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INTEGRATION OF SOCIO-ECONOMIC AND HYDROLOGICAL INFORMATION IN THE TONLE SAP LAKE, CAMBODIA

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ABSTRACT

Integrated management of water resources asks for a comprehensive approach that analyses *and* integrates information of various types. For example the Integrated Water Resources Management paradigm (IWRM) emphasises coordinated management of water, land, and related resources to maximize economic and social welfare without compromising sustainability of vital ecosystems (GWP, 2000). Thus, information needed in integrated water management includes hydrological, environmental, economic, as well as social data. This paper presents experiences from the on-going integration of socio-economic and hydrological information in the Tonle Sap Lake of Cambodia. It is argued that the integration is possible, but it asks not only for understanding of hydrological, hydrodynamic, and socio-economic factors, but also of basic environmental functions such as fish and rice productivity. Also participation of local people is essential as they can contribute remarkably for understanding of the complex interconnections between society and water resources.

1 INTRODUCTION

In many developing countries a majority of the people are dependent on water-related natural resources, such as aquatic resources and floodplains, for their livelihood. At the same time, the amount and quality of information available on both livelihoods and water resources is often limited, and the uncertainties related to data high. It is therefore particularly important to develop practically-orientated approaches for integration between hydrological and socio-economic data in these countries, as this allows better understanding of the water management options' impact to the natural resources, and consequently, to people's livelihood.

In this paper the approach and initial results from the on-going work on integration of socio-economic and hydrological information from the Tonle Sap Lake are presented. The integration has strong practical basis as the approach for integration is developed within the Lower Mekong Modelling Project (WUP-FIN2) that continues the work of the Tonle Sap Modelling Project (WUP-FIN). Both of these projects are complementary to the work of the Water Utilization Programme of the Mekong River Commission (MRC).

The Tonle Sap Modelling Project started in June 2001 and its aim was to create better understanding of physical, chemical and biological processes in the Tonle Sap Lake, and to assist in the maintenance of sustainable conditions of the lake (MRCS/WUP-FIN, 2003). To achieve this, a set of hydrodynamic and water quality models was developed. In order to link the model results better into the complex reality of the Tonle Sap Area, the models were complemented with environmental and socio-economic surveys and analyses.

In the integration work, the data produced by hydrodynamic and water quality models are linked with socio-economic information derived from socio-economic databases and participatory village surveys. The type of information used in the integration therefore varies remarkably, making the actual integration far more challenging. Different tools and methodologies, such as topographic zoning in GIS, are used to facilitate the linking between different datasets. Finally, it should be noted that in this paper the term "hydrological information" is used to describe hydrological, hydrodynamic and water quality information.

2 CAMBODIA AND TONLE SAP

The population of Cambodia is concentrated in the fertile floodplains along the Mekong River and the Tonle Sap Lake, emphasising the importance of water bodies for the country. Although relatively rich in natural resources, Cambodia remains among the poorest countries in Asia. A great majority of the population is strongly dependent on natural resources for their livelihood. Rice cultivation is by far the most important source of income: more than 70% of the Cambodian labour force is employed in the agricultural sector. The proportion of agriculture from GDP is, however, decreasing due to the rapid development of industry and service sectors (World Bank, 2002).

The Tonle Sap Lake, also known as the Great Lake, lies in the central plains of Cambodia. The lake is connected to the Mekong River through a 100-km long Tonle Sap River. The Tonle Sap Lake is well-known for its rich biodiversity and extraordinary water regime with huge seasonal changes in water level and volume. These exceptional floods are caused by the Mekong River: during the southwest monsoon the water level in the Mekong River rises so fast that part of the floodwaters run to the Tonle Sap River. This causes the Tonle Sap River to reverse its flow back towards the Tonle Sap Lake. Thus, the lake loses its only outlet and as a result the water depth in the lake rises from 1 meter up to 10 meters and the surface area expands from 2500 km^2 up to 15000 km^2. This enormous change in water volume extends the lake in every autumn over vast floodplains consisting of flooded forests, shrubland and rice fields.

The extraordinary water regime of the Tonle Sap Lake and Tonle Sap River has resulted in exceptional biodiversity and highly productive aquatic ecosystem. Migration of different fish species and other aquatic animals between the Tonle Sap Lake and the Mekong River is extensive and diverse and as a result the Tonle Sap Lake is regarded as the most important fish breeding ground for the entire Mekong. The Tonle Sap Lake is therefore extremely important for the whole Mekong Basin.

It is estimated that almost half of Cambodia's population benefits directly or indirectly from lake's resources. The Tonle Sap Lake and Tonle Sap River also offer the most important source of livelihood for up to one million people (Bonheur, 2001). The most important sources of livelihood in the Tonle Sap Area are fishing and rice cultivation. While people living close to the lake depend strongly on fish, a majority of the people actually live further away from the lake and has rice cultivation as their main source of livelihood.

When considering the Tonle Sap Area's relatively abundant natural resources, it is surprising that a large proportion of its population live in severe poverty: the region actually has the highest incidence of poverty within all the regions in Cambodia (MoP, 1999). Part of the reason for this is that the access to natural resources, including access to the fishing areas, is unequal and land tenure inadequate. This combined with growing population pressure has led to the overexploitation of the natural resources that most of the people in the area are directly dependent on.

The extreme poverty together with significant dependency on natural resources is particularly alarming since availability of the most important natural resources is in a clear decline (Keskinen, 2003). For example fish catch from the Dai fisheries of the Tonle Sap River has been decreasing three consecutive years and, in 2004, was lowest ever recorded (Hortle et al., 2004). Thus, successful management of the Tonle Sap Lake and its vast natural resources demands deep understanding of environmental and social issues and their interconnections. The integration between socio-economic, hydrological, and water quality information aims to improve this understanding.

3 HYDRODYNAMIC AND WATER QUALITY MODELS

The hydrodynamic and water quality models developed under the Tonle Sap Modelling Project offers a tool to examine the linkages between flooding, water quality, ecology and socio-economy. Next, the principle and structure of the models is presented. More detailed description of the model application and results can be found in Kummu et al. (2005) in these same conference proceedings.

3.1 Hydrodynamic model principles and structure

The models applied for the Tonle Sap Lake are three dimensional (3D) EIA Flow Model for the detailed current studies, and 3D EIA Water Quality Model for calculating the transport and processes of a selected water quality parameters and hazardous materials. The models have been developed by the Technical Research Centre of Finland and the Environmental Impact Assessment Centre of Finland (EIA Ltd.) during the last 20 years and have already been used in over 230 applications.

The model data consists of temporal and spatial data. Data processing tools convert spatial data into model grids which are optimised for calculation accuracy and speed. The model system can calculate efficiently large geographical areas by utilizing dynamically coupled model grids with varying accuracy. Monitoring data (historical and on-line) is directly accessed from the monitoring database. Because model results are often utilized in GIS, all numerical model results can be output directly into a GIS database.

3.2 Model characteristics

The 3D EIA Model System has been set up for the Tonle Sap Lake for simulating elements such as water levels and currents, inundation of the floodplain, and suspended sediments rates. The model system can be also used for constructing different development scenarios and assessing their impacts. Examples of such scenarios are the dam trapping scenario, which will be introduced later, and scenarios of changes in land-use, water-use or, say, infrastructure.

The model can be classified as a 3-dimensional baroclinic z-level model and it is based on the standard Navier-Stokes equations in a rectangular grid. Hydrostatic assumption, Boussinesq approximation and incompressibility of water are used in the model formulation.

The complicated hydrodynamic and sedimentological characteristics of the Tonle Sap Lake system necessitate use of a sufficiently versatile model. The EIA 3D model can solve basically any dynamic or static flow and sediment situation. With the EIA model it is possible to calculate 2D solutions as well, although usually 3D solutions are more appropriate e.g. for erosion, sediment transport, and oxygen concentration studies (Koponen et al., 2003).

3D Water Quality Model has been set up for the lake for simulating the transport and processes of selected set of water quality parameters and hazardous materials. Water quality is modelled with water flow derived from 3D Flow Model, which is used to compute the dispersion of nutrients and other substances from given sources. In addition to moving along with water, the modelled substances may diffuse, sediment, re-suspend, decay and react with each other. Figure 1 presents the EIA 3D model structure.

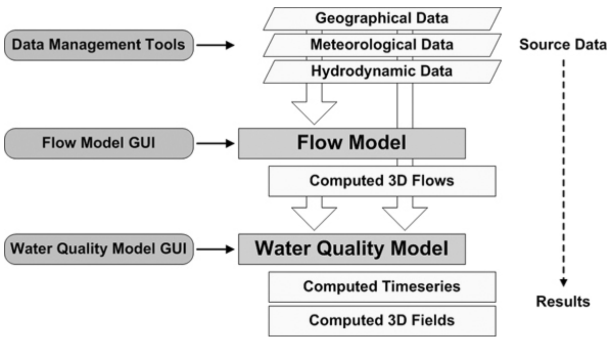

Figure 1. EIA 3D model structure.

The model's input data include among others bathymetric data for model grid, wind measurements, boundary flows, sources and values of transported substances, and flow and water level measurements for model calibration.

As an output the 3D EIA Model gives computed 3D time-dependent flow field for the modelled area; time series of flow speed, direction and water level; time-dependent fields of other computed variables (e.g. temperature, salinity, suspended sediments, oxygen concentration, flood arrival and duration); time series of computed variables; and animations of flow and computed variables.

The hydrodynamic and water quality models are connected to the database consisting of GIS-data and various hydrological and water quality measurements. The database and the models are run through a common graphical user interface (GUI) and model outputs can therefore be directly utilised in the standard GIS-environment. Thus, the common difficulty of integrating socio-economic information with the hydrological models can in this case be addressed by connecting the socio-economic information to the topography of the study area. Consequently, both the socio-economic information derived from the databases, and the flood and water quality data derived from the models was arranged according to the topographic zones, and analysed together in GIS.

4 SOCIO-ECONOMIC ANALYSIS

The socio-economic analysis of the Tonle Sap Area can be divided into three main components: 1) analysis of the existing socio-economic databases and creation of own GIS-based socio-economic database; 2) participatory village surveys and their analysis; and 3) analysis of other sources of information. The focus of the socio-economic analysis is on water-related livelihoods and trends of natural resources.

The constructed socio-economic database and participatory village surveys were the primary information sources for the analysis. Information derived from the two main components varied considerably: while databases produced mainly extensive quantitative data, participatory village surveys had much smaller sample with a strong focus on qualitative data (Keskinen, 2003).

While the created socio-economic database covered the entire Tonle Sap Area, it had several inconsistencies and biases typical to most databases. Participatory village surveys, on the other hand, covered only a tiny part of the entire survey area. Nevertheless, they were able to provide up-to-date qualitative information that confirmed, and partly contradicted, the information derived from the socio-economic databases and also answered questions that the databases were not able to address.

In order to facilitate the integration with the results of hydrodynamic models, the gathered quantitative socio-economic data was arranged and analysed according to topographic location (i.e. elevation) of the villages in GIS. To verify the information derived from the socio-economic databases, all topographic zones were covered also by the participatory village surveys.

Altogether four topographic zones were formed. In addition, urban areas were analysed 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. An exceptionally high flood like that in 2000 can also cover most of Zone 3 and parts of Zone 4 (Figure 2).

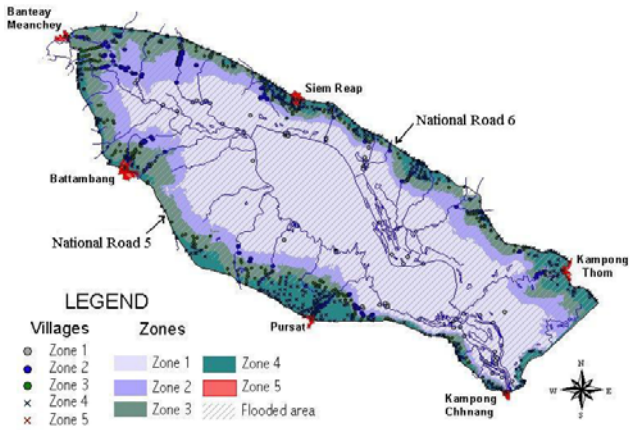

Figure 2. The Tonle Sap Area with topographic and urban zones and flooded area in 2000 (Keskinen, 2003).

5 FLOODPLAIN ECOLOGY

The reasons for the rapid deterioration of natural resources in the Tonle Sap Area are naturally many, but environmental issues are definitely among the most important factors. Therefore the analysis of the linkages between water resources and livelihoods requires also thorough understanding of the floodplain ecology. The ecological perspective provides insight for factors that are important for the well-being of the ecosystem. The ecosystem services, such as production of fish and rice, sustain and fulfil human life (Daily, 1997).

Local ecological features are steered by the physical environment. The most important physico-chemical environmental factors are availability of solar radiation, nutrients, respiratory gases and water. The fluctuation of water level on floodplains is the dominating factor that causes the biota to respond by adaptations and produces characteristic community structures (Junk, 1997). Ecosystems that face fluctuation between terrestrial and aquatic conditions are called floodplain ecosystems, or pulsing ecosystems. Traditionally, ecologists have limited their studies in terrestrial ecosystems while limnologists have concentrated on aquatic systems. However, proper understanding of the ecology of floodplains is reached through wider perspective that answers questions about the functioning of a floodplain system as a whole, and about the roles of the organisms in the system (Junk, 1997).

Due to years of political unrest and resulted scarcity of institutional, financial and academic resources, the ecology of the Tonle Sap Area has remained relatively unexplored until very recently. The amount of information is gradually increasing and results from different individual studies and projects are already available (e.g. Sarkkula et al., 2003 and 2004). However, coherent and comprehensive knowledge of the functioning of the floodplain ecosystem is still lacking.

Ecology of the diverse fish species, other aquatic organisms and the community they constitute is known on a relatively general level only. Flooding and floodplains play important roles in providing environment and conditions for fish migration, reproduction, feeding and sheltering (Sarkkula et al., 2004). Two broad classes of fish may be distinguished in Tonle Sap: white fish, that are flowing water fishes and are intolerant to severe environmental conditions such as lack of oxygen. They therefore migrate from the floodplain to the lake and river during the dry season. The second class is black fish that are still water fishes and adapted to survive the hypoxic conditions of the standing waters of floodplain (Hoggarth et al., 1999).

Research conducted in the area offer some good reference points in the interconnections of hydrology and fisheries. Latest observations suggest that fish catch that used to correlate relatively well with the flood level, has started to show a clear decreasing trend in the traditional Dai fisheries (Hortle et al., 2004).

During the dry season the landscape of the floodplain is characterised by the forests and shrublands nearby the lake and tributaries, grasslands and rice fields dominating the middle elevations and finally the vicinities of the national roads along which most of the villages in study area are located. After a period of inundation, forests and shrublands provide nutrients, food and shelter for a variety of organisms that have survived the aquatic conditions by different strategies such as migration, dormancy and production of flood resistant seeds. These organisms now reach their most productive condition in terrestrial environment.

Rice fields are situated mainly in Zones 2, 3 and 4. Deepwater rice, or floating rice, is cultivated in the lowest and most flood damage-prone fields. Deepwater rice is sown some weeks before flood arrival so that the plant is strong enough to grow according to the advancement of the flood. The plant tolerates temporary submersion and the stem can elongate even 15 cm in 24 hours (Catling, 1992). Most of the rice cultivated in the Tonle Sap Area is rainfed lowland rice. It is grown higher up in fields that receive lower flood. Floodwater depths of 50 cm or more and silt-carrying rapidly rising floods may be detrimental to rainfed lowland rice (Javier, 1997). However, sediments brought by floods also replenish soil nutrients. Only a small part of the available rice fields is used for fully or partially irrigated dry season rice cultivation.

6 APPROACH FOR INTEGRATION

A sound framework for structuring thoughts, and research, is essential when the subject is as multidimensional and complex as the nature-human system of the Tonle Sap. This section presents the overall framework used in the integration in Tonle Sap. The framework was developed based on the needs and ideas that emerged during the research and it therefore can still be developed further.

The approach for integration relies on three concepts, namely on substance, methodologies and context (Figure 3). The core of the framework is the actual substance that consist of socio-economy, ecology and hydrology. The integration between these can be carried out with two different methodologies that are based on data and on experience. Finally, the context of the integration consist of geographical area (Tonle Sap) and of a specific analysis tool (GIS) coupled with the model results.

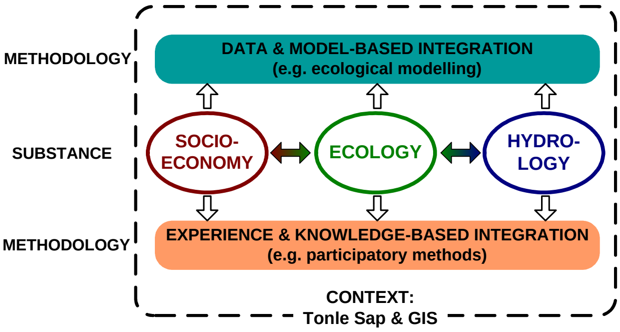

Figure 3. Framework for integration.

6.1 Substance

The actual substance of this research is exceptionally broad. The core substance areas are socio-economy, ecology and hydrology. All of these are already alone extremely broad topics and a group of specialists would be needed to cover extensively the different disciplines falling within them. However desirable and necessary detailed specialist knowledge may be, this particular research benefits more from careful integration of cross-disciplinary information for creating a holistic picture of the interconnections between the different disciplines.

Figure 3 shows the connections between the three substance areas: as can be seen, ecology acts as a connecting factor between socio-economy and hydrology. The Tonle Sap Area provides an excellent example of nature-human system where the interconnectivity of the system is fairly apparent. This is not anymore the case in most western societies where traditions and established practices of academic research have strengthened the division between man and nature. Cross-disciplinary research between neighbouring disciplines is breaking the strictest division but it seldom crosses the gap traditionally found between human sciences (social and political sciences) and natural sciences.

In this paper we have presented the substance divided into hydrology, ecology and socio-economy. This division reflects the traditions of academic research and is illustrative only. In reality, the substance forms a continuum with no clear borders from physical characteristics of water to the abstractions of human cognition.

Different parts of this continuum have traditionally been studied by using methods most suitable for that particular area. Methods utilised in natural sciences dominate in the hydrology-end of the continuum. As we approach the socio-economy-end of the substance, methods used in human sciences become more important. In the integration, the multidimensionality and complexity of the substance must be addressed by developing an approach that combines and utilises the most suitable elements of the different research methods.

The main challenge related to the substance areas is lack of relevant and up-to-date information that is comprehensive enough. The information used in the integration therefore consists of pieces of quantitative data of varying sizes and types, and pieces of qualitative research, expert and local knowledge. While the data derived from the hydrodynamic and water quality models is fairly complete and entirely quantitative, the socio-economic information consists of both quantitative and qualitative information. In addition, information on ecology of the Tonle Sap System remains relatively scarce. Most problematic is the integration between the different types of information i.e. between quantitative data and qualitative knowledge.

6.2 Methodologies

The two methodologies used in the actual integration are ‘Data and model-based integration’, and ‘Experience and knowledge-based integration’ (Figure 3). While the former requires comprehensive quantitative data from all three substance areas, the latter utilises local and expert knowledge and provides a kind of shortcut through the maze of quantitative data. The two methods are by no means exclusive but are ideally used to support and complement each other.

The idea at the beginning of this research was to determine quantitative relations between possible hydrological changes and their impacts on people’s livelihoods at the lake. Reaching that kind of information would be simplest, from engineering point of view, by utilizing integration based on data and modelling.

Soon it became clear that due to lack of data on the area’s ecology, and to differences in the type of socio-economic and hydrological information available, it was impossible to determine those relations in quantitative manner. If comprehensive ecological data existed, representation (i.e. quantitative modelling) of the functions of the hydrological-ecological-socio-economic system would be possible. However, even in that case construction of the model would be a laborious task, and problems with different types of data as well as with inaccuracies and uncertainties should still be dealt with.

Alternative methodology for integration is based on experience and knowledge. This methodology focuses on descriptive research on the functions of the Tonle Sap system. The most important methods applied in it are literature review, expert interviews and participatory village surveys.

Literature review provides basic understanding on the functions of nature-human system. Knowledge obtained from other locations with similar environmental conditions is to a certain extent applicable in Tonle Sap as well. Finally, information gained from other research projects in the Tonle Sap Area provide useful background information that can be used to complement and crosscheck our information.

Building on knowledge gained from the literature review, expert interviews and participatory village surveys can be employed. Expert and local knowledge is achieved through interviews, discussions and exercises that are based on the methods of participatory rural appraisal (PRA). These methods enable a level of flexibility that does not exist in quantitative data analysis. Participatory methods can also be used to partly solve, or bypass, the lack of data.

If the availability and/or quality of the data is inadequate, particularly on ecology, to analyse the interconnections between hydrology and socio-economy, participatory exercises provide a valuable tool to understand these connections in practical level. After all, local people are the most important source of information on the impacts that water resources have on livelihood and other socio-economic factors. Local people may not fully understand the interconnections between hydrology, ecology and their livelihoods, but they are usually able to describe and analyse in a very detailed manner the impacts that the changes in hydrology and water quality have for example on rice crop or fish catch.

The information achieved from the participatory exercises is usually not enough alone, but when combined e.g. with statistical analysis of existing quantitative data on fish catches and hydrology, they can provide lot of additional information. Whatever methodology is used, the limitations of human mind and the complexity of the nature-human system of Tonle Sap has to be remembered. As the complexity of the subject increases, our understanding of it tends to decrease and simplifications have to be made. This naturally decreases the accuracy of integration.

6.3 Context

The geographical area, i.e. Tonle Sap, and the analysis tool based on GIS, constitute the context of our integration. Unlike the methodologies, both of these elements were defined already at the beginning of integration.

In this research the Tonle Sap Area was defined to be the area of the Tonle Sap Lake and its floodplain, excluding the Tonle Sap River; in practice this was the area between the National Roads 5 and 6. The second element i.e. GIS was utilised in arrangement and analysis of both socio-economic and hydrological information.

7 INTEGRATION RESULTS

The integration was started by analysing information related to socio-economy, natural resources and hydrology according to topographic zones and land use classes in GIS. Table 1 shows an example of the results of this analysis. From the table it can be clearly seen the connection between different kind of livelihoods, land use types, and the proximity to the water resources.

Table 1. Selected socio-economic factors from the Tonle Sap Area (Census, 1998 and JICA, 1999).

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	All zones
Location (+asl)	0-6 m	6-8 m	8-10 m	10m-Roads	Urban	
Area [km2]	8 531	2 407	2 292	1 574	73	14 876
Villages	88	82	313	554	121	1158
Literacy rate	35,7%	44,3%	48,9%	51,2%	66,0%	52,9%
Children 0 - 4 years	13,9%	14,7%	13,7%	12,9%	10,6%	12,7%
Flooded shrub	42,7%	13,3%	0,6%	0,1%	0,0%	26,8%
Paddy field	1,0%	27,8%	77,9%	78,3%	14,3%	25,4%
Water bodies	31,3%	0,4%	0,3%	0,3%	0,0%	18,1%
Abandoned fields	4,3%	43,0%	13,0%	2,7%	0,2%	11,7%
Agriculture, hunting & forestry	26,1%	91,0%	83,5%	77,0%	21,5%	63,4%
Trade	10,3%	2,1%	4,9%	8,3%	30,2%	12,0%
Fishing	55,2%	2,1%	2,4%	1,4%	0,6%	5,7%
Public administration & defence	1,2%	1,0%	1,4%	2,4%	11,5%	4,0%
Transport & communication	2,3%	0,8%	1,7%	2,5%	9,5%	3,7%
Manufacturing	1,9%	0,8%	1,6%	2,5%	6,7%	3,1%

7.1 Fishing

As can be seen from the table above, more than half of the people living next to the lake in Zone 1 have fishing as their primary source of livelihood. Thereby a clear majority of the people in this zone are heavily dependent on aquatic resources. According to Baran et al. (2003) among others, the extent of flooded area and flood duration are driving environmental factors in fish production. Figure 4 illustrates the extent of flooded area and the flood duration in years 1997, 1998 and 2000.

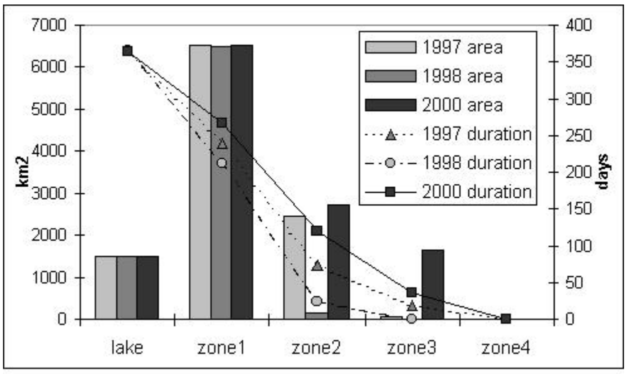

Figure 4. Flooded area and flood duration.

The years presented in Figure 4 were selected as examples for three different kinds of flood. In year 1997 Tonle Sap experienced a flood that was close to long time average. Year 1998 brought less water from the Mekong to the Tonle Sap, and as a result the flood was the lowest one between years 1995 and 2001. The highest flood of that period occurred in year 2000. Figure shows clearly how conditions for fish growth differ between years, with flooded area and flood duration in the floodplain being clearly highest in year 2000.

The rate of sedimentation affects the fertility of the ecosystems and may also influence the productivity of fisheries (van Zalinge et al., 2003). Figure 5 describes variation in sedimentation between different years. The figure also presents a dam trapping scenario where the incoming sediment load to the Tonle Sap in 2000 has been halved to illustrate the possible effect of upstream dam construction to the sediment influx. For the sedimentation analysis we have divided the lake into eastern and western parts.

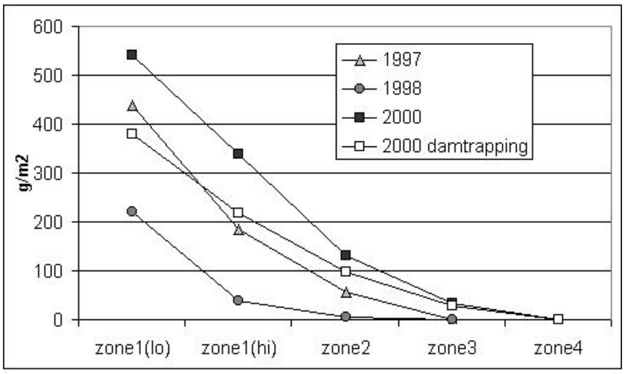

Figure 5. Average sedimentation in the western part of the lake. Zone 1 is divided into lower (1-3m) and upper (3-6m) parts.

As can be seen from Figure 5, low flood in year 1998 brings clearly less sediments to Zone 1 than floods during other years. In the dam trapping-scenario, the sedimentation decreases most radically in the zones closest to the lake that are also the largest in area and essential to the diverse ecology of the area. That most probably leads in reduction of fertility in the flooded forests adjacent to the lake that form important habitats and breeding areas for many fish species.

One of the most important qualities of the habitats especially for fish spawn and fry is the dissolved oxygen concentration which is illustrated by land use classes (JICA, 1999) in Figure 6. The figure presents the average oxygen concentration near the bottom of floodplain.

A useful generalisation is provided by Baran et al. (2004), who estimate in their "rough classification" that dissolved oxygen values above 4 mg/l are acceptable to almost all fishes. Values between 2 and 4 mg/l are acceptable for black fishes but too low for white fishes, while values below 2 mg/l are too low for all fishes. However, due to long-term adaptations to floodplain oxygen conditions it may be possible that also some species in Tonle Sap are at least temporarily less sensitive to hypoxia. For example, in the Amazonian River system, which is more thoroughly studied and where floodplain conditions are characterised by pulsing system alike, there are many fish species that are able to tolerate short-term oxygen levels as low as 0,5 mg/l (Junk, 1997).

Figure 6 shows that oxygen conditions are generally better during the years with higher floods. Particularly inundated forests and shrublands, that are regarded as the most important habitats for fish, are better oxygenated when the flood is greater.

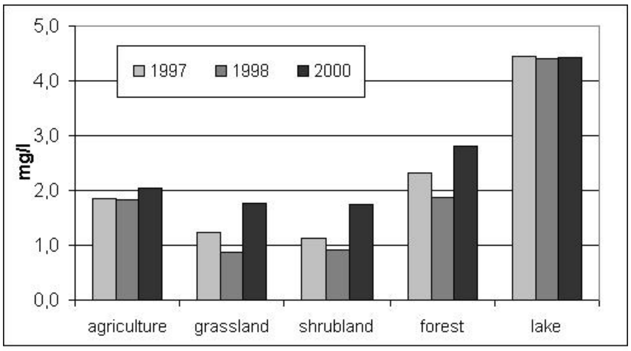

Figure 6. Average dissolved oxygen concentration in the eastern part of the lake.

7.2 Rice cultivation

Table 1 shows clearly that a great majority of the people in every other zone than Zone 1 have agriculture as their main source of livelihood. Thus, understanding the water-related factors affecting rice productivity is also necessary. Figure 5 serves as an example of the possible threat that rice production may confront as decreased sedimentation due to dam trapping results in disturbance of flood-induced natural replenishment of soil nutrients. Although the immediate impact of possible changes in sedimentation to rice production are likely to be modest, the long-term impacts can nevertheless be serious.

Droughts and too rapidly rising floods pose more acute threats to rice cultivation. The rapidity of flood rising is particularly critical for floating rice that is mainly cultivated in Zones 2 and 3. Although floating rice forms only small part of all rice cultivated in the area, it is important source of livelihood to many poorer villages that do not have access to better agricultural land higher up.

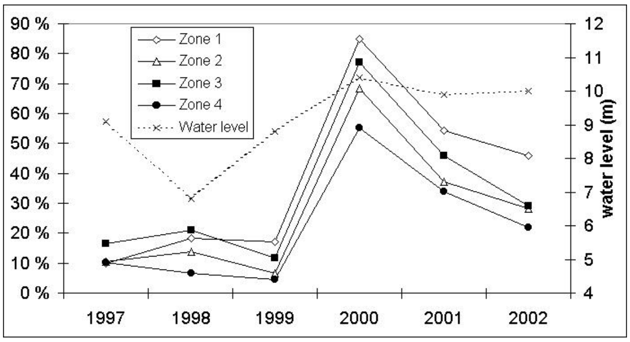

Figure 7. Loss of floating rice and the water level (MRCS/WUP-FIN 2003).

Occasionally flood may rise so fast and high that floating rice crop gets destroyed. Figure 7 shows losses of floating rice in different zones between years 1997-2002 together with water level in Kampong Luong's water level station in Tonle Sap. In medium flood-year 1997 and low flood-year 1998 the floating rice crop losses were low. Record-high flood in 2000 destroyed more than half of the floating rice crop in every zone and left many villages with severe shortage of food. Also the floods in following two years were voluminous which partly explains relatively high crop losses. Rapidity and height of the flood are not the only, but usually the most important factors causing crop losses. Other factors causing losses include drought, pests and plant diseases. For more information on both quantitative and descriptive integration, see Nikula (2005).

8 CONCLUSIONS

There are numerous interconnections between socio-economy and hydrology, and the examples presented in the previous section act only as demonstrations of those links. Understanding and knowledge of those interconnections remains still very inadequate. As our research advances and more information is produced and made available in the Tonle Sap Area, we will be able to provide more information on those linkages, and to test and develop our approach for integration even further. For example, the ability of the EIA models to provide scenarios for the use of planning and impact assessment is found highly useful and it will be exploited more in the future. Next, some key aspects of the integration work are highlighted.

The development of the Integrated Water Resources Management paradigm demonstrates that an integrated approach is an absolute necessity for environmentally sustainable and socially just management of water resources. Standard practices for integration do not exist and several problems are confronted in the practical integration work.

One of the most important questions is how to connect the diverse types of information. In the case of Tonle Sap, the problem of connecting the varied socio-economic information with the data gained from hydrological measurements and models is contemplated. Another as important question is how to carry out the integration in a participatory way, i.e. how to ensure the true participation of local people in the analysis and integration process. Also the management-support function of the research projects has to be kept in mind, as research must provide as accurate information as possible for management and decision making even in the case of a complex system with lack of reliable, long-term data.

This paper has addressed these questions by presenting the approach and experiences from the on-going integration work in the Tonle Sap Lake, Cambodia. Our aim is to create an approach that is sound and comprehensive and yet easy to understand and apply. Although developed specifically for the Tonle Sap Area, the aim is that this approach could be applied in other areas as well. Although the work is still on-going, certain conclusions can already be made. These are described below.

During our integration work it became very clear that in addition to detailed sectoral studies, more overall understanding of the system is needed; otherwise the actual integration is not possible. Analysing the studied system and region comprehensively, even in a simplified manner, is thus extremely important. In our work, a comprehensive research approach helped to understand the ecology's role as a key linkage between hydrology and socio-economy.

Also context where the data is arranged and analysed can help remarkably, or alternatively make more difficult, the integration between different factors. In Tonle Sap, socio-economic information had to be analysed in a way that takes into account the nature of water and floods. Thus, the socio-economic analysis could not be based on administrative boundaries, which is usually the case, but on the area's geography. Only in this way can socio-economic links to e.g. floods and water quality be studied in detail.

Also participation of local people in integration process is possible, but it requires much more than just rapid participatory assessments that complement measurements and database analysis (which was more or less the case in the Tonle Sap as well). Biggest difficulty is how to involve local stakeholders, like villagers as well as NGOs and government officials in provincial and district level, into actual planning and implementation work. This difficulty is linked with problems related to e.g. language and cultural understanding as well as lack of long-term perspective and commitment. We believe that the way to address this problem is to base the work as much as possible on local resources and people, and thus also to put remarkable effort on capacity building. This means that enough resources must be allocated to facilitate participation, networking and mutual learning with local stakeholders.

Perhaps the most critical question that emerged during our work was how to carry out the modelling work so that it is able to respond to the actual needs of the local people. From our point of view the answer is that socio-economic analysis with strong emphasis on participation must be in-built part of every water modelling project. In addition, socio-economic work needs to interact closely with other project components from the very beginning of the project.

It can be concluded that modelling of as complex and multidisciplinary a system as Tonle Sap can benefit greatly from socio-economic analysis, and in particular from participatory approach. This is particularly important in situations where the lack of data and/or its poor quality makes modelling of the system impossible, or at least incomplete.

Experience and knowledge-based integration presented in this paper can be utilised to employ local and expert knowledge. It can provide mainly qualitative information for data verification or even for data replacement. We believe that when this knowledge is combined with information from the measurements and models, the output of the modelling project will be much more sustainable and better connected with local needs and expectations.

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