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IWRAM DSS – A MODELING APPROACH FOR INTEGRATED WATER RESOURCES ASSESSMENT AND MANAGEMENT IN NORTHERN THAILAND

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ABSTRACT

The Integrated Water Resources Assessment and Management (IWRAM) project has been a collaborative effort involving input from Thai and Australian researchers and management agencies. This project has successfully developed approaches to integrating stakeholder participation and computer models from agronomy, economics, hydrology and soil science to consider management options for catchments in northern Thailand. An integral development has been the evolution of an IWRAM decision support system that reflects local priorities and expertise. IWRAM DSS links biophysical models of rainfall-runoff, soil erosion and crop yield with socioeconomic models of farmer decision making and economic impacts. This paper describes the evolution of IWRAM DSS, the model components and their integration. It then describes some uses of the system, and demonstrates that a powerful integrated assessment tool can be built using a simple framework.

1 INTRODUCTION

In Northern Thailand, agricultural expansion has produced competition for water at various scales, resulting in erosion problems, downstream water quality deterioration, groundwater depletion, biodiversity loss, and shifts in the distribution of economic and social well-being and equity. In the past, water resources in Thailand have been surplus to demand. This has strongly influenced the lifestyle of the Thai people who have settled along the sides of rivers growing vegetables, rice, fruit and fishing. Increases in population mean that forest and water catchment areas are being encroached by agriculture and associated infrastructure such as dams and roads.

Increased demand for water has coincided with greater variability in climate with consequent increases in flooding and drought (Saifuk and Ongsomwang, 2003). Management of the headwaters and catchments is vital to sustain rural livelihoods and support the growing population and pressures of urbanization.

While prudent and rational resource management is a collaborative effort between government agencies and the people, implementation can be enhanced by tools that enable analysis of alternative water management scenarios. The IWRAM decision support system (DSS) is such a tool. Developed as part of a collaborative project between Australian researchers and Thai researchers and managers, the IWRAM DSS has evolved to reflect the needs and priorities of the Thai managers.

1.1 The need for an integrated approach

The introduction of integrated catchment management is a relatively recent phenomenon in Thailand. Traditionally government agencies have operated independently to deliver services such as water storage and supply, and agricultural extension to rural communities. This can result in promotion and adoption of activities to increase production (and associated cash return) at the expense of land condition and water use. Acknowledging that this is not sustainable, the government's imperative is to achieve a balance - by developing high productivity and carrying capacity of the catchment whilst achieving acceptable environmental quality and protection of land and water resources.

An integrated approach supports the assessment of biophysical and socioeconomic impacts for a range of alternate management scenarios. The IWRAM project has been working at the sub-catchment scale (~100 sq km) in Northern Thailand, to build a decision support system to:

- 'optimize' land use activities according to the needs and opportunities of the local community
- investigate the impacts of alternate activities (land use and management practice change) on catchment condition
- recommend alternate crops and practices for sustainable land management and income sustainability.

During the life of the IWRAM project, three variants of the IWRAM DSS have been developed to support these investigations. The variants reflect a range of factors, including:

- access to data
- spatial scale
- priorities of partner management agencies
- selection of catchment condition measures
- availability of agency staff.

The IWRAM approach has matured during these developments to a stage where it can be promoted as an integrative framework to support informed water and land resource management at any level (Letcher et al., 2004). The following section gives a general overview of the IWRAM approach, and a general description of the study areas and their issues. The configurations of the DSS variants, including a discussion on key drivers for those configurations, are then described.

2 INTEGRATIVE FRAMEWORK

To support informed debate and policy initiatives in catchment management, it is useful to develop a framework that brings together knowledge and understanding of

- the key issues facing the catchment in the short, medium and long terms
- the key biophysical processes in the catchment that support analysis of the key issues
- the key social and economic motivators and dependencies in the catchment that support analysis of the key issues
- meaningful and compatible measures (indicators) to assess likely impacts of these scenarios within the catchment
- linkages between these four components.

It is taken for granted that the project, and in particular the DSS development, has a strong participation component with engagement of key stakeholders.

The IWRAM framework addresses these components through inclusion of:

- scenarios that capture the key issues under investigation
- models that simulate key biophysical processes and have predictive capability
- models that simulate key socioeconomic processes and have predictive capability
- indicators that support comparison of scenarios
- an integrating engine that links scenarios, models, data and indicators, and supports 'what if' analyses.

The sophistication and complexity of the models and the integrating engine are totally dependent on the selection of scenarios and indicators, themselves dependent on the particular application. As with development of any software tool, no code should be written without an analysis of end-user needs, team skills, software life cycle (including maintenance and distribution) and training and extension.

The comments below relate specifically to implementation in regional Thailand. For a broader, more detailed, description of the IWRAM framework see Letcher *et al.* (2004).

2.1 Participation

Effective and sustainable catchment management can only be achieved through development of appropriate policies and adoption of appropriate on-ground husbandry. Experience confirms that strong involvement of key players in the policy development phase is crucial to adoption and compliance. This extends to development of any decision support system that purports to support catchment management. There is little gain in developing a DSS to support the analysis of a range of initiatives, if it is not accompanied by an analysis of attitudes, opportunities and barriers that limit local communities from accepting and implementing those initiatives.

The intended use of the DSS will determine the appropriate participation program, which can range from inclusion in data collection, DSS design, development of scenarios for analysis and their assessment. It is not the purpose of this paper to discuss appropriate participation processes and principles – suffice to say that participation plays an important role in both DSS development and the role of such tools in water resource management and assessment.

2.2 Scenarios and their development

The critical stage in DSS development is identification of the issues. What are the questions to be answered in terms of resource allocation and 'best practice'? What are the concerns? For example, is the likelihood of erosion important if considering introduction of new crops and/or new management practices into a region?

While the specific issues shifted during the lifetime of the IWRAM project, the focus of the IWRAM DSS remained focused on the spatio-temporal distribution of water supply, erosion, crop yield and deficit, and farm income throughout case study catchments. Input drivers were climate, commodity prices, government regulations and investments.

2.3 Model selection

In terms of water allocation, integrated assessment models must be able to consider a range of land use and management activities that impact on catchment yields. They must be able to consider the impact of changes in flow on water use, as well as the influence of land use and water use decisions on water availability. Aspects of the catchment system that may need to be represented include agricultural practices that affect water use or rainfall-runoff generation, the impacts of changed vegetation cover including forest area, the impact of water availability on crop and livestock production, and the impacts of changed water and land management policy on households, farms and regional communities.

The detail with which these system components are considered and represented depends on the scale at which the management questions are to be answered, the types of land and water use activities present in the catchment, and the type of management options to be considered.

In the context of northern Thailand, they will include, but not be confined to, a set of biophysical models (e.g. rainfall-runoff, water storage and availability, soil erosion), a set of agricultural production models (e.g. crop growth, water use, gross margin) and a set of socioeconomic models (farmer decision-making, socioeconomic impact).

Model selection is also influenced by data and resources availability, including access to professionals with modeling skills. It is far better to develop less complex models, with a local flavor, that address the issues and match the data, than use imported models that over-parameterize, over-complicate and side-track the development.

2.4 Indicators and their development

Regardless of the particular models used, the IWRAM approach identifies a range of indicators to evaluate the impact of alternate management scenarios. Indicators are a product of the models that have been selected - they are either model outputs or a transformation (e.g. re-expressed as a rating rather than a raw number, or aggregated in some way) of those results. The choice of indicators is an iterative process between end-users and model developers (and in fact also influences the choice of models in the first place).

For integrated assessment, they must provide meaningful measures so that scenarios can be 'weighed up' according to their likely impact on the state of both the natural and human resources of the catchment. For more complex assessments, this may extend to include externalities such as impacts on upstream and downstream users.

In the IWRAM DSS, indicators include:

- Biophysical
    - Base stream flow (ML)
    - Stream flow following abstraction (ML)
    - Irrigation (mm)
    - Erosion (tonnes/ha)
- Agricultural
    - Crop water demand (mm)
    - Crop yields (tonnes/ha)
- Socioeconomic
    - Cash per household (baht)
    - Total household income from agriculture (baht)
    - Off-farm income (baht)
    - Hire cost (baht)
    - Rice deficit (kg/household)
    - Cost of rice deficit (baht).

2.5 Integrating Engine

Within the DSS framework, the integrating engine has the role of pulling together (and executing) the component models, and providing the interface for describing and analyzing scenarios. Each variant of the IWRAM DSS uses a different integrating engine, though they are all examples of a coupled model approach.

The engine, or core module has the job of 'translating' scenarios into the parameter sets of the component modules, scheduling and executing the component models in the right order, and configuring the spatial and temporal outputs from the models.

Importantly an integrating engine enforces consistency of catchment representation (e.g. delineation of the landscape into homogenous modeling units) as the component models share a common database. The interface should also be independent of the underlying models so that it can be easily adapted to reflect user feedback.

3 CASE STUDIES

3.1 Study Areas

The IWRAM project is based in catchments of the Ping River basin in the north of Thailand. Phase I focused on the Mae Chaem catchment, with Phase II moving to the Mae

Rim, Mae Kuang and Mae Ping catchments (Figure 1). These catchments are in the Chiang Mai and Lamphun provinces of Thailand. The Ping River is one of four main rivers in Northern Thailand and flows southwards from the north-west to join the Chao Phraya River, the most important river in Thailand, cutting through the Central Plains through Bangkok, the capital of Thailand. Within Phase II, a small sub-catchment of the Mae Rim (called P37) was selected for model development and testing.

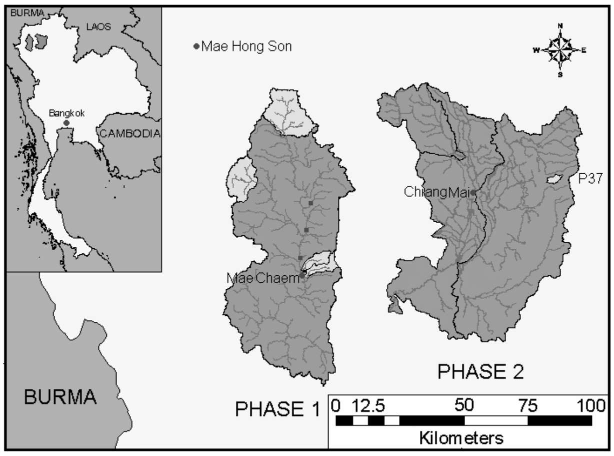


Figure 1: Locations of Phase I and Phase II study areas

Resource management in the study areas has largely focused on sustainability of water and forest resources. In recent years, this has expanded to include sustainability of the local communities themselves. Declining water quality and forest cover is of concern to policy makers, local farmers and lowland farmers. There is a pressing need to introduce conservation management practices, particularly in the highlands, to arrest soil erosion and reduced soil fertility.

IWRAM DSS development, and associated field work, has been supported by a significant collaboration between government agencies (the Department of Land Development, the Royal Forestry Department and the Royal Irrigation Department), and universities (Chiang Mai University and The Australian National University) under the guidance of the Royal Project Foundation.

The main objective was to work with catchment managers to improve the livelihoods of local communities. The development of a DSS to serve as a common tool for interested agencies has been an important component of the project. In addition to the role of the DSS in assessing catchment condition, DSS development encourages (in fact requires) a collaborative and multi-disciplinary team approach that values different skill sets, disciplines, agency agendas and policy-making cultures. It provides a vehicle for cross-agency collaboration and interfaces practising field scientists with researchers and policy makers.

3.2 IWRAM DSS Development

The phases of the IWRAM project described here ran from 1997 through to June 2004. The case studies in Phase I (1997-2001), selected by local resource managers, reflect different biophysical, cultural and policy drivers of changes, including upstream/downstream water conflict; access to forest resources; agricultural intensification and extension, and soil degradation.

The DSS developed during this Phase is known as the *Integrated Modeling Toolbox* (Letcher *et al.*, 2002) that comprises a Biophysical Toolbox (Merritt *et al.*, 2004) linked to socioeconomic models. This is quite a complex software application using a node-link framework and was developed and coded by the Australian team.

A great number of lessons were learnt during this phase and the Thai team were keen to adapt these concepts and develop their own DSS, *IWRAM-DSS* in Phase II.

IWRAM XL (E**X**tension **L**ayer) was also built during this Phase to support the conceptualization of IWRAM-DSS.

From a software development perspective, the progression of ideas and their implementations in the various DSSs clearly demonstrates 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 latter was developed primarily as a educational tool. The following section describes these variants and their uses, and assesses their relevance and contribution.

4 THE INTEGRATED MODELING TOOLBOX

4.1 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. The purpose for the DSS was to assist the Land Development Department in its land use planning activities.

4.2 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.

4.3 Study area representation

The Toolbox utilizes a nodal structure to represent the stream network. This supports modeling of trade-offs between upstream and downstream users. Household decisions in a catchment upstream of a node are aggregated and modeled 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-runoff 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 subcatchment is largely described by land units 88 and 99 – low sloping clay soils suitable for paddy agriculture. This system is described in Tansiri and Saifuk (1999).

The resultant RMUs do not have unique soil characteristics and land qualities, i.e. different RMUs can have the same soil and topographic characteristics.

4.4 Model selection

The Toolbox contains socioeconomic decision making models; a biophysical modeling toolbox; and a socioeconomic impact simulation model (Letcher *et al*., 2002). The biophysical toolbox contains a crop model, a hydrological model, a water allocation model, and a soil loss model (USLE) (Merritt *et al*., 2004).

The *crop model* was developed to support dynamic simulation of crop yields, without requiring large amounts of highly specific soil data. The CATCHCROP model (Perez et al., 2002) predicts crop yield, actual evapotranspiration, surface runoff, deep drainage and crop water demand.

The *hydrological model* was based on the IHACRES rainfall-runoff model (Jakeman and Hornberger, 1993). This model was favoured by the Australian team as it performs well yet only requires rainfall and temperature (or pan evaporation) data for input, and stream discharge data for calibration.

The *soil loss model* to estimate *gross erosion* is based on the Universal Soil Loss Equation (USLE) modified to suit conditions in Northern Thailand.

The Integrated Modeling Toolbox models decisions on land and water use, at household scale.

The *socioeconomic decision making* model uses a linear program (LP) to solve a constrained optimization. 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 maximizing profit or minimizing risk.

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

4.5 Model integration

The Toolbox underwent a number of design and platform changes. The final product is a collection of programs (Matlab, Fortran, Java) which can be run separately or in combination, with clearly defined execution sequences and data flows. The integrative framework is graphically represented in Figure 2.

Land use decisions, based on expected returns and water availability, are simulated within the socioeconomic decision models. 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 passed out of the Biophysical Toolbox to the socioeconomic impact model, where the impact of actual yields on a series of socioeconomic indicators is calculated.

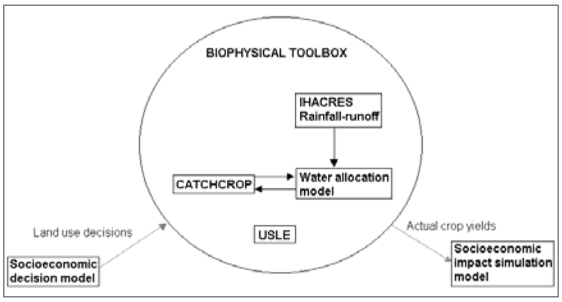


Figure 2: The integrative structure of the Integrated Toolbox showing the main models and their linkages

4.6 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. These are comprehensively described in Merritt *et al.* (2004) and Letcher *et al.* (2002).

Perhaps the most important use (in hindsight) of the Toolbox has been its role in building a local multi-disciplinary team who can promote IWRAM principles and practices.

4.7 Assessment

From a technical perspective, the Toolbox has been successful as evidenced by the fact that it continues 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 of the DSS. These problems mainly related 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.

5 IWRAM-DSS

5.1 Issues

The benefit of shared experience clarified the approach that the Thai team wished to follow. The initial Toolbox developments taught the Thai team a great deal about integration of models and scenario development. It was then important to put that into practice, and what better way than for the Thai team to take ownership of the component models, and the integrative framework. This is in addition to other initiatives to support the uptake and delivery of IWRAM, including extensive fieldwork, an information website (http://www.iwram.org), development of training materials, and extension of the IWRAM program to 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 Section 5.6.

5.2 Design imperatives

The first imperative was to select a land classification scheme that conformed to the Thai land use planning system. Land Modeling Units (LMUs) were devised and are described in Section 5.3.

The second design imperative was to couple the DSS with a 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 program used in the socioeconomic model. This was driven by three factors: (1) the processing within linear programs is not obvious (ie ‘black box’) and does not engender transdisciplinary learning; (2) the optimization paradigm does not sit comfortably with the world view of the biophysical modelers; and (3) the need to disaggregate results beyond the ‘representative’ decision-maker (as used in a linear programming approach).

5.3 Case study representation

The RMUs of the Toolbox have been replaced by Land Modeling Units (LMUs). These are intersections of land units (described in Section 4.3) and ‘current’ land use. The land unit map does not change – however 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. The fact that the Thai team has been able to do this is a credit to their collaboration and a keystone of integrated catchment management.

5.4 Model selection

A decision tree approach was selected to replace the linear program in the *socioeconomic decision model*. The revised model is a crop choice model whose structure (a decision tree) has been generated using a data mining program. 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, labor, 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. This model is described in Ngamsoksuke *et al.* (2005).

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 modeler 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 and is described in Pratummintra (2004).

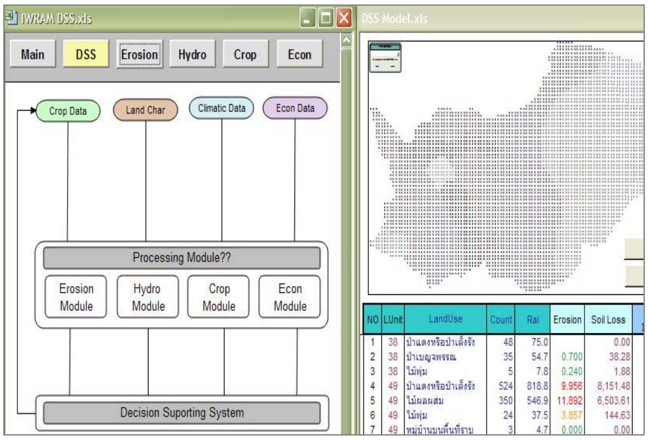
The *hydrology model* is very different to that in the Toolbox, using the US Soil Conservation Service’s curve number (CN) approach to estimate direct runoff from rainfall events. This has been implemented in a prototype version of the model which is described in Witthawatchutikul et al. (2005).

5.5 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 Section 6). It is anticipated that the two paths will merge with the add-in of GIS functionality to the VBA application (via ArcObjects).

In the GIS version, the GIS itself provides the integrative functionality. 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, it 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 3 is a screen grab of the Main worksheet and demonstrates its open and transparent style. The user can select a component model, or go to another worksheet to build LMU scenarios.



NO	LUnit	LandUse	Count	Rai	Erosion	Soil Loss
1	38	ป่าแดงหรือป่าเต็งรัง	48	75.0		0.00
2	38	ป่าเบญจพรรณ	35	54.7	0.700	38.28
3	38	ไม้พุ่ม	5	7.8	0.240	1.88
4	49	ป่าแดงหรือป่าเต็งรัง	524	818.8	9.956	8,151.48
5	49	ไม้ผลผสม	350	546.9	11.892	6,503.61
6	49	ไม้พุ่ม	24	37.5	3.857	144.63
7	49	หมู่บ้านบนพื้นที่ราบ	3	4.7	0.000	0.00

Figure 3: The DSS module of IWRAM-DSS showing the component models and the style of interface

The core modules of IWRAM-DSS are operational, allowing investigation of alternative land use scenarios based on a range of crops, practices and farmer choices in LMUs. Assessment indicators are erosion and gross margin. Crop water needs and use (from the crop model) and water availability (from the hydrological model) will be available when these models are validated and linked into the DSS.

5.6 Uses

IWRAM-DSS is a system under 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 utilization 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 farmer's crop choice. In the first instance, this has been limited to the role of credit availability in farmer decision making. An assessment of the usefulness of the model for this purpose is in Ngamsomsuke *et al*. (2005).

5.7 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 is 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 that, have been well learnt and continue to inspire the Thai team.

Planning is under way for the first IWRAM-DSS training workshop in early 2005. This will provide an opportunity for the IWRAM team to evaluate the coupling of their models. The workshop will demonstrate the component models as well as their integration and will serve to inform the design of the next version of the DSS.

6 IWRAM XL (EXTENSION LAYER)

6.1 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. It is still in a development stage and requires considerable work to be a quality product.

6.2 Design imperatives

The first design imperative was to demonstrate that a powerful integrative framework can be built using simple tools (such as Microsoft's 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 centralized databases to rationalize and synchronize information. For example the economists, the crop modeler 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 subcatchment avoided the need to consider the complexity of spatial relationships such as onsite and offsite 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.

6.3 Model selection

As IWRAM XL is only a teaching tool, 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 complimented with an *Erosion Explorer* module to explicitly investigate the likely impact of alternate 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, but not implemented.

6.4 Model integration

IWRAM XL consists of three main components - LMU Maker, Model engine, Output display and export module, linked as shown in Figure 4.

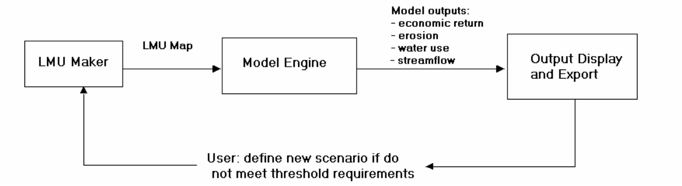


Figure 4: Diagram of IWRAM XL components

Figure 5 shows the data flows between the component models and the integrating module. The input data are 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 lookup tables and maps, and for model execution. The key input is the LMU map. This is firstly assessed again erosion thresholds. If the LMU map exceeds these thresholds, then the user is expected to create an alternate biophysical or socioeconomic scenario.

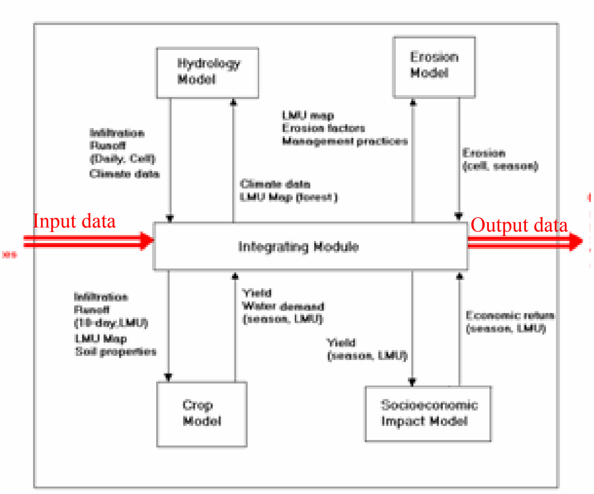


Figure 5: Diagram of the modules and data flows within IWRAM XL

The 'economically optimal selection' scenario would use the *Socioeconomic LMUMaker* to create broad land use maps and constraints. Crop choices are then modified from this to determine a modified land use which meets erosion thresholds in an economically efficient way.

6.5 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.

6.6 Assessment

This approach to DSS development is very different to its predecessors. It is at the very low tech end of the market. 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.

7 DISCUSSION AND CONCLUSIONS

The aim of the project 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). A significant part of the project was the development of a DSS to support the formulation and assessment of a range of scenarios based on their likely effects on the natural environment and the livelihoods of the local people.

An equally important objective was to develop local and enduring capacity in approaches to integrated water resource assessment and management. We believe that the DSS development phases, and their implied ownership of the issues and principles of IWRAM, clearly demonstrate the success of the project, certainly in terms of the return on investment in the team members themselves. Successful IWRAM depends on collaboration and the development of workable and appropriate modes of associated research with a wide range of scientists from different cultural backgrounds is crucial.

Adoption of IWRAM DSS within the relevant government agencies would be the ultimate measure of success – however it is not within the jurisdiction of the project to legislate. Indeed, the most immediate use for the IWRAM DSS is to promote and educate. The best investment is in people, not products. In the words of the Thai team, “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.” (Royal Project Foundation, 2003).

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