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Integrated Water Resources Assessment and Management (IWRAM) Project: Integrated Toolbox

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INTEGRATED WATER RESOURCES ASSESSMENT AND MANAGEMENT (IWRAM) FRAMEWORK PROJECT

BACKGROUND

Due to mounting and conflicting human pressures, stakeholders in northern Thailand are facing a crucial policy problem typical of many regions in Asia, namely how to plan for the sustainable and rational use, protection, conservation and management of land and water resources.

Project objectives and output

This project focuses on assessment of upland agricultural systems. It uses an international, inter-disciplinary team approach to develop ***decision support tools*** that will assist the Royal Project Foundation, government and other stakeholders to identify and assess the implications of a series of 'what if' scenarios.

The framework aims to be sufficiently generic and portable to be applicable in other agricultural, agro-forestry and aquaculture resource management environments.

The Research Partnership

The IWRAM project is a collaboration between a number of Thai and Australian agencies: Royal Project Foundation of Thailand; Australian Centre for International Agricultural Research; Department of Land Development; Office of Highland Development, Australian National University; Royal Forestry Department; University departments from Chiang Mai, Maejo and Kasetsart.

The first phase of the project focuses on the Mae Chaem river basin, a 4,000 km^2 subsidiary of the Ping River in northern Thailand. It commenced in late 1997 and will be completed in late 2000.

THE RESEARCH PARADIGM

Multi-disciplinary analysis - the disciplines used in this integrated analysis include economics; hydrology; anthropology; social psychology and crop science.

Modelling - Scenarios are 'what if' tools developed to explore likely trends in resource use. Scenarios may be developed around agricultural or conservation policies, demographic change, potential climate variability, or changes on the world market for exported goods. Input from a range of ***stakeholders*** are being obtained to define scenarios that reflect current decision making processes. The decision support tools are being designed to portray effects of the various scenarios on multiple ***indicators*** and the trade-offs between them.

The way in which scenarios apply the decision support tools is through an integrated modelling approach. Hydrological modelling of sub-catchment processes is being combined with ***models of household decision making.*** Households are being grouped into "***Resource Management Unit***" (RMU) ***types*** based on similarities in biophysical, economic and socio-cultural attributes. The RMU situates the socially and economically constituted agricultural household in its biophysical environment. One of the aims is to examine the way in which different RMU types respond to scenario conditions and the implications of upstream decision making on other households in the catchment. A Decision Support System will integrate the models and link them to a geographical information system (GIS).

Case Studies

Five sub-catchments with varying patterns of resource management and use are being used as case study areas for developing and trailing the decision support tools. The case-studies, selected by and involving local resource managers, reflect different biophysical, cultural and policy drivers of change. They will develop and assess alternative scenarios for addressing the issues present in these sub-catchments. Case study issues include upstream/downstream water conflict; access to forest resources; agricultural intensification and extension and soil degradation.

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Integrated Water Resources Assessment and Management (IWRAM) Project: Integrated Toolbox

Abstract. The integrated toolbox of the IWRAM Decision Support System links household scale socio-economic models with a biophysical modelling toolbox (Merritt *et al.*, 2001). In the biophysical toolbox, land use decisions are "painted" onto the catchment by the user. By contrast, the integrated toolbox simulates land use decisions by using models of household decision making. This allows the user to investigate the social and economic constraints on land and water use, and to look at the impacts of climate, prices and management policies on households. The impact of household decisions on a range of biophysical indicators is able to be demonstrated and trade-offs between upstream and downstream users of water are also able to be investigated.

1. Introduction to the IWRAM Project

The Integrated Water Resources Assessment and Management (IWRAM) project, within the first project phase (1997-2001), has developed an integrative methodology to allow stakeholders to explore the economic, environmental and socio-cultural implications of different levels and patterns of cultivation and other water use in a representative catchment.

Through a consultative process, the project established that one of the main challenges for resource managers is to balance the various socioeconomic and environmental trade-offs that are associated with resource management decisions. The IWRAM framework was thus developed to provide managers with tools that they could use to explore alternatives in this complex assessment process.

The IWRAM package includes a number of models and a computer-based Decision Support System. The methodology comprises a toolkit that integrates various disciplinary contributions including agronomy, climatology, economics, hydrology and soil science. The toolkit has been imbedded within a decision support system to allow users to create scenarios and run these scenarios through the toolkit's models. A range of biophysical and socioeconomic indicators are produced as outputs. The decision support system is designed to assist stakeholders to identify and assess socio-economic and environmental impacts of scenarios. The DSS is comprised of a 'Biophysical Toolbox' that can be implemented as a stand-alone tool and an 'Integrated Toolbox' that links a socioeconomic model with the biophysical toolbox to explore economic trade-offs and impacts of various scenarios (Figure 1).

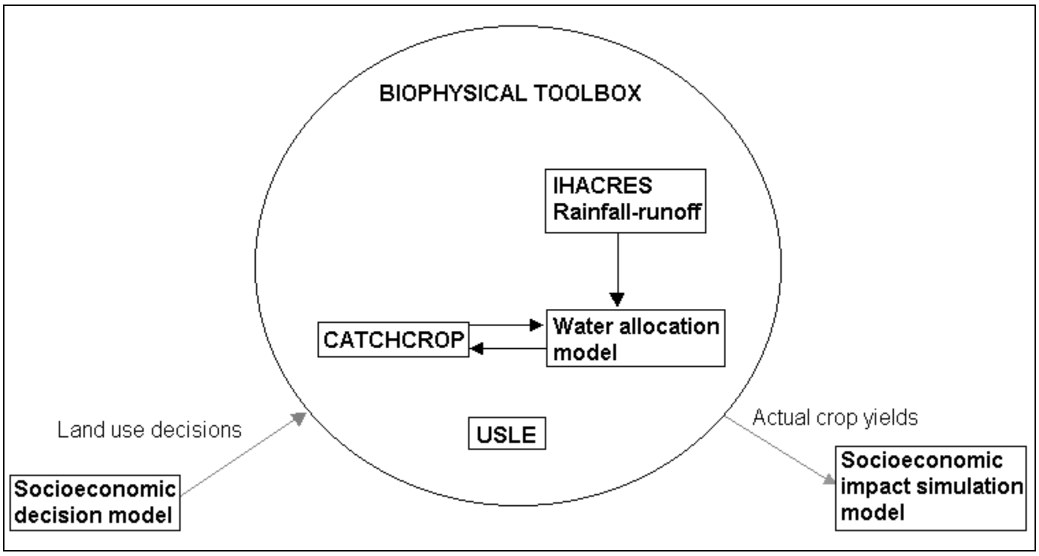


Figure 1. The IWRAM DSS (from Jakeman and Letcher, 2001)

The focus for the project has been placed on subcatchments of the 4,000 km^2 Mae Chaem catchment (Figure 2). In the Mae Chaem catchment, a microcosm of much of rural South East Asia, rapid agricultural intensification, rural development initiatives and government conservation policies have created points of tension in relation to land and water resource management. These demands:

- are multi-sectoral;
- have both on-site and off-site effects; and
- involve multiple choices over uses of scarce resources, particularly water.

The IWRAM methodology is designed to allow stakeholders to explore the dynamics of these multi-objective environments.

The methodology has to be able to incorporate information of different kinds – spatial, time-series, financial, political and cultural. To focus this diverse information, the unifying factor is the scenario. A ‘data $\rightarrow$ scenario $\rightarrow$ modelling $\rightarrow$ indicators’ framework was adopted.

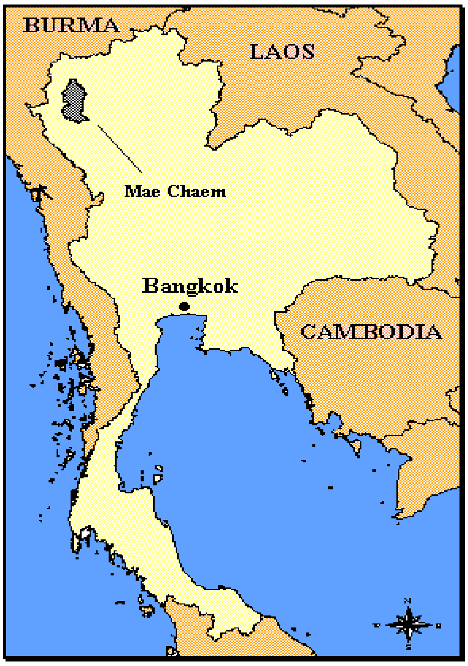


Figure 2. Location of the Mae Chaem catchment

The IWRAM project recruited personnel with a number of discipline backgrounds to staff the four research components. There were ‘mirror’ teams in Thailand and Australia who collaborated on these components. Over the four years of the project there was considerable turn-over of staff. This occurred in Thailand as well as Australia. Some staff were appointed for quite specific and limited tasks, while others gave occasional, ‘in-kind’ input. As with any large-scale research activity, not all the ‘experiments’ attempted in the project succeeded and some contributors’ inputs did not produce results that have been retained in the final products. Others, such as consultants and commentators, helped steer the research program without making direct research inputs of their own.

The following people have made significant contributions:

Bio-physical component	Barry Croke, Tony Jakeman, Wendy Merritt, Pascal Perez, Somporn Sangawongse, Sergei Schreider, Kamron Saifuk, Bandith Tansiri
Economic component	Penporn Janekarnkij, Padma Lal, Rebecca Letcher, Suwanna Praneetvatakul, Varaporn Punyawadee, Michelle Scoccimarro
Socio-cultural component	Nootsuporn Krisdatarn, Helen Ross, Andrew Walker
Decision support system component	Nick Ardlie, Claude Dietrich, Karn Trisophon

Initially, significant stakeholders for the DSS were the Royal Project Foundation and the Land Development Department. The Land Development Department aims to utilise the DSS to assist its landuse planning activities. Other agencies and groups have now become actively involved. Adoption is being facilitated by training workshops on the individual model components and the DSS itself.

The IWRAM project is a collaboration between a number of Thai and Australian agencies:

- Royal Project Foundation of Thailand (RPF),
- The Australian Centre for International Agricultural Research (ACIAR),
- The Australian National University (ANU),
- Thailand's Department of Land Development (DLD),
- The Office of Highland Development (OHD),
- The Royal Forestry Department (RFD)
- The Royal Irrigation Department (RID),
- University Departments from Chiang Mai, Maejo and Kasetstart.

2. Scales in Integrated Assessment

An important consideration when constructing decision support systems is determining the appropriate scale at which modelling should take place. This scale is determined by the key features of the issues focussing development of the decision support system, as well as by socio-cultural considerations in the management of the resource. The IWRAM DSS models resource management decisions as taking place at the household scale. This scale was chosen as it was considered that the household was the main driver of agricultural production decisions in Northern Thailand (Scoccimarro *et al.*, 1999). Future applications of the nodal network integrative framework utilised by the IWRAM DSS may rely on a different scale of decision making (eg. the regional or village scale) and will almost undoubtably include additional types of resource users, such as industry or aquaculture. The IWRAM framework which has been developed is sufficiently generic to allow for these alterations.

3. Household decision models

Decisions on land and water use are modelled within the integrated toolbox as taking place at the household level. These decisions are made in response to expectations on the level of land, water and labour available to a household.

Households are classified into a number of different types, called Resource Management Units (RMU). For a detailed discussion on Resource Management Units and their application in the IWRAM Project see Scoccimarro *et al.* (1999). These RMU types differ according to their access to land and water in the catchment. For example, one RMU type may be households who own only irrigated paddy land, while households in another RMU may own some irrigated paddy and some rainfed upland. The types of RMU which may be seen in a catchment are summarised in Table 1 (taken from Scoccimarro *et al.*, 1999).

Table 1. RMU types

RMU	Description
1	rainfed paddy only
2	irrigated paddy only
3	rainfed upland only
4	irrigated upland only
5	rainfed and irrigated paddy
6	rainfed paddy and upland
7	rainfed paddy and irrigated upland
8	irrigated paddy and rainfed upland
9	irrigated paddy and upland
10	rainfed and irrigated upland
11	rainfed and irrigated paddy and rainfed upland
12	all types
13	irrigated paddy and upland and rainfed upland
14	rainfed paddy and upland and irrigated upland

Each household is assumed to be constrained in their activities by their access to land, water and labour. Households are modelled as aiming to generate as much profit as possible given a choice of crops, and expectations on the amount of land, water and labour that will be available to them. However other objectives such as maximising yield or minimising risk and uncertainty could also be modelled (this would require some changes to the source code of the model). Social constraints, such as the need to grow rice as a subsistence crop during the wet season, are included as constraints on household decision making. For example, households are mostly limited to growing rice in the wet season in order to meet their subsistence needs. Cash cropping is assumed to take place in the dry season. The model allows for different choices of fertiliser level on crops as well as for the choice of whether to irrigate a crop. The model uses linear programming to solve the constrained optimisation, using separate tables for the wet season and the dry season.

Decisions made at the household level are fed through the biophysical toolbox and impacts of actual crop yields and actual water availability are then simulated on the household. Rice deficits, as well as overall household economic performance, are simulated and used to indicate social and economic trade-offs involved with different scenarios.

4. Nodal structure

In order to consider the impacts of household decision making on the hydrological system, and to model trade-offs between upstream and downstream users, the IWRAM DSS uses a nodal system. This means that household extraction decisions in an area are aggregated and are modelled as occurring from a specific point along the river. Total water supply, modelled using a hydrological model (see Merritt *et al.*, 2001), is also simulated at this point or node. Households in an area are divided into a number of representative RMU and the decisions of individual households are aggregated by summing up decisions of each RMU type present at the node.

The nodal structure is illustrated within Figure 3 for the 43.5 km^2 Mae Uam subcatchment showing (as red dots) two nodes – an upstream and downstream node at which spatial and temporal estimates of discharge are provided. Figure 3 additionally illustrates the land units within catchment (See Merritt *et al.*, 2001). Issues of crop water use exist with low slope land units suitable for paddy agriculture, whilst in steep lands (shown in orange and green) susceptibility to erosion is an additional issue of concern. The nodal structure implemented within the IWRAM allows these considerations to described for both nodes and hence identifying potential differences in impacts between upstream and downstream areas.

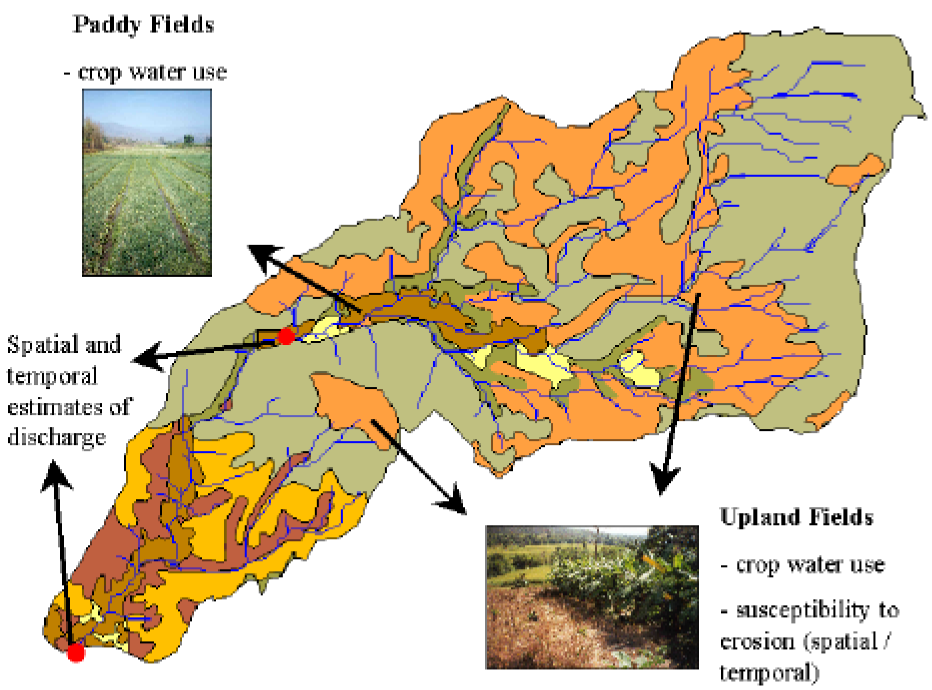


Figure 3. The Mae Uam catchment showing the nodal structure implemented within the IWRAM-DSS and the Biophysical Toolbox.

Households of the same RMU type are modelled as having the same access to land, water and labour at a node. This means that the same land use decision is made by each of these households. Individual household decisions at the node are aggregated across individual RMU and then across RMU types and the aggregate land use decision is fed to the biophysical toolbox as an aggregated land use and management decision for the node.

Users of the model are able to change the total number of households of each RMU type at each node, as well as changing the access each of these RMU have to land, labour and water resources. In this way they are able to explore changes that could happen in the catchment as a result of forest clearing for agriculture, as well as for migration into the catchment.

5. Input data requirements

Data and assumptions required to run the integrated toolbox are brought into the DSS using text files which may be linked to a graphical user interface (GUI). The model has been structure to read input from a folder structure of the form toolbox => node => rmu where the rmu folders are for each rmu type and season at the node.

5.1. Toolbox level inputs

5.1.1. Climate years

The years over which the model is run are controlled by the years.txt file. This file is formatted as:

start year

end year

and is saved in the Toolbox level.

5.1.2. Prices

Price information for the crops which are considered by the model is contained in the price.txt file in baht. This file contains a list of prices (arranged vertically) corresponding to each of the crops. A value for every crop should be placed in this file even if the crop is not an option for any RMU in the run (i.e. a zero can be placed as the price for any such crop). The order in which crops should be represented in this file corresponds with the crop code order given in Table 2.

Table 2. Crop Codes

Crop	Code
Paddy Rice	01
Upland Rice	02
Soybean	03
Ground nut	04
Maize grain	05
Maize forage	06
Cabbage	07
Potato	08
Onion	09
Fruit temperate	10
Fruit tropical	11

5.1.3. Production costs

Information on the cost of producing each crop at different levels of fertiliser input is given in the costs.txt file in baht. As with the price.txt file, a value should be placed in for each crop for each level of fertiliser application, regardless of whether or not the crop is considered by the model (a zero value may be used for these crops). This is a tab delimited file which is structured as shown in Table 3.

Table 3. costs.txt file format

$c_{1,1}$	$c_{1,2}$	$c_{1,3}$
$c_{2,1}$	$c_{2,2}$	$c_{2,3}$
…	…	…
$c_{11,1}$	$c_{11,2}$	$c_{11,3}$

5.1.4. Wages

A single wage is assumed for labour leading to off-farm income and for hire labour on farm. This wage is contained in the wage.txt file as a single number in baht.

5.2. Node level inputs

5.2.1. RMU Information

The file rmuinfo.txt is a tab delimited file which contains information about the households at the node. It should be formatted as shown in Table 4.

Table 4. rmuinfo.txt file format

RMU type +10
Number of households
Average number of people per household

For example, this file may be as shown in Table 5.

Table 5. Example of rmuinfo.txt file format

12	13	18
65	108	191
3	2	4

5.2.2. Land Unit Information

Information on the land units present at a node and their current characteristics is required to disaggregate household level decisions which are made on paddy and upland to land units (which are finer than the paddy/upland distinction). The file landunits.txt contains this information on the land units at a node. This file should be formatted as shown in Table 6.

Table 6. landunits.txt

land unit number	current agricultural area (ha)	total land unit area (ha)	paddy (1)/upland(2)
…	…	…	…

5.3. RMU level inputs

5.3.1. Wet and dry season LP tables for each RMU for each node

In order to run the integrated toolbox a text file called table.txt which forms the basis of the tableau for each RMU for each season (wet and dry) must included in each of the RMU level folders. These folders should be named 'rmuxy' where x is the rmu identifier plus 10 and y represents season (1 is wet season, 2 is dry season). For example, such a folder may be called rmu121, which is a folder for wet season inputs for RMU 2. These tableaux contain information on assumptions about crops considered by the RMU in each season and expected yields for these crops. The text file must have the structure shown in Table 7 in order to be read by the software and should be tab delimited.

Table 7. table.txt file format

0	0	yield y_j	...
0	0	Symbol s_j for crop activity j	...
1	-1	H_j	...
0	*0*	w_j	**...**
0	0	fixed 0 or 1	...
0	*0*	*fixed 0 or 1*	...

H_j is the expected hours of labour required for performing activity j on a rai of land,
y_j is the yield in tonnes per rai,
w_j is the irrigation water (ML) expected to be required to perform activity j on a rai of land (note this row does not exist for RMU 3 which has no access to irrigation).

Note that the final row may not exist in RMU where only one type of land (paddy or upland) is able to be accessed. Where two types of land are able to be accessed , paddy should come before upland in the table.txt file.

Land is divided into two types: paddy and upland. Access to these types would depend on RMU type. Three basic options are available: access to paddy only; access to upland only; access to both paddy and upland. The choice of whether land is irrigated or not affects the crops able to be grown and the irrigation water use, but not the land constraint.

For example, the tableau for RMU8 for a node in the dry season may be as in Table 8.

Table 8. Example tableau for RMU8

0	0	124.8	121.6	118.4	318.4	553.6	772.8
0	0	10320	10321	10322	20310	20311	20312
1	-1	22.3	22.3	22.3	18.6	18.6	18.6
0	0	0	0	0	0.516	0.748	0.965
0	0	0	0	0	1	1	1
0	0	1	1	1	0	0	0

The crop code used to describe cropping activities is constructed as follows:
The first number indicates whether the crop is rainfed (1) or irrigated (2).
The next two numbers indicate what crop is being grown (in this case 03 is soybean). A full list of codes for all crops in the crop model was given in Table 2.
The next number indicates the land type: 1 for paddy; 2 for upland.
Then the next number indicates the fertilisation level where 0 is no fertiliser, 1 is half fertilisation and 2 is full fertilisation.

Note that the same crop (eg paddy rice) is considered to be two different cropping activities if it can be grown with two different levels of fertiliser. Equally irrigated and rainfed options for the same crop are considered to be different cropping activities.

5.3.2. Initial resource constraints

Also in each RMU level folder there should be a file called constraints.txt, which contains information about expected land, water and labour constraints for the household. This water constraint is used only in the first year of the run and then is updated in each year (see Section 6). This file should be set out as shown in Table 9. If any land type is not present in that household (i.e the limit is zero) then that row should be left out of the file. If the household has no access to irrigation (i.e. RMU 3) then that row should also be left out of the file.

Table 9. constraints.txt file format

Labour (hours)
Irrigation (ML)
Paddy (rai)
Upland (rai)

6. Multi-year scenarios

It is possible to run the integrated toolbox over several years. If this is done then the expected volume of irrigation water available to an RMU for each successive year (used in the household decision model) is updated on the basis of what has happened in previous years. In the first year the expected quantity of irrigation water is that which was input by the user (see Section 5). In all other years the expected value is the actual amount of irrigation water used by the household in the previous year (i.e. naive expectations are assumed).

7. Links to the Biophysical Toolbox

Once an integrated scenario has been specified, the economic decision model (utilising a linear programming algorithm) is run. This model calculates the area of paddy and upland devoted to different cropping activities in each season (note: a cropping activity includes crop type, level of fertilisation, and whether the crop is irrigated and rainfed). In order for this land use decision to be passed to the biophysical toolbox, land use decisions made by the RMU on paddy and upland areas must be disaggregated by land unit and totals over all RMUs for each crop activity must be calculated. The input file landunits.txt constraints information which is used to disaggregate these decisions on land units (see Section 5.2.2).

This file also specifies which land units are paddy and which are upland.

For example:

Paddy: 23, 45, 88, 99
Upland: 25, 47, 49

The procedure by which land use decisions are disaggregated by land unit is as follows:

1. Disaggregating land types to Land Units

Take for example disaggregation of paddy. The set of land units specified by the user as corresponding to paddy is given in Table 10.

Table 10. Example of land units corresponding to paddy

LU	Current agricultural land	Total land
LU_1	g_1	t_1
LU_2	g_2	t_2
LU_3	g_3	t_3
LU_4	g_4	t_4
. . .	. . .	. . .

Clearly g_i £ t_i for all i. Several household types may have access to some paddy as given in Table 11.

Table 11. Household access to paddy

RMU	paddy (rai)	hh
$RMU1_1$	b_1	h_1
$RMU1_2$	b_2	h_2
. . .	. . .	. . .

where the b_m are the area of paddy belonging to a household of RMU type m and h_m is the total number of households of RMU type m at a node.

Then the total cultivation land upper bound is $\sum_m b_m h_m$.

$\sum_m b_m h_m \leq \sum_i t_i$ otherwise the land allotted to households exceeds the amount of such land available at the node. If b_m are chosen such that this is not the case then an error message "Land exceeds total available" is given.

Let q_i be the required land area for LU_i and let d_i be defined as follows

$$d_i = \sum_m b_m h_m \frac{g_i}{\sum_{j=1}^{4} g_j} \qquad (1)$$

case 1: user constraints b_m are such that $d_i \leq t_i$ for all i

In this case, q_i is set proportional to the percent of current land $g_i/S_j g_j$, namely

$$q_i = d_i \qquad (2)$$

Note that since (1) together with case 1 hypothesis yields $d_i \leq t_i$, the above yields the correct inequality $q_i \leq t_i$.

This includes both the case where agricultural land in the model is less than current agricultural land and also some cases when encroachment onto non-agricultural land occurs.

case 2: user constraints b_m such that $d_i > t_i$ for some i.

This can occur when agricultural land is expanded into currently non-agricultural land areas. In such a case the apportioning (2) has to be modified since it would lead to the inconsistent relationship $q_i \geq t_i$.

Repeat the following iteratively until the condition $q_i = \min(q_i, t_i)$ is met for all i

For $\{j: d_j - \min(d_j, t_j) = 0\}$

$$q_j = \frac{t_j - d_j}{\sum_{l=1}^{n}(t_l - d_l)} \times \sum_i \left(d_i - \min(d_i, t_i)\right) + \min(d_j, t_j)$$

where n is the total number of such j, l is an index over these j, and i is the index over all land units.

else

$q_j = \min(d_j, t_j)$

The final allocation of paddy by land unit is then q_i for land unit i. The same procedure is then followed for upland areas.

2. Disaggregating cropping activities to Land Units:

Given the situation outlined above and assuming that the households of RMU type m have areas $a_{m,j}$ devoted to cropping activities (j) on paddy. That is, the areas devoted to each activity on each RMU as given in Table 12.

Table 12. Area of paddy activities by RMU

Activity	RMU1	RMU2	. . .
Activity 1	$a_{1,1}$	$a_{2,1}$	. . .
Activity 2	$a_{1,2}$	$a_{2,2}$	. . .
Activity 3	$a_{1,3}$	$a_{2,3}$	. . .
.	.	.	. . .
.	.	.	. . .
Activity n	$a_{1,n}$	$a_{2,n}$	. . .

Note that it is possible for $a_{m,j} = 0$ for any m or j.

Disaggregation of cropping activities to Land Units then takes places as follows:

For activity j:

$$g_{a_j} = \frac{\sum_m a_{m,j} h_m}{\sum_m \sum_j a_{m,j} h_m}$$

then the disaggregation (by area) of cropping activity j by land unit i is

$$k_{j,i} = q_i \times g_{a_j}$$

This calculation is repeated for all cropping activities, on both paddy and upland areas.

8. Economic impact simulation model

This model runs after the biophysical toolbox to calculate the impact of actual yield and water availability on household income and on total rice deficits. The algorithm used by this model can be described as follows:

1. Calculate the area weighted average yield for each activity.

If q_i is the final allocation of paddy/upland by land unit as given by the disaggregation procedure (see Section on Links to the Biophysical Toolbox) and

$g_{a_j} = \dfrac{\sum_m a_{m,j} h_m}{\sum_m \sum_j a_{m,j} h_m}$ as given by the disaggregation procedure ($a_{m,j}$ is the area devoted to activity j in a household of RMU type m, h_m is the number of households of RMU type m at the node).

Then $k_{j,i} = q_i \times g_{a_j}$.

The area weighted average yield of activity j is then

$w_j = \dfrac{\sum_i k_{j,i} y_{j,i}}{\sum_i k_{j,i}}$ where i corresponds to land units.

2. Calculate the total yield of different crops for each household in each RMU.

$t_{m,j}$ = $a_{m,j}$´w_j

3. Calculate the rice deficit for each household in each RMU.

For {j: activity j is a type of rice production}

Total rice grown by the household is

$$r_m = \sum_j t_{m,j}$$

and the rice deficit is

$$d_m = \begin{cases} 300 \times p_m - r_m & if \quad r_m \le 300 \times p_m \\ 0 & otherwise \end{cases}$$

where p_m is the average number of people in households of RMU type m.

4. Calculate the labour deficit/surplus for the household.

If the scenario is run through the integrated toolbox then total labour hired and off farm labouring for each household is given by the solution to the economic decision model (LP). Thus the cost of hiring labour is given by:

$hc_m = Hirelabour_m$ ´ $wage$

and the total off-farm income obtained by the household is given by

$of_m = OFlabour_m$ ´ $wage$

5. Calculate the household cash for each year.

The total cash in each year for each household is then given by

$$cash_m = \sum_j \left(p_j \times t_j - c_j\right) - hc_m + of_m - d_m$$

9. Socio-economic Indicators

Outputs of the integrated toolbox are in the form of indicators. Biophysical indicators are also output from integrated scenarios. These indicators are the same as for the biophysical toolbox (see Merritt *et al.*, 2001). Additionally as set of socio-economic indicators are also provided. These indicators are given by RMU by node and changes in the social and economic 'performance' of a household due to different climatic and upstream land use choice scenarios to be investigated and 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 indicators provided are:

1. Cash per household in baht. This indicator describes the 'economic performance' of households of each RMU type.
2. Total household income from agriculture in baht. This indicator describes the agricultural income from their land use choices.
3. Off-farm income in baht. This indicator shows the reliance of different households on off-farm income.
4. Hire cost in baht. This indicator shows the total wages paid by households to hired labour in each year. It shows the extent to which production relies on hired labour.
5. Rice deficit in kilograms. It is assumed that each person in a household requires 300 kilograms of rice to survive. This indicator shows how much of this rice requirement must be met by purchasing rice. Most households have a strong preference to produce their own rice.

6. Cost of rice deficit in baht. This indicator shows the cost to the household of purchasing unmet rice requirements.

10. Scenarios and Results

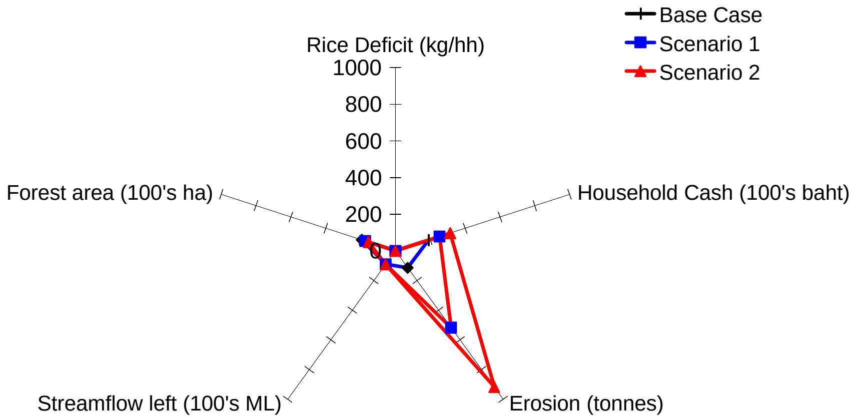
To illustrate the way in which the IWRAM DSS can be used to consider trade-offs between stakeholders and also between environmental, social and economic outcomes in the catchment, the model has been run to consider a number of forest encroachment scenarios. These scenarios have been run on the Mae Uam subcatchment. This subcatchment is modelled as two nodes in series (see Section 4). It is assumed for the results shown in this paper that forest encroachment is occurring through current householders in the catchment increasing the amount of land available for their own agricultural use, as opposed to through additional migration of families into the catchment. Two separate forest encroachment scenarios have been run which can be compared to the Base Case (or current situation). These translate into a 10% change in forest cover (Scenario 1) and a 20% change in forest cover (Scenario 2). The input assumptions for these scenarios, as well as for the base case, are described in Table 13.

Table 13. Scenario input assumptions by RMU (area in rai)

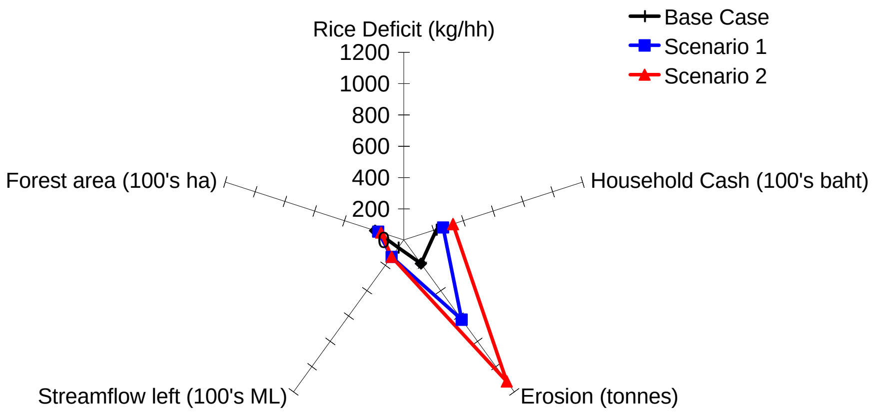
	Base Case		Scenario 1		Scenario 2	
	Paddy	Upland	Paddy	Upland	Paddy	Upland
Node 1						
RMU 2	2.5	0	3.1	0	3.7	0
RMU 3	0	2.1	0	10	0	17.9
RMU 8	2.7	1.3	3.4	6.2	4	11.1
Node 2						
RMU 2	3.1	0	3.5	0	3.9	0
RMU 3	0	2.5	0	5.7	0	8.9
RMU 8	2.3	1.2	2.6	2.7	2.9	4.3

These scenarios were then run for three separate years, corresponding to different climatic regimes: 1988; 1990; and 1993. The results for these runs for both nodes in Mae Uam are given in Figures 4 and 5.

Node 1, 1988



Node 1, 1990



Node 1, 1993

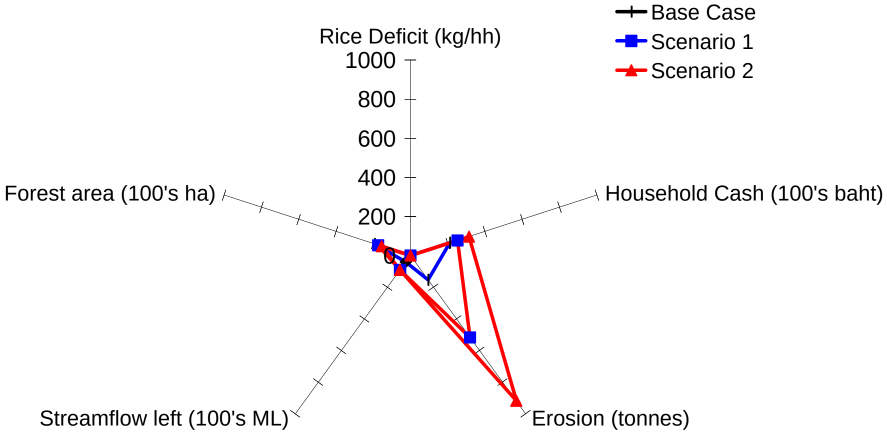


Figure 4. Results for forest encroachment scenarios, Node 1

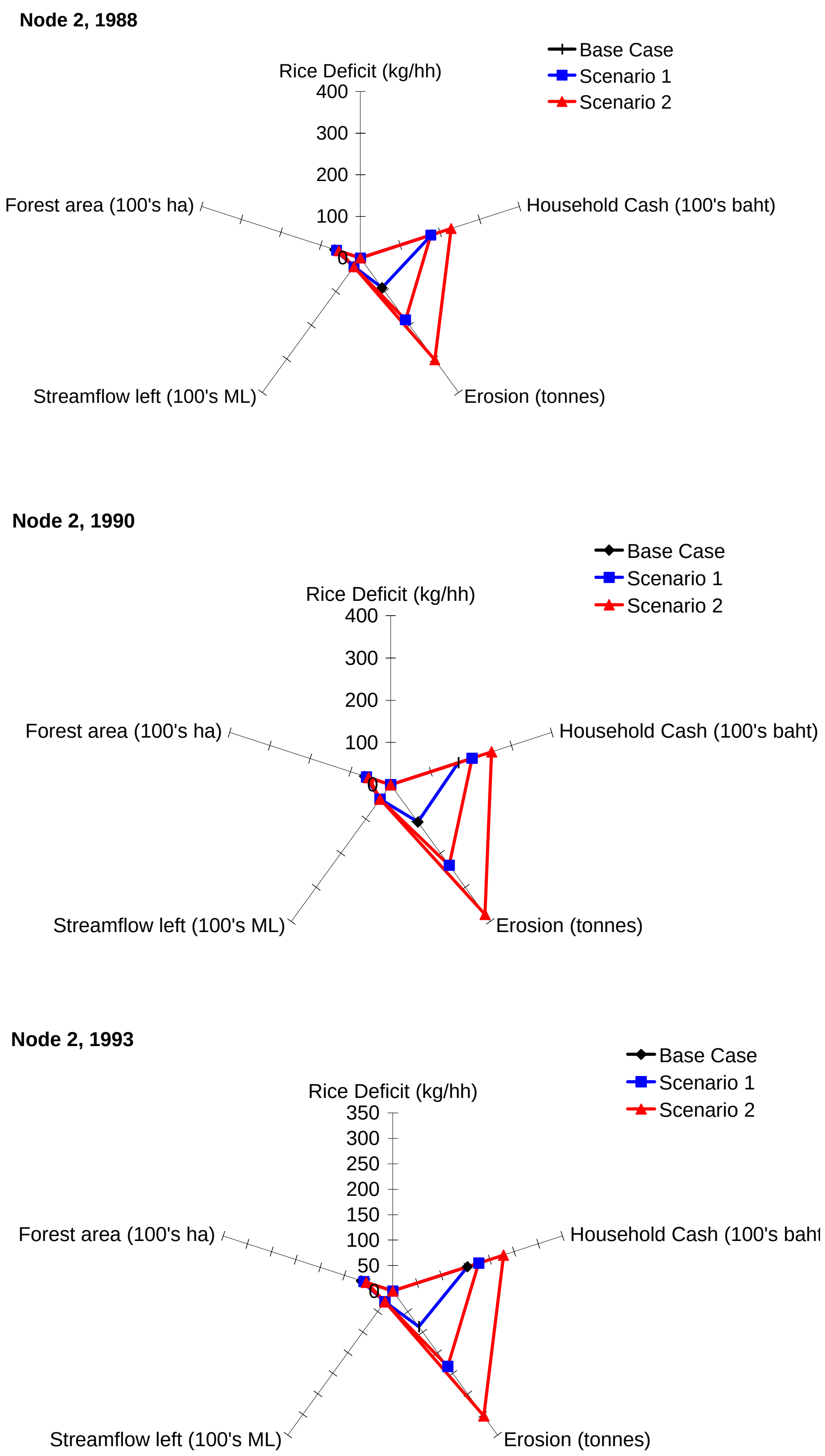


Figure 5. Results for forest encroachment scenarios, Node 2

While the magnitude of the impacts shown differs between nodes and years, the pattern of impact is the same across these. It can be seen that at both nodes the impact on streamflow left over (after irrigation) is fairly mild. In this case no change in the rice deficit is observed (this result depends critically on the number of people assumed to be living in each household). Increasing the area of land available to agriculture for each of the households, and thus reducing forest area, increases household cash levels. This positive economic benefit must be traded off against reasonably substantial increases in erosion that come as a consequence of this deforestation. Erosion is seen to approximately double with each change in forest area.

11. Discussion and conclusions

This paper has outlined the development of an integrated toolbox for the IWRAM project. This toolbox can be used to consider trade-offs of a variety of land and water development options. It has been developed to consider subcatchments of the Mae Chaem catchment in Northern Thailand. The toolbox provides indicators of social, economic and environmental performance which change in response to a number of drivers, including climate and development of agricultural lands. The models in the toolbox have been developed to run on a scenario basis.

Future work on this framework will be done to ensure it is able to be applied in other catchments within Thailand, and also in other countries internationally. Components for considering urban and industrial water use, as well as for other resource intensive primary products such as aquaculture will be considered.

12. References

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