceedings modelling and simulation society of Australia and New Zealand (MODSIM 2003), 4, 1667–1672.

Parson, E.A. 1996. Three dilemmas in the integrated assessment of climate change. Climatic Change, 34, 315–326.

Perrin, C., Michel, C. and Andreassian, V. 2001. Does a large number of parameters enhance model performance? Comparative assessment of common catchment model structures on 429 catchments. Journal of Hydrology, 242, 275–301.

Refsgaard, J.C., Henriksen, H.J., Harrar, W.G., Scholten, H. and Kassahun, A. 2005. Quality assurance in model based water management — review of existing practice and outline of new approaches. Environmental Modelling and Software, in press.

Rykiel, E.J. 1996. Testing ecological models: the meaning of validation. Ecological Modelling, 90, 229–244.

STARS 2004. Network for Sustainable Terrestrial, Aquifer and Riverine Systems. Information at <http://stars.net.au>.

Wooldridge, S., Kalma, J. and Kuczera, G. 2001. Parameterisation of a simple semi-distributed model for assessing the impact of land-use on hydrologic response. Journal of Hydrology, 254, 16–32.

Appendix

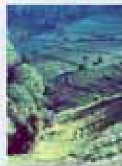
Brochure for the Integrated Water Resource Assessment and Management project

Integrated Water Resource Assessment & Management Project

Integrated Water Resource Assessment and Management Project is a joint academic research between Thai and Australian organizations. The Royal Project Foundation provides the fund and takes on the roles of coordination for all aspects and project leader. The Australian National University assumes the responsibility of principal investigator and The Australian Centre for International Agricultural Research (ACIAR) provides the financial support. The project aims at developing decision support software for the management of land and water of Northern Thailand.

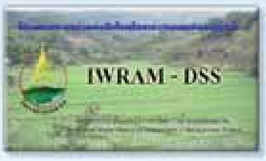


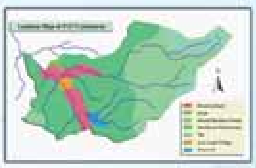
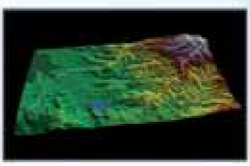




The area under investigation are Mae Rim, Second-part of Mae Ping and Mae Kuang catchments in the province of Chiang Mai of Northern Thailand.

IWRAM DSS SOFTWARE



FRAMEWORK

The framework of research is integrative process to include biophysical and economy of the catchments. The DSS relates all elements through erosion, crop, hydrologic and socio-economic models and GIS.

Crop Model is a mathematical model developed to clarify or predict plant growth and yield under various seasonal influences and on different types of soils.

Socio-Economic Model is a predictive model for cost-revenue estimation to aid in making decision on crops by farmers under socio-economic constraints.

Erosion Model is used for soil conservation planning and appropriate conservation measures selection. It will also be used for survey and assessment of soil erosion.

Hydrologic Model is a conceptual or physically based procedure for numerically simulating a process or processes which occur in a watershed (NWS.NOAA). The IWRAM; model is developed to predict discharge or water available at some specified locations for the DSS in idenifying appropriate crops.

Integrated Water Resource Assessment and Management Project
Royal Project Foundation 65 Suthep Road, Chiang Mai 50200
Email address: iwram@yahoo.com, iwram@iwram.org Website: www.iwram.org

INTEGRATED WATER RESOURCE ASSESSMENT AND MANAGEMENT PROJECT

SUPPORT DECISION - MAKERS IN NORTHERN THAILAND

ISSUES

Erosion

Modelling erosion based on rainfall, landscape, landcover information and management practice.

Water Availability

The Hydrologic model is developed to estimate effective rainfall for Crop model and predicting daily runoff.

Crop Production

The Crop model is developed to calculate crop yield and water use for each crop and land unit combination.

Farmers' Decision Making

Crop Choice and Economic Impact models are developed. This Socio-economic model will help indicating the cost and return for the individual farmer requirement. At a watershed scale, these models will reflect the capability of land in view of farmers' economic.

APPROACHES

Methodology

Collaborative development of integrated database, models and decision support system (DSS) softwares for watershed.

Assessing a wide range of 'what if' scenarios about land and water management in terms of spatiotemporal indicators.

DSS Outputs

Developed for predicting productivity and biophysical impacts of a wide range of management scenarios.

Royal Project Foundation

Royal Irrigation Department

Department of Land Development

Department of Water Resource

Department of Agriculture

National Park Wildlife & Plants Conservation Department

Chiang Mai University

Maejo University

Kasetsart University

Australian Centre for International Agricultural Research

The Australian National University

Royal Project Foundation 65 Suthep Road, Chiang Mai 50200 Tel : +66-0-5381-1500-2 ext.3 Fax : +66-0-5327-6776, Email address : iwram@yahoo.com, iwram@iwram.org Website : www.iwram.org