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CHAPTER 6

MATHEMATICAL MODELING IN INTEGRATED MANAGEMENT OF WATER RESOURCES

MAGICAL TOOL, MATHEMATICAL TOY OR SOMETHING IN BETWEEN?

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Introduction

Are models useful for management and decision making on water resources? Are the efforts put into them justified? In this chapter we argue that mathematical modeling is one of the few options available to look at the questions of future changes and impacts of human activity on water resources. Models and their results, however, are often mistrusted, underutilized or misused in management and decision making, and as a result the role of models in water management seems to be both controversial and unclear.

Critical questions related to the use of models in decision making on water resources include: What is the connection of modeling to social, economic and political aspects of water management? Do models provide an adequate representation of biophysical processes? Do models present their results in a form that addressed the actual needs of policy- and decision-makers? Do decision-makers and other "non-modelers" understand the limitations included in the models and their results? Are there strategies in model development and communication that can help allay unreasonable fear and mistrust of mathematical models? How can the perceived legitimacy, credibility and transparency of modeling be improved?

This chapter presents, drawing on examples from the Mekong region, our ideas and suggestions on responding to changing user needs, model content and user interfaces as well as on increasing the linkages between modeling and other critical issues in water management. We argue that further work is needed on linking hydrological and environmental issues with social and economic activities to facilitate balanced modeling and impact assessment, and consequently, decision making. This will require multi- and cross-disciplinary approaches for both modeling and impact assessment, and better communication and interaction between modelers and non-modelers. This, in turn, helps to produce more transparent and relevant information, and creates stronger scientific and social basis for impact assessment and management decisions.

Integrated modeling and assessment of water resources

Challenges for integrating multidisciplinary information

Successful implementation of environmental management policies requires thorough understanding of environment and its linkages with the surrounding society. Due to the complex nature of these issues and their interconnections, various kinds of mathematical models have been developed to support management and governance. Models are used to improve understanding of cumulative and aggregate effects, to provide forecasts, and to help to quantify scenarios, which in turn are helpful for long-term planning.

However, the role of models in environmental and water management is controversial. There appears to be two totally different schools of thought regarding the use of models. While some managers and scientists look at the models as basically mathematical toys of over-enthusiastic engineers with only weak connection to real problems, others value models above anything else trusting almost blindly their results. As a consequence, models and their results are often either poorly integrated in the decision making, or the management is based completely on their results without proper consideration of the limitations and uncertainties of the models and their results.

This chapter looks at the strengths and weaknesses of mathematical models based on the experiences from the integrated water management in the Lower Mekong Basin. Integrated and balanced management of water resources is an extremely challenging task, as it should take into account several different fields from environment to economy and society. Information needed in water management thus comprises not only hydrological but also environmental, social, economical and political information and data. Collecting information on these wide-ranging fields is an enormous challenge, not to mention actual analysis and comprehension of the issues.

The biggest challenge, however, is successful integration of these different types of information. It requires open and long-term cooperation between researchers from different disciplines, preferably as a multidisciplinary team working together from the very beginning of analysis work. This naturally necessitates also some sacrifices, such as sharing of financial resources and project achievements within the team. On the other hand, it also shares the workload and most probably brings new kind of ideas and approaches for the entire team. However, the success of integration may be threatened by the reluctance of the decision-makers to adopt new kind of information that conflicts with prevailing understanding and management strategies. Achieving greater integration thus demands a change of mindset from both researchers and decision-makers, and it can be rather time-consuming and even frustrating experience for all the parties involved.

The authors note the valuable contribution by Somlyódy (1994) to the issues addressed above. He points out tremendous gaps in the integration of environmental management, technology and society, between different disciplines and professions, barriers in legislation, institutions and decision making, and lack of future visions supported by science. Related to this, Nancarrow (2005) addresses some interesting issues on modeling, and particularly on the relationship between modelers and social scientists. She points out some differences in their overall approaches (to simplify: modelers simply assume a problem and start by defining and collecting data needed to solve it, while social scientists start by identifying the different stakeholders and how they see and define the problem) and also addresses challenges related to working in multidisciplinary teams.

Over the past decade, many of the gaps have become narrower, through a number of scientific, institutional and other initiatives and cooperative efforts that have led to progress in integrated approaches. These include for example the concept of Integrated Water Resources Management (IWRM), EU-funded European Forum for Integrated Environmental Assessment (EFIEA), international conventions such as the Mekong River Agreement and its implementation by the Mekong River Commission (MRC) as well as activities by different research institutions and NGOs in developing more cooperative and integrative approaches.

Approaches for integrated modeling and assessment

Integrated Modeling and Assessment (IMA) has evolved rapidly over the last decade as a new scientific concept to address the need for more multi- and cross-disciplinary approaches. Rotmans (1998) notes the increasing recognition for the field of Integrated Assessment (IA) but at the same time recognizes that the methodological basis is lagging behind the expectations from the outside world. Parker et al. (2002) give a review of state and position of IA modeling, concluding that the science behind IA modeling is often not new and in many ways it can be considered to be the combining of old areas of science and research to consider problems in new, more holistic ways.

One of the main methodological problems in IA modeling is the scale, and the resolution of different scales for different system components. Jakeman and Letcher (2003) point out some important considerations within IA modeling; appropriate time periods and time steps to choose over which to model the highly variable ecosystems, handling model complexity by keeping the level of integration of issues and disciplines manageable and developing methods to characterize model uncertainty.

Janssen and Goldsworthy (1996) discuss the importance of attributes of multidisciplinary teams and research efforts, that are required for success in IA modeling. They emphasize the importance of the teams developing their own sets of norms and values and conclude that attitude, communication skills, education and experience are all important attributes. Communication is a central issue both internally among the team members and externally with decision-makers, stakeholders and other scientists. Parker et al. (2002) and Jakeman and Letcher (2003) highlight that the process of IA and modeling is actually as important as the product of any particular project. Learning to work together and recognizing the contribution of all team members can create a strong scientific and social basis created to address the environmental problems of the twenty-first century.

In this chapter, we seek to illustrate what models are, how they are used and how different people perceive them. Experiences are derived mainly from work done in the Mekong region, and in the Tonle Sap Lake in particular. The use of modeling tools for supporting sustainable environmental, social and economic development is underlined. An essential part of this work is capacity building for future use and maintenance of the developed tools by the end users in the region. We also discuss standard as well as tailored models and try to see how they fit to different kind of needs of problem solving.

There is a great number and variety of models developed for the Mekong basin, with overlaps and weak connections between the models being the rule rather than the exception (annex 7.1). This can be seen to illustrate the common difficulties to coordinate between individual modeling approaches as well as lack of proper understanding of the capabilities of different models by many managers and decision-makers. The Mekong River Commission (MRC) has a key role and opportunity to create a solid model and information base for hydrological, environmental and socioeconomic impact assessment to support the development planning in the Mekong basin. To this end, this chapter also discusses the ongoing work on MRC's Decision Support Framework (DSF).

Specific attention is paid to the questions and problems of integrated assessment and modeling. The case study in the Tonle Sap Lake and its floodplains offers a complex, challenging and important task in this respect. Finally, conclusions are drawn to identify barriers and possibilities for developing the integrated assessment and modeling platform, for bringing the new information to the disposal and use of the decision-makers, and for linking modeling better with other aspects of water management.

Modeling: The outline

What are models?

Contemporary methodological literature on natural resources management presents a wide array of analytical and computational approaches, most of which are closely related with modeling. The different approaches range from various statistical techniques (empirical) to process models with difference or differential equations (mechanistic), and from decision making models and optimization (pragmatic) to checklists and impact matrices (verbal). Much of the practical application of these models is in one way or another related to various administrative needs.

In environmental and socioeconomic modeling, the planning and management component is typically crucial. This is simply due to implicit role of human being in such systems, since the concept of "environment" per se without a human being is equally as absurd as "socioeconomy" without a human being (or, at least in the context of the Mekong region, without environment). Sutherland (1983) sees the combined use of models in decision making as "an art of getting things done." For this purpose, he has categorized decisions and consequent modeling approaches into four main categories described in box 6.1.

Water and ecosystem model use can be divided into research, engineering, environmental management and socioeconomically orientated branches. Typical uses in research are, for instance, comprehensive ecosystem models describing detailed nutrient and carbon cycles and large number of species or classes of species. Engineering applications can for example include design of control structures such as embankments, culverts and gates, or finding optimal dredging solutions.

An individual working with environmental problems, decision making, and environmental policies, inevitably comes across persons whose approaches and conventions to scientific problem solving and decision making are very different. This is partly due to the constantly evolving state of the field, and partly due to the great interdisciplinarity; environmental studies is at the cross-roads of several tradition-rich pure and applied sciences.

Engineers, economists, biologists, sociologists, etc., have all their own paradigmatic backgrounds. Communication problems and intolerance, and even prejudice concerning approaches are very common. Take as an example the word "model" itself which has several different meanings. Synonyms such as ideal, exemplary, and perfected can be found among adjectives, miniature, saint, idol, representation, symbol, prototype, example, and replica among nouns, and pose and mimic among verbs (cf. Somlyódy and Varis 1993). The exact interpretation depends on context and convention. A brief description of water and ecosystem modeling is given (box 6.2).

Box 6.1 Four main model categories

Operational models: Provide enhanced possibilities and support for real-time management and decision making through automated data retrieval from the water body in question. Such data is often being used in real-time operations such as reservoir operation, flood protection or treatment plant operation. Models for short-term predictions are needed. Typically, the most essential features of data stream are filtered out.

Tactical models: The basic task is to find input-output relations between key variables of the system. In surface water modeling, monitoring data is usually used to construct models, which allow for instance "what-if" type of scenario analysis and trade-off analysis between different stakeholders and water users.

Strategic models: By definition, a strategic analysis should be used to project current situations to states, which have a significant probability of occurrence. Environmental and social impact assessment, medium-term planning and other tasks in which the system is exposed to potential structural changes are typical situations for the use of this category of models. Game theoretic models, simulation, probabilistic risk analysis and scenario analysis are typical computational approaches.

Directive models: Problems such as sustainability, adaptivity, resilience, and description of possible future events are included in planning and management of the evolution of the system in the long run. The problems and data sources of the systems are essentially more expert-judgment based, policy and politics related, and subjective.

Box 6.2 Mathematical models

Numerical model is itself a simplification of the reality and it attempts to describe the real world phenomena based on the physical and chemical laws, and functions derived from biology, ecology and socioeconomics. It offers an extension and tool for brainwork to analyze complicated processes and their interconnections.

With the model, it is possible to simulate processes that are difficult or impossible to describe or research any other way, including analysis of the probable future changes and their impacts. The model can describe various phenomena and analyze the effects of changes in independent (i.e. explanatory) variables on dependent variables.

Who develops, who benefits?

Among the biggest challenges within the environmental modeling is the gap between modelers and potential model-users i.e. environmental planners and managers. This gap has often been large due to various reasons, the lack of communication and prejudice towards models and their results being among the simplest but biggest hindrances. Modelers and model-users often speak different languages, with modelers far too often resorting to too technical terms and/or not explaining clearly the basic principles and assumptions behind the models. Modelers and model-users also have usually different needs and demands: while modelers want to develop more advanced models with long-term perspective, planners and managers actually need quick and simple model results that are accurate enough. Although modelers put a lot of effort into developing advanced models, they rarely put equal amount of time to transferring the model outputs into simple—and simplifying—results that planners and managers could more easily use. This kind of imbalance between time allocated for modeling on one hand, and for communications and cooperation on the other, is also unfortunately prevalent in other stages of the modeling.

Consequently, the role of model-users has become increasingly important and has led to increased efforts in user training and development of more user-friendly model interfaces. The successful transfer of model results to the end-users is naturally an absolute necessity for sustainable use of the models. But the information exchange must happen both ways: model developers also have to listen to the decision-makers and managers from the very beginning of model development—only in this way the models will be able to answer to the most urgent problems and questions that the managers face. As a result, in recent years there has been a general tendency to involve environmental managers and planners, limnologist, biologists and other "non-modelers" better into model use and even development. This diminishes the gap between the "non-modelers" and the modelers and improves the usefulness of the models for both management and research and development.

The dialogue between the modelers and model-users is particularly important because managerial decisions on natural and environmental resources are usually bound to forecasts and assessments with very high uncertainty. Due to economic, time-related and other practical constraints, it is often difficult or impossible to collect thorough enough empirical data, especially in developing countries where existing resources and information are usually more limited. The MRC has been no exception on this, and is still facing wide gaps in its environmental information on the Mekong region. However, the MRC is still to be commended for promoting a basic research programme in the Mekong region, developing the data and information bases, and building the capacity of the national institutions in its member countries.

Standard or tailored modeling?

Regulatory needs. In practice, environmental modeling is still a relatively heterogeneous field with a great number of commercial and public modeling tools available. This is as much due to the rapid evolution of the field as the wide gap between model developers and end-users. This problem is particularly valid in planning and management settings. There are almost as many models as there are modelers and there exist few "best-approach" guidelines to help select the most suitable model for the issue at hand.

On the other hand, the diversity must be tolerated otherwise no progress is possible. Moreover, the tasks to which models are being used are diverse enough that no generic environmental models are realistic. Many large government agencies or commercial companies have developed selections of environmental modeling tools to address various needs. Some actors include the United States Environmental Protection Agency (EPA) and the European Commission (EC) from the public side, and the Haestad Methods and Danish Hydraulic Institute (DHI) from the business side. Such standardization is justified as certain model products become well-known and the communication around them becomes easier. However, such models are often understood as being more general-purpose tools than what they actually are and often leads to ignoring the case specificity of the actual problem to be solved.

Box 6.3 Example of standardized models in the United States

The USA has established and implemented a Data Quality Law (Public Law 106-554, 2001) to improve standardization and legitimacy of environmental information. Its objective is to "ensure and maximize the quality, objectivity, utility and integrity of information (including statistical information) disseminated by federal agencies." Mathematical models have been also classified to this category and a list of models that fulfill the quality criteria of the law has been published by the US EPA. In the best case, the law could add to the transparency and use of sound science in formulating regulatory policy.

The first experiences seem to be, however, rather disputable. Many citizens groups and environmental activists say that the act is biased in favor of industry, that it dismisses scientific information and will always be more useful to those seeking to decrease government regulation (Rick Weiss, *Washington Post* August 2004). It seems that the best results from the social and environmental development point of view are achieved by a continuing debate between the interest groups, active public media and awareness raised with the help of scientific information. Maybe science should not be disputed in courts of law, except in cases of misuse or falsification of information.

Limits of standardized model packages. The uses of standardized model packages are justified due to the transparency and reliability requirements that are particularly important in sensitive political settings. Many environmental changes and problems impact various different stakeholders and can even be internationally sensitive issues. Many standardized model packages are also relatively strong in presenting and communicating the model structure and model results to the decision-makers and other non-users, thus potentially decreasing the possible gap between modelers and non-modelers. In addition, standardized model packages that have a strong training component may offer relatively easy way to start exploring the basic possibilities—and limitations—of modeling. However, there are cases in which quick modeling implementations with standard modeling packages do not necessarily go hand in hand with credible modeling results or development of sustainable planning tools.

The authors of this chapter are of the opinion that tailoring of models to a specific case usually pays off. The reasons are fundamental: The use of a standard modeling tool confines research approach to the limits of the tool. The problem-solving aspect and production of the most useful information becomes a secondary goal, and fitting the problem to suit the standard approach the primary one. In this case, the inherent limitations of a standard model and approach constrain the whole modeling process from the model construction to the end use of the results.

Standard tools can undermine the reliability of the modeling results. It is relatively easy to assume that a use of a standard tool is more or less “automatic,” the results will be practically always correct, and that application doesn’t require any special experience or understanding of modeling principles. This may lead to fallacious assumptions in setting up the model, passing erroneous data to the model and accepting results without proper checking. Finally, the model results are likely to be used without the user’s proper understanding about the limitations of the assumptions that the models are based on. Tailoring necessitates the modeller to dwell deeper into the problem at hand and the modeling techniques applied to it. In this way, it protects against at least the most blatant negligence.

The cases where using tailored models instead of standardized model packages can be more beneficial are further illustrated by the following examples:

1. A modeling case may contain elements that are impossible or difficult to model with any standard approach. An example where major tailoring is needed is a case where different areas need to be coupled: this kinds of areas include e.g. floodplains, river channels, reservoirs, lakes and coastal areas.

2. Standardization may stifle local model development. The best way to train and maintain competent modelers is to involve them in model development. If research and development is externalized, also the quality of the modeling work that any institution is involved in suffers. For this reason, even if an institution is planning to use only standard tools, it is strongly recommendable that it is still involved at least on some level on model research and development as well.

When using tailored modeling tools, it is naturally important to involve decision-makers and other users of the model results in the tailoring of the model. However, their role is not always that straightforward, as they may not always be even able to formulate the problem or required outputs in concrete terms. It is therefore no wonder that they may not be eager, or able, to guide in deciding on the exact approach for modeling. In this kind of case, probably the best option is to first have thorough discussion between the modelers and end users on the expected outcomes of the modeling, and then produce a pilot version of the model with some sample outputs so that the user can comment on them and be thus better included in model development.

Standardized model selection and evaluation. More important than model standardization is to standardize model selection and evaluation procedures. In weather forecasting, standard evaluation methodology has helped model comparison and development. In environmental modeling, however, globally accepted evaluation procedures are still lacking. Because of this, model users and project evaluators have often great difficulties in selecting the right tools for their work, and in ranking different approaches.

There are areas such as applied meteorology where complicated, well-established numerical models are in operational, everyday use, and are used to give predictions i.e. weather forecasts to people. However, the interpreters of the results that the meteorological models provide are still there. Experts in meteorological processes that are able to translate the forecasts of often several different numerical models to the language of an ordinary person—in this case for example, decision-makers operating under the considerable uncertainties of weather—are still a prerequisite for successful use of meteorological models, and consequently good weather forecasts,

In operational cases such as flood forecasting of rivers, the situation is not very different from the meteorological model use. Well-established hydrological models—often a combination of statistical, physically-based, risk-analytical etc. tools—are operated by a hydrological service. This service then communicates forecasts to different stakeholders and users in forms that are (or at least should be) easily understandable.

Way forward for modeling

In order to look at ways to improve the utilization of models and model results in actual management and decision making, and therefore to define the possible way forward for modeling, we should also understand the different kinds of experiences—both positive and negative—with modeling.

In a positive experience on modeling, model development and use facilitates cooperation and dialogue between wide range of disciplines and sectors from computational physics to socioeconomics and environmental policy-making. This kind of multidisciplinarity enables an extensive use of the tools in assessments, encourages making an analytical approach in problem formulation and solving, and directs and stimulates information collection. In this way it may also potentially offer an important platform and basis for transboundary water management.

Frustration with model development can be experienced, for example, in cases where model results are not trusted or seriously taken into account, or are omitted from decision making because of political reluctance or other short-term interests. This kind of situation does question the efficiency of the vast efforts made for developing technically high quality models, and also underlines once again the importance of open communications between the modelers and decision-makers. How can we better link models and other research activities with governance practices? How can we lower barriers for better penetration of scientific and technical information into decision making? These questions deserve serious attention in the research on integrated assessment and modeling.

Finally, it is very important to state the obvious fact that no model, whether for water management, economics or other fields, is an appropriate reason for replacing a human being. Models are like any other tools that require a skilled user, and are useful only if conducted and operated properly but could otherwise even be dangerous. A model without a competent user is like a car without an experienced driver.

Modeling the Mekong River

The Mekong River basin is no exception among the world's rivers as it has been subject to a broad spectrum of modeling efforts over the years (a bulk of the resulted model products are listed in annex 6.1). Many models have been developed and used, and many players are working with them. What are the main questions in the Mekong region that modelers are trying to answer? Why are these questions important? Is anybody coordinating the work or is coordination needed at all? Why there are so many models? Is there something that the old models have not been able to answer, and if so, why? Managers and planners don't actually need new models that are even more elaborate, but rather a single model that is simple but accurate enough. How could this be achieved?

Key lessons learnt from past modeling exercises

Why do various agencies and actors still keep developing models for the Mekong? To what end? In this short summary, there is little possibility of making a thorough scrutiny and thus provide answers to all these questions. However, some general outlines can be provided.

First, it is important to notice that the different models developed for the Mekong region serve many fundamentally different purposes. Most of them have been used either in scientific investigations or as planning and management instruments. Thereby they belong in some cases to tactical, but in most cases to strategic level, often used also in scenario analyses. Typically, the data and knowledge management properties are very crucial and numerical models are used in combination with geographic information systems, statistical models and risk-analytic tools. The accuracy and precision of such tools cannot reach the same level as those models that are used for operational purposes—in a data-affluent, single-purpose setting. Rather, they are more analogical to regional or global climate models used, for instance, in climate change research than to operational weather models.

Second, the field of actors in the basin is diverse. National agencies are active in this regard particularly in Vietnam and Thailand. The Mekong has been an attractive and important topic to for research. There has been tens of academic modeling studies carried out, for example, in the Mekong delta alone. In addition, the Mekong region has been a major target of an array of bilateral and multilateral development co-operation efforts over decades. This has resulted in great diversity of activities which are very difficult to manage; coordination and synthesis are seriously needed.

In these and several other regards, one of the key organizations in the Lower Mekong Basin is the MRC. Therefore, we will focus here on the MRC's concurrent modeling efforts. Donor-driven organizations such as the MRC are particularly challenging since externally driven development initiatives do not easily get rooted in the region. For obtaining sustainable results, the riparian experts and institutions should feel that they are the "owners" of such modeling tools. This is easier in cases in which the initiative comes from inside the countries. However, countries such as Laos and Cambodia have had considerable capacity shortcomings and external input has been seen as an important contribution in the field of water and environmental management. The contribution of the MRC has been considerable here, although it has not been fully capable of creating sufficient links to local experts in the riparian countries. The extension of the training efforts to a wider community of modelers and model users, including academics, is seen as way to increase sustainability and utilization of the modeling tools, as discussed repeatedly in this chapter. This would also shore up the MRC's efforts to recruit modelers.

Box 6.4 Models in development cooperation

Many of the Mekong-related models have been realized as development cooperation projects or programs. Bringing "western" models and modeling approaches into the projects also brings several new things into modeling and model use. One of these is the definite need to integrate social and economic analysis and impact assessment tools with traditional engineering. The problems of the most vulnerable and poorest people cannot be addressed without social considerations and participatory approaches. The great challenge in most cases is to integrate qualitative social information with traditionally quantitative nature-scientific and technological data. In addition, many development co-operation projects have also not properly understood the political, institutional and cultural context where they have been working.

Perhaps the greatest challenge is to provide sufficient training and capacity-building for the beneficiaries and to guarantee sustainable use and benefit of the developed modeling and assessment tools in future. Too many "products" of past development initiatives have been put aside without use. To be honest, full success in this respect also seems impossible. The problems do not lie only in the attitudes and capabilities of the supplier, but also in the barriers with and limitations of the receivers. Naturally there are gaps in technical skills and experience, but they are not the most difficult to overcome. Sometimes the limitations in language skills block a good part of the information transfer. Moreover, the poor countries are often unable to provide long-term work contracts and assignments for young people, and thus a reason for these staff to commit to learning and using this new knowledge.

Both the donor community and implementation agencies should therefore pay increasing attention to follow-up training and cooperation on modeling and impact assessment. This is best done with established trainee networks, preferably by coordinated and collaborative efforts with different actors and institutes. The Tonle Sap case presented later in this chapter shows one practical experience on the integrated modeling approach as well as capacity building and its challenges.

Modeling activities at the MRC

The MRC is one of the most powerful international organizations in the region along with ADB, Asia-Pacific Economic Cooperation (APEC), Association of Southeast Asian Nations (ASEAN), Greater Mekong Subregion (GMS), and various large non-governmental organizations. However, a lot is needed to merge their approaches closer to each other with more open collaboration and information sharing. Among the riparian countries, Cambodia, Vietnam, Lao PDR and Thailand are members of the MRC, but China and Myanmar [Burma] are only dialogue partners. A lively scientific-technological cooperation with these upstream countries is a necessity for comprehensive basin-wide hydrological, environmental, economical and social impact assessment. This issue is also well addressed by the MRC, and its new Strategic Plan 2006–2010 recognizes promotion and improvement of dialogue and collaboration with China and Myanmar as one central objective of the organization.

The contemporary MRC is based on the Mekong Agreement, which was signed in 1995 by the four member countries. Related to the Agreement, the following vision for the Mekong River basin was defined: "An economically prosperous, socially just and environmentally sound Mekong River basin." These strategic outlines that form the backbone of the MRC are very interesting. In fact, they are very much in accordance with the principles of Integrated Water Resources Management (IWRM). Therefore, the MRC's ongoing modeling efforts are performed also in the broad framework of IWRM.

The MRC is currently working on a comprehensive rolling plan and planning process for the Lower Mekong River Basin. This includes the basin's parts that are within the member countries. This comprehensive plan, the Basin Development Plan (BDP) is supported by a massive six-year background analysis—or a series of analyses—under the title Water Utilization Programme (WUP) funded mainly by the Global Environment Facility (GEF).

Water Utilization Programme (WUP)

The WUP aims at helping the MRC member states to implement key elements of the 1995 Mekong Agreement. It provides technical and institutional capacities required for longer-term cooperation to manage the basin's water and ecological resources in a sustainable manner. One of its core activities is the Integrated Basin Flow Management (IBFM), realized jointly by the WUP and the MRC Environment Programme (EP).

IBFM activities are designed to provide information to the decision-makers on the predicted benefits and costs of land and water development of the Mekong basin. This information is aimed at facilitating discussions between the countries to reach a balanced and sustainable economic, environmental and social development in the basin.

Numerical models play a key role in the IBFM process, leaning on the development of the MRC Decision Support Framework (DSF). The DSF comprises a set of hydrological models and flood analysis procedures. So far, the IBFM process has focused on hydrological characteristics as basis for the flow rules, leaning on the properties of the present DSF. However, for widening the scope of IBFM approach, more advanced analytical methods are needed. These include, for example, water quality models for simulation of material transports in the river and in the floodplain and assessing consequent environmental, economic and social impacts under various flow regimes.

Strengthening the model base for impact assessment

The model and knowledge base i.e. MRC's Decision Support Framework (DSF) is the cornerstone of IWRM as well as of the IBFM process. A major challenge for, and interest of, the MRC is to build a scientifically validated, credible and sustainable model platform to support basin development planning, hydrological forecasting, and integrated environmental, economic and social assessment. In this regard, there is still lot of work to do with the DSF. The MRC would benefit greatly from continuing validation and scientific review of the model system, which is necessary for its transparency and credibility, not least in the transboundary context. Widening the platform to an ensemble of models for different scopes, involving model comparison and cross-validation, would most likely lead to increasing credibility and additional usefulness of the DSF. Without doubt, all this would lead to more effective Mekong basin development planning and decision making by the MRC.

An elementary part of the model base is to build a riparian capacity to take care of its maintenance, development and future use, to effectively respond to any emerging development plan with regional importance. Building of wide national capacity and potential in the member countries is necessary, extending from MRC to national agencies and academic institutions. This allows continuing capacity forming and updating for this entire user community and resource. Moreover, international scientific and research networks offer wide range of possibilities for developing countries for training and R&D cooperation. The EU, among others, is showing a growing interest in the Mekong region and in becoming a noteworthy partner in this field.

Related to this, it is essential to make the model base architecture open and modular to facilitate capacity building and avoid possible risks of dead ends in system development. The model engines must be possible to change and be compatible with each other. Modeling is a continuous process and new generations of models appear frequently and need to be easy to use.

Consultants, who are largely responsible for developing models at the MRC, should share responsibility for developing tools which meet the needs of their clients. Moreover, open source software and license-free model systems would widen the possibility of national bodies, including universities, accessing and using the MRC-sponsored tools. This could add remarkably to the confidence on the models as well as their development. The extensive use of models, for a multitude of purposes and case studies in the riparian countries, would have a strong positive effect in the long-term sustainability of the developed tools.

Basin Development Plan

The model and knowledge base (DSF) also forms the foundation for the development scenario assessment of the MRC Basin Development Plan (BDP). According to the 1995 Mekong Agreement, the BDP is: "The general planning tool and process that the Joint Committee of the Mekong River Commission would use as a blueprint to identify, categorize and prioritize projects and programmes to seek assistance for and to implement the plan at the basin level."

The objective of the BDP is "sustainable development of the water and related resources of the basin for the mutual benefits of the riparian countries and people living in the Mekong River basin." In the medium term, the programme will develop a framework for regional cooperation among the riparian countries to develop the Mekong River basin through implementation of a well-defined and established BDP. The BDP is therefore a central planning tool for the MRC's new "Mekong Programme," a regional cooperation programme that, by using the concept of Integrated Water Resources Management (IWRM), aims to achieve more effective and balanced use of water and related resources in the basin. The knowledge and capacity building process and a dialogue with the public, stakeholders and political levels run parallel with the basin development planning process. The big challenge for the MRC is to develop and implement a holistic model system to serve as an integrated planning tool for its sub-regions as well as basin wide planning needs.

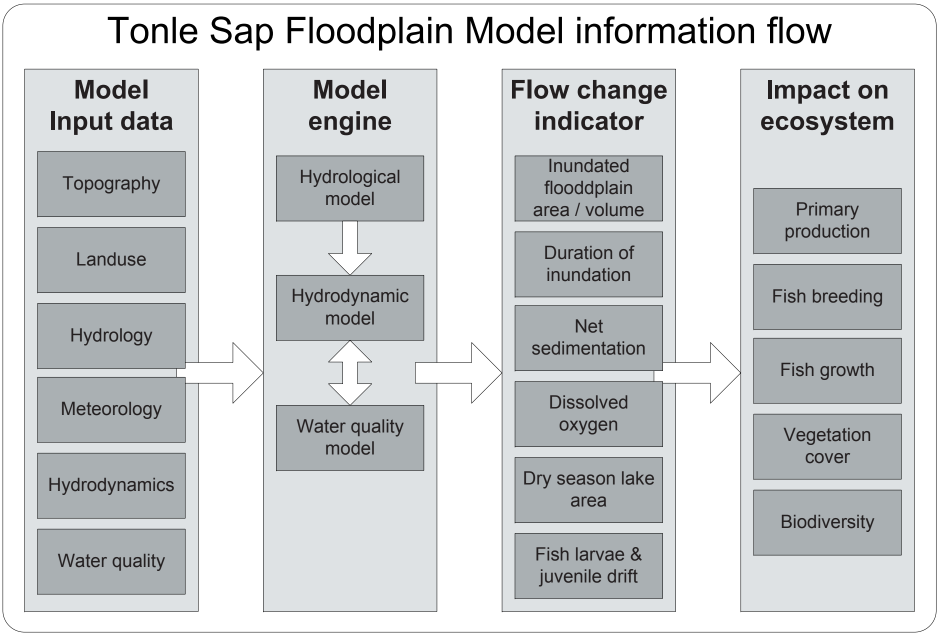
WUP- FIN tools supporting the MRC

Complementary to the MRC's Water Utilization Programme (WUP) is the WUP-FIN Project, which focuses on capacity building in modeling and impact assessment for socioeconomic and environmental analyses. This kind of multi- and cross-disciplinary approach, linked to national institutes, aims contributes to the development of enhanced hydrodynamic models as well as environmental and socioeconomic impact assessment tools for the Lower Mekong Basin.

Part of the WUP-FIN project is to develop an integrated modeling approach using a gridded, hybrid and multidimensional (1/2/3D) model. The river and floodplain system is characterized by slope, physical, chemical and biological gradients, horizontally and vertically. The GIS-type of system allows for integrating floodplain information, such as infrastructure and land use, with water and environmental parameters. This is complemented by socioeconomic data and information for further analysis and impact assessment.

In addition to WUP and national institutes, the Flood Management and Mitigation Programme (FMMP) as well as the Fisheries and Navigation sectors of the MRC are key users and beneficiaries of the WUP-FIN modeling and impact assessment tools. It is anticipated that the WUP-FIN Lower Mekong Basin hybrid hydrodynamic model will serve the FMMP for improved flood forecasting accuracy in place and time over the river and floodplain system. In addition, the three-dimensional hydrodynamic and water quality model can be an efficient tool in navigational planning and development, environmental impact assessment and management of accidental cases (e.g. oil spills) and contingency planning. The Fisheries Programme benefits from the integrated hydrodynamic and water quality models applied to the LMB floodplains and to the Tonle Sap flood pulsing system in particular. The WUP-FIN Project is continuing this work by creating a framework for modeling terrestrial and aquatic productivity of the pulsing system. The work focuses on the role of sediments and nutrient brought to the system by flood waters for maintaining its biological productivity, floodplain vegetation impacts, and the indicators of fish reproduction rates in the floodplains.

Figure 6.1 Model flow chart from model input to impact analysis in the Tonle Sap area



Integrated model of the Tonle Sap system

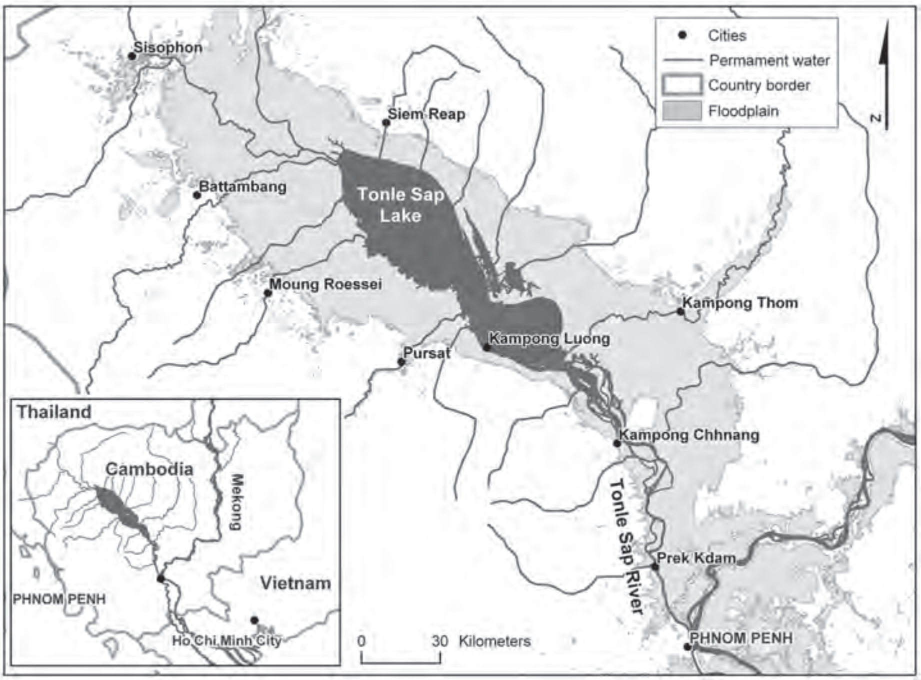
In the following, the application of the WUP-FIN models and analysis tools to the Tonle Sap system is presented as a practical example of integrated modeling and impact assessment process (figure 6.1). The application also shows the need and justification of developing an advanced model system for this kind of complex hydrodynamic, environmental and social entity. The model development and application work has been accompanied with training and capacity building given for the model users and decision-makers at the MRCS and at the national institutions, including both governmental and academic institutions. The mode of training has covered workshops and courses, on-the-job training, support to academic research and dissertations and curriculum development, joint publications and conference papers as well as support for the trainees to reach international training and study positions. All this has been aimed at increasing the skills of the trainees in modeling and impact assessment methodologies as well as enhance their knowledge in the functioning of the Tonle Sap Lake and floodplain system.

The Tonle Sap Lake in Cambodia is the largest permanent freshwater body in Southeast Asia and a very important part of the Mekong system (figure 6.2). The lake is among the most productive freshwater ecosystems in the world (e.g. Bonheur 2001, e.g. Lamberts 2001, Sarkkula et al. 2003). The high ecosystem productivity is based on the flood pulse from the Mekong and the transfer of terrestrial primary products into the aquatic phase during flooding. The pulsing system concept was developed and studied in great detail in the Amazon basin by Junk (1997), and it is a very useful concept also applied to the Tonle Sap. Due to the flood pulse and extensive floodplain, the lake offers many of the Mekong fish species ideal conditions for feeding and breeding (Poulsen et al. 2002). The lake also works as a natural reservoir for the Lower Mekong Basin, offering flood protection and contributing significantly to the dry season flow to the Mekong delta.

Ecosystem processes

Despite the extreme importance of the lake and its floodplains, its ecosystem processes and biological productivity are poorly understood. To better understand the lake's ecosystem and develop impact assessment tools, the WUP-FIN Project has developed mathematical models for the Tonle Sap Lake and floodplain. To support development of the models, extensive physical, chemical, biological and socioeconomic primary data collection was carried out. A physically based distributed hydrological model was applied to the Tonle Sap watershed and three-dimensional

Figure 6.2 Tonle Sap Lake and its floodplain as a part of Mekong system

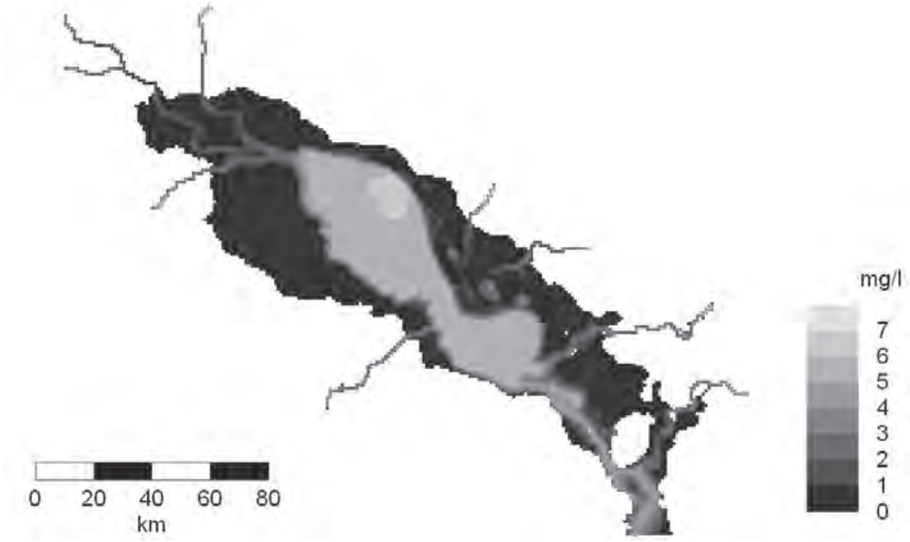


hydrodynamic and water quality model developed for the Tonle Sap Lake, floodplain and the Tonle Sap River up to Prek Dam.

The projected infrastructure development in the Mekong basin, including increased irrigation and hydropower construction at both local and regional levels, threatens the Tonle Sap's vulnerable ecosystem. For example upstream developments in the Mekong River such as dam construction have already led to significant trapping of sediments and nutrients (Kummu et al. 2006b), and may have significant impact on the flood regime and timing of the flood in LMB and Tonle Sap Lake in the near future (Adamson 2001). These changes may have a great influence on the productivity of the lake's ecosystem (e.g. Sarkkula et al. 2004, e.g. Sarkkula et al. 2003). The models developed during the WUP-FIN Project can thus be used to estimate possible impacts on the Tonle Sap Lake due to the local and upstream developments (Kummu et al. 2006a, WUP-FIN 2003).

Available model results from the WUP-FIN Project can be achieved for both natural and scenario cases, and include tributary inflows, flow speed and direction, flooding characteristics, dissolved oxygen concentrations (figure 6.3), sedimentation (figure 6.4), larvae and juvenile fish drift (Sarkkula et al. 2004) as well as pollution dispersion from floating villages.

Figure 6.3 Calculated average oxygen conditions in the Tonle Sap Lake and floodplains. Year 1998 on left and year 2000 on right.



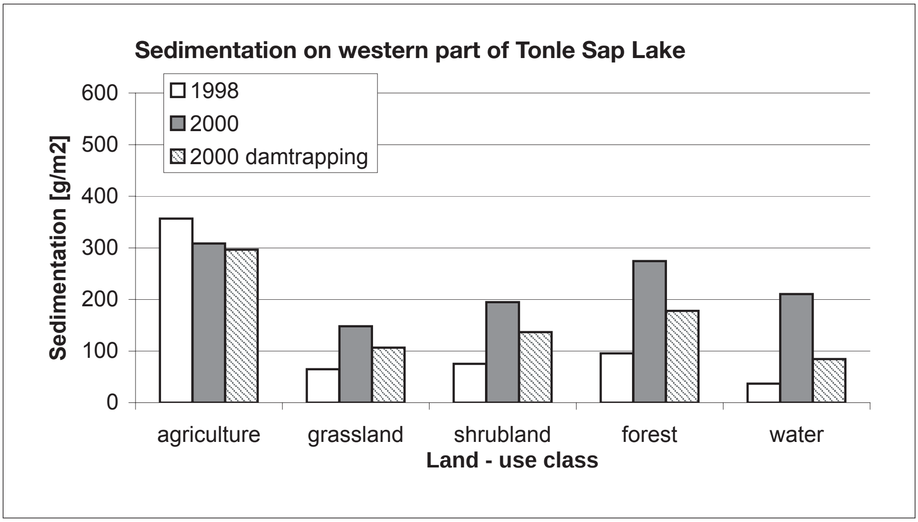
Socioeconomic analysis

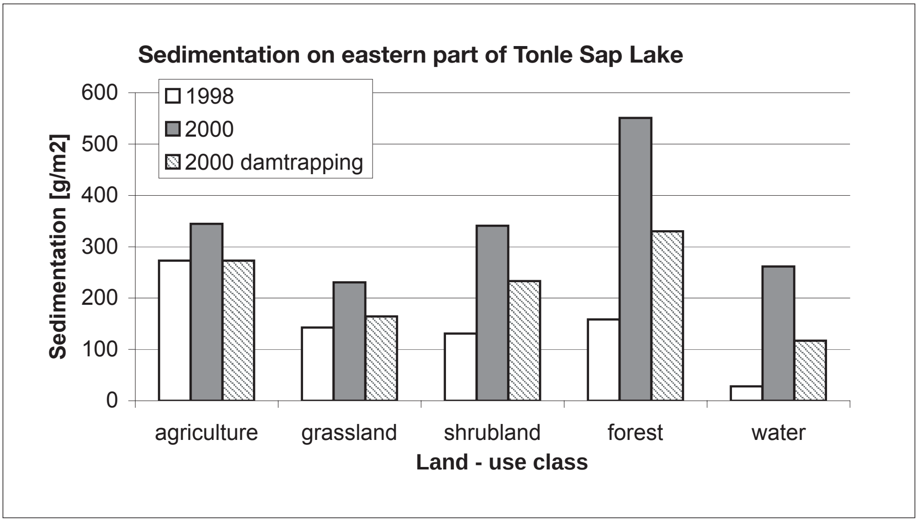
In order to facilitate impact assessment and to link modeling better to social, economic and governance issues, the models developed within the WUP-FIN Project were complemented with socioeconomic and policy analyses. The socioeconomic analysis consisted of three main components: 1) analysis of the databases and creation of a new GIS-based socioeconomic database; 2) participatory village surveys and their analysis; and 3) analysis of other sources of information including literature reviews and expert interviews. The focus of the socioeconomic analysis is on water-related livelihoods and trends of natural resources (Keskinen et al. 2005).

The socioeconomic analysis thus consisted of two main phases: assessment and integration phases. Assessment phase was carried at the beginning of the project and it analyzed the most important water-related socioeconomic issues in the area, which then helped to set the focus for the actual modeling work and issues that the modeling aimed to tackle. The second phase was implemented at the latter half of the project, and it aimed to integrate the model results with social and economic information and this way to assist social impact assessment, and ultimately, to give balanced management recommendations (Keskinen et al. 2005a).

In order to facilitate the integration with the results of hydrodynamic and water quality models, the gathered quantitative socioeconomic data was arranged and analyzed according to topographic location (i.e. elevation) of the villages in GIS. All topographic zones were covered also by the participatory village surveys, although their small sample size meant

Figure 6.4 Calculated sedimentation results for different land use classes (agriculture, grassland, shrubland, forest and water). Diagram on top shows sedimentation for the western part and right for the eastern part of the lake





that this coverage was indicative only. Altogether four topographic zones were formed. In addition, urban areas were analyzed separately and they formed the fifth zone. The entire Tonle Sap Lake falls within Zone 1, and most of its floodplain within Zones 1 and 2. Exceptionally high floods like that in 2000 can also cover most of Zone 3 and parts of Zone 4 (Keskinen 2006).

Outputs from socioeconomic analysis derived from the above-mentioned activities include:

- increased understanding of livelihood structure in the area, including seasonal variation and diversity of livelihoods as well as livelihoods' connections to water resources and natural resources
- recognizing some recent trends of livelihoods, natural resources and water-related factors
- linking the achieved socioeconomic information with the topographic location, hence facilitating the connection with the hydrology of the floodplain
- detailed analysis of the different sector policies' impact to environmental sustainability, economic growth and poverty reduction (as part of policy analysis work)

It must be emphasized that although one part of the WUP-FIN Project also included modeling (see below), the analysis presented above was not carried out for modeling purposes per se, but rather to guide modeling through increased understanding of the socioeconomic situation in the Tonle Sap area, and together with model results and other information, to facilitate more balanced social and environmental impact assessment.

Policy analysis

Socioeconomic analysis within the WUP-FIN Project was complemented with policy analysis of different water-related sector policies in the Tonle Sap Area. For the purposes of policy analysis, the so-called WUP-FIN Policy Model was created. Although bearing the name "model," WUP-FIN Policy Model is actually very different from the hydrodynamic and water quality models as it is based on Bayesian Causal Networks (box 6.5), and aims to analyze in a broader manner the impact of different water management policies to society and environment (Varis and Keskinen 2006).

The policy analysis aimed thus to link the results of the hydrodynamic and water quality models with broader environmental, economic and social factors, and therefore to support management and decision making. The Policy Model based on Bayesian Causal Networks enables a systematic risk analysis of different types of factors, and also allows uncertainties to be taken into account in the modeling—characteristics that are often lacking but definitely needed when analyzing the complicated interconnections and impacts of different policies.

Box 6.5 Bayesian Network

The Bayesian Network methodology is based on the systematic analysis of causal interconnections in complex systems under high uncertainty. It allows the analysis of risks to various components of the environmental and social system under concern, as consequences of policy strategies under evaluation. Trade-off analyses between different development objectives can be made, and policy combinations that create win-win situations between the competing stakeholders can be sought (Varis 1998, Varis and Fraboulet-Jussila 2002)

The results from the policy analysis show that some, but not all, of the sector policies included in the analysis are crucial for both the economy and poverty reduction. The measures that decrease the huge shortcomings in education and governing institutions are obviously the ones that most strongly support these two goals. At the same time, with every scenario and sector policy, uncertainties related to their impacts remain very high and must therefore be appreciated. The reason for high uncertainties result partly from the lack of data, but even more importantly from highly complicated network of direct and indirect impacts that tend to be inconsistent in many cases, thus increasing uncertainty of possible impacts.

The sector policies included in the Policy Model appear, however, to be relatively toothless to environmental problems, particularly if defined as “environmental sustainability” as is done in the Mekong Agreement. This is most probably due to the following reasons. First, the concept of environmental sustainability is not easy to be conceptualized concretely enough so that it would be easy to treat analytically. Second, as the majority of the population of the Tonle Sap Area live in villages and make their living from the lake or the floodplain in a direct way, the environmental issues are closely bound to social issues. Social developments therefore are tightly bound to environmental impacts, and the improvements in social conditions tend to introduce both positive and negative environmental impacts which cancel each other, seemingly to a great extent. The situation would most probably be different if the area’s governance system was more developed and transparent (Varis and Keskinen 2006).

Integration of socioeconomic, ecological and hydrological information

As was mentioned earlier, integrated management of water resources as well as impact assessment of different flow scenarios asks for a comprehensive approach that analyses and integrates information of various types. The identification of crucial issues in terms of policies, their interrelations, their social, economic and environmental impacts and the outcome to various vulnerabilities and stakeholder trade-offs is not a trivial thing, but at the same time it offers a unique learning experience. Often such a procedure reveals major new areas for research.

The social and environmental impact assessment requires thorough understanding of the linkages between hydrology, ecosystem and social and economic issues, as well as of the impacts that these different factors experience due to the changes in water regime. Figure 6.5 shows a simplified illustration of the interconnections between the three main factors together with different components of the WUP-FIN Project. Consequently, social and environmental impact assessment of the WUP-FIN Project builds on the integration of social and economic information with modeling results and information on environment, ecosystem processes, and land use.

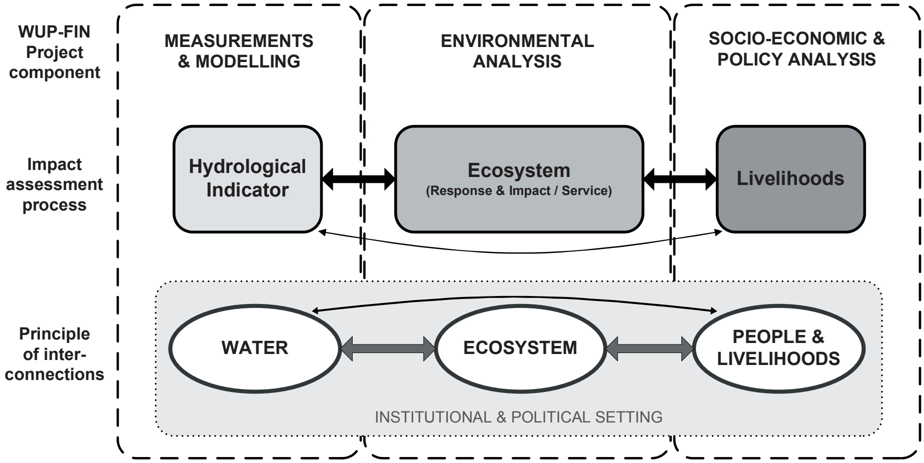
The integration between hydrological, ecological, social and economic information can naturally be carried out in different ways, depending on the local setting and the overall context of the modeling and impact assessment work. Common to all of these different approaches is the challenge in facilitating the linkages between diverse socioeconomic information and other information sources and datasets, in particular with modeling results. This is partly related to the differences in type of information available: while mathematical models are based on quantitative data, socioeconomic analyses are commonly founded on both quantitative and qualitative information. Since qualitative information is practically impossible to include into conventional mathematical models, quantitative data is typically preferred when linking these different elements together. However, quantitative social and economic data has its own problems and biases, and utilization of both quantitative and qualitative socioeconomic information results in more comprehensive understanding of the social and economic situation in the area (Keskinen 2006).

The challenges described above can be tackled in different ways. As was explained earlier, in the case of Tonle Sap Area, the integration was facilitated by carrying out the socioeconomic analysis according to GIS-based topographic zones that could then be linked with model results (Keskinen 2006). Other possibilities exist as well, such as re-organizing existing social and economic information based on flood characteristics as was done in the Cambodian Mekong Floodplains (Keskinen et al. 2005b).

In the WUP-FIN Project, two different kinds of methods were used for integration (Keskinen 2006, Keskinen et al. 2005b, Nikula 2005):

1. Quantitative integration of socioeconomic, land use and hydrological data with the help of GIS and topographic zones, and
2. Descriptive integration combining quantitative and qualitative information on interconnections and causalities between hydrological, ecological, economic and social issues.

Figure 6.5 Framework for impact assessment and integration of hydrological, ecological and socio-economic information together with different WUP-FIN Project components



Initially, the idea was to determine relations between possible hydrological changes and their impacts on people's livelihoods at the lake largely quantitatively with the help of GIS and topographic zones. Soon it became clear, however that this kind of quantitative integration was not enough to understand thoroughly the intricate interconnections between hydrology, environment and social and economic aspects. The main reason for this are the limitations related to quantitative data: most of the interconnections remain poorly understood and analyzed, and many of them cannot anyhow be presented comprehensively in quantified terms. Also, the traditions of different disciplines from computational hydrology to participatory methods in sociology hampered the integration. This unease could have probably been reduced with a careful design of the project components in the early stages of the project. Consequently, also more conceptual approach for integration, descriptive integration, was applied.

The basic idea behind the descriptive integration is first to identify the most relevant hydrological indicators/parameters (e.g. flood level), then define the response of the ecosystem or ecological mechanisms that their potential changes cause (e.g. decrease in inundated habitats), then recognize their most important ecological impacts (e.g. fish production), and finally consider impacted livelihood activities, together with the immediacy that the impact is felt. This entire "impact process" is presented with so-called impact tables, where the direction and intensity of the impacts are specified based on data, information and knowledge available for this specific impact. For more information on descriptive integration, please refer to Keskinen (2006) and Nikula (2005).

Initial experiences from the integration work emphasize the need for a more comprehensive approach that makes use of a wide array of different methodologies and information sources, preferably together with a multidisciplinary team. Hydrological models contribute significantly to understanding the lake's complicated hydrological regime, but their usefulness for assessing social and environmental impacts is limited. To further work on impact assessment, more qualitative methods have to be applied. Local and expert knowledge is needed: when local and expert knowledge is combined with information from the measurements and models, the output of the modeling project will also be much more sustainable and better connected with local needs and expectations.

Conclusions and the way ahead

The chapter has discussed several issues related to water modeling: model technology and development, the relation of models to environmental and social impact assessments, and the usefulness of models in supporting planning and decision making. Examples have been derived mainly from experiences in the Mekong River basin, particularly within the context of the MRC. Some key conclusions and concerns have emerged for further research and practical applications on modeling and impact assessment:

- Modeling has potentially an important role in water management, particularly for analyzing future scenarios and their impacts as well as for complex, multi-dimensional systems such as the flood pulse of the Tonle Sap Lake.
- However, in order to link modeling with real world problems, the entire approach of modeling has to be updated: modeling projects must link better with the other dimensions of water management, most importantly with the society its is studying. This linkage should preferably be created from the very beginning of any modeling exercise, and enough time and resources should be allocated to it.
- Modelers and modeling projects need to focus more on cooperation and communications, by enhancing dialogue with decision-makers and other stakeholders, and by increasing the transparency and intelligibility of the models and their result. A way for the latter would be to provide decision-makers and other non-modelers possibility to actually try—and potentially also use—modeling and model applications by themselves.
- Related to this, bringing new information in a clearly understood form to the awareness of the managers, decision-makers and the

public calls for a professional skill. A modeler cannot usually replace a professional journalist in this task.

- Collecting primary information on hydrological, environmental and social and economic processes is a key for developing the model system and consequent, integrated impact assessments. All possibilities to cooperate openly with other research teams should be utilized.
- Model system needs to respond sufficiently to the complexity of the environment and context where model is applied; standardized and commercial approaches are not always the solution, so the possibilities should be open also for tailored model systems.
- One of the most difficult tasks in modeling work lies in training of the regional experts for long-term sustainability, maintenance and future use of the developed skills, technology and knowledge on modeling and impact assessment.
- Related to this, the risk of losing trained key personnel is a real threat in the Mekong region. Here the stability and long-term work of the MRC Secretariat's modelers group is of central importance for developing and maintaining technical skills both at the Secretariat and in the member countries.
- Risk of sustainability losses can be mitigated by continuous and effective cooperation between the model developers (presently mainly international consultants and the riparian experts) and the national line agencies, institutes and universities. The role of national universities in long-term capacity building cannot be over-emphasized, and they should be closely involved in the training and development of the models.

However obvious the needs for an integrated and cooperative approach for impact assessment in transboundary water basins are, there seems still to be a long way to go. Some progress in integration of teams from natural and engineering sciences has been made, but integration with the social sciences is still only dawning. To date, the approach adapted by modelers to address these more multidisciplinary connections has typically been just "to add some social stuff" to their models (Nancarrow 2005). This may have been predominantly just to satisfy the demands of the donors and/or decision-makers, but it doesn't really change the fundamental problems with modeling. The real change may come through establishment of teams for integrated assessment and modeling with balanced and equal participation by modelers, social scientists, policy experts and other non-modelers. This may help to formulate the right questions to guide model development and to end up with relevant answers and solutions from society's point of view. This may also help to bring new information and recommendations to the decision-makers.

Improving the connection with decision-makers is not without barriers and obstacles, either. Neither political attitudes and interests nor financial constraints are easy to overcome. The responsibility to rise above these barriers rests mainly on modelers, who need to develop models and present the model results in such a clear way that they are acceptable and understandable by planners, managers and decision-makers. This evident barrier makes one to think that a great deal of the effort put in modeling and its technical development should actually be released for collaboration and communication with decision-makers to ensure that the results achieved by (typically not cheap) modeling projects are really utilized in planning and decision making. The necessary resource for this could be easily released from scattered model developments, if only the decisions for more collaborative and concerted modeling work can be taken, and implemented.

The challenges described above lead one inevitably to think that the "spiritual side" of the long discussed and awaited—and still largely pending—integrated approaches has been mostly ignored. Reaching new milestones in the cumbersome road of integrated approaches thus necessitates identification of the mental and social barriers preventing true integration of the people involved. This does concern the research teams as well as the institutions and organizations, and also their governance methods and practices. The solution may rest in better mutual appreciation and listening between the involved individuals, teams, stakeholders and interest groups. The importance of multidisciplinary research for natural resources management is indeed obvious. As pointed out by Janssen and Goldsworthy (1996), to really achieve this, the most important attributes are attitude, communication skills, education and experience.

Annex 6.1. Selected modeling efforts in the Mekong region.

Hydrological Modeling

US Army Corps of Engineers (SSARR): first basin wide watershed model for Mekong region around 1960. Simulate runoff from rainfall and snow melt, and river systems including operations of reservoirs and diversions (Tanaka 1998).

MRC-DSF (SWAT & IQQM): SWAT, soil and water assessment tool, runoff for each Mekong sub-basin. IQQM, Integrated Quantity and Quality Model, movement of the runoff generated by SWAT model down the river system. Models are part of MRC's Decision Support System (DSF) (e.g. Jirayoot and Trung 2004; WUP-A 2003).

MRCS/WUP-FIN (HBV & VMOD): Tonle Sap sub-catchment and Songkhram watershed in Thailand, 1D lumped HBV model and 2D distributed watershed model (VMOD) (WUP-FIN 2003).

TSLV Project: WUP-JICA and Tonle Sap Vicinities project, 1D hydrological model down from Kratie to support the 2D hydraulic model (TSLV Project 2004).

University of Washington (VIC): Basin wide 2D distributed watershed model.

IWMI (SLURP): Basin wide Semi-Distributed Land-Use Runoff Process hydrological model (Kite 2000; Kite 2001).

Ibbit (TOP Model): Flow hydrograph model for Nam Gnouan Catchment in Laos (Ibbit 2000).

University of Yamanashi (YHYM): Basin wide Yamanashi Hydrological Model, 2D grid based distributed hydrological model (Kudo et al. 2004).

Tohoku University (BTOP/MC): Distributed discharge model used for sediment movement study, Middle Mekong Basin (Kudo et al. 2004).

Herath et al (IISDHM): flood hydrographs simulation up to Kratie (Tran 2000).

Nanjing Institute of Hydrology and Water Resources (LSM): Yunnan part of Mekong, Lancang river Simulation Model (LSM), lumped rainfall runoff model (Liu unpublished).

Hydrodynamic modeling

SOGREAH: Mekong delta model in 1963. Quasi 2D flow equations.

Delft (WENDY): Hydraulic model for Mekong Delta Master Plan.

Wolanski: 2D model for coastal erosion in Mekong delta (Wolanski et al. 1996).

SAL99: 1D hydraulic model to simulate flow, salinity intrusion, BOD, and propagation of acid water (Tran 2000).

HMS (KOD Model): 1D flood model for Mekong delta.

SIWRP (VRSAP): 1D hydraulic and water quality model for Mekong delta (Tran 2000).

HMS (HYDROGIS): Flood and salinity intrusion forecasting in Mekong delta.

Kyoto University (KYOTO): 1D river network & 2D overland flood model (Inoue et al. 2000).

MRCS/WUP-A (ISIS): 1D hydraulic model for Lower Mekong floodplains (from Kratie down to sea including Tonle Sap Lake) (Tes and Trung 2004).

MRCS/WUP-FIN (3D EIA Model): Applications for Tonle Sap Lake, Vientiane—Nongkhai section of Mekong, Nam Songkhram floodplains, Lower Mekong Basin floodplains (downstream from Kratie to the South China Sea), Chaktomuk junction in Phnom Penh, Tan Chau area, Tieu River Mouth, and Plain of Reeds (WUP-FIN 2003).

Tonle Sap vicinities (Mike 11): Used in Cambodia floodplains to study multi-functional hydrologic roles of Tonle Sap Lake and vicinities (TSLV Project 2004).

DHI (Mike21): 2D hydrodynamic model with curvilinear coordinate system applied to Chaktomuk area for understand the erosion and sedimentation characters

AIT (PWRI): Combined 1D and 2D surface-river flow model applied to Cambodian floodplains (Dutta et al. 2004)

Notes

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CHAPTER 6
Mathematical modeling in integrated management of water resources

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