Integrating knowledge for river basin management

Progress in Thailand

Edited by Anthony J. Jakeman, Rebecca A. Letcher, Santhad Rojanasoonthon, susan cuddy and Anthony Scott

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Foreword

Sustainable development requires land, water and vegetation management to be integrated with effects on ecosystems and the local communities and cultures that depend on those resources. Few experiences and technical tools exist to support such integrated management.

In a project supported by ACIAR, researchers have pioneered the development of an integrated water resources assessment and management (IWRAM) framework. A set of linked models, accessed through a computer-based decision-support system, allows users to explore the impacts of policy, planning and regulatory options on aspects such as soil erosion, water availability and the socioeconomic conditions of households and communities.

In Thailand, researchers built on the original project, transferring the framework to more complex catchments and customising and implementing it for different agricultural, water regulation, social and vegetation systems.

The project demonstrated the suitability and versatility of the IWRAM approach which was relatively easy to modify and adapt to suit conditions in Thailand.

Both the Thai and Australian teams benefited from the sharing of ideas. The Thai researchers were able to apply, expand and modify the approach to suit their cultural practices and aspirations, while the Australians gained in knowledge from working with a new set of problems and disciplinary expertise.

The project demonstrated that multi-disciplinary and multi-agency teams can be successfully built to tackle multi-issue problems.

In terms of modelling software, the project has provided resource managers at national, provincial and local levels with a robust, uncomplicated approach for investigating management scenarios and policy options for sustainable land and water use.

This technology is being used in the field to analyse hydrological, erosion, crop and economic data. The model is being applied and tested in different catchments, and integrated into the routine practices of the various agencies in Thailand that make up the user group.

The aim of this book is to share the project team's experiences in developing tools for assessing how to manage resources from a catchment or watershed-wide perspective. The achievements in this approach to integration and the lessons learnt should be of interest to all those involved or interested in natural resource management—researchers, students, managers, technical advisers and the wider community.

ACIAR is pleased to publish this important book which can also be freely downloaded from our website at <www.aciar.gov.au>.

Peter Core
Director

Australian Centre for International Agricultural Research

Contents

Preface

This book has arisen as a legacy of a series of projects that ran from 1997–2004 to support development of a framework for, and institutional strengthening in, integrated water resource management in Thailand. This activity was a close collaboration between Australia and Thailand, financially supported by the Agricultural Systems Economics and Management research program of the Australian Centre for International Agricultural Research (ACIAR), the Thailand Government through its various agencies and the Royal Project Foundation of Thailand, and the Australian National University. The project aims were to support sustainable use of Thailand's rural catchments, specifically in relation to their land and water management, while maintaining a robust local economy.

The project was undertaken in two phases: the first saw the development of an integrated approach to water resources assessment and management (IWRAM) within a Thai context, the second the re-implementation of the approach to suit local expertise and support extension of the methods to river basins in northern Thailand. Key outputs have been the development of the IWRAM decision support system (DSS), an IWRAM website at <http://www.iwram.org> and a series of publications in both Thai and English-language versions.

The writing of this book has provided the opportunity to reflect on this work and synthesise it into a form that can serve as a key reference in water resources assessment and management for a broad audience of practitioners, managers, scientists and students.

In offering this work to the broader community, we wish to thank team members and participating agencies for their vision, dedication and expertise in tackling an issue that can be perplexingly complex, and have a far-reaching impact on all aspects of our society. All the team members devoted considerable time and energy to the various projects. The relationships have developed into a true partnership where each group and country's participants value and learn from the other. The partnership has not only advanced the 'discipline' of integrated assessment for water resources management, but also has turned into an enduring one in which we will work together for some time to come.

Acknowledgments

Many people and organisations have contributed to this project.

The project team thanks in particular the Thailand Royal Project Foundation and ACIAR for their contributions in developing and supporting this collaborative engagement between Thai and Australian researchers, and for the key role they have played and continue to play in the pursuit of sustainable development of natural resources within Thailand.

Other contributing organisations include:

- Land Development Department of Thailand
- Thailand Office of Highland Development
- National Park, Wildlife and Plant Conservation Department
- Royal Irrigation Department of Thailand
- Agriculture Department
- Water Resources Department
- Asian Institute of Technology
- Chiang Mai University
- Maejo University
- Kasetsart University
- Australian National University.

The following people have made significant contributions to the IWRAM project: Chaiyasit Anechsamph, Nick Ardlie, Robert Argent, Artorn Boonsaner, Chris Buller, Thirayuth Chitchumnong, Barry Croke, Susan Cuddy, Boonma Deesaeng, Claude Dietrich, Fayen d'Evie, Benchaphun Ekasingh, Tony Jakeman, Penporn Janekarnkij, Voratas Kachitvichynukul, Nootsuporn Krisdatarn, Padma Lal, Rebecca Letcher, Sureewan Mekkamol, Wendy Merritt, Kamol Ngamsomsuke, Suwit Ongsomwang, Sura Pattanakiat, Pascal Perez, Jitti Pinthong, Suwanna Praneetvatakul, Somjate Pratummintra, Varaporn Punyawadee, Prapaddh Riddhagni, Santhad Rojanasoonthon, Helen Ross, Somporn Sangawongse, Parisa Saguantham, Kamron Saifuk, Sergei Schreider, Michelle Scoccimarro, Anthony Scott, Sompop Sucharit, Bandith Tansiri, Karn Trisophon, Andrew Walker, Pongsak Witthawatchutikul.

Prepared by IWRAM team, Royal Project Foundation

Sourcing of material

As mentioned earlier, this book is a synthesis of a team effort. While much of that effort has been documented in the literature (journals and conference proceedings), it is hoped that bringing it together in this book will make it accessible to a broader audience. This book then draws on a great deal of earlier project material, in particular documents written by team members Santhad Rojanasoonthon, Kamron Saifuk, Pongsak Witthawatchutikul, Benchaphun Ekasingh, Kamol Ngamsomsuke, Anthony Jakeman, Rebecca Letcher, Barry Croke, Wendy Merritt, Susan Cuddy, Anthony Scott and Pascal Perez. Special mention should be made of material derived from the PhD thesis of Wendy Merritt, and chapters by Jakeman and Letcher from a forthcoming book about integrated assessment.

The future

Since the formal completion of the project, the Thai and Australian teams have continued to work together. For example, in January 2005 they jointly organised the SIMMOD Conference in Bangkok (see <www.mssanz.org.au/simmod05>). This was a simulation and modelling conference with the theme of integrating science and technology in support of resource management for sustainable development. It attracted some 200 participants from the region and produced a valuable set of conference proceedings. Both teams are now taking their experiences and applying them to projects in their own countries. And they are exploring ways to work together again in new partnerships in integrated assessment in the greater Mekong subregion.

Santhad Rojanasoonthon, Anthony Jakeman, Susan Cuddy and Parisa Saguantham

Members of the IWRAM team
September 2005

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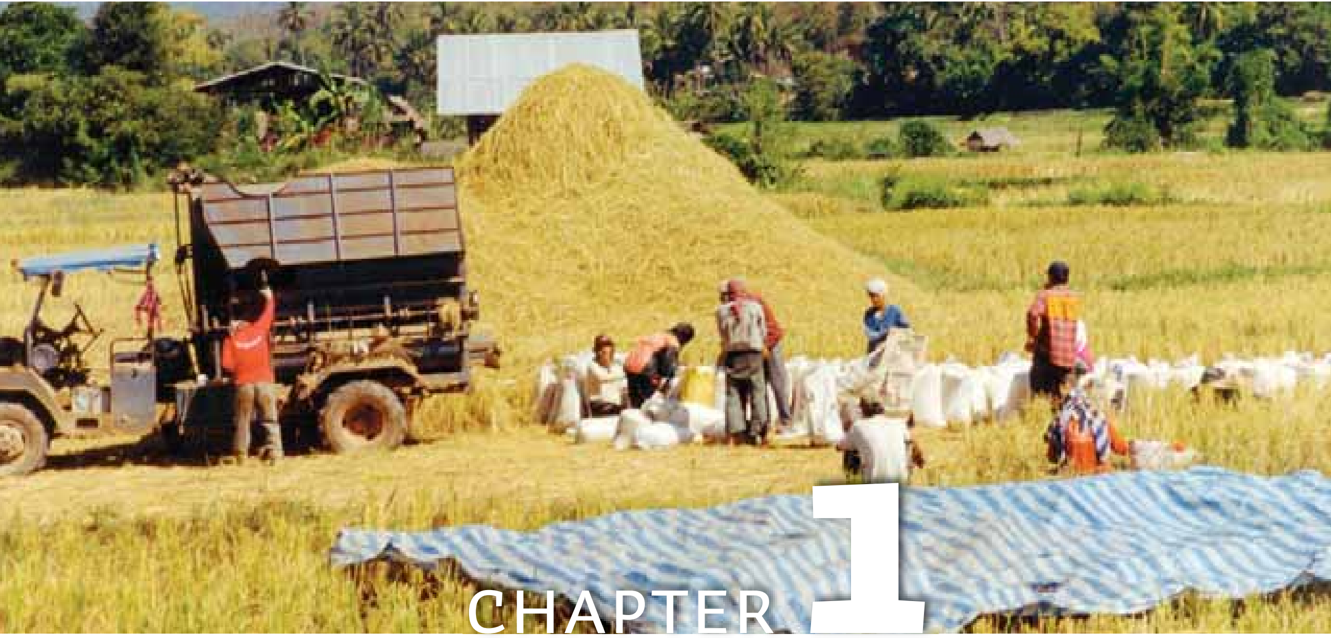

Integrated water resources assessment and management

Anthony Jakeman, Rebecca Letcher, Kamron Saifuk and Suwit Ongsomwang

Summary

Throughout the world, the pressures of agricultural intensification are leading to over-exploitation and non-sustainable use of available land, water and forest resources. In Thailand and other parts of the developing world, these problems are often more striking because of rapidly increasing demographic changes and the urgent need to improve food security and reduce poverty.

In northern Thailand, the pressure on the agricultural sector to increase both productivity and export earnings is very evident. Forested highland areas are being cleared for agricultural production, which is leading to soil erosion and fertility problems on the middle and upper slopes. Water use is also increasing and this is causing conflicts, for example between the highlanders and lowlanders. Declining water quality is being caused by increased

soil erosion and sedimentation, which are attributed in part to decreases in forest cover in the upland areas. Shifts are also occurring in the distribution of economic and social wellbeing between communities.

Integrated water resources management (IWRM) has been embraced internationally as a way forward to address the management of water, land and related resources in order to balance socioeconomic needs with the sustainability of vital ecosystems. As yet there are few case studies reporting on IWRM approaches in practice and, in particular, the assessment needed for such management. The aim of this book is to document and demonstrate our experiences in developing tools for assessing how to manage resources from a catchment or watershed-wide perspective. The achievements in our approach to integration, and the lessons learnt, should be of interest to all those involved or interested in natural resource management — researchers, students, managers, technical advisors and the wider community.

Known as the Integrated Water Resource Assessment and Management (IWRAM) project, the work began in the late 1990s. The objectives broadly were to develop a framework and tools for assessing options to manage land and water resource issues in northern Thailand. The project was a partnership between the Australian National University and the Thai Royal Project Foundation, Thai Government agencies and universities. The partnership developed an integration framework whose main components were a set of biophysical models to assess hydrology, erosion and crop growth and integrate these with a socioeconomic model. These models were embedded within a decision support system (DSS) that allowed users to test different land use, climate and policy scenarios. These scenarios were run through the models, and the DSS provided a range of biophysical and socioeconomic indicators as outputs. The DSS was designed to assist stakeholders to identify and assess both socioeconomic and environmental impacts of the scenarios. This chapter introduces the concept of integrated water resources management and gives an overview of the IWRAM project.

Introduction

In developing countries throughout Asia, rapid population growth makes it difficult for agricultural production to keep pace with the rising demand for food. These countries are already cultivating most of the arable land and are now being forced to use marginal land. The problem is being exacerbated by the increasing degradation of land and water resources, which is being caused by deforestation, poor farming practices, extraction of surface- and groundwater for irrigation and urban supplies, and uncontrolled dumping of wastes and contaminants. The natural resources on which life depends — fresh water, cropland, fisheries and forests — are increasingly being depleted or strained.

Environmental degradation in Asia is accelerating, putting at risk people's health and livelihood and hampering the economic growth needed to reduce the level of poverty in the region. This is the scenario depicted by the Asian Environment Outlook 2001 released by the Asian Development Bank (ADB 2001).

Yet, economic productivity and environmental improvement are not mutually exclusive, and can go hand in hand, with significant improvements achievable at low cost. In order to achieve these gains, environmental and development policies must be integrated at national and regional levels.

The management of land and water resources increasingly faces the challenge of moving towards more-sustainable utilisation. Economic opportunities provided by development activities, such as clearing forests for agriculture and damming rivers for irrigation or hydro-electric generation, need to be balanced by conservation measures that reduce both on-site impacts (such as land degradation and biodiversity decline) and off-site impacts (such as the deterioration of downstream water quality).

This creates a challenging public-policy dilemma of balancing the conservation of land and water resources with the continued use of these resources by local communities.

Given the complexity of natural resource issues, there is an urgent need for integrated solutions based on an understanding of the whole system rather than addressing individual issues in isolation.

Integrated water resources management (IWRM)

During the past 15 years, the concept of sustainable development has become a major international policy initiative. There has also been an increasing realisation that water resource and land use planning can no longer be undertaken in isolation. This has resulted in a move towards integrated management at a catchment or watershed scale.

At the broadest level, the adjective 'integrated' in IWRM relates to the need to consider this so-called triple bottom line or three pillars of sustainability, as expressed in the following definition of IWRM, from GWP–TAC (2000), that has been adopted throughout the book:

> Integrated Water Resources Management (IWRM) is a process which promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

Integration can also be viewed as having several more-specific dimensions, as discussed below.

- **Integration of issues.** A typical but by no means exhaustive list from Jakeman et al. (2005) is:
    - the continuing need for new opportunities and new practices in agriculture and other industries, to feed the world
    - land and river degradation, including salinisation and erosion
    - surface- and groundwater allocation, including allocation for environmental needs
    - water quality protection
    - pest management
    - maintenance of terrestrial and aquatic biodiversity
    - indigenous and recreational value, and value for other non-extractive uses
    - equitable management and distribution of resources
    - changing patterns of settlement and an ageing population

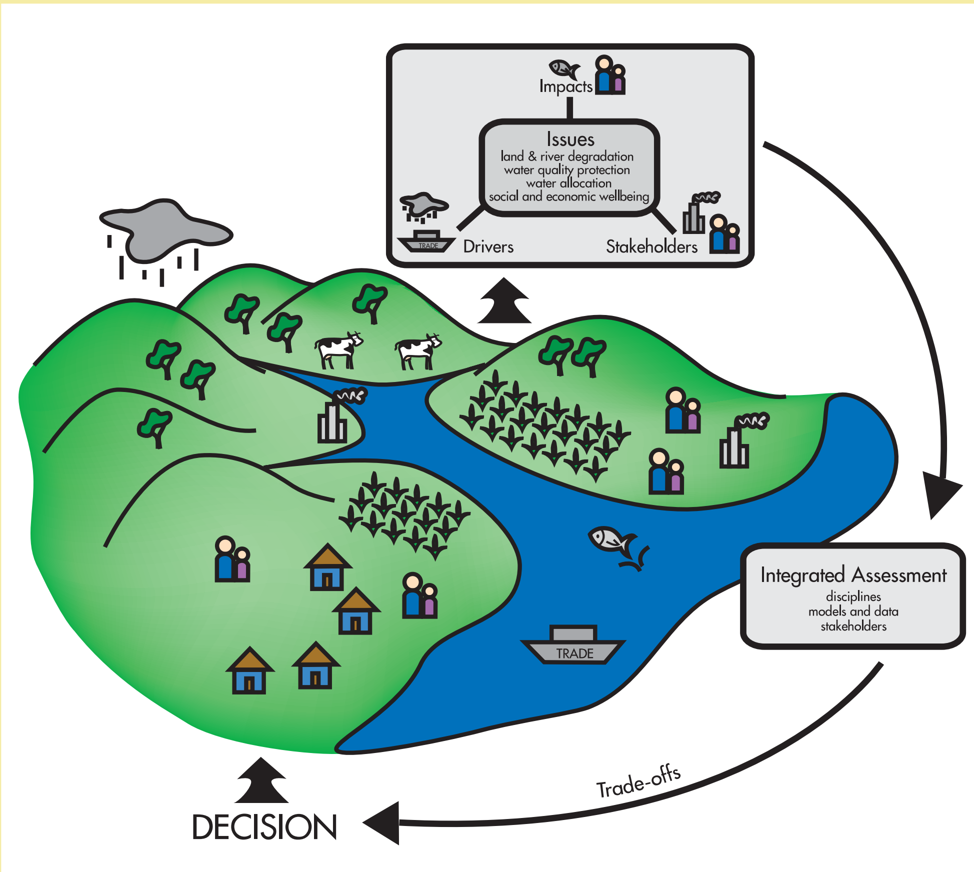

Figure 1.1 The different types of integration in water resource management

- educating the public about the environment
- the potential impacts of climate change and climate variability.

IWRM avoids treating issues in isolation and aims for joint treatment of the major issues, for the simple reason that these may be in conflict and that trade-offs between their solutions might need to be sought.

- **Integration of the parts of a river basin.** This naturally follows if issues are being integrated. At the most aggregated spatial level this means relating the effects of different land uses to impacts on the waterways (streams, estuaries and groundwater systems). It also means selecting indicators of sustainability that can be used to compare trade-offs under different scenarios or management options. Trade-offs may be needed not only between and within various socioeconomic and environmental indicators, but also between different parts of a river basin and over different time frames.
- **Integration of major drivers.** Outcomes are determined by a range of drivers and system interactions. Drivers can be uncontrollable: like climate episodes, longer-term variability and change, or commodity prices and international policies. Controllable drivers are the ones that can be used to influence outcomes. These include instruments such as taxes, subsidies, trading schemes, regulations, public and private investments and education. Both categories of drivers need to be considered for integration.
- **Integration of different scientific, engineering and other disciplines.** To deal with the triple bottom line of IWRM, knowledge from a wide range of fields, such as economics, hydrology, earth sciences, sociology, psychology and ecology, needs to be targeted and integrated.
- **Integration of people involved or interested in a management problem.** This is usually referred to as public participation, which means that all relevant stakeholders, such as government at various levels, industry groups, environmental sectors and the wider community, are involved in assessment and decision-making processes.
- **Integration of models, methods, data and other information.** A wide range of assessment methods and software is available that can be used for IWRM. They must be carefully integrated to develop an overall framework that provides a valid assessment of the key issues.

Integrated assessment, discussed in Chapter 3, is a 'whole of system' approach that provides a framework for linking the complex, interacting processes that occur within a catchment. It recognises both the individual components and the linkages between them, and that a disturbance at one point in the system might be translated to other parts of the system. It also recognises that there can be multiple stakeholders with different (and often conflicting) aims. In particular, trade-offs between economic, social and environmental outcomes must be considered to improve the sustainability of catchment systems.

These types of complex interactions lend themselves to consideration by modelling approaches. In particular, integrated models are required to describe the links between economic, social and environmental system outcomes under various management and climatic regimes. The development and application of these models can enhance communication and interaction between different disciplinary teams and stakeholders. They can also provide a clearer perspective on the integrated nature of the problem.

Modelling can also provide a focus for capacity-building through training and the development of training materials. This focus can have the benefit of exposing catchment managers, local stakeholders and researchers from more narrowly focused perspectives to other ways of thinking about change in the system. In this way it can enhance the integrated system understanding.

A growing body of work now exists which applies integrated modelling to water management problems—see, for example, Greiner (1999), McKinney et al. (1999), Rosegrant et al. (2000) and Jakeman and Letcher (2003). Most of these integrated modelling approaches are still at early stages of development and are being refined for various geographic areas and management issues. The IWRAM project in northern Thailand, which commenced in 1997, is one such project. At the time of its commencement, there were relatively few applications that attempted to integrate so broad a range of disciplines (including environmental, social and economic), particularly for a case study in Southeast Asia. This meant that much of the understanding of the project team and methods for integration applied had to be developed within the project.

International approaches to water resources management

Internationally, there are many similarities in water resource management approaches and objectives. The following section provides a brief overview of the approaches taken in Europe, the USA, Australia, Africa and Southeast Asia.

Europe

European water resources management is being driven by the Water Framework Directive (WFD) (EC 2000). In summary, the WFD requires that all partners in a given river basin manage their waters in close cooperation, irrespective of administrative borders, and according to clear environmental objectives. Based on a catchment approach, it aims at:

(a) the provision of a sufficient supply of good-quality surface- and groundwater to ensure sustainable and equitable water use

(b) a significant reduction in pollution of groundwater

(c) the protection of territorial and marine waters

(d) achieving the objectives of international agreements, including those that aim to prevent and eliminate pollution of the marine environment.

Several key mechanisms are applied to make these aims operational. A crucial role is played by the ‘river basin management plan’, which is to be produced and updated every six years for each river basin (or catchment). Management objectives are coordinated through a set of targets for so-called ‘good status’ of both surface and groundwater. These consider both ecological protection, through targets for biological quality, and chemical protection, through a set of targets for minimum chemical quality. Good status targets should be achieved by 2015. Other objectives are defined for specific areas, such as bathing or drinking water, where more stringent conditions are required. For groundwater management, the basic assumption is that it should not be polluted at all. Management of groundwater includes a prohibition on any discharges to groundwater, and requirements to monitor all groundwater bodies to detect changes in chemical composition and to reverse any existing trends caused by anthropogenic pollution. Groundwater quantity is also protected.

Another key component of the WFD is the promotion of public participation in river basin management.

USA

In the United States, federal government policy has been developed to support locally based water-management groups and a watershed-management approach (US EPA 2001). In October 2000, the federal government issued the 'Unified federal policy for ensuring a watershed approach to federal land and resource management' (Federal Agencies 2000). This policy supports the watershed (or catchment) as the basis of management, and specifies that the federal agencies involved will work with 'States, Tribes, local governments and interested stakeholders' to identify and improve the condition of priority watersheds. The use of watershed-management plans and water-quality targets is also supported.

Regional watershed coordination teams have been developed in 12 large river basins, to improve inter-agency coordination and help leverage resources. Watershed teams work with local stakeholder and watershed groups to assist with coordination, monitoring and restoration. US EPA (2001) discusses the status of watershed management in the US and gives many examples of locally based watershed-management initiatives. It also identifies many of the problems or shortcomings with the practice of watershed management in the USA, including difficulties with partnerships and coordination, monitoring and research, funding, and technical assistance and evaluation.

Australia

In Australia, the Council of Australian Governments (COAG), consisting of the prime minister, State premiers, chief ministers and the president of the Australian Local Government Association, endorsed in 1994 an agreement on sustainable reform of the water industry. This agreement was aimed at achieving improved economic efficiency and environmental sustainability of the water industry. COAG supported the need for coordinated action to stop the widespread degradation of natural resources (COAG 1994), and identified a number of problems with the existing system including:

(a) cross-subsidies in the service provision to various groups

(b) impediments to the transfer of irrigation water from low- to high-value uses

(c) service delivery inefficiencies

(d) problems in clearly defining roles and responsibilities of many institutions in the water industry

(e) the need for massive asset refurbishment in rural areas.

The COAG agreement addressed many of these problems. For rural water provision, these included changes to pricing and water allocation. It was agreed that pricing regimes should be 'based on the principles of consumption-based pricing, full cost recovery and desirably the removal of cross subsidies which are not consistent with efficient service, use and provision'. Further, 'where cross-subsidies continue to exist, they be made transparent' (COAG 1994).

An important part of the COAG process involved the government consulting with the community on aspects of the framework (Russell 1996). For this reason, and because of the broad nature of the changes required, the initial implementation period for these reforms was set at five to seven years. It was agreed that a full framework should be implemented by 2001. Since that time, each of the States involved has moved to implement these reforms, with integrated catchment management and recognition of the need for improved stakeholder involvement in the policy development underlying much of this reform. Additionally, water quality and river flow objectives have been set for many catchments and detailed catchment-management plans drawn up.

Africa

Significant moves towards IWRM have been made in Africa, with policies very similar to those under the EU WFD being implemented. Van Koppen (2003) discusses water reform in sub-Saharan Africa, and the role that African governments have played in the move towards IWRM. Differences between these countries, and others elsewhere, in terms of initiating IWRM, are identified. In particular, the relative abundance of water resources, but scarcity of economic resources to harness the water, are identified as a key difference in the African context.

The Southern African Development Community (SADC), which consists of the governments of Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe, released a protocol on shared watercourses (SADC 1995, 2000). The objective of the protocol is to 'foster closer cooperation for judicious, sustainable and coordinated management, protection and utilisation of shared watercourses and advance the SADC agenda of regional integration and poverty alleviation' (SADC 2000). To achieve this objective, the protocol seeks to foster the introduction of sustainable and equitable utilisation of the shared watercourses by facilitating:

(a) the establishment of agreements and institutions for the management of shared watercourses

(b) the harmonisation and monitoring of legislation and policies for planning, development, conservation, and allocation of the resources

(c) research and technology development, information exchange, capacity building, and the application of appropriate technologies (SADC 2000).

Van der Zaag and Savenije (1999) present a comparison of management in the SADC and the EU, finding that there has been a significant convergence between the two organisations concerning the central role of the 'river basin' in management.

Another example of African IWRM is in the Nile River Basin, which is shared by 10 countries—Burundi, Democratic Republic of

Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda. IWRM is being implemented through the Nile River Strategic Action Program and the Nile Basin Initiative, which commenced in May 1999 (NBI 2003). The program stresses the requirement to work at local and national levels and focuses strongly on the need for stakeholder involvement.

Southeast Asia

Integrated water resources management is attracting interest in Southeast Asia, as pressures on water resources become more evident from local to international scales. These pressures are interrelated with forms of economic and social development, from changes in agricultural practices to industrial and urban development. Population increase, which demands higher agricultural productivity and fuels urban growth, plays an important role in these changes.

An example of IWRM in Southeast Asia is the management of the Mekong River Basin, which involves coordination of activities and decisions across Thailand, Vietnam, Laos and Cambodia—see, for example, Jacobs (1995). This coordination is undertaken through the Mekong River Commission. In 1995 an agreement was made between countries in the commission that shifted the management focus from development of large-scale projects to sustainable development and management of natural resources (MRC 1995). A basin development plan is being drafted (MRC 2003). This plan strongly supports community participation in natural resource management in the basin. The overall approach of the plan is to achieve basin-wide benefits while taking account of national interests and balancing development opportunities with resource conservation (MRC 2003).

The plan is expected to involve themes of environment, human-resource development, socioeconomics, poverty reduction, gender equity and public participation (MRC 2003). Other programs, including an environment program, a capacity-building program and an agricultural, irrigation and forestry program are also being undertaken to implement the 1995 agreement.

Catchment issues in Thailand

Like many other countries in Asia, over-exploitation of land and water resources has accompanied Thailand's increasing population and rapid economic growth over the past few decades. Agricultural development has focused in many instances on short-term economic gains and neglected the longer-term social and environmental costs (TDRI 1995; Tungittiplakorn 1995).

Traditionally, the agricultural focus was the production of rice for subsistence purposes. However, over the past few decades, the system of agricultural production has undergone a dramatic transformation. Population growth has resulted in the expansion of paddy land, to the point where it now occupies almost all flat or near-flat land in Thailand. Forests have been cleared from the hillsides for cash crops, while rivers are being dammed for irrigation water and hydro-electricity generation. Although these activities have provided valuable economic opportunities and contributed to the reduction in rural poverty, they are becoming increasingly unsustainable because of their on- and off-site impacts. There are also increasing and highly publicised conflicts over the use and ownership of natural resources such as water and timber.

One of the main sources of conflict relates to the off-site impacts of deforestation in the highlands. Between 1961 and 1986, forest cover in Thailand declined from 53% of the total land area to 29%, corresponding to the clearing of about 45% of Thailand's forest resources (Phantumvanit and Sathirathai 1988). Lowland farmers claim that the clearing of vegetation on upland slopes has disrupted the hydrological cycle by reducing dry-season flows and leading to much higher risks of flash floods during the wet season (Walker 2003). An important task for resource managers is to demonstrate the validity of these claims and the extent to which changes in land use in the highlands contribute to downstream impacts.

Another management concern is the conversion of farmlands to non-agricultural uses, especially in the lowlands. Rapid urban and industrial growth has resulted in increasing demand for farmlands. Good agricultural land is being converted to housing projects, golf courses, resorts, hotels and industrial areas. These developments trigger increases in land prices and contribute to the scarcity of arable land, which in turn trigger increased conversion of forests to new farmland in the highlands and more-intense use of the existing farmland. Reducing fallow periods and cultivation of marginal land may exacerbate on-site soil erosion. In turn, increased soil erosion may contribute to increased turbidity and sedimentation downstream.

The environmental issues in Thailand's highlands are interrelated with social and cultural issues and attitudes. In addition to the ethnic Thai villages, around 700,000 hill people with nine distinct cultures inhabit the highlands. Impoverished local farmers, many of them members of these hill-dwelling ethnic minorities, are widely blamed for the destruction of forests and soil erosion, though in reality the causes of the current environmental problems are far more complex. Other causes, such as the effects of earlier commercial logging, as well as other development activities such as the construction of dams and increased water use for irrigation, receive less attention.

One of the challenges of northern development is to improve the economic welfare of the highland communities while maintaining their cultural traditions and minimising environmental impacts. While various highland development projects have raised the standard of hill-village infrastructure, the hill peoples still have less access to education and health services, and tend to earn lower incomes than other sectors of the Thai population. Through its National Policy on Hill Tribes, the Thai Government has an official commitment to integrate the hill peoples into the Thai state, to raise their economic welfare and to assist them to maintain their unique cultural heritage.

In Thailand, conventional approaches to natural resource utilisation have tended to be top-down. Decisions about implementing large-scale developments have been based on economic appraisal of individual projects. The belief that all values are commensurable, and that economic (cost–benefit) analysis alone can help resolve conflicts in use, has led to its predominant use in the past. These appraisals have tended to focus on short-term economic gains and neglected the longer-term social and environmental costs (Godfrey-Smith 1979; Enters 1992, 1995). Such fragmented decision-making processes of the past have allowed the over-exploitation of land and water resources resulting in major impacts downstream.

More recently, Thailand has been moving towards formal catchment-based environmental management, with forests now managed according to a watershed classification system, and the Department of Land Development also conducting land use planning by watershed units (Krairapanond and Atkinson 1998). Specific catchment-management projects, supported by research, have been conducted in catchments including the Mae Chaem (Roth et al. 1989) and Mae Taeng (TDRI–HIID 1995). Highland development projects such as the Sam Mun Highland Development project (SMHDP 1994) have included catchment-based participatory land use planning.

A key challenge facing the Thai Government is to continue the development of integrated plans for the sustainable use of natural resources. These plans must consider the local people, the region or catchment and the nation as a whole, while maintaining a balance between environmental impacts and economic prosperity.

The IWRAM project in Thailand

In 1997 a collaborative project known as the 'Integrated water resources assessment and management' framework began between Australian researchers and the Thai Government. The overall aim of the project was to develop an integrated approach to water resources assessment, in order to assist the Thai Government identify and assess options for use of land and water resources that would promote the inhabitants' socioeconomic and cultural welfare, while minimising impacts such as soil loss, flooding, drought and downstream water pollution. The project examined the implications of different levels and patterns of cultivation and water use in northern Thailand, using the Mae Chaem catchment of the Ping River basin as a case study, with a view to later extension to other catchments.

The Thai collaborators were organised under the auspices of the Royal Project Foundation, with much of the development activity contributed by the Department of Land Development and its Office of Highland Development. Other government agencies, such as the Royal Forestry Department, the Ministry of Agriculture, the Royal Irrigation Department and the Office of the National Water Resource Committee, contributed to the project in various ways. University collaborators included Chiang Mai, Kasetsart and Maejo universities. The Australian team members were all from the Australian National University (ANU), with the project managed by the Integrated Catchment Assessment and Management (ICAM) Centre. Australian funding came from the Australian Centre for International Agricultural Research (ACIAR).

The Thai partners' interest was initially in developing sophisticated land and water resources environmental modelling capacity, based on research work at ANU. In the process of developing the initial proposal, they became interested in the broader integration offered by including social and economic research. The project's environmental and socioeconomic assessment capabilities have since become focused on the development of a decision support system (DSS) which is designed to address the issues which commonly arise in the decision-making process.

In a report on the 'National implementation of the Rio commitments' (UN 2000) there was recognition that Thailand had a large number of agencies involved in water resources, and that this could lead to conflicts in planning and management activities. The IWRAM DSS has been developed to assist these agencies to make more-informed and coordinated decisions about water resource management. Development of the DSS has been undertaken in phases, so that there are several software systems that have been developed and implemented under the banner of the IWRAM DSS. Each new phase of development has been undertaken to deal with issues of adoption and extension identified in previous phases. Importantly, the integration framework and concepts underlying these different systems are the same.

The IWRAM DSS is a computer-based tool that comprises a database, a set of biophysical and socioeconomic models and a user interface. The biophysical models include crop, hydrologic and erosion models. These are linked to two socioeconomic models to explore economic trade-offs and impacts for the various scenarios being tested.

Scenarios may be developed around agricultural or conservation policies, demographic change, potential climate variability, or changes on 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. Rather, it supports good decision-making by helping users to explore key relationships relevant to the various environmental and socioeconomic trade-offs in catchment management. Similarly, the DSS does not provide an 'optimal' outcome, as this is dependent on the perspective and objectives of the DSS user. By offering a transparent and repeatable process, it helps users to explore some of the expected and unexpected impacts of various scenarios.

A particular aim of the project was that the framework for evaluating water resources management could be easily applied to catchments other than the Mae Chaem catchment. Consequently, emphasis was placed on using a modelling framework that allows the addition of new models or tools and removal or replacement of obsolete tools.

As an outcome of the IWRAM project was the development of a DSS, some limitations were placed on the modelling approaches. Firstly, the chosen approaches could not be too complicated or data intensive. Otherwise, this may have led to problems of model identifiability where parameters possess a large range of uncertainty. Even technical stakeholders within government departments may not have the expertise or time required to use a complicated DSS. In addition, the availability of data as well as other resources did not warrant the development of highly complicated modules. Secondly, the choice of appropriate models for the crop, erosion and hydrologic modules was constrained by the availability of field and catchment data for calibration and validation of model behaviour. Additionally, the biophysical components of the DSS had to be integrated with social and economic modelling components (Letcher et al. 2002). The strength of the assumptions made in the socioeconomic modelling did not warrant a detailed biophysical modelling approach. Overall, the aim was to establish, for given scenarios, the directions and magnitudes of changes in indicators.

Although considerable effort has been made to keep the biophysical models relatively simple in terms of model structure and the number of model parameters, the DSS is still quite complex, particularly in terms of the interactions between the models.

The aim with integrated models of this type should not be to provide absolutely accurate estimates. This task proves too difficult given the inherent complexity of natural systems and the scant data usually available.

The IWRAM DSS was developed through strong collaboration with government agencies and universities in Thailand and, as such, represents the state of the art in Thai river management and modelling. The application demonstrates a conceptually strong and potentially transferable approach to integrated modelling of catchment-management questions.

Perhaps the most successful aspect of this project was the partnership that emerged and strengthened over time. It had the cooperation and full engagement of all relevant government departments (including Land Development, Royal Irrigation, Royal Forestry, Agriculture and the Office of the National Water Resources Committee). The DSS became the focal point for joint workshops, planning sessions and training courses, all of which encouraged a better understanding and an integrated approach to catchment management. The DSS has provided a common framework for planning and assessment.

This monograph gives a detailed account of the IWRAM project and the development of the DSS. It also describes the general framework and underlying principles of integrated water resources assessment, with a particular emphasis on Southeast Asia, with the intention that similar projects might be initiated in other parts of the region.

Chapter 2 gives the context for this project by describing the various policies governing natural resources management in Thailand. It also presents details of the case study site, the Mae Chaem catchment in northern Thailand. Chapter 3 reviews the principles and approaches to integrated assessment of water resources.

The next few chapters present the technical details of the biophysical and socioeconomic models, as well as a description of the integrated DSS. The results of the case study are then presented in Chapter 10. Finally, the conclusions and lessons drawn from the project are presented in Chapter 11.

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CHAPTER 2

Natural resource management policies in Thailand and their use in the Mae Chaem catchment

Benchaphun Ekasingh, Wendy Merritt and Anthony Scott

Summary

This chapter presents an overview of the natural resource policies for land and water management in Thailand. If the objectives of the Integrated Water Resource Assessment and Management (IWRAM) project were to be achieved, it was essential to gain a clear understanding of these policies, and how they influence catchment management decisions in northern Thailand.

The second part of the chapter presents a description of the Mae Chaem catchment in northern Thailand, which was used as a case study for the IWRAM project.

Introduction

Thailand's past three decades of rapid economic development stimulated a massive expansion in the demand for water: for power, irrigation, and domestic and industrial supplies. This growing demand is expected to continue, with a predicted increase of more than 100% between 2000 and 2010 (Lorsirirat 2004). In the past, the government devoted significant resources to the development of these new water supplies. But a different and more complex set of challenges is now being faced. These include the following:

- Is the resource base, including both water and the catchment, being managed in a sustainable manner?
- Are there opportunities for more-effective management of existing sources of water supply?
- How is water allocation and utilisation determined, to ensure equitable distribution and efficient use of water?
- Who will provide and deliver services, and who will pay for them?
- How will the availability of water for agricultural, urban and environmental uses change under future land-management policies?

Other water-management problems, arising from agricultural intensification, are the related issues of on-site erosion and declining water quality. Traditionally, shifting cultivation did not significantly elevate soil erosion compared with undisturbed land (e.g. Lal 1975). However, under increasing hill-tribe populations, this system of cultivation has become more intensive, with the cultivation period increasing and the regeneration period decreasing (Liengsakul et al. 1993).

In the steep highland regions of northern Thailand, which are inherently prone to erosion, agricultural intensification has led to elevated rates of erosion (Turkelboom et al. 1997). In an effort to minimise the impact of agricultural (and other human) activities, various Thai Government agencies and departments have developed policies for the improved management of land and water resources.

If the objectives of the Integrated Water Resource Assessment and Management (IWRAM) project were to be achieved, it was essential to gain a clear understanding of these policies, and how they influence catchment-management decisions in northern Thailand. Hence, the first part of this chapter presents a summary of the natural resource policies that shape land and water management in northern Thailand.

The second part of this chapter presents an overview of the Mae Chaem catchment in northern Thailand, which was used as a case study for the IWRAM project.

Background

In Thailand, recent awareness of the threats that human activities pose to the environment has sparked considerable efforts from government to conserve natural resources and promote sustainable development. This culminated in 1997 with the adoption of a new constitution that required every person to conserve natural resources and the environment as provided by law (UN 2000).

The government body responsible for coordinating the management and development of water resources at the national level is the National Water Resource Committee, which was set up in 1996. Its main functions are (UN 2000):

- preparing and submitting for cabinet approval objectives and policies for water resources development at all scales
- providing guidelines, support, and coordination to other agencies in preparing development plans or projects
- approving and overseeing the plans
- prioritising and controlling the allocation of water resources between sectors
- supervising and maintaining water quality
- improving laws and regulations related to the development, control and maintenance of water resources and their quality.

The government agencies that coordinate water resource management and development at a policy level include the Royal Irrigation Department (RID), the Department of Mineral Resources (DMR), the Department of Rural Development (DRD) and the Department of Health. Provincial governors' offices and local administration offices operate at the district level, and administration organisations play a role at the sub-district level. Table 2.1 details the mandates of the relevant bodies with regard to water management.

The state of water resources is closely linked to land use and management, and both land and water resources must be managed concurrently if management is to be successful. For example, under the 8th National Social and Economic Development Plan, the Land Development Department (LDD) undertook, between 1997 and 2000, to promote sustainable agriculture by considering land use planning, land and water conservation systems, erosion control systems, integrated agricultural systems, improved cropping systems, and forest expansion and conservation.

Table 2.1 Functions of government agencies involved in water resources management in Thailand (UN 2000)

Agency	Function
Royal Irrigation Department	Development of water resources and management of irrigation and drainage systems nationwide
Department of Mineral Resources	Management of groundwater resources nationwide
Department of Rural Development	Rural development, including domestic water development
Department of Health	Freshwater quality monitoring nationwide
Office of the Permanent Secretary of the Ministry of Public Health	Hospital waste management
Provincial Governors' Offices	Management of provincial natural resources
Local Administration Offices	Management of resources and environment within their jurisdiction
Sub-district Administration Offices	Management of resources and environment within their jurisdiction

In 1997, the Thai Cabinet adopted a 'Policy and prospective plan for enhancement and conservation of national environmental quality, 1997–2016', prepared by the Office of Environment Policy and Planning. The plan details goals, policies, and implementation guidelines for the effective use of land resources (UN 2000). In the plan, the Thai Government is committed to a number of policies relating to the development, conservation and rehabilitation of water resources. Concerning surface-water resources, these are:

- to develop and conserve surface- and groundwater sources at the basin level, taking into account socioeconomic and environmental impacts
- to improve the efficiency of administration and management of surface-water resources
- to promote optimal use of surface-water resources so as to maximise benefits and minimise environmental impacts.

Similarly, the plan explicitly promotes the sustainable use of groundwater resources.

With respect to fostering the linkages between national forest programs and land-management policy in the highlands, the LDD has an Office of Highland Development which, in cooperation with the Watershed Management Division of the Royal Forest Department, coordinates and facilitates the implementation of policies and programs related to the management of highland areas. Tasks include:

- preparation of land use plans that clearly identify watersheds
- identification of land-development activities suitable for highland areas
- participation in the preparation of management plans for the management of river basins impacting on highlands
- preparation of highland area management plans for each province, district and sub-district.

A number of policy and management options have been investigated in an effort to overcome emerging environmental concerns. The main government agencies in Thailand involved in the implementation of policies for agricultural and other land uses are the RID, the LDD and, more recently, the Ministry of Natural Resources and Environment, which was established in 2002.

The National Economic and Social Development Plans

Over the past five decades, Thailand has produced a set of national economic and social plans to guide the development of the nation, and this included plans for the management of water resources. The 1st national plan covered the period 1961–66. During this period, the emphasis for water resources development was on the construction of irrigation schemes and dams and hydro-electric power generation. This focus continued through the 1960s and 1970s. In the 7th and 8th national plans, between 1992 and 2001, there was a changing focus to a more integrated catchment approach to water management, with consideration of a broader range of issues such as water quality, increasing water-use efficiency, improved coordination of efforts by different government departments, and involvement of the local people in the planning process.

The 9th national plan (2002–2006) builds on the objective of a *balanced development of human, social, economic, and environmental resources*. A priority goal is pursuance of *good governance* at all levels of Thai society in order to achieve real and sustainable people-centred development. In relation to water resources management, priority is given to:

- shifting from investment in additional water-supply schemes to better and more-efficient management of existing water supples, and promoting the sustainable management of all natural resources
- development of comprehensive catchment-wide water-management strategies rather than a project-by-project approach
- better pricing of water to encourage more-efficient use and less wastage
- increased public participation in decisions and formulation of policy.

The national water vision and policy

The National Water Resources Committee (NWRC) was set up to coordinate a national approach to water management. One of the initial tasks of the NWRC was to develop water resource management plans, which would be coordinated by river basin committees (RBCs), for the 25 river basins across Thailand. A sub-committee was established for the Chao Phraya basin as a pilot scheme. The RBCs were to have three major responsibilities: addressing priorities in water resource issues; promoting public education and sustainable water resources management; and facilitating local public consultations with stakeholders and beneficiaries. A master plan was to be developed for each river basin. Each plan will include details about:

- future water development—to alleviate water shortages
- water allocation and utilisation—to ensure equitable distribution and efficient use of water
- water conservation—to maintain and improve the environmental condition of natural watercourses
- flood mitigation—to reduce the loss of life and property in flood-prone areas
- improving water quality by reducing or eliminating sources of pollution
- salinity treatment—to address natural and anthropogenic problems of salinity
- improved wastewater treatment in urban and industrial areas.

In 2000, a national water vision and national water policy were also developed and approved by the government. The vision states:

> By the year 2025, Thailand will have sufficient water of good quality for all users through an efficient management, organizational and legal system that would ensure equitable and sustainable utilization of its water resources with due consideration on the quality of life and the participation of all stakeholders.

The aim of the national water policy was to translate this vision into practical actions. The following are some of the many issues covered by the policy:

- development of new laws and improvement of existing laws related to the management of water resources

- creation of water-management organisations both at national and river-basin levels: the national organisation is responsible for formulating national policies; the river-basin organisations are responsible for preparing water-management plans through a participatory approach
- emphasis on suitable and equitable water allocation for all water-use sectors, and fulfilling basic water requirements for agricultural and domestic use
- provision and development of raw water resources while ensuring suitable quality and conserving natural resources and the environment
- promotion and support for participation, including clear identification of its procedures, and clear guidelines on the rights and responsibility of the public, non-government and government organisations in efficient water management
- acceleration of preparation of plans for flood and drought protection, including warning, damage control and rehabilitation.

Challenges of water resources management in Thailand

In a report on the national implementation of the Rio commitments, the United Nations (2000) recognised that having so many agencies involved in water resources issues, combined with poor coordination between the agencies, is a major hurdle for the Thai Government in its effort to reach its water management objectives. Currently, water resources are administered and managed by eight different ministries, each with different priorities and programs that are sometimes overlapping or in conflict. The National Water Resources Committee lacks the authority or operating mechanism to oversee and coordinate these different groups. Inadequate and sometimes conflicting legislation is also a problem. Conflict management too is becoming an important issue. With an increasing level of consultation with stakeholders and local communities, many conflicts centred around environmental issues and compensation for those affected by development projects are occurring. These conflicts are expected to increase as competition for water intensifies in the future.

Efforts are under way to address these problems and promote efficient water allocation through the development of integrated watershed management (IWM) strategies and revisions of water laws.

Natural resources classification systems

Land use and watershed classification are closely linked activities which play a significant role in the integrated management of natural resources. In Thailand, there are three key classification systems: the Watershed Classification System, a modified FAO framework for land evaluation, and the National Forest Zones classification.

Watershed classification system

In 1982, the Office of the National Environment Board (ONEB) was commissioned to devise a detailed national watershed classification system (Krairapanond and Atkinson 1998). Watershed classes were derived from topographic, soil, geology and forest maps and reflect the sensitivity of the land to erosion and other forms of degradation. Multivariate analyses were carried out to determine statistical relationships between variables and a general equation for the prediction of watershed classes (WSC) was determined as:

$$WSC = a + b.(\text{slope}) + c.(\text{elevation}) + d.(\text{landform}) + e.(\text{geology}) + f.(\text{soil}) + \text{forest}$$

where *a* to *f* are constants, and the landform variable reflects the recent erosion history (Krairapanond and Atkinson 1998).

Between 1985 and 1995, the total land area of the entire country was classified into watershed classes (WSC) 1–5 (Table 2.2). In 1995, the Thai Cabinet approved the use of this watershed classification system by all government agencies involved in land management.

However, it is important to note that the system classifies broad land areas and, before it can be used as a management tool, considerable work is needed to designate detailed land uses within each class. A detailed description of the watershed classification system is provided by Krairapanond and Atkinson (1998).

There have been some criticisms of this classification system (Sathirathai 1995), in particular that the guidelines are too crude to be used for land use planning, as they do not provide sufficiently detailed information for management at a farm level. It has also been suggested that the classification should include socioeconomic and cultural factors.

Table 2.2 Watershed classification system implemented in Thailand

Class	Landform/erosion hazard	Land use prescription
WSC1A	High elevation and very steep slopes. Extremely prone to erosion.	Comprise protected forest and headwater source areas. Should remain as permanent cover.
WSC1B	As above.	Similar physically and environmentally to 1A, although portions have been previously cleared for agriculture or villages. Special conservation and protection measures. Reforestation and/or agroforestry encouraged.
WSC2	Less subject to erosion than WSC1A or WSC1B.	Areas of protection or commercial forests. Logging and mining allowed within legal boundaries. Grazing and certain crop production can occur if soil-conservation measures are in place.
WSC3	Upland areas with steep slopes. Less prone to erosion than WSC2.	May be used, with appropriate soil-conservation measures, for commercial forest, grazing, fruit trees or certain crops.
WSC4	Gently sloping land.	Arable crops, fruit trees and grazing. Moderate need for conservation measures.
WSC5	Gentle slopes to flat areas.	Paddy fields or other intensive agricultural uses. Few restrictions.

Land evaluation and planning

For its land use planning projects, the Land Development Department (Land Use Planning Division) in Thailand adapted the land-evaluation methodology proposed by the Food and Agriculture Organization of the United Nations (FAO 1976, 1983). While the approach still retains the structure of the FAO (1976) framework for land evaluation, it has been modified for use in Thailand to incorporate previous policies relating to forestry, particularly those concerning watershed classes.

FAO framework

The FAO (1976) framework for land evaluation sets out basic concepts, principles and procedures for land evaluation and is primarily designed to provide tools to support rural land use planning. The framework defines principles on which land evaluation should be based (FAO 1976, 1983). Land suitability appraisals should explicitly consider the proposed land use and assess its long-term profitability and sustainability. These appraisals are defined by economic criteria and require a comparison of the outputs of, and the inputs needed for, different types of land use. A multidisciplinary approach is required to adequately represent the physical, economic, social and political context. Key to the evaluation framework is that multiple land use types are compared to identify the optimal use.

The framework sets out the general procedure by which the suitability of a land type for different land uses can be classified (Figure 2.1). Land use types are matched with land units to construct suitability classes. Land units reflect unique combinations of soil, vegetation, hydrology, landform and climate. In order to identify appropriate land uses, land units are assigned land-quality ratings (from very good [1] to very poor [5]). Land-quality ratings include factors such as erosion hazard or climate regime, and are compared with land use requirements to give suitability classes of: highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N). Land use requirements express acceptable limits in terms of the land-quality rating (e.g. an erosion limit of 31.25 t/ha).

The LDD approach: defining land units

The Land Development Department in Thailand has developed a land-unit approach that 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). Liengsakul et al. (1993) applied the FAO framework to a district in the Chiang Mai province of northern Thailand to locate new sites for permanent cropland in the highlands.

The approach adopted by the LDD within the IWRAM project is illustrated in Figure 2.2. Data requirements are provided in Table 2.3. Defining land units is not a purely biophysical procedure. The land use, irrigation, land-improvement and forest-policy maps are constrained by socioeconomic and political contexts in addition to the biophysical characteristics of the land. The incorporation of previous policies for land evaluation appears to be the major modification of the FAO framework. The land units that are derived are used to develop land-suitability classifications according to the FAO framework. The land use requirements for a certain land use include the consideration of crop requirements (e.g. moisture availability), management requirements (e.g. soil workability) and conservation requirements. Key diagnostic factors used to develop land-quality ratings are listed in Table 2.4.

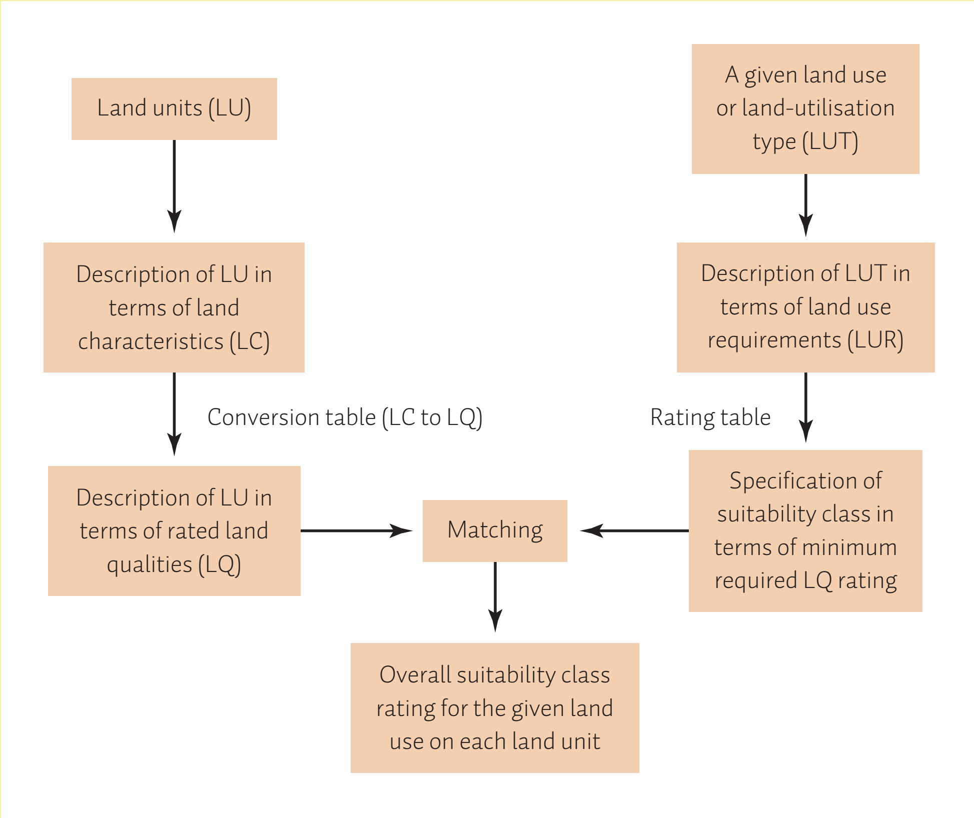

Figure 2.1 Schematic representation of the determination of the suitability of land units for a given use on the basis of land qualities. Source: van Diepen et al. (1991)

National forest zones

The Royal Forestry Department and Land Reform Department classify forests into four zones:

A – those areas suitable for agricultural activities

B – areas designated for economic uses

C – conservation zones

N – not considered.

Natural and disturbed forests are managed differently in conservation areas than in other zones. In conservation zones and watershed classes 1 and 2, natural forest areas are protected, while in disturbed areas, reforestation—as either natural forests or plantations—is a priority. Areas currently forested are nominally protected in the remaining forest zones and watershed classes. If disturbed forest areas are unsuitable for alternative land uses, they are reforested (see Figure 2.3). Otherwise, the land can be used for agriculture, agroforestry or other land uses.

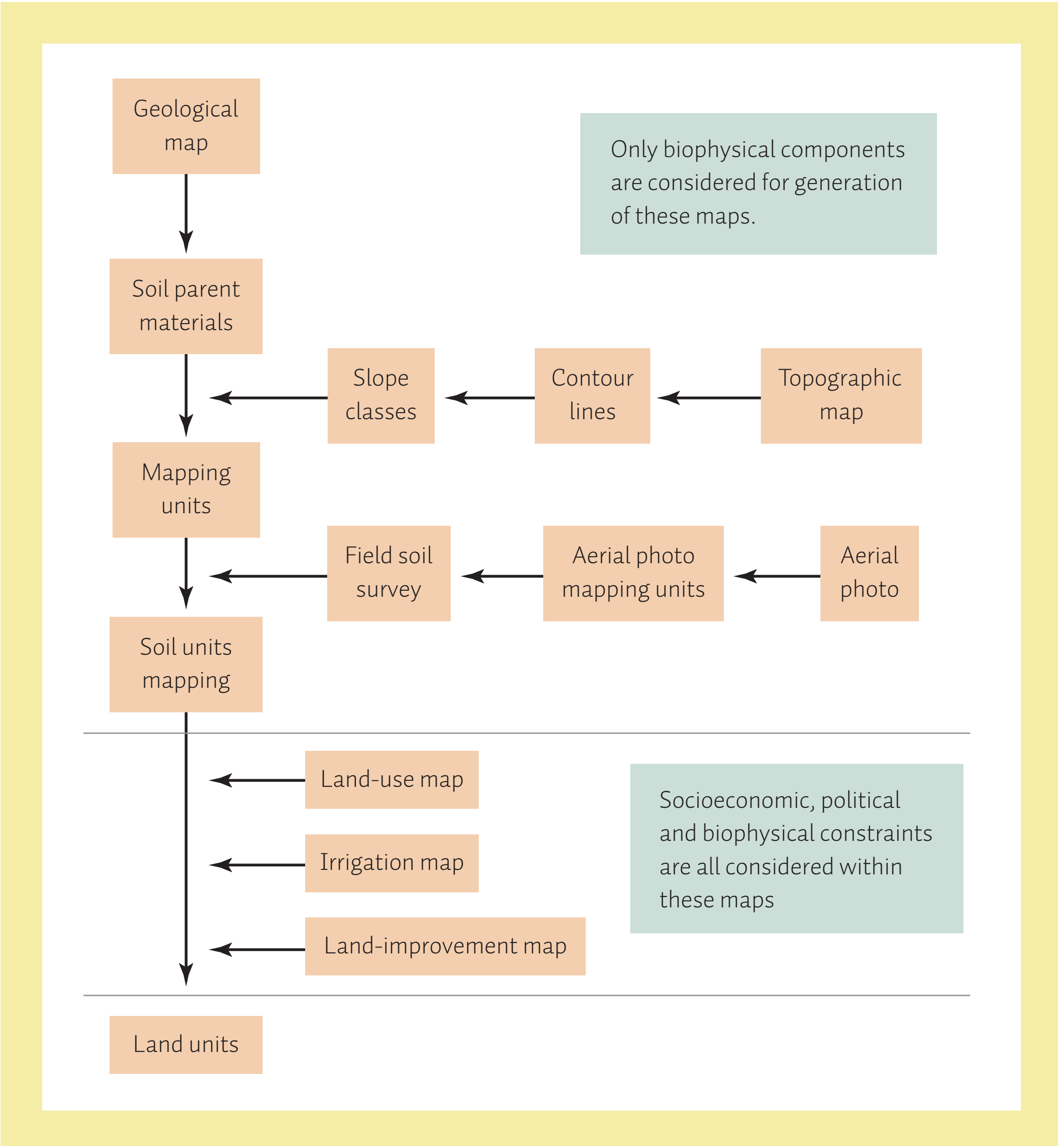

Figure 2.2 Procedure for the generation of 'land units' employed by the Land Development Department (LDD) in Thailand. Source: LDD

Table 2.3 Mapping requirements for land use planning in the highlands of northern Thailand

Material	Description of Mae Chaem data
Topographic map (1:50,000)	
Geological map (1:250,000)	
Soil unit mapping (1:10,000)	Generated from topographic and geological map, with the exception of Wat Chan for which a detailed soil map exists.
Aerial photo (1:15,000)	Used (along with ground surveys) as a 'ground check' of the soil map generated.
Land use map (1:10,000)	Classifies land use according to paddy field, terraced paddy field, annual crop, perennial crop, shifting land, natural forest and plantation forest (LANDSAT imagery 1995–96).
Irrigation map	Indicates areas of rainfed and irrigated agriculture within the site (obtained from Land Development Department Division 6).
Land-improvement map	Land improvements include terracing and hillslope ditches (management improvements in the land-unit methodology include these two in addition to irrigation).

The Royal Project Foundation

The Royal Project Foundation (RPF) of Thailand was officially founded in 1991 by His Majesty the King of Thailand with the objectives of assisting hill tribes to:

- reduce the destruction of natural resources (forests and watersheds)
- stop opium production
- appropriately use the land (by farming only on suitable land)
- produce crops that benefit Thailand's economy (RPF 1995, 2004).

The RPF operates 4 research stations and 34 development centres across the Chiang Mai, Chiang Rai, Lamphun, Mae Hong Son and Phayao provinces. The research stations largely focus on developing crops that are suitable for the cooler, mountainous regions of Thailand and fostering cooperation between universities, government agencies and local hill tribes. The development centres concentrate on communicating to farmers recent results from the research stations, as well as encouraging the use of appropriate soil and conservation practices. Although not officially founded until 1991, the Royal Project has been operating in some form since 1969. Since that time, the organisation has been involved in the establishment of fisheries, land acquisition for needy farmers, development of irrigation structures, reforestation of water catchments, animal husbandry, education and improving medical standards. The RPF works closely with government departments, such as the RID, LDD and the Royal Forestry Department. The RPF played a key role in the IWRAM project, coordinating work and promoting communication between the various groups involved.

Table 2.4 Land use requirements as prescribed by the Land Development Department, Land Use Planning Division Thailand. Source: Tansiri and Saifuk (1999)

	Land quality	Diagnostic factor
A. Crop requirements		
	Radiation regime	Radiation
	Temperature regime	Mean temperature in growing period
	Moisture availability	Requirements in growing period (mm), inundation (month)
	Oxygen availability	Soil drainage (class)
	Nutrient availability	Nutrient availability (N, P, K, organic matter), nutrient status (class), reaction
	Nutrient retention	Cation-exchange capacity, base saturation
	Rooting conditions	Effective soil depth (cm), watertable depth (cm), root penetration (class)
	Flood hazard	Frequency (years/episode)
	Excess of salts	Electrical conductivity of saturation (mmho/cm)
	Soil toxicities	Jarosite depth
B. Management requirements		
	Soil workability	Workability (class)
	Potential for mechanisation	Slope (class), rock outcrop (class), and stoniness (class)
C. Conservation requirements		
	Erosion hazard	Slope (class), soil loss (tonne/rai/year)

The Mae Chaem catchment

The Mae Chaem catchment, situated in the northwest of the Ping River basin (Figure 2.4), was selected as the focus for the first phase of the IWRAM project. The Ping River basin (33,900 km^2) is one of the main feeders of the Chao Phraya River flowing south before being joined by the Nan River. As is typical of much of Thailand, and indeed much of the world, stakeholders in the Ping River basin are experiencing difficulties in developing policies to plan for the sustainable use of land and water resources (Jakeman et al. 1997). These difficulties are often exacerbated by the fact that the relationships between biophysical and sociocultural processes are highly complex, particularly the influence of changes in land use on natural resources (Enters 1995; Scoccimarro et al. 1999).

Figure 2.3 Regeneration on an abandoned upland field in the Mae Pan sub-catchment of the Mae Chaem catchment, northern Thailand. Photo by W.S. Merritt, November 2000

Human settings

In the Mae Chaem catchment, the population of the highland regions is comprised mostly of hill-tribe people (Karen, Hmong, Akha and Lisu), while in the lowland regions Thai locals are predominant. The hill-tribe population migrated from Laos, Myanmar and China over the last century.

Policy and management settings

The watershed classification of the Mae Chaem catchment (see Figure 2.5) shows that much of the catchment, particularly in the northern and western regions, has been classified as WSC1A. This class is to be protected from any exploitation of natural resources unless necessary for forest and ecological rehabilitation (Krairapanond and Atkinson 1998). All residents located in these areas were to be evacuated and relocated. This is not reflected in the land-cover maps from the late 1990s, where existing areas of agriculture within the region have remained, despite the policy of relocation.

Combined with forest zoning policy undertaken by the Land Reform Department (LDD, pers. comm. 2000), there is little remaining land available for development within the Mae Chaem catchment. This is illustrated in Figure 2.6 for the Upper Mae Yort sub-catchment (148 km^2) located on the western side of the Mae Chaem catchment. Overlaying the watershed classes (A) with the forest zoning plan (B) leaves two small areas (12.4 km^2) in the south of the catchment legally available for alternative land uses (C). Also, much of the existing agriculture from the 1997 land cover (D) would not be allowed.

Climate

Thailand has a monsoonal climate for up to seven months of the year (Turkelboom et al. 1997). Annual rainfall within the region is highly variable from year to year, ranging, for example, from 745 mm in 1993 to 1804 mm in 1994 at Ban Mae Mu. The wet season starts in mid-to-late May and extends through to October, reaching a peak in July–August (Figure 2.7). Approximately 95% of rainfall in the Mae Chaem catchment occurs during the wet season. The mean annual rainfall surface in Figure 2.8, generated using the ANUSPLIN program (Hutchinson 2000) and data from 79 stations in the Chiang Mai and Mae Hong Song provinces, shows a general trend of decreasing rainfall westwards across the catchment.

Topography

Elevation within the Mae Chaem catchment varies from 475 m to 2560 m above sea level (Figure 2.9), and slope ranges from 0° to 78°.

Land use

Three time slices (1985, 1990 and 1995) of land-cover information were obtained for the entire Mae Chaem catchment from the National Research Council (NRC) of Thailand. A summary of the land cover for these time slices is shown in Table 2.5. Between 1985 and 1990, the percentage of land classified as forest fell by 10%, from approximately 3380 km^2 to 2980 km^2. This was converted mainly to upland agriculture—fields and fallow fields—in the upper half of catchment, with slight increases in the amount of paddy.

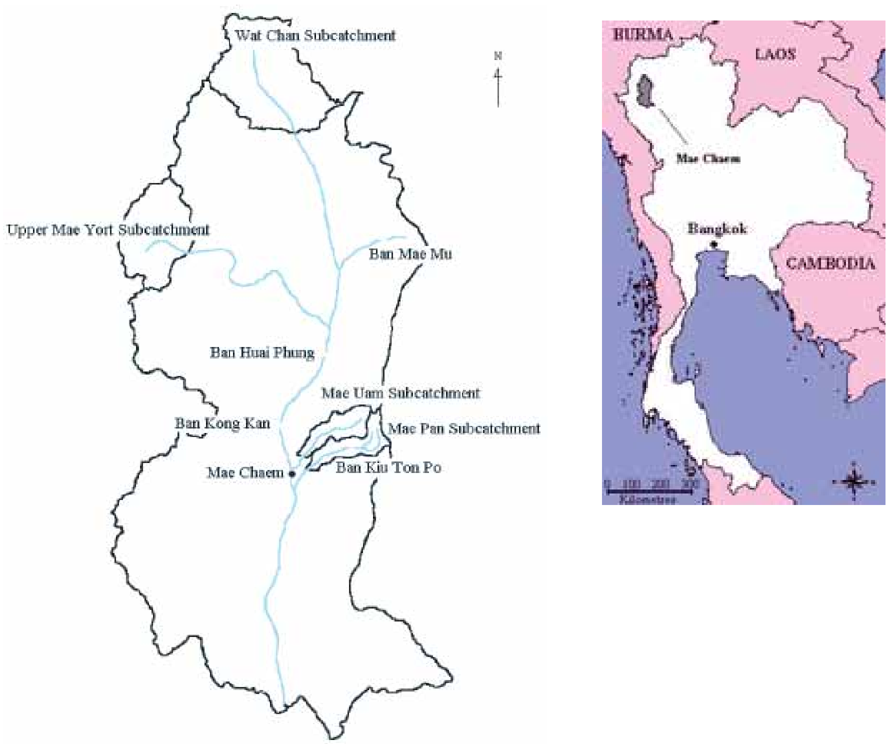

Figure 2.4 Location of the Mae Chaem catchment in northern Thailand

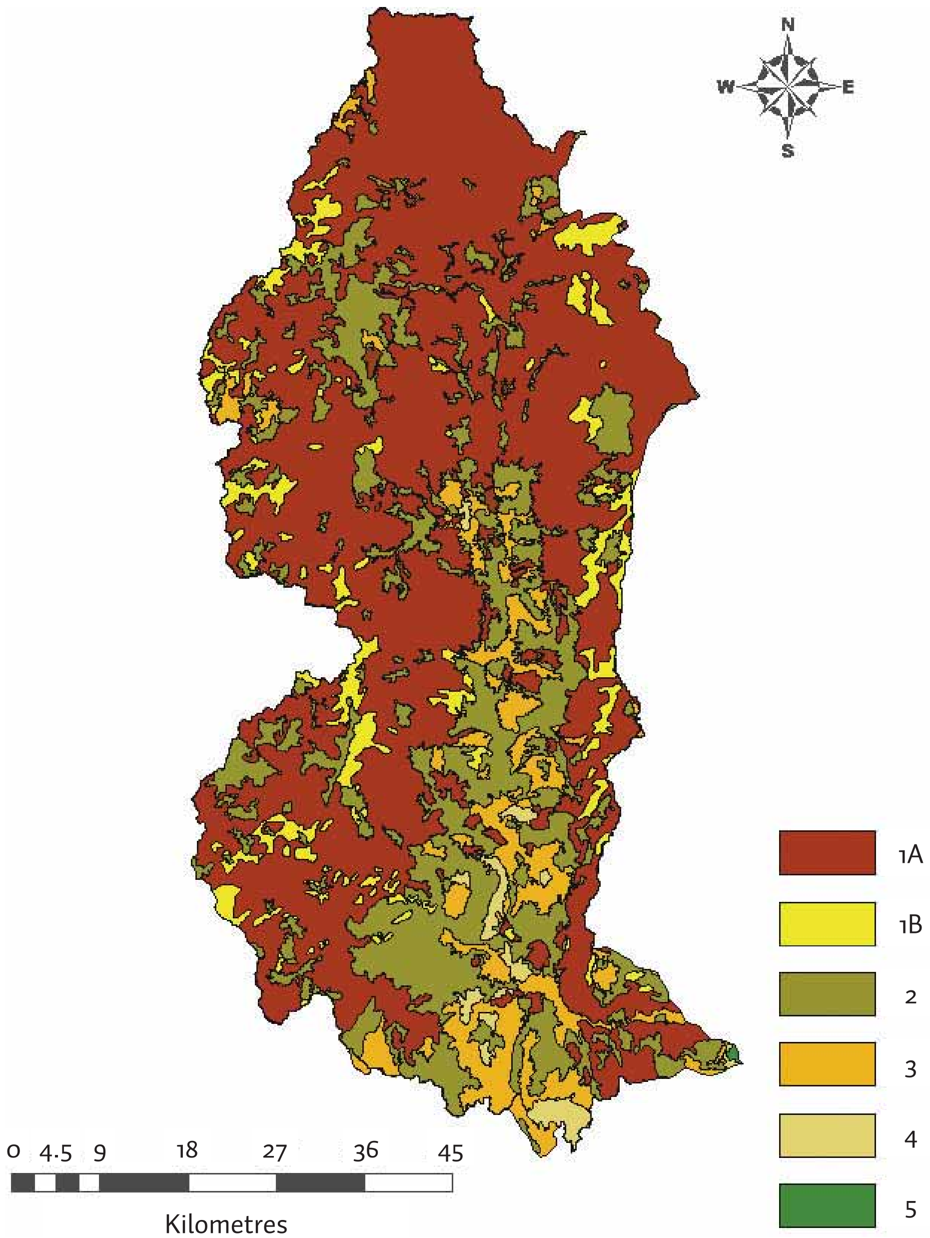

Figure 2.5 Watershed classes within the Mae Chaem catchment provided by the National Research Council of Thailand. Details of the watershed classes are provided in Table 2.2.

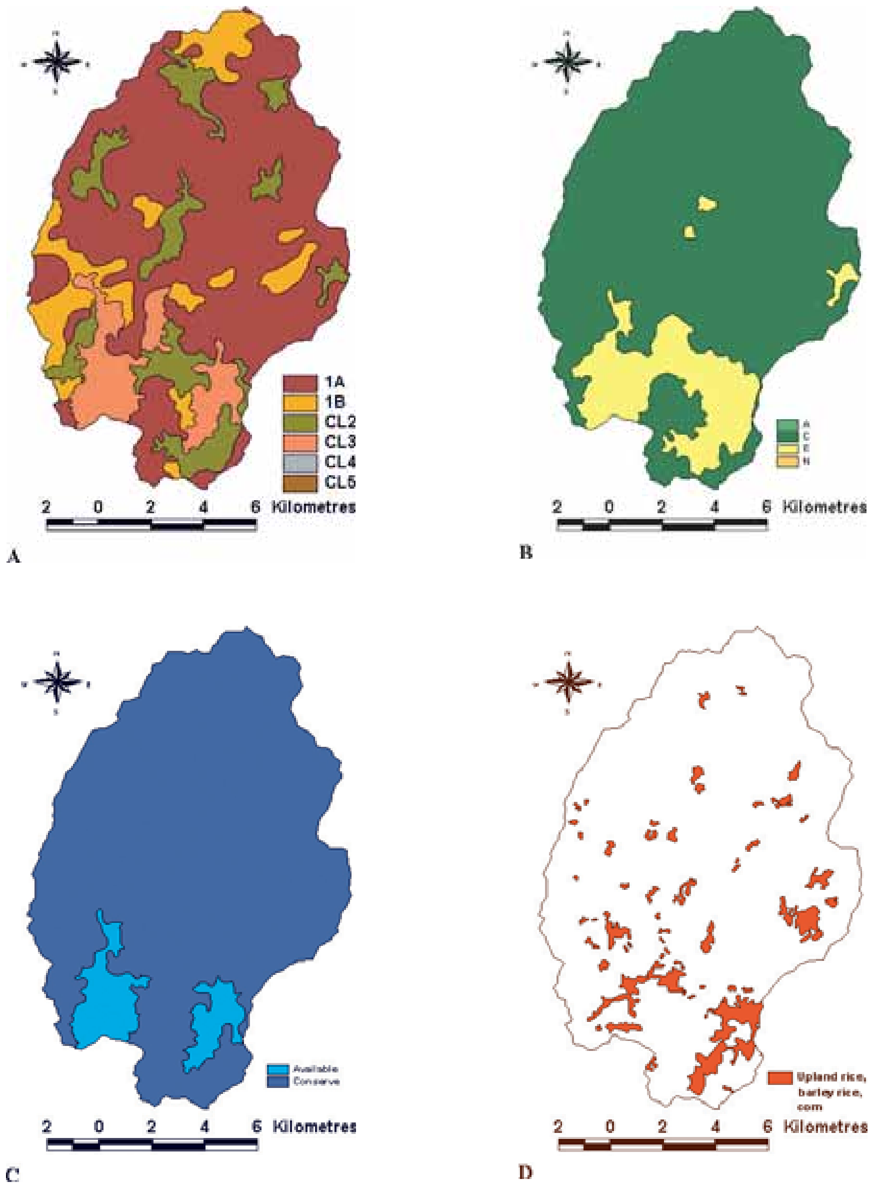

Figure 2.6 Policy effects on land availability for agriculture: A, watershed classes; B, forest zones; C, available land use; and D, 1997 agricultural areas within the Upper Mae Yort sub-catchment. Source: A, B and D were provided by the Land Development Department in Thailand.

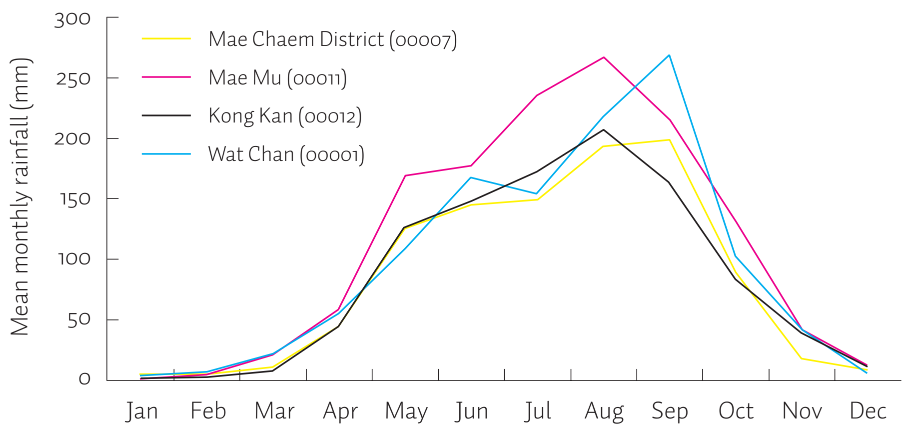

Figure 2.7 Mean monthly rainfall (mm) for four rain-gauge stations in the Mae Chaem catchment, northern Thailand

Table 2.5 Percentage land use for Mae Chaem catchment in 1985, 1990, and 1995 (original land-cover data were a product of the IGBP–START project and were provided to the Integrated Water Resource Assessment and Management project by the National Research Council of Thailand)

Land cover class	Percentage area		
	1985	1990	1995
Forest	88.07	77.71	79.80
Paddy	0.93	1.43	1.62
Urban	0.01	0.05	0.06
Upland field	5.17	7.49	5.77
Water	0.01	0.02	0.02
Upland fallow field	5.81	13.31	12.75

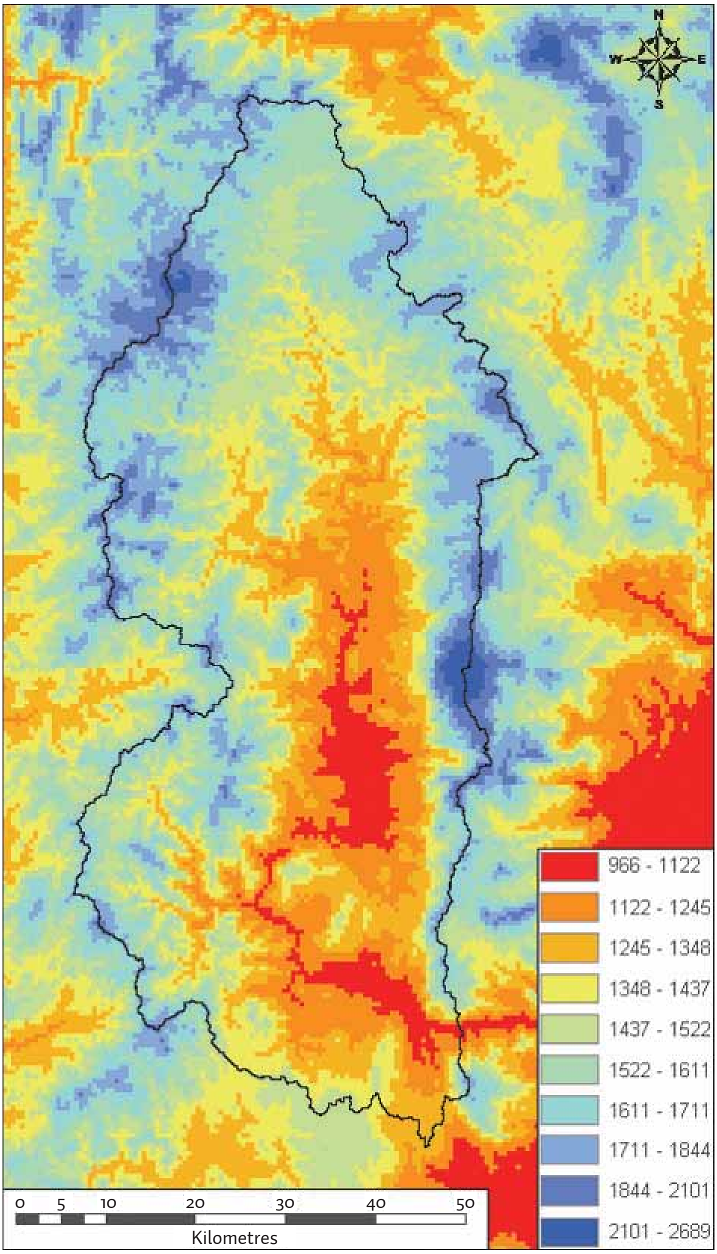

Figure 2.8 Map of mean annual rainfall (mm) across the Mae Chaem catchment and surrounding areas of northern Thailand

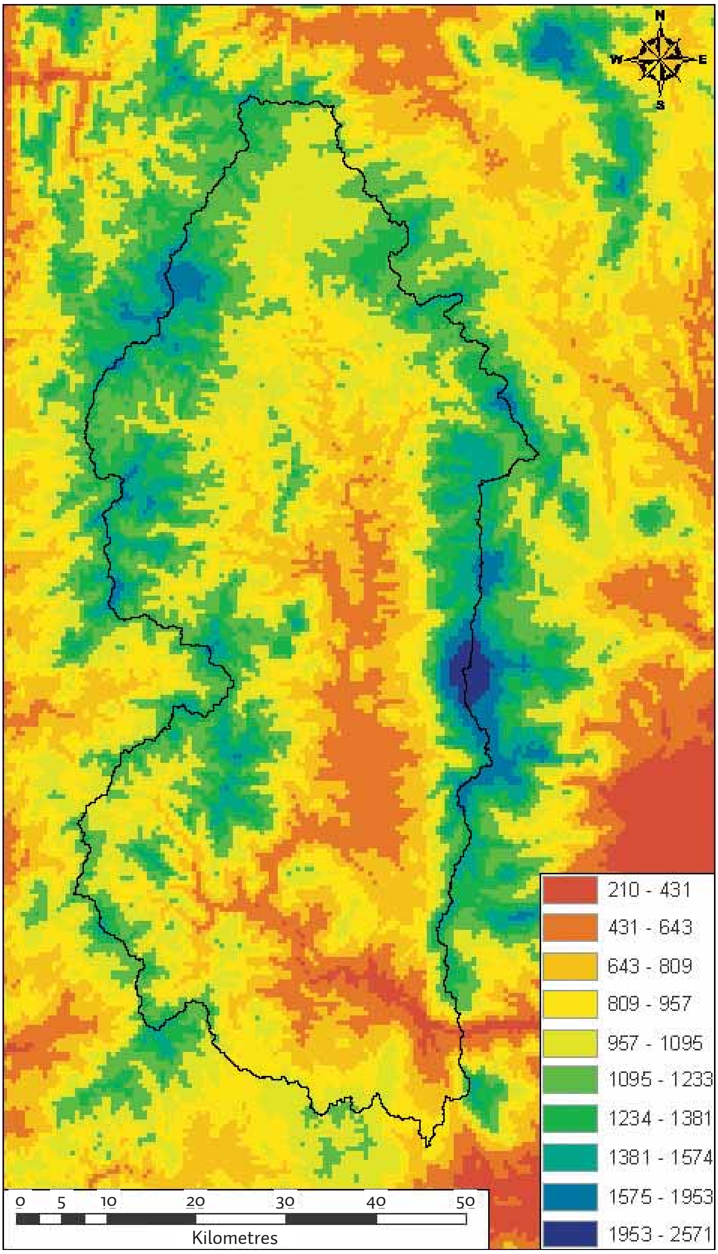

Figure 2.9 Digital elevation model for the Mae Chaem catchment, northern Thailand. Source: Dr Somporn Sangawongse

There was relatively little change in land cover between 1990 and 1995, with slight increases in forest area observed. Agriculture within the Mae Chaem catchment predominantly involves the growing of crops such as upland rice, maize and some vegetables. Figure 2.10 shows some examples of these agricultural activities. Terraced agriculture commonly exists on moderately to steeply sloping lands (Figure 2.10A). Some fruit orchards exist within the catchment, such as the orchard shown in Figure 2.10B. On gently sloping lands, intensive agriculture such as paddy fields is undertaken (Figure 2.10C). Figure 2.10D shows mixed agriculture including a longan orchard and Figure 2.10E shows an upland rice field after harvesting. The major crop grown in the wet season is rice for subsistence purposes, combined with limited agricultural cash crops.

Figure 2.10 Examples of agricultural activities within the Mae Chaem catchment, northern Thailand: (A) terraced agriculture within steep headwaters; (B) remains of an orchard on a slope affected by mass movement; (C) intensive agriculture on paddy fields with furrow irrigation; (D) longan orchard near San Kieng village in Mae Pan; and (E) upland rice field after harvest. Photos A and C by S. Yu. Schreider, and B, D and E by W.S. Merritt

The Mae Chaem catchment has only relatively small-scale streamflow regulation compared with catchments located closer to Chiang Mai. Examples of engineering structures present in the catchment are shown in Figure 2.11. A common form of irrigation used on fields of low slope in the Mae Chaem catchment is the basin irrigation method (Figure 2.12), otherwise known as paddy irrigation (Stein 1979). This method requires the division of a field into small units with a level surface. Small banks (or bunds) 30–50 cm high are constructed around each unit to form a basin. For crops that require periods of inundation, such as paddy rice, the basin is filled with water that is retained until it infiltrates into the soil or until the farmer drains off the excess water.

Soils and land units

The LDD provided land-unit information for the Wat Chan, Upper Mae Yort, Mae Uam and Mae Pan sub-catchments of the Mae Chaem catchment. The dominant land unit in the sub-catchments is land unit 49 (dark green in Figure 2.13), which comprises silty textured soils on steeply sloping land. The Mae Uam and Mae Pan sub-catchments have a large proportion of low-sloping clay soils suitable for paddy agriculture (land units 88 and 99), although the extent of these land types is limited in the Wat Chan and Upper Mae Yort sub-catchments. Table 2.6 describes the soil and topographic classes of the Upper Mae Yort, Wat Chan, Mae Uam and Mae Pan sub-catchments and the areal extent of each land unit.

Figure 2.11 Examples of irrigation structures in sub-catchments of the Mae Chaem, northern Thailand: (A) a small irrigation canal in the Mae Pan sub-catchment; (B) a weir in the Mae Pan sub-catchment. Photos by W.S. Merritt, November 2000

Figure 2.12 Paddy agriculture in the Mae Chaem catchment, northern Thailand, showing small banks (bunds) bordering plots on gently sloping lands

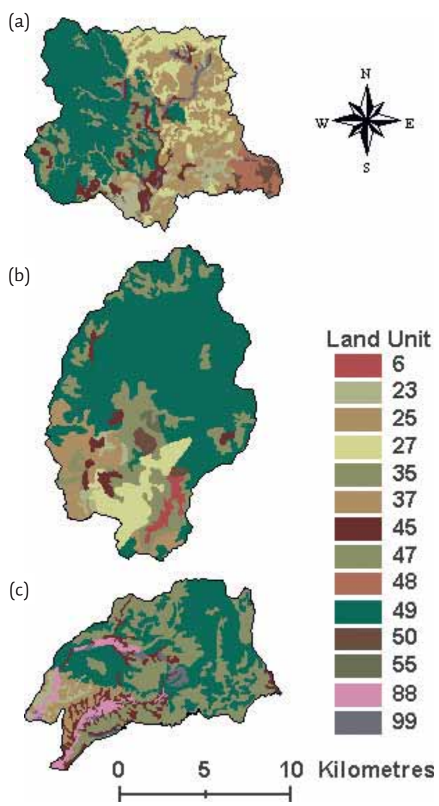

Figure 2.13 Land-unit classification for the Integrated Water Resource Assessment and Management study sub-catchments of the Mae Chaem catchment, northern Thailand (from top to bottom: (a) Wat Chan, (b) Upper Mae Yort, (c) Mae Pan and Mae Uam sub-catchments. GIS coverages were provided by the Land Development Department, April 2000.

Table 2.6 Land units in the Mae Chaem catchment of northern Thailand. Source: provided by Land Development Department, April 2000

Land unit	Soil texture/description	Slope class	Wat Chan (km^2)	Upper Mae Yort (km^2)	MaeUam/Mae Pan (km^2)
6	Shallow loam and gravel soils	D or E	0	2.6	0
8	Shallow loam and gravel soils with 2–10% rock outcrops	A or B	0	0	0
10	Shallow loam and gravel soils with 2–10% rock outcrops	C	0	0	0
12	Shallow loam and gravel soils with 2–10% rock outcrops	D or E	0	0	0
23	Deep loam soils	A or B	7.6	2.1	2.4
25	Deep loam soils	C	27.5	2.9	5.7
27	Deep loam soils	D or E	14.8	11.2	0
35	Shallow clay and gravel soils with 2–10% rock outcrops	C	0	5.8	0
37	Shallow clay and gravel soils with 2–10% rock outcrops	D or E	0	10.0	0
45	Deep clayey soils	A or B	6.9	3.7	7.6
46	Deep clayey and gravel soils	A or B	0	0	32.6
47	Deep clayey soils	C	10.7	21.2	32.6
48	Deep clayey and gravel soils	B	4.0	0	0
49	Deep clayey soils	D or E	41.6	84.5	35.0
50	Deep clayey and gravel soils	D or E	1.8	2.0	0
55	Medium deep clayey and gravel soils	D or E	0	0.9	0
88	Deep clayey irrigated paddy soils	A or B	0	0	5.1
99	Deep clayey paddy soils	A or B	2.7	0.8	1.8

Note: A – 0–8%, B – 8–16%, C – 16–35%, D – 35–60%, E – > 60%

Discharge

There are five streamflow gauges in the Mae Chaem catchment, of which three were used in the development of the hydrology models. These stations were the Kong Kan, Huai Phung and Mae Mu stations (Figure 2.14). The Kong Kan sub-catchment drains an area of 2157 km^2 above Mae Chaem city—the largest urban settlement in the Mae Chaem catchment. The Huai Phung catchment is located further upstream, draining an area of 1180 km^2, and the Mae Mu catchment is an upland catchment draining an area of 68.5 km^2. Table 2.7 shows annual discharge and run-off coefficients for the three stations. The data from the other two gauging stations were of dubious quality and were excluded from the analyses.

Conclusions

In most countries throughout the world, there has been an increasing realisation that water resource and land use planning can no longer be undertaken in isolation. In Thailand this has

Figure 2.14 Discharge gauging stations in the Mae Chaem catchment, northern Thailand, used in the application of the discharge regionalisation procedure. The focus catchments of the Integrated Water Resource Assessment and Management project are shown. Mae Chaem city is indicated by the large dot.

Table 2.7 Run-off coefficients for the Kong Kan, Mae Mu and Huai Phung sub-catchments of the Mae Chaem catchment, northern Thailand

	Nam Mae Chaem at Ban Huai Phung	Nam Mae Chaem at Ban Huai Phung	Nan Mae Mu at Ban Mae Mu
Mean slope (°)	19	19	14
Forest area (km^2)	2024	1113	65
Annual run-off (mm)	274	243	463
Average run-off coefficient	0.23[a]	0.20[a]	0.34[b]
Long-term mean annual rainfall (mm)	1191	1214	1362

[a] Average run-off coefficient calculated over 1985 to 1994.
[b] Average run-off coefficient calculated over 1988 to 1994.

resulted in a number of government policies that aim to protect these natural resources and encourage sustainable development of agricultural systems.

However, there are many government departments and agencies that are involved in the management of land and water resources, and poor coordination of activities has been recognised as a major hurdle for the Thai Government. In addition, the exact impacts of forestry and agricultural activities on land and water resources are often hotly contested—due to a limited understanding of the key biophysical processes and complex social characteristics of the catchment. Efforts are now under way to address these issues, and promote the sustainable management of water resources through the development of integrated watershed management (IWM) strategies and revisions of water laws. The techniques developed in the IWRAM project can help the various government agencies improve coordination and explore solutions to water resource conflicts, through the use of decision support systems (DSS).

It is important to note, however, 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. Similarly, the DSS does not provide an 'optimal' outcome, as this is dependent on the perspective and objectives of the DSS user. By offering a transparent and repeatable process, it helps users to explore some of the expected and unexpected impacts of various policy options that are being considered by the government.

The Mae Chaem catchment is a typical example of the issues and pressures facing natural resources management in northern Thailand. It provided a good case study for testing the IWRAM DSS. The catchment also had the advantage of having relatively good sets of environmental, social and economic data available for use.

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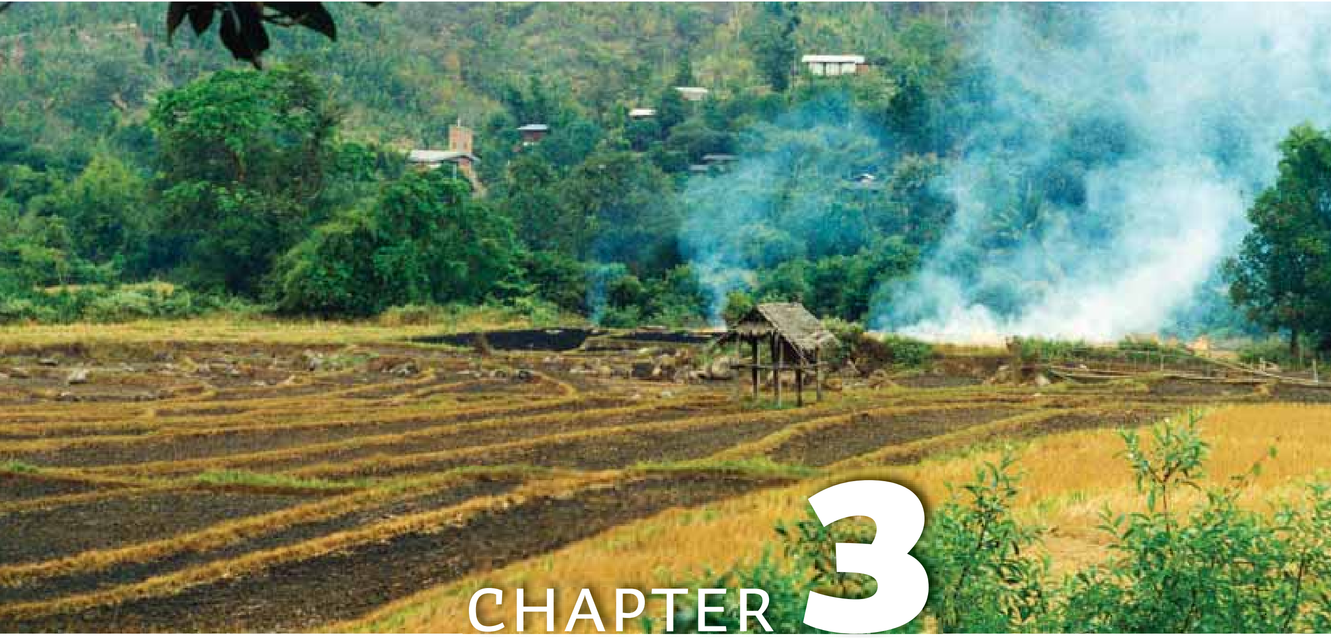

Principles of integrated assessment

Rebecca Letcher, Anthony Jakeman and Benchaphun Ekasingh

Summary

To meet the challenges of sustainability, catchment management and natural resources management in general, requires an approach that utilises an integrated assessment of resource-use options and environmental impacts. The assessment must include the consideration of multiple issues and stakeholders and the key disciplines within and between the human and natural sciences, and multiple scales of system behaviour. Integrated assessment is an emerging discipline that attempts to address the demands of decision-makers for management that has ecological, social and economic values and considerations. This chapter outlines the principles of integrated assessment that were applied and extended in the Integrated Water Resources Assessment and Management project.

Figure 3.1 Highland village in northern Thailand, surrounded by small plantings of mixed crops and orchard trees. Photo by Anthony Scott, June 2004

Introduction

In many regions of the world, the degradation of river basin catchments is having significant long-term impacts on the environment and agricultural productivity. There is an urgent need for a coordinated response. However, researchers and managers have lacked comprehensive tools for assessing all of the issues and impacts in a collective manner.

In the past, natural resource decisions tended to be narrowly focused and disjointed—see, for example, Ewing et al. (1997). Earlier approaches failed to deal with the many interconnections and complexities within and between the physical and human environment. In the management of water resources, decisions focused on only a portion of the catchment and were implemented incrementally, with little consideration for the long-term impacts. Development activities concentrated on the physical control of water for economic gain, while environmental and social effects were, at best, given token consideration. Local communities were also rarely involved in decision-making processes. Integrated water resources management (IWRM) and integrated catchment management (ICM) are management approaches that were proposed to deal with these issues. These concepts were introduced in Chapter 1. They involve a holistic approach to management, considering multiple issues involving many stakeholders and interest groups. This integrated management approach requires consideration of many different types of impact trade-offs, and relies on a policy-focused approach to research and assessment that integrates understanding from many sciences and social sciences. This approach is referred to as integrated assessment (IA).

In the following sections, the features of IA are outlined, starting with different uses of the term 'integration'. A definition of the term 'integrated assessment' is also provided before the features and issues associated with IA are discussed.

What is integration?

In terms of modelling and assessment, there are at least five main types of integration that are referred to under the generic term 'integration', as summarised by Letcher and Bromley (2005) and Parker et al. (2002). See also Chapter 1 for a complementary discussion. The most demanding integration problems, such as those involving the wellbeing and equity of current and future generations, will involve all the types. Examples of each type of integration are presented below.

1. **Integration of models.** This requires combining two or more models of catchment processes at a variety of scales. These processes may be biological, chemical, physical, economic or social. Commonly, models may be combined to describe more than one aspect of the physical or biological features of the catchment, such as the surface- and groundwater systems. However, integration may also entail combining modelling techniques from a broad range of disciplines such as hydrology and economics. Obviously, this type of integration may embrace not just the integration of models but also the integration of different disciplines, scales and issues.

2. **Integration of disciplines.** This involves the integrated consideration of two or more disciplinary views of a catchment problem. For example, a hydrogeologist may consider a dryland salinity problem to be a consequence of deforestation in the upper catchment, whereas an economic view of this may be that off-site impacts of deforesting the upper catchment are not being incorporated in the decision to deforest. An integrated approach to such a problem typically needs to reconcile these two views of the causes and effects of the problem.

3. **Integrated treatment of issues.** Suggested management options for many catchment problems have impacts on other resource and environmental issues within catchments. For example, management options for dryland salinity often involve reforesting a significant proportion of the upper catchment. This may also reduce the amount of erosion in the upper catchment, improving water quality and reducing sediment and nutrient discharge to the lower catchment. However, large-scale reforestation may also affect the amount of run-off that is generated, potentially 'drying up' the catchment, and reducing water availability to downstream users. Considering the effects of management options on a range of resource and environmental issues within the catchment may improve management decisions and reduce the chance of unforeseen negative impacts.

4. **Integration of scales of consideration.** The resource and environmental components of a system may operate at different spatial and temporal scales.

While catchment boundaries may be most appropriate for considering hydrologically related issues such as run-off generation or erosion, social and economic boundaries are unlikely to coincide with these boundaries. Important processes in the economic system may occur in households or on farms, whereas social boundaries may follow electoral boundaries or may be linked to infrastructure such as roads and schools. Even within the physical system of the hydrological cycle, the ground- and surface-water systems operate at very different spatial and temporal scales. The surface-water system is likely to respond to a rainfall event within hours or days, while the groundwater system may continue to respond for many years. Treatment of issues at different scales requires some degree of compromise, and often a more simplified representation of parts of the system.

5. **Integration with stakeholders.** The level to which research outcomes are applied and adopted will often depend on how connected are stakeholders to the research output and how relevant research outcomes are applied to policy and extension activities. Integration with stakeholders may vary from simple education and communication of research findings to large-scale inclusion of stakeholder views and knowledge at all stages in a project (co-design).

These types of integration are not totally independent of one another. In many cases, the distinction between these types of integration is not clear. An integrated treatment of environmental, social or economic issues may require an integration of modelling techniques at a variety of scales. Some level of stakeholder integration is likely to be a feature of any integrated modelling exercise.

Features of integrated assessment

Integrated assessment has been defined as (Pahl-Wostl 2003, p.465) the:

> …integration of knowledge from different disciplines with the goal to contribute to understanding and solving complex societal problems, that arise from the interaction between humans and the environment, and to contribute in this way to establishing the foundation for sustainable development. Modelling and participatory processes should include stakeholder groups and the public at large.

Integrated assessment provides a vehicle for addressing all key issues affecting the sustainability of a catchment by combining the knowledge and understanding from different research areas, such as economics, psychology, ecology and hydrology. A better understanding of the complex interactions occurring within a catchment must include the needs and concerns of communities and industries, as well as the environment.

The key features of IA, summarised by Jakeman and Letcher (2003), are that it:

- is a problem-focused activity using an iterative, adaptive approach that links research and policy
- possesses an interactive transparent framework that enhances communication
- is a process enriched by stakeholder involvement and is dedicated to adoption
- connects complexities between the natural and human environment, recognising spatial dependencies, feedbacks and impediments
- attempts to recognise essential missing knowledge.

Tools and techniques are now available to assess the effects of resource use and management in an integrated way that provides good guidance for decision-making. The increasing availability of spatial databases and improving information technology are facilitators for such assessment. More importantly, the science of IA is maturing to the point where knowledge acquisition and practice of this discipline should now accelerate to provide positive benefits for assessing the ecological, social and economic effects of decisions, as well as guidance on the ways that management might be effective.

The role of models and decision support systems in integrated assessment

The development and use of models is a major activity of IA. This is because people think and communicate in terms of models as simplifications of reality. The types of models include:

- data models that are representations of measurements and experiments
- qualitative conceptual models as verbal or visual descriptions of systems and processes
- quantitative numerical models that are formalisations of qualitative models
- decision-making models that transform the values and knowledge into action.

Figure 3.2 describes the role of models in IA and shows the links between policy and other stakeholder communities and researchers. Model conceptualisation can act as a focus for dialogue and communication of system understanding, issue definition and development of a shared understanding of trade-offs and impacts.

Documenting models and/or putting them into computer code makes their nature and assumptions more explicit and facilitates integration with other models. Such explicit models allow us to represent the complexities and interactions within human and environmental systems. When incorporated in computer software, models allow us to run scenarios more efficiently and, in particular, to calculate and assess the ensuing trade-offs among indicators of environmental, economic and social outcomes.

A major advantage of integrated models is their ability to capture the dynamics of the whole system, not just of individual components. This allows the exploration of feedbacks between different processes and models, such as the economic and physical systems or other processes occurring over different spatial and temporal scales.

Computer-based decision support systems (DSS) can increase the value of models and information being used for integrated assessment. Ewing et al. (1997) describe DSS as ‘computer based simulation models designed to enable the user to explore the consequences of potential management options’. The benefits of a DSS are in providing:

- a way of interconnecting different models and exploring trade-offs
- a library of integrated data sets
- a library of models, methods, visualisation and other tools
- a focus for integration across researchers and stakeholders
- a training and education tool
- a potentially transparent tool.

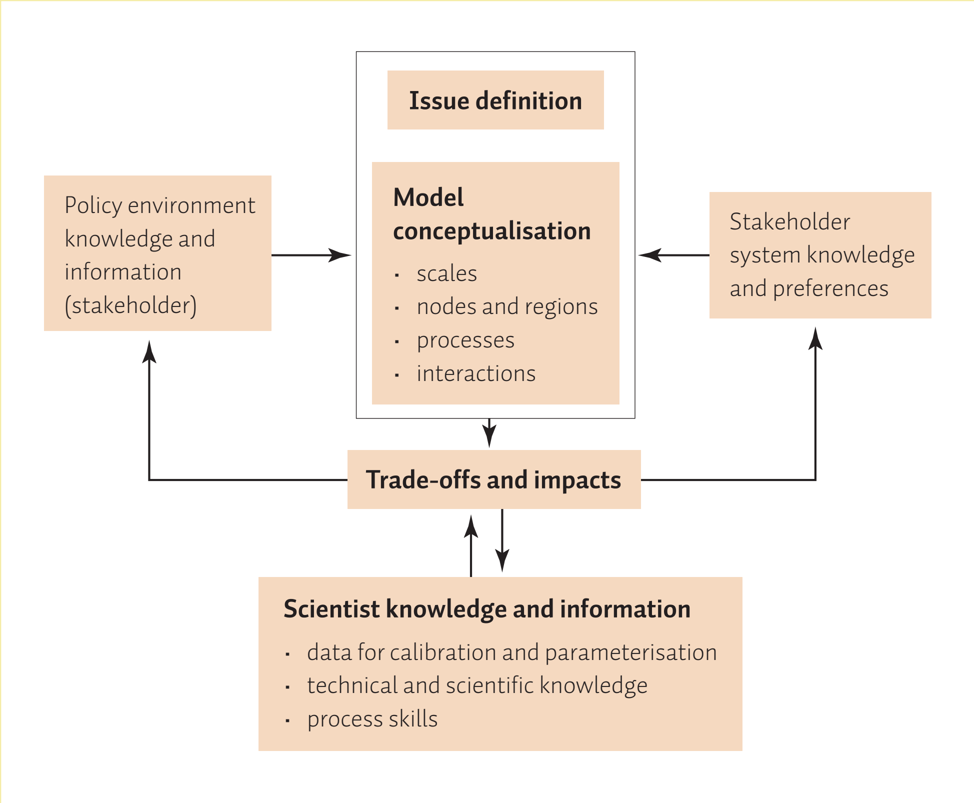

Figure 3.2 Models and their role in integrated assessment. Source: Letcher and Jakeman (2003)

Key issues in integrated assessment

What to include and what not to incorporate in an IA modelling activity should be determined at the outset as explicit considerations. The system being modelled should be defined clearly as well as its physical, socioeconomic and institutional boundaries. Boundary conditions can then be modelled as constraints or as input scenarios whose values can be perturbed in line with stipulated assumptions. Some of the following modelling considerations should commonly arise with respect to the management of natural resources:

- Climate variability and episodes – These often have a profound effect on outcomes. Variability can affect the returns of an investment in production as well as the response of an ecosystem, while episodes such as floods can have an inordinate effect on outputs. Both raise issues of appropriate time periods and time steps over which to model.

- Model process complexity – Once the basic processes and causal relations are decided upon, often there is still much scope for selecting the level of underlying detail, including the spatial and temporal discretisation. Data paucity, especially of system behaviour, should limit the model complexity. For example, in modelling of flow and transport, spatial data on catchment attributes may be very useful to structure and discretise a model in fine detail but this complexity is unwarranted if flux measurements used for model calibration cannot support the level of parameterisation—see, for example, Jakeman and Hornberger (1993).
- Beyond business-as-usual scenarios – The nature of environmental or social decline may mean substantial changes to the current situation are required. Other public and private investments, policy incentives and institutional arrangements will be needed to change resource activities.
- Modelling long leads and time lags – The time frames for returns on investments and for ecosystems to respond to changes affect both the period and the temporal resolution over which models are run and indicators computed.
- Narrowing modelling objectives – In addition to simplifying types of models, scales, system boundaries etc., it is critical to keep the level of integration of issues and disciplines manageable.
- Model uncertainty – It is desirable to reduce and, where possible, characterise uncertainty; the latter needs methodological attention by IA researchers.
- Error accumulation – This can occur in models when the outputs for one time step become the inputs for the next time step, and any errors or offsets can gradually accumulate. It also occurs when the outputs from one model are transferred to another model. Error accumulation is often ignored, but in reality can be a significant issue and deserves considerable attention.
- System representation – There is a need to balance the extent of the capacity to characterise feedbacks and interactions with keeping model components and linkages effective but efficient.

Recognising broad objectives

Given the complexities and uncertainties of integrated modelling, it should be accepted that its broad objective is to increase understanding of the directions and approximate magnitudes of change under different options. Typically, it cannot be about accepting or treating simulation outputs as accurate predictions. An advance that is required is to make possible qualitative differentiation between outcomes, with at least qualitative confidence; for example, a particular set of outcomes or indicator values might be categorised as overall better than, worse than or negligibly different from another set (for instance the do-nothing, current situation) with high, moderate or low confidence. This is enough to facilitate a decision as to the worth of adopting a policy or controllable change. Results from IA modelling 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 deficiency.

Participatory modelling

Public participation can be defined as direct involvement of the public in decision-making. Clearly, it can occur at various levels. Arnstein (1969) describes a ladder of citizen participation. According to Mostert (2005) there are several reasons for organising public participation. These include the possibility of:

- more informed and creative decision-making
- greater public acceptance and ownership of the decisions
- more open and integrated government
- enhancing democracy
- social learning, the ultimate objective, to manage issues.

Mostert also states that it is important that public participation is organised well, so as to avoid limited and unrepresentative response from the public, disillusionment, distrust, less public acceptance, more implementation problems, less social learning, and complication of future participatory processes. He stresses the need for sensitive processes, taking into account the culture (e.g. natural and socioeconomic conditions, ideology) and subculture (e.g. environmentalists, industrialists, managers). He argues that if water management is to be participatory, research supporting water management should also be participatory. Not only should the public have access to research results, presented in an understandable way, but also it should have a say in what is researched and how, and participate in the research process itself.

Integrated assessment and 'independent' experts can provide an important and useful mechanism for raising the level and quality of public participation in environmental management. Involving communities in model development can not only add to the validity of the final model developed but also can create an opportunity for constructive interaction between stakeholders. This allows them a less-threatening focus for developing a shared system understanding than would interactions focused on resolution of specific environmental conflicts. An integrated model can capture a shared understanding of system processes and can allow people to manage disagreements about system assumptions. Delivery of models through software or development of a DSS can permit the model developed to be reused to make management decisions after the end of the research project. Conflict over management options can often be resolved as conflict over key system assumptions. In these cases, conflict may be managed by identifying areas of disagreement or gaps in knowledge, and by improving system understanding through targetted data collection or system observation. Any such resolution of the conflict is usually positively received by most stakeholders, as they feel their concerns were heard and responded to by the process.

In the setting of targets to achieve greater sustainability, subjectivity, uncertainty, potential conflicts and the specifics of the river basin all imply that a process is required that must involve continuing choice for the community. There will always be trade-offs to be identified across a multidimensional spectrum of possible system states. Selection of targets may initially be based on a relatively narrow vision, but eventually should be based on broad perceptions of benefits and costs. The selection should also be moderated by the quality of existing knowledge and the capacity to effect actions to meet those targets. This means that all targets are interim, and the process of both assessment and management must explictly allow for improved knowledge and understanding, as well as new conflicts and issues arising as old solutions cause new, unforeseen problems. A long-term vision of the aims of assessment and management, and monitoring for both improvements in sustainability and unforeseen consequences of actions, are necessary to create sustainable landscapes. Landscapes evolve, so solutions that improve short-term sustainability may be inadequate or may become problematic in the long term. Management and assessment processes must acknowledge and embrace the dynamic nature of landscapes.

Adaptive management

Adaptive management (Holling 1978) and active adaptive management (e.g. Allan and Curtis 2003) are laudable principles with the potential to improve our management of the environment through learning. With respect to modelling, adaptive management can involve the development of: ways to gather, record and share conventional and unconventional environmental system information; improved tools to capture and express qualitative knowledge; methods for testing knowledge, identifying gaps and designing experiments; development of monitoring techniques able to distinguish the effects of changed management practices from the large natural variations associated with most systems; approaches to screening and testing a broad range of alternative policies; and incorporation of the principles of feedback control to achieve acceptable behaviour insensitive to disturbances and modelling error.

In essence, adaptive management can usefully be about developing management-revision principles, experiment designs, outcome indicators, and monitoring practices to achieve sustainable management in evolving environments. 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.

Some of the essential issues confronting adaptive management can be identified by examining what factors are crucial in the long-established use of designed feedback in control engineering:

- simplification of dominant behaviour
- measurement of the output variables whose behaviour is to be controlled
- consideration of robustness of control-system performance
- observability and controllability
- comparison between measured and desired output to determine error and the formation of control action.

Such ideas are commonplace in control engineering, but it is surprising how little discussion there has been about their relevance to environmental modelling and management.

Targeting disciplinary gaps

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 the biophysical and socio-economic characteristics of farmers, industries or households, is crucial to developing more sophisticated integrated scenario modelling and other policy analyses (e.g. Allan and Curtis 2003). Very little of this type of data exists for river basins. 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 integrated model building is one way of extracting and using such information. These techniques have the bonus of allowing stakeholders into the model development phase, to ensure they have a better understanding of, and opportunity to feed into, the assumptions underlying these types of models. Hare et al. (2003) present one of the recent comparisons of different participatory processes.

Artificial-intelligence techniques offer an interesting and useful alternative to theory-based models of socioeconomic processes. Many economic and social models are based on theoretical assumptions of the drivers of decision-making, such as maximisation of profit or utility. These models can be very difficult to validate, as sufficient information on people's responses to changes in the components of the system of interest is often not available. Artificial-intelligence techniques offer an opportunity to develop data-driven models of these processes, through use of interview and survey data. This development would then allow testing of the performance of these models and the management recommendations arising from them. Importantly, it is possible to investigate whether or not the management recommendations coming from theory-based socioeconomic models differ from those derived from data-driven modelling approaches, or whether the relative differences in system performance are similar regardless of the approach used. This would allow more-focused development of these approaches for management, and would assist modellers in determining the appropriate level of complexity to add to these models, giving a better grasp of the robustness of the approaches they currently apply.

Discussion and conclusions

Effective and equitable management of our natural resources has many dimensions. Integrated assessment is a process that attempts to address these dimensions and the need for more informed management. Integrated assessment modelling recognises the complexity of natural systems and human interactions with them. The following are our conclusions about the development of IA:

- Analysis frameworks for characterising integration problems have come of age, but there is still much that is problem-specific: scales, models and their linkages vary. However, it is mainly by continuing to perform IA on specific problems that this emergent discipline will fully mature.
- There is a need for more-comprehensive model testing and, in particular, the development and application of methods for quantifying the sensitivity and uncertainty associated with the results. For complex data-deficient systems of the type that occur in IA problems, this is a challenge that is essential to meet.
- Data availability is a severe constraint for obtaining more-informed and confident decision support, and this was a particular issue in northern Thailand. Typically, more measurement information is required about system behaviour such as fluxes of water and pollutants, as well as key information on social and economic systems within catchments.
- Further core disciplinary research is required which targets the questions that need to be answered by researchers in IA: for example, in socioeconomic models, how

to incorporate aspirations and capacity for change; and in biophysical models, how to make flow prediction in ungauged catchments.

- Software platforms that facilitate the IA process are being developed, but more work and technical support of products are required. Platforms that integrate spatial data with modelling and facilitate model reuse and integration are a priority.

How much, however, should we expect IA to take a similar form in Southeast Asian countries to that in the West? Even within the broad principles outlined in this chapter, there is considerable diversity among Western countries in management and hence in some of the IA methods required. Across Australia, for instance, different States have different approaches to the structure and operation of their catchment management. At the scale of large river basins around the world, the Murray–Darling Basin Commission, the Columbia River basin, the Great Lakes, and the Fraser River basin (Dorcey 2004) have adopted somewhat different structures, necessarily because of differences in their institutional settings and the issues they address.

Some of these differences in approaches to management are due to scale. Face-to-face processes are workable in small catchments (Landcare scale), but highly institutionalised forms representing governments and other established organisations (e.g. Murray–Darling Basin Commission, Columbia River Task Force, Mekong River Commission) have so far been chosen for large catchments. Such structures may or may not be supplemented with broad public-participation processes.

On what dimensions is IA likely to develop differently in Thailand and Southeast Asia? Different legislative and administrative frameworks will certainly have a bearing, but need not be limiting. Approaches to participation will need to be somewhat different and (as in Western countries) cater for differences in political culture, social structure and scale. In information terms, Southeast Asian countries have far less extensive and reliable biophysical and socioeconomic data available to assess the state of the environment and the potential impacts of planned interventions and unplanned changes. Even data known to exist may be hard to procure. With such data quantity and quality problems it will be necessary to rely more on subjective, expert advice about biophysical outcomes in relation to the effects of different resource use and management. In particular, simpler biophysical models with modest input requirements must be developed and their uncertainties quantified and communicated as far as practicable.

An important question is how appealing IA and other forms of integrated resource management will prove in Thailand. Incentives in other countries have included resource-use conflicts, such as conflicts between upstream and downstream water users, or recognition of land degradation on a scale that requires a co-operative solution. These ingredients are certainly present in northern Thailand, where concerns about forest cover, water resources, and the agricultural activities and livelihoods of the ethnic groups of the mountains, meet. They are also present in surrounding countries, especially with respect to the water resources of the Mekong River. There is no reason to assume, however, that the introduction of IA will ensure that the environmental and social considerations integral to the process will be assessed on an equal footing with the more conventional logic of 'economic development'.

The following chapters on the Integrated Water Resources Assessment and Management project in Thailand illustrate the potential value of IA and the associated modelling in quantifying the biophysical and socioeconomic impacts that may result from management interventions and uncontrollable factors.

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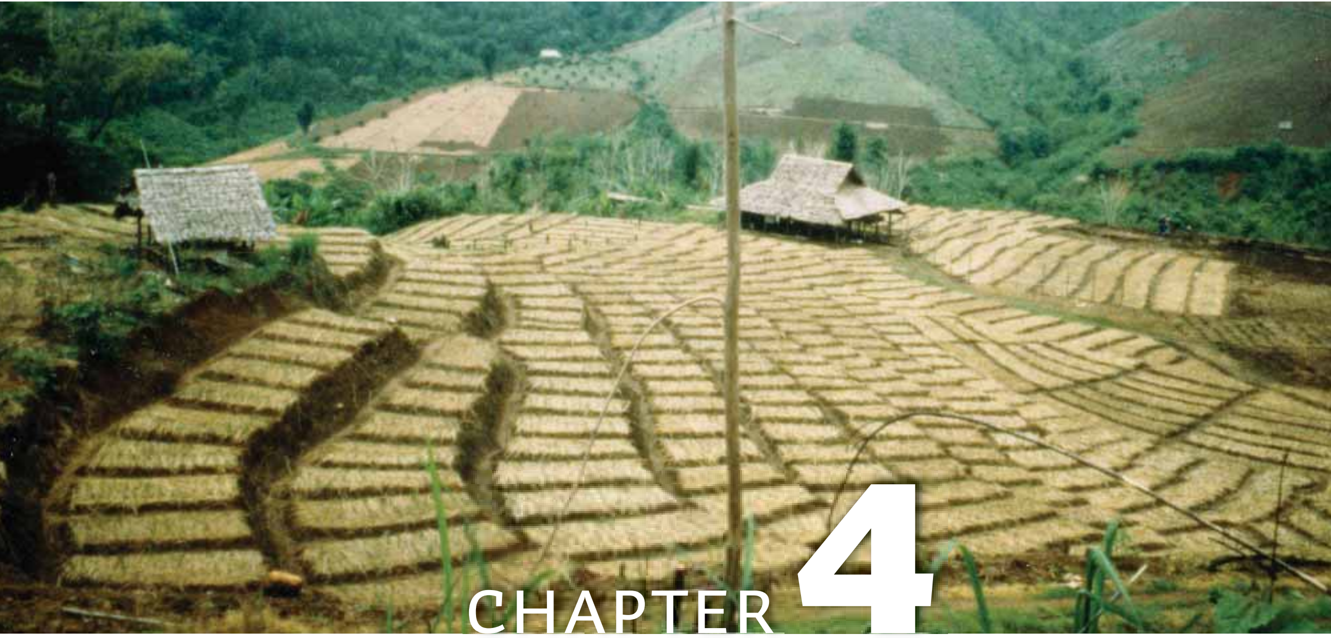

Designing the Integrated Water Resources Assessment and Management project framework

Requirements and their implications

Rebecca Letcher, Susan Cuddy and Santhad Roganasoonthon

Summary

Decision support systems (DSS) are a common tool for formalising system knowledge or understanding and delivering this to a decision-making user group. These systems are commonly computer-model based, although it is possible to produce non-computer-based DSS. Designing a DSS requires consideration of the user group, the problem focus of the research and the requirements these place on both component models and the integrative framework underlying the system. This chapter provides an introduction to the DSS framework, the approach adopted and its components. The component models are described in detail in Chapters 5–8.

Introduction

In northern Thailand, agricultural expansion has produced competition for water at various scales and has resulted in erosion problems, downstream water quality deterioration, groundwater depletion, biodiversity loss, and shifts in the distribution of economic and social wellbeing and equity. The monsoonal nature of rainfall also intensifies demand for water in the dry season and, with the seasonal shift in flow regimes, especially at larger scales where dam regulation is more considerable, this exacerbates the impacts on in-stream biodiversity and habitat.

The Integrated Water Resource Assessment and Management (IWRAM) project developed a methodology to assess these issues. The project's environmental and socioeconomic assessment capabilities focused on the development of decision support software designed to address the issues which commonly arise in each stakeholder's decision-making—and especially where their responsibilities and activities affect one another. Attention was given to the issues of water supply, erosion, rice deficit and farm income in relation to input drivers such as climate, commodity prices, technological improvements, government regulations and investments. Data collection focused on the sub-catchment scale (approx. 100 km^2) within the Mae Chaem catchment (4000 km^2) in northern Thailand (Figure 2.4). Decision support system (DSS) development has occurred in phases, with several different products being generated using the same integration concepts to meet different delivery and adoption requirements.

The main stakeholder focus for the DSS was the Land Development Department, which is utilising the DSS to assist its land use planning activities. However, other government agencies and universities also became involved in the development of the DSS, and this provides them with the capacity to undertake their own integrated assessments of future development and policy scenarios. Adoption by government departments and universities was facilitated by training workshops on both the individual model components and the DSS itself. The development of the DSS had three primary objectives:

- to provide a common tool for the government agencies concerned with water resource management
- to investigate the benefits and impacts of land use change and land conversion that might occur in the catchment
- to recommend alternative crops and management practices for sustainable land and water management, as well as income sustainability.

Requirements of the Integrated Water Resource Assessment and Management decision support system

The term 'decision support system' has been used to describe a number of different approaches to the provision of information for decision-making for many types of systems, including environmental, health and business systems. Many authors have attempted to provide a definition of the term, to the point where the definition is arguable—see, for example, Simon (1973), Lowes and Bellamy (1994), Abel et al. (1996), Gough and Ward (1996), Kersten and Micalowski (1996), Wu (1996), Ewing et al. (1997) and Rizzoli and Young (1997). The definitions provided in the literature range from the view that any computer-based system that supports decision-making is considered to be a DSS, to the other extreme where a DSS is considered to be a system which has modelling capabilities and is used by decision-makers to solve unstructured problems (Kersten and Micalowski 1996). A more general definition provided by Ewing et al. (1997) is that DSS are 'computer based simulation models designed to enable the user to explore the consequences of potential management options'.

Rizzoli and Young (1997) provided a review of environmental DSS and suggested that an ideal DSS should have a number of properties. It should assist in decision-making for unstructured and semi-structured tasks and support and enhance managerial judgment. A DSS should be aimed at improving the effectiveness, rather than the efficiency, of decision-making. It should combine the use of models or analytical techniques with data access functions while still focusing on the features that provide ease of use for inexperienced users. Lastly, it should be flexible and adaptable to allow for changes in the decision-making context.

Decision support systems generally include three main components: a database, a model base and a user interface. The model base can include features to aid in connecting tools and models. Kersten and Micalowski (1996) stress that a DSS should be simple and consistent, stating that a DSS should 'present a simplified version of the problem to the decision maker while maintaining its underlying complexity' and asserting that DSS should be consistent in their representation of processes and calculation of solutions and that the needs of the user must be addressed by the DSS.

Rizzoli and Young (1997) propose that the desirable features of environmental DSS, when intended only as an end user application, are:

- the ability to deal with spatial data—that is, the inclusion of a geographic information system (GIS) component
- the ability to provide expert knowledge specific to the issue of interest
- the ability to be used for diagnosis planning, management and optimisation
- the ability to assist the user during problem formulation and the selection of solution methods.

Where the DSS is intended as a development tool, Rizzoli and Young (1997) suggest that two additional properties are of interest:

- the ability to acquire, represent and structure the issue of interest
- the capacity to separate data from models for model re-usability and prototyping.

The properties identified by Rizzoli and Young (1997) are all technical requirements on the construction of the DSS and, by extension, on the software used to create the DSS. El-Swaify and Yakowitz (1998) provide a less technically based introduction to multiple objective DSS suggesting that

> Ideal decision tools for valid recommendations on land, water, and environmental management must include quantitative and analytical components; must span and integrate the physical, biological, socioeconomic, and policy elements of decision making; and must be user-friendly and directly relevant to client needs.

The IWRAM framework is a DSS that uses an integrated scenario modelling approach, rather than an optimisation-based approach. That is, the DSS framework has been developed to consider 'what if' questions relating to policy and management of the system, rather than to provide the model user with the 'best' option under given criteria. It should be noted, however, that optimisation-based applications could be developed using the same framework but would require a different 'front-end' or decision support platform.

The framework needed to bring together knowledge and understanding of the key issues facing the catchment in the short, medium and long terms. It needed to represent the key biophysical processes in the catchment that support analysis of the key issues, as well as key social and economic motivators, dependencies and impacts. It also needed to provide meaningful and compatible measures (indicators) to assess the likely impacts of various scenarios within the catchment, as well as to capture the linkages between processes and their representations.

The IWRAM framework achieves this through:

- 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 impact assessment and comparison of scenarios
- an integrating engine that links scenarios, models, data and indicators, and supports 'what if' analyses.

Figure 4.1 shows the linkages between the IWRAM approach and the IWRAM framework.

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.

The design of the DSS was based around three basic concepts:

- the DSS outputs were to allow spatial analysis and display
- the DSS must be easy to modify and be applicable to different catchments and environments
- each module must be able to stand alone.

The ability to visualise outputs as maps and networks is now a standard feature of DSS. This can be achieved through: (1) developing the DSS in a GIS package; (2) incorporating GIS-type functionality into the DSS; or (3) through exchange of data in a compatible format. The particular implementation chosen is determined by the sophistication desired of the DSS, access to GIS software and the programming resources and skills available to the DSS development team.

Decision support systems are designed to support the exploration of unstructured questions, i.e. 'what-if' analysis. As the extent and range of the 'what-if' questions changes during the lifetime of the DSS development, it is important that it has clear and easily accessed data structures that can be readily modified by the users (not just the DSS developers).

Capability to extend a DSS to other catchments is dependent on the specificity of the issues (and the models chosen to support exploration of those issues), and the DSS design. For the IWRAM project, it was important that the same DSS software could be applied to all catchments in the study area.

The development of stand-alone modules reflected two realities: team members came from different government agencies with different computing standards; and the DSS design had to allow sub-teams to work independently as they rarely had the opportunity to work together. The integration is then achieved through design and data standardisation, rather than through integration of the models per se. Of course there are inherent dangers in this approach, such as incompatibility of models. However, such dangers can be managed by strict adherence to design principles, good communication and rigorous project management.

Role of stakeholders

Effective and sustainable catchment management can be achieved only 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 DSS 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.

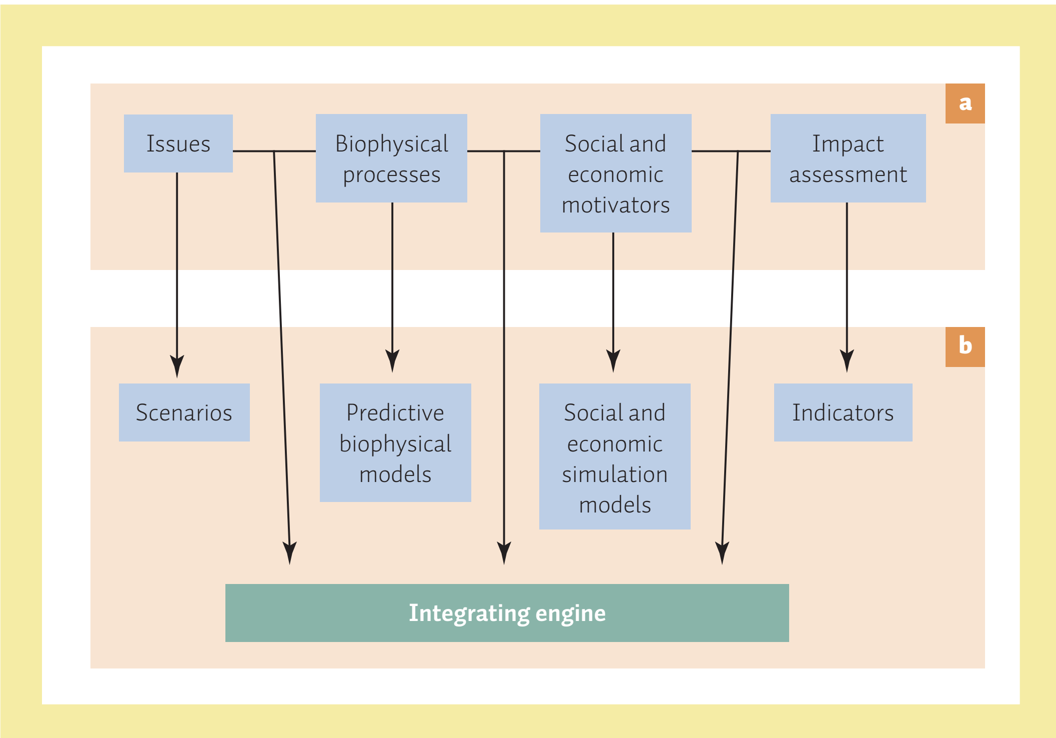

Figure 4.1 Relationship between the Integrated Water Resources Assessment and Management (IWRAM) approach and the IWRAM framework showing the linkages between the components: (a) gives the components of the IWRAM approach; (b) is the IWRAM framework

The intended use of the DSS will determine the appropriate participation program, which can range from inclusion in data collection, to DSS design, development of scenarios for analysis and their assessment. Mostert (2005) provides a good overview of participation in IWRM.

The IWRAM project in northern Thailand substantially enlarged the number of government organisations involved, from the Land Development Department to include Royal Forestry, Royal Irrigation, Agriculture, and the Office of the National Water Resources Committee. These agencies saw themselves contributing to the development of modelling tools in order to understand and assess options to address erosion, water supply, forestry protection, subsistence needs and agricultural development. The departments worked together in developing and incorporating the modelling components in a software system for widespread application. The modelling also provided a focus for capacity-building through training and the development of training materials. This focus has had the benefit of exposing managers and researchers from otherwise fairly narrowly focused disciplinary perspectives to other ways of thinking about change in the system. In this way it has enhanced their integrated-system understanding.

Participation occurred at two main levels in the IWRAM project. At the government-agency level, stakeholders were involved in a co-design process. This meant that researchers and government agency staff were equal partners in the design of the project and methods. This was necessary to ensure uptake of results by government-agency decision-makers and to make sure that tools being developed were appropriate to the Thai situation. This participation was enabled through workshops and a collaborative project approach involving many project partners. The second form of participation was less collaborative and focused more on information gathering. This participation involved surveys of farmers and households in the study area and was used to develop an understanding in the project team of the ways in which decisions are made by these groups, and the constraints under which they operate.

Framework development

Within the framework there are four interrelated components. The choices of what constitutes these components—i.e. what models, what indicators—is iterative and may finally be decided by the limiting factor (which is often availability of data). This section discusses the components and how they were selected for the northern Thailand IWRAM project.

Issues and scenarios

Together with stakeholders, the issues to be addressed by the DSS were articulated and focused around the relationships between

- water (supply and demand)
- agricultural land use (tradition and practice)
- poverty alleviation (farmer net income) and subsistence production
- environmental state (erosion, forest maintenance, and sustainability of land and water resources).

The driver for the DSS design was then the formulation of these issues into scenarios and the indicators and models that would be required to satisfy their analysis. These scenarios fall into the following broad classification.

Climate scenarios

Climate variability and extreme events can often have a profound effect on outcomes. Short-term fluctuations such as droughts or floods can affect agricultural production, water availability, and rates of environmental degradation, such as soil erosion. Three typical climate scenarios might consist of a 'normal' hydrologic year, a 'wet' year and a 'dry' year.

Long-term shifts in climate can also have major effects on the catchment, such as altering the average annual rainfall or temperature, which in turn might affect the economic viability of different types of crops or land uses. In this case, the integrated models might be tested for consistent but small increases or decreases in climate variables (such as annual rainfall) over a time interval of 10 years or more.

Forest-encroachment scenarios

For these scenarios, it is assumed that forest encroachment occurs through current householders in the catchment increasing the amount of land available for their own agricultural use, as opposed to additional migration of families into the catchment. Forested areas on steeper slopes of the upper catchment are converted to farmland, while the existing cropping in the cleared valleys remains unchanged. Increasing the amount of land available to the existing households for production, increases their socioeconomic wellbeing, as both household cash and rice production rise, implying increased food security and increased disposable income to households. However, this increase in social and economic wellbeing would be expected to come at the expense of the environment, with a likely increase in erosion and reductions in biodiversity related to the removal of forest.

Migration scenarios

The forest encroachment scenarios are based on current landholders increasing their access to land and water by removing forest in the catchment. An alternative scenario of concern in many catchment areas in northern Thailand is where migration of new landholders into the catchment occurs. Lowland farmers are often concerned about how such migration is likely to affect their access to water. Resource-management agencies are also concerned with potential increases in erosion as a result of this type of forest encroachment. A migration scenario might include an increase in the number of farmers in the upper reaches of the catchment and a change in land use from forest to farmland along some of the upper slopes.

Price-shock scenarios

The impact of a change in the price of agricultural products can also be tested. A typical scenario might be a drop in the price of rice and soybeans. This would be expected to affect household income and might also influence the relative mix of crops grown.

Deforestation scenarios

Scenarios of forest conversion might range from the extreme scenarios of 30–50% deforestation across all land units and removal of forest from steeply sloping land, to the more probable scenarios of removal of forest from the more-accessible land suitable for agriculture.

Land-management scenarios

Another potential use of the DSS is to help government departments with their land use planning activities. The DSS can be used to estimate the economic, social and environmental effects of different crop and land-management combinations across different parts of the catchment.

A conceptual framework to support all these scenarios may be very complex and trade-offs between complexity and practicality are required. A sample conceptual framework that would support a range of price-shock scenarios is given in Figure 4.2.

In addition to the above, a 'base-case' scenario is always defined which describes the current land use and management practices. This is often used to provide a comparative measure of improvement/degradation for the 'what-if' scenarios.

Finally, note that a scenario is a modelling tool that allows a user to explore a change in natural resource management on biophysical and socioeconomic processes. Scenarios thus reflect stakeholders' different interests and objectives. In this regard, while an individual stakeholder may have a single objective, the multi-objective nature of natural resource management is embedded in the IWRAM DSS by illustrating the consequences, spatially and temporally, of management strategies on a range of biophysical and socioeconomic indicators.

Regional structure

The temporal and spatial scales at which processes are represented are influenced by a wide range of factors, including the scale at which management decisions are taken, the scale at which the DSS is to be used, the scale of available data and the emphasis of the investigation (e.g. on analysis of policy or of particular management practices).

The IWRAM models operate at a number of spatial and temporal scales. These are described in detail in Chapters 5–8 and in summary in Chapter 9.

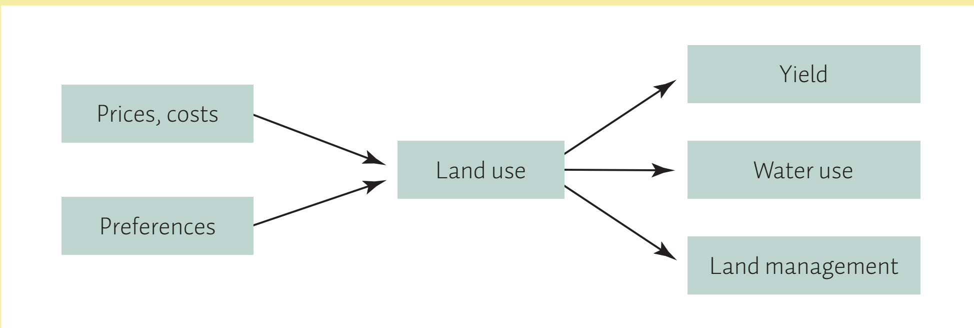

Figure 4.2 Example of conceptual framework: an agricultural catchment affected by changes in crop prices

The unifying spatial scale for all modelling was the node. Nodes are identified through the stream network as distinct zones of activity in catchments where information on the trade-offs between indicators is required. Thus, the spatial and temporal scales of the various models are synchronised at these nodes.

Nodal network approaches are a common framework for considering water-allocation problems—see, for example, Fedra and Jamieson (1996), Jamieson and Fedra (1996a,b), ESS (1999), McKinney et al. (1999), Rosegrant et al. (2000), Letcher and Jakeman (2003) and Letcher et al. (2004). In this type of model framework, a river basin is represented as a series of nodes. Nodes represent points where extraction and other activities impacting on the stream are aggregated for a region and modelled. Regions refer to land or users attached to a node. These may be defined by physical boundaries (e.g. sub-catchment areas) or by social, economic, technical or political boundaries, depending on the problem being addressed by the model. An example of this type of boundary may be the property areas of irrigators extracting along a reach of the stream between two nodes. Flows are generally routed from upstream nodes to downstream nodes and thus impacts of upstream land and water-use activities on downstream users are modelled.

Spatial representation

The treatment of space, and how the catchment is delineated, is important both from the perspective of how scenarios are cast (e.g. 'What is the effect on "the catchment"/"the household"/"the river network" of ...') and the style of modelling that is selected as most appropriate to underpin the analysis.

There are basically four different approaches to treating space in a model.

1. **Non-spatial models** do not make reference to space. For example, regional and national economic impacts arising from a change in the management of a system (e.g. modelled using a choice-modelling approach) may not refer to any particular spatial scale.
2. **Lumped spatial models** provide a single set of outputs (and calculate internal states) for the entire area modelled. For example, the impact of a change in management practice on soil erosion may be modelled using a simple function as a total change in erosion for the entire catchment. In this case, the catchment is not disaggregated into smaller units and the interactions between parts of the landscape are not considered.
3. **'Region'-based spatial models** provide outputs (and calculate internal states) for homogeneous sub-areas of the total area modelled. These sub-areas are defined as homogeneous in a key characteristic(s) relevant to the model, e.g. homogeneous soil types or similar production systems. For example, the catchment may be disaggregated into smaller regions that are homogeneous in one or more attributes, such as drainage, soil type, slope class etc. Interactions between these three 'regions' are then considered by the model. The model can also output impacts for each of these regions.
4. **Grid or element-based spatial models** provide outputs (and calculate internal states) on a uniform or non-uniform grid basis. Neighbouring grid cells may have the same characteristics but will still be modelled separately, as opposed to homogeneous

region-based spatial models where these areas would be lumped together. For example, when considering the impact of land use changes on terrestrial ecosystems, the landscape may be divided into a uniform grid, where the descriptors of that grid cell are based on either a single measurement or an average of measurements in that cell (e.g. landcover, species distribution, soils). These cells may then be modelled either independently or as a connected series of cells (i.e. each cell affects the outcomes in neighbouring cells) depending on the way in which the model has been conceptualised.

For integrated models the entire model may not operate using a single approach. For example, a grid-based model of rainfall run-off may be used to feed a single, spatially averaged output to an economic or ecological model. The spatial approach of the integrated model is generally at most as disaggregated as the least spatially distributed model in the integrated system. Disaggregation of models to different spatial scales can lead to many difficulties in integrated models, as the spatial scales of interest in one component model may be quite different from those of a model from a different discipline.

Spatial representation in the IWRAM framework

Three main spatial representations are used in the IWRAM framework. Two of these—land units and land-modelling units—are used to underpin 'region-based' spatially explicit models. The third is a standard, grid-based approach to modelling, where the catchment area is divided into a uniform grid. In addition, some socioeconomic models in the system were focused on household scales. The term 'resource management unit' was used to represent households that shared specific characteristics, such as access to irrigated paddy land or to rainfed upland fields. Land units and land-modelling units are explained in more detail below.

Land units

Land units (LU) are a basic delineation of a region. It is a term familiar to agricultural practitioners worldwide. A land unit is defined using the FAO land-evaluation definition (FAO 1976) as an area with homogeneous land qualities influencing crop performance, and with the same management and practices.

Land-modelling units

A common unit used in IWRAM is the land-modelling unit (LMU). This is a 'homogeneous' area used to disaggregate a catchment for the purposes of modelling. The concept of 'homogeneous' is applied in terms of various appropriate ecological, physical, social or economic characteristics, usually defined by the model question being considered. Common characteristics underlying the definition of LMUs in the model are topography, climate, soils, geology, ecological community, farm production or industry type and policy scales. LMUs are generally considered to be intersections of these key characteristics so that each region or modelling unit considered by the model is 'relatively homogeneous' in terms of these characteristics. LMUs are generally associated with a set of activities that interact with the hydrological cycle in a defined way. More than one LMU can be linked to each node.

Within IWRAM, LMUs are commonly derived from the intersection of land units with another attribute. If this attribute is land use (the pattern of which may change from one scenario to the next), then LMU maps need to be created dynamically as part of the scenario investigation. For example, a scenario to explore the impact of an increase in area of a particular land use would firstly create a new land use map. This would then be intersected with the LU map to create a new LMU map, which is the spatial representation input to the various IWRAM models.

Model requirements and implications

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- 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 the generation of rainfall run-off, 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 policies 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.

Model selection is also influenced by data and resource availability, including access to professionals with modelling skills. It is far better to develop less-complex models with a local flavour, that address the issues and match the data, than use imported models that over-parameterise, over-complicate and side-track the development. These models also have limited scope for broad-scale adoption.

Scenario requirements

The scenarios to be explored place several requirements on the structure, components and conceptualisation of the IWRAM DSS.

Climate scenarios

To address these scenarios, the DSS should be capable of predicting streamflow and water availability in response to a range of rainfall sequences.

Forest-encroachment scenarios

The DSS should be capable of defining new land use maps that represent the reduced area of forest (and the land uses that replace it). It would need to support analysis of the impact on farmer income of access to agricultural land, but be able to trade this off against the environmental degradation caused by removal of forests. This degradation may be measured in terms of consequent water quantity and quality, soil erosion, reduction in biodiversity etc. In particular, the influence of deforestation on streamflow yields and erosion must be represented.

Migration scenarios

Scenarios of this class are similar to the forest-encroachment scenario in that the conversion of forest to agricultural land is a trade-off between the environmental impact of that reduction and the potential increase in income to the community. However, in this case, the increased income is not captured by the residents, but by the immigrants. To support this analysis, the DSS should be capable of differentiating between residents and immigrants and adjusting any economic analysis as a consequence. In addition, the off-site impacts of greater demand and use of resources in the upper catchment on down-stream availability needed to be represented.

Price-shock scenarios

To support assessment of these scenarios, the DSS should be capable of incorporating changes in crop prices and reflect the connection between farmer decision-making and crop prices.

Deforestation scenarios

To support analysis of such scenarios, the DSS would need to be capable of knowing the extent and location of the forest areas, and be capable of selecting a sub-set of these based on the intersection of one or more attributes (e.g. proximity to another land use, forest area of a particular slope class). It would need to be capable of replacing the forest with an alternative land use. It may need to know about soil types if soil movement is to be considered as part of the scenario analysis.

Land-management scenarios

The DSS should be capable of differentiating between alternative land-management policies that vary spatially across the catchment. It should consider the mix of land uses and their management, and support analysis of the impacts of these. Ideally, it should also consider the attitude of residents to the introduction of alternative management practices and the need to provide incentives for their adoption.

Implications

These scenario requirements have a number of implications for the conceptual structure and component models of the DSS. These are summarised in Table 4.1.

Remembering the need to have stand-alone modules, these requirements can be met by the development of a small number of models, namely a crop model, hydrology model, erosion model and two socioeconomic models (decision and impact). These model components are described in detail in Chapters 5–8.

Model selection

Despite the apparent availability of biophysical models from the scientific literature, all of the models integrated into the DSS required some adjustment to take into account the environmental factors of Thailand's highland areas, such as the steep slopes and high monsoonal rainfall or the agricultural factors associated with the crop- and land-management techniques of the highland farmers. Some models also needed further development to account for the data inadequacies, either in the form of inputs and parameters to drive the models or as outputs to assist in their calibration.

Thailand represented both challenges and opportunities for the development of models of decision-making and socioeconomic impact. Survey data for households within catchment areas could be collected and analysed relatively cheaply (compared with working in Australia), allowing for a comprehensive data-set with which to design and test models. Most stakeholders, however, were biophysically focused and had a strong resistance to adopting overly complex representations of economic processes, such as optimisation-based investment models. Economic research thus focused on providing useful, accurate tools and information that was accessible to a broad range of project partners.

Table 4.1 Model requirements and their implications in the Integrated Water Resources Assessment and Management decision support system

Requirement	Component model affected	Model implication
The integrated model had to be as simple as possible while retaining accuracy to allow for shorter run times, simpler integration and more uptake of the DSS.	All model components	Models should be as simple as possible. Adding complexity to component models should occur only where this is necessary for the model accuracy and usefulness.
Capable of predicting crop yield and water use under variable climatic conditions and with different access to irrigation water	Crop model	A crop model was required that was detailed enough to represent key processes in the water-limited growth of crops.
A large variety of crops able to be simulated for yield and water use	Crop model	The model had to be available or able to be calibrated to locally produced crops. This meant that a locally available model or one that had already been used in northern Thailand was desirable.
The availability of surface water under different climatic and land-cover conditions had to be simulated	Hydrology model	The model had to be sensitive to rainfall, temperature and changes in forest cover.
Erosion should be able to be simulated under different crop-choice and land-management options, on a variety of slopes and soil classes.	Erosion model	The model needs to be adapted for the local conditions experienced in Thailand (including very steep slopes).
The impact of changes in water availability on people in different parts of the catchment should be able to be estimated. These should include 'economic' and 'social' indicators, including the capacity of people to meet their subsistence needs.	Economic impact model	The model must consider cash and subsistence production given different crop yields under various climatic and irrigation-access scenarios.
The model should reflect farmer preferences in cropping patterns in response to changes in prices and water availability.	Decision model	The model should contain a decision component that simulates changes in farm production decisions under different price, climate and irrigation access scenarios.

In practice, most models represent a compromise between rigour and utility. In other words, they are generally not purely empirical or mechanistic. These 'intermediate approaches' are very useful for resource-management evaluation if correctly constructed, and provide a good compromise between empirical and mechanistic models.

One common misconception is that model accuracy invariably increases with model complexity. In fact, the opposite can sometimes be true. A model with fewer parameters can be easier to calibrate and can give more accurate predictions than a complex model, even though it has lower explanatory value. Williams and Probert (1983) identified the importance in restricting the number of parameters without significantly sacrificing the theoretical principles or predictive capacity of the model.

Intended model use

Perhaps the most important factor in determining the appropriateness of a model is its intended use. This determines the processes to be considered and their level of detail, and the model accuracy required. For example, an emphasis on erosion–productivity requires detailed consideration of soil processes, but this may not be as important for, say, pest damage studies. Intended use also determines the complexity of the model—that is, the number of processes to be included and the level of detail. For example, if an annual crop yield is all that is required, a relatively simple empirical approach may be perfectly adequate, if not more appropriate, than a more-complicated mechanistic approach.

Data availability

In catchment- or regional-scale studies, the issue of data availability becomes of utmost importance. Mechanistic models often require a large amount of physical data, such as a variety of soil parameters, which are rarely collected during land surveys and are available at only a few experimental sites. Empirical models tend not to require such large quantities of data and are computationally simple, but have limited meaning. Therefore, intermediate approaches may represent a suitable compromise between data requirements and physical meaning. Problems of data availability are exacerbated in developing countries, where detailed information for supporting complex models is less often collected.

Outputs and indicators in the IWRAM decision support system

The IWRAM DSS was developed to allow users to understand socioeconomic and environmental trade-offs resulting from a variety of management and climate scenarios. These trade-offs include the off-site impacts of upstream resource-use decisions on water availability, erosion and household poverty downstream, as well as the on-site benefits of such changes. Indicators and outputs of the IWRAM DSS have been designed to allow these trade-offs to be estimated and understood for the scenario types outlined previously.

The biophysical indicators used in the IWRAM DSS can be summarised as follows:

1. Crop yield (tonnes/ha)
2. Crop water demand (mm). This is the total crop water demand required for the crop to evaporate at full potential.
3. Irrigation (mm). This is the total irrigation applied throughout the season. If crop water demand does not exceed the amount of water available within the stream then irrigation is the same as crop water demand.
4. Residual streamflow (ML). This indicator shows wet-season, dry-season and annual streamflow following abstractions for crop irrigations.
5. Erosion (tonnes/ha)
6. Forest area (ha).

The socioeconomic indicators are provided at different spatial scales in different implementations of the DSS. They allow for 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 indicators provided are as follows:

1. Cash per household (baht). This indicator describes the 'economic performance' of households.
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 have a strong preference to produce their own rice.
6. Cost of rice deficit (baht). This indicator shows the cost to the household of purchasing unmet rice requirements.

Regardless of the particular models used, the IWRAM approach identifies a range of indicators to evaluate the impact of alternative 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.

Linking it all together — the 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 analysing scenarios. Each variant of the IWRAM DSS uses a different integrating engine, though they are all examples of a coupled-model approach to integration.

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 homogeneous modelling 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.

Implementation

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.

All of the integrated approach projects in which we have participated have reinforced the rather obvious point that software development must be undertaken with a clear picture of the target audience, the specific issues and the uses. Thus, while a sophisticated, object-oriented software platform may be both useful and desirable in some circumstances, in other cases a spreadsheet-based model may be more useful for extending project ideas and science. Having different software products aimed at different audiences can also be a useful outcome of a project. On the other hand, software development should not be the primary objective of the work undertaken. The software is a tool to enhance communication and interaction between different disciplinary teams. It should be a focus of the project mainly in so far as it encourages communication of ideas and enhanced understanding of the integrated nature of the problem.

Conclusions

This chapter summarised the requirements placed on the DSS and its components and gave a brief overview of the ways in which they were addressed in the IWRAM framework. This provides some background for the challenges in developing a tool and improved understanding for integrated water resources management. Chapters 5–8 describe each of the component models and their implementation in detail. The description focuses on ways in which the design of these components was affected by the model requirements.

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