STUDY OF THE INFLUENCE OF BUILT STRUCTURES ON THE FISHERIES OF THE TONLE SAP

PROJECT DOCUMENTS AND RESULTS

Technical Assistance project to the Kingdom of Cambodia
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Executing agency:
Cambodia National Mekong Committee

Implementing agency:
WorldFish Center

Partner institutions:
IFReDI (*Fisheries Administration*)
Tonle Sap Biosphere Reserve Secretariat
EIA Ltd. (*WUP-FIN consortium*)
Biota BD

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Table of Contents

KNOWLEDGE SUMMARY

At the Mekong Basin scale, the most significant built structure type evaluated by the TA was large-scale dams and associated reservoirs. The hydrological modeling analysis shows that upstream damming in "intensive" and "extreme" development scenarios could reduce inflows to the Tonle Sap Lake by 10 to 25% in dry years. The annual flood could also be delayed for up to a month and end two weeks earlier than normal.

Upstream damming would increase river discharge in the dry season, and expand the surface area of the Tonle Sap Lake by 300 to 900km^2. These rising water levels would result in permanently inundating some flooded forests, ultimately killing the trees. It would also have ecological impacts on the floodplain by trapping massive amounts of sediment, likely resulting in reduced fish productivity and soil fertility in some areas.

Dams would have a major impact on fisheries by disrupting migration patterns and routes, since 87% of Mekong fish species for which information is available are migratory. Because these migratory species make up a dominant part of Cambodia's fisheries, dams could seriously impact the country's economy. The loss of even a small percentage of this fishery represents tens of thousands of tons and millions of dollars worth of fish. While the reservoirs created by dams are sometimes considered a way to create new fisheries upstream, a literature review worldwide shows that this typically would not compensate for the loss of fisheries downstream. In the Mekong, only 9 species are known to breed in reservoirs. Other mitigation measures such as fish passes have not proven effective in the Mekong region, as the intensity of fish migration is so high that it cannot be accommodated by conventional fish passes.

At the Tonle Sap Basin scale, the TA assessed localized influences of roads, irrigation schemes, and large fishing gears. The case study shows that the roads there do not significantly affect water flows in the floodplains thanks to culverts. However, the location and design of roads is key in determining their impact on fish habitat and migration, as well as their management and operation. The road management committee in the study area, for example, prohibits culverts on the road from being blocked by fishing gears, a commendable practice that should be encouraged elsewhere in the country.

Small-scale irrigation reservoirs in the Tonle Sap floodplain so far have had a limited impact on water flows and quality due to the relatively small volume of water they trap. However, the cumulative effect of these reservoirs might be significant if their number continues to increase. The case study shows that irrigation schemes can offer a range of economic opportunities to some villages that directly benefit from them, while villages downstream may suffer a reduction of fish in the river and the rice fields.

Large-scale fishing fences made of bamboo and nylon nets are unique to the Tonle Sap Lake and its floodplain, with the total length of 409km. Experiments show that these fishing fences do not significantly slow the water flows. However, they clearly block fish movements, even more so when nylon nets are attached. A better understanding of fish ecology, including migration corridors, is essential to determine the optimal design of large-scale fishing fences to ensure a sustainable level of harvest.

Overall, the case studies found that negative impacts of built structures do not depend solely on technical and engineering factors; they also depend significantly on the way structures are managed and operated. It is clear that management and social issues associated with built structures, such as access to benefits, use rights and regulations, and operations, can be perceived at the local level as more crucial than the technical design of the structure itself.

I BACKGROUND

A Overview of the project

1. The fishery resources of Cambodia, originating mainly from the Tonle Sap Lake, rank first in the world for their productivity and fourth for their total catch despite the small size of the country. The floodplains contribution to income, employment, and food security is higher than in any other country. However the natural productivity of the Tonle Sap's floodplains is threatened if the flood pulse, the temporarily submerged habitats, and the migration routes of the Tonle Sap are not given attention. In relation to this, the influence of Built Structures, that modify the hydrology of the system, needs to be better assessed at the ecological and socioeconomic levels.

> **Built Structures** consist in a diversity of man-made constructions that contributes to changing the hydrology of a natural system. They can:
> (i) oppose water outflow (e.g., dams, weirs, irrigation schemes, dykes);
> (ii) prevent water inflow (e.g. embankments, polders, levees);
> (iii) change water inflow or outflow (e.g., roads, canals, large scale fishing gear);
> (iv) degrade water quality (e.g., factories, mines, sewers).

2. Built structures primarily influence hydrology, but they also influence, directly and indirectly, the environment, fisheries and the livelihoods of people who depend on aquatic resources [Kummu *et al.* 2005]. Figure 1 illustrates a process in which built structures trigger a string of impacts. A given built structure---a small embankment for example---leads to some form of floodplain modification. The flood plain modification then causes direct effects on hydrology and fish, and in turn catalyse changes in the way that people use resources through increased or reduced access to fisheries or opportunities to develop other livelihood aspects. Some of these changes may induce further modifications to the floodplain, such as extention of the embankment or development of paddy fields around it. These modifications will then generate their own impacts on hydrology that can be considered as the "unintended" impacts of the original built structure, i.e. small embankment. The combination of technical, bio-physical and social interactions that result from the introduction of a built structure require a multidisciplinary approach if the impacts, cumulative effects and trade-offs of the new constructions are to be understood.

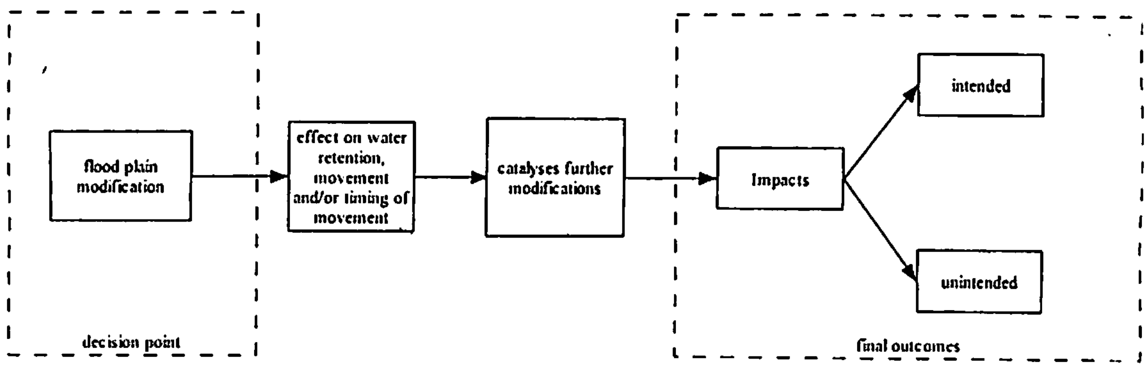

Figure 1: Process by which built structures achieve impacts

3. In October 2005, the Asian Development Bank proposed a Technical Assistance to the Kingdom of Cambodia for the study of the influence of Built Structures on the fisheries of the Tonle Sap. This 10-months technical assistance was accepted by the Cambodian Government on 26th December 2005, and has started officially on May 1st 2006. The closing date of TA was originally scheduled at the end of February 2007, however, it was later extended for 3 months to 30th May, 2007, in order to allow for sufficient time to incorporate the results of field work in December and January into publication outputs, and for a more thorough review of draft materials by relevant government agencies.

B Project Administration

4. The project office was established at the Tonle Sap Biosphere Reserve Secretariat (TSBRS), equipped with eight desks, five computers, five backup disks, a printer and with an Internet connection. Initially there were minor problems in setting up the project office as the space provided by TSBRS was not in functional order, and the existing Internet connection was already saturated. However with some additional expenses, the office became operational by the second month of the TA implementation, with the Internet access of the whole TSBR Secretariat being upgraded. The project office was primarily used as the regular work space by the CNMC counterparts, the WUP-FIN consultants, and the domestic consultants.

5. WorldFish Center's Mekong regional office in Phnom Penh provided financial, administrative, and logistical support to all the TA consultants for implementing their activities in Cambodia throughout the duration of the project. A TA coordinator was added to the project team in order to assist the team leader in setting up administrative and financial arrangements among partners, negotiating subcontracts and oversee their execution, facilitating implementation of field activities, organizing meetings and workshops, and overseeing publication production processes. The additional involvement of the TA coordinator has allowed the team leader to delegate administration tasks, and to focus on research coordination. Three national counterparts respectively from the TSBR Secretariat, from the Fisheries Administration and from the Ministry of Environment were also hired to assist the national project director and facilitate the coordination with these line agencies.

C Scientific Approach

6. Streamlining the approach of all thematic research components. Having to strike a balance between comprehensiveness and feasibility in implementing the planned activities, and for cross-disciplinary integration of the results, the team resolved a number of issues regarding the scope and emphasis of research: 1) selecting focus built structures; 2) selecting geographic scales of analysis; and 3) selecting sites within each study area.

7. Focus built structures. The Database component identified at least 46 types of built structures1, which necessitated that a few major types of structures be selected for in-depth study. After extensive discussions between components and an assessment of major existing structures prevalent within the Tonle Sap catchment basin, it was decided that the TA focuses on four main types of structures: dams, irrigation schemes, floodplain roads/dykes, and large-scale fishing gear. Dams are a type of construction whose negative impacts on the environment and fisheries are relatively well known, as well as their benefits for hydropower or irrigation. Irrigation schemes (including canals) combine water retention and land use changes, with subsequent modification of environmental and socioeconomic patterns. Roads in floodplains are almost always associated with dykes; they result in floodplain fragmentation and loss of habitat for fish, while facilitating social exchanges and trade. Lastly, large-scale fishing gear is unique to Cambodia, where fences made of bamboo and nets are set up in the floodplain to concentrate fish into the net; fenced fishing lots now cover 3140 km2 and each of the current 81 lots uses on average 20 to 40 km of fence. In addition, the influence of these large-scale fishing structures on the lake's hydrodynamics was previously unknown. Influence of dams was considered through integration into hydrological modelling, mainly at the Mekong level; irrigation schemes and canals were examined through a case study of Stung Chinit; floodplain roads/dykes were studied in Pursat province; and large-scale fishing gears were assessed in the area around Prek Toal.

8. Geographic scales of analysis. The review of existing studies showed that the productivity of Tonle Sap fisheries is a function of extensive local floodplains, fishing effort, sub-basin tributaries--which contribute 30% of the Tonle Sap water, and the hydrological and ecological influence of the Mekong river mainstream. Thus it was necessary to address three scales of influence in the TA: i) Tonle Sap floodplains; ii) Tonle Sap tributaries, and iii) Mekong catchment basin (Figure 2). The contribution of each component to each scale is detailed in Table I. The scale of the Mekong catchment basin has been addressed by the Hydrology and Fisheries components. The scale of Tonle Sap tributaries as well as the local scale were addressed by almost all components.

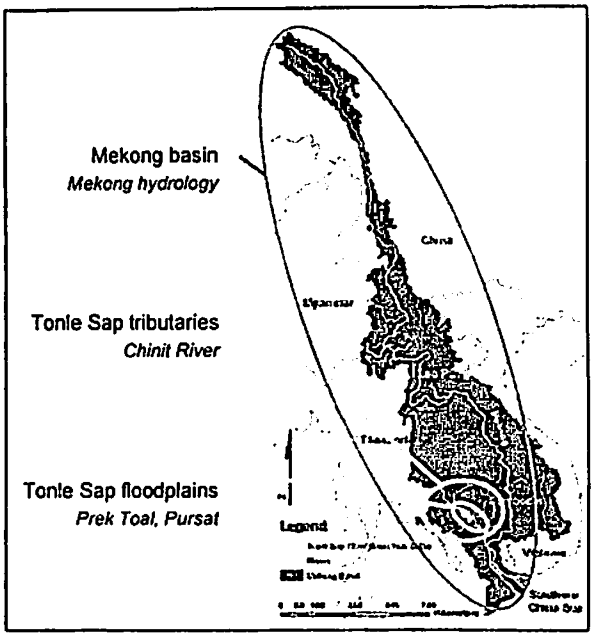

Figure 2: Geographic scales covered by this study

[1] Created water bodies (ponds, reservoirs, irrigation schemes, irrigation canals, transportation canals, pipes, irrigated, areas, stilling basins), constructions (bridges, culverts, tunnels, road embankments, railroad embankments, reservoir, dikes, polders, dikes, levees, flood control embankments, ripraps, reinforced banks, flood, gates, sluice, gates, navigation, locks, weirs, docks, dykes, breakwaters, piers, pumping, stations, hydropower, stations, run-of-the-river dams, irrigation dams, diversion dams, check dams, drop structures, spillways, fishways) and large scale fisheries (bag net fishery, river barrage, lake fenced lots, lift nets)

Table 1: Geographic scales covered by each component

Component	Scale		
	Local	Sub-basin	Basin
Database	Yes	Yes	--
Hydrology	Yes	Yes	Yes
Environment	Yes	Yes	Yes
Fisheries	Yes	Yes	--
Livelihoods	Yes	--	--
Policy outreach	Yes	Yes	Yes

9. *Selected sites within each study area.* Resolving the issue of selecting specific locations for field data collection was a major coordination challenge faced by the TA. Hydrology, fisheries, and livelihoods components had different requirements in order to successfully detect and document the influence of built structures from a water, fish or social perspective. Much discussion was held among the team members to devise a set of criteria that could accommodate the essential needs of all components. The assessment methods were tailored by component detecting either the difference *before/after* the construction of a structure, or a spatial contrast, i.e. *inside/outside* the zone of influence of a built structure and *upstream/downstream* contrast in terms of the hydrology of streams. A combination of both was used at the Stung Chinit irrigation site. The structures itself had already existed since the Khmer Rouge era and had been influencing local hydrology and fish ecology, while the irrigation scheme was only recently rehabilitated and had just started operating in July 2006, hence too soon to observe significant effects on livelihoods. One overarching criterion was that the sampling locations should be very contrasted in order to better sort out entangled factors inherent to the presence of built structures and to allow generic lessons to be drawn.

10. Existing background information on candidate sites was compiled and reviewed, and pre-survey scoping visits were made to each of the selected study areas in order to determine specific sites that meet the criteria. The tables below list the sites selected for detailed data collection for each thematic component. Each component chose to sample slightly different set of villages/locations to survey because of the nature of the information that was required was different from component and component. In addition to these sites listed below, the Database component and Hydrology component conducted extensive field data collection around Tonle Sap Lake for calibrating the built structure database and the hydrological modelling, which was part of sub-basin and basin scale analysis, and not part of local-scale studies.

11. In Pursat, following locations were identified based upon their position a) in front of or behind a road acting as embankment; b) distance from road access; and c) away form influence of embankment or road.

Table 2: Selected sites around the floodplain roads in Pursat

		Selected by			
		Hydrology component	Fish component	Livelihoods component	
				Socioeconomics	Perceptions
LOCATION	Village				
Outside of influence	Doung Chua		x		
	Krang Veng		x		
Along the road	Ou Ta Prok Main		x	x	x
	Chong Khlong		x	x	x
	Kampong Lor		x		
Upland from the road	Ou Ta Prok Up			x	x
	Moat Prey		x		

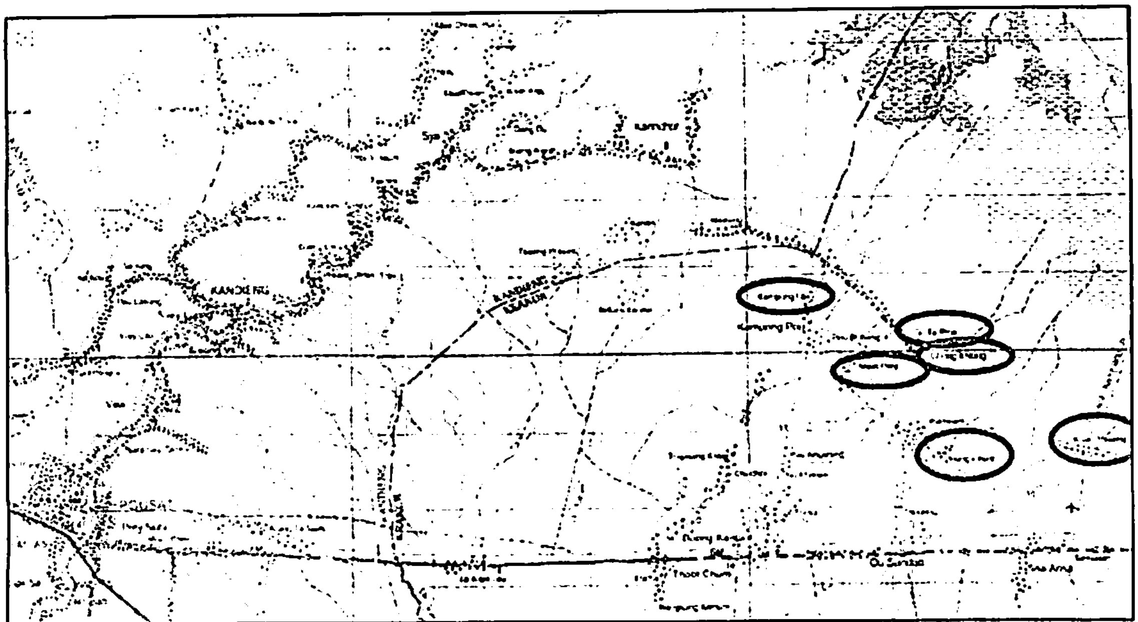

Figure 3: Map of the Pursat study site and sampling locations

12. In Stung Chinit, following sampling locations were selected according to a combination of criteria and of requirements between components (Table 2).

Table 3: Selected sites around the Stung Chinit irrigation scheme

			Selected by			
			Hydrology component	Fish component	Livelihoods component	
					Socioeconomics	Perceptions
LOCATION	**Village**	**Inside/outside**				
Upstream	La'ak	outside the scheme; loses livelihoods opportunities	x	x		x
	Prey Dom	outside the scheme; might benefit from it		x		
Mid-stream	Snao	inside the scheme; benefits from it	x	x	x	x
Downstream	Sa'ang	outside the scheme; might benefit from it	x	x	x	x
	Thnot Chrum	outside the scheme; loses livelihoods opportunities		x		

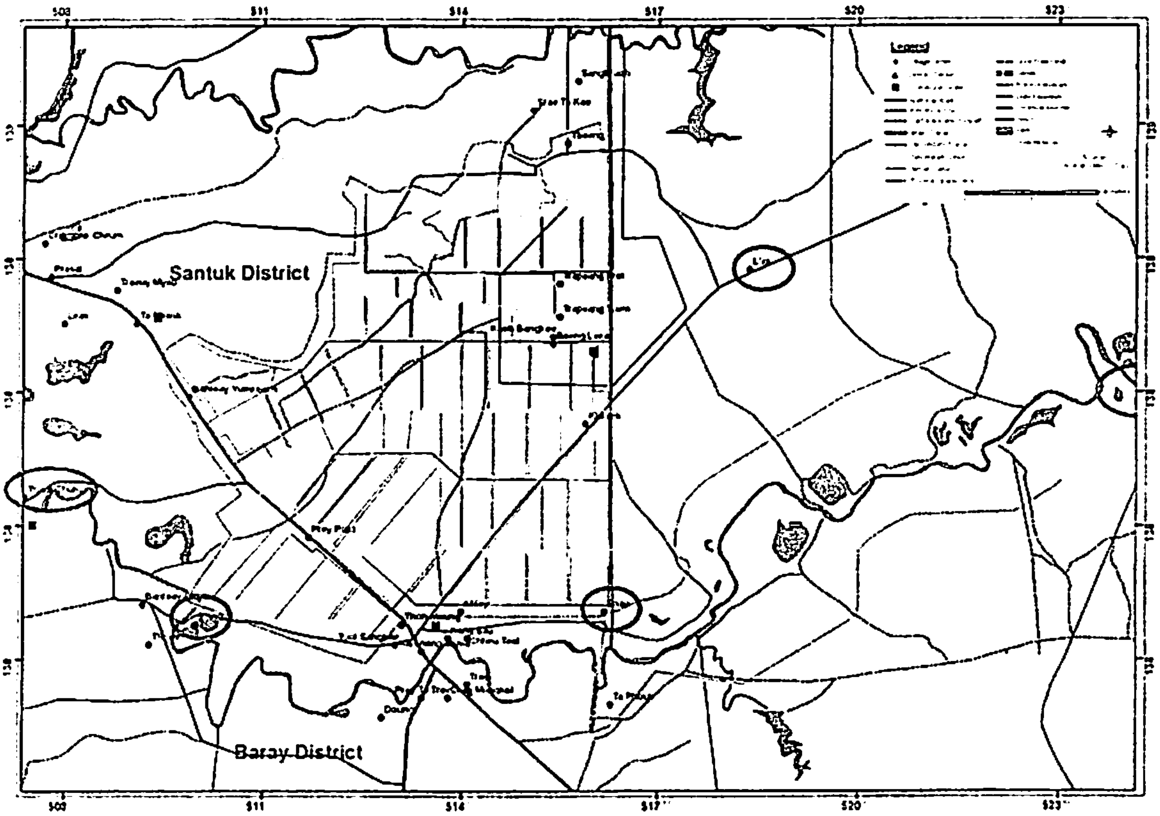

Figure 4: Map of the Stung Chinit study site and sampling locations

13. In the study area near Prek Toal, following sampling locations were selected based upon their location with regards to the fishing lot number 2, and the lake. Thvang was selected as it is located on the northern bank of the Sangke River, formerly within the fishing lot number 3 which was abolished in 2000. The distance to the Prek Toal conservation area and the livelihood opportunities derived from it was an additional element of stratification among the villages.

Table 4: Selected sites around the fishing lots number 2

		Selected by			
		Hydrology component	Fish component	Livelihoods component	
				Socioeconomics	Perceptions
LOCATION	**Village**				
Influence of fishing lot #2, near the lake (no community fisheries area)	Peak Kantiel				x
Influence of fishing lot #2, near the lake (with community fisheries area)	Prek Toal	x	x	x	x
Far from fishing lot #2 and the lake (with community fisheries area)	Thvang		x	x	x
Between Prek Toal and Thvang	Anlung Ta Or		x		
	Kampong Prahok		x		

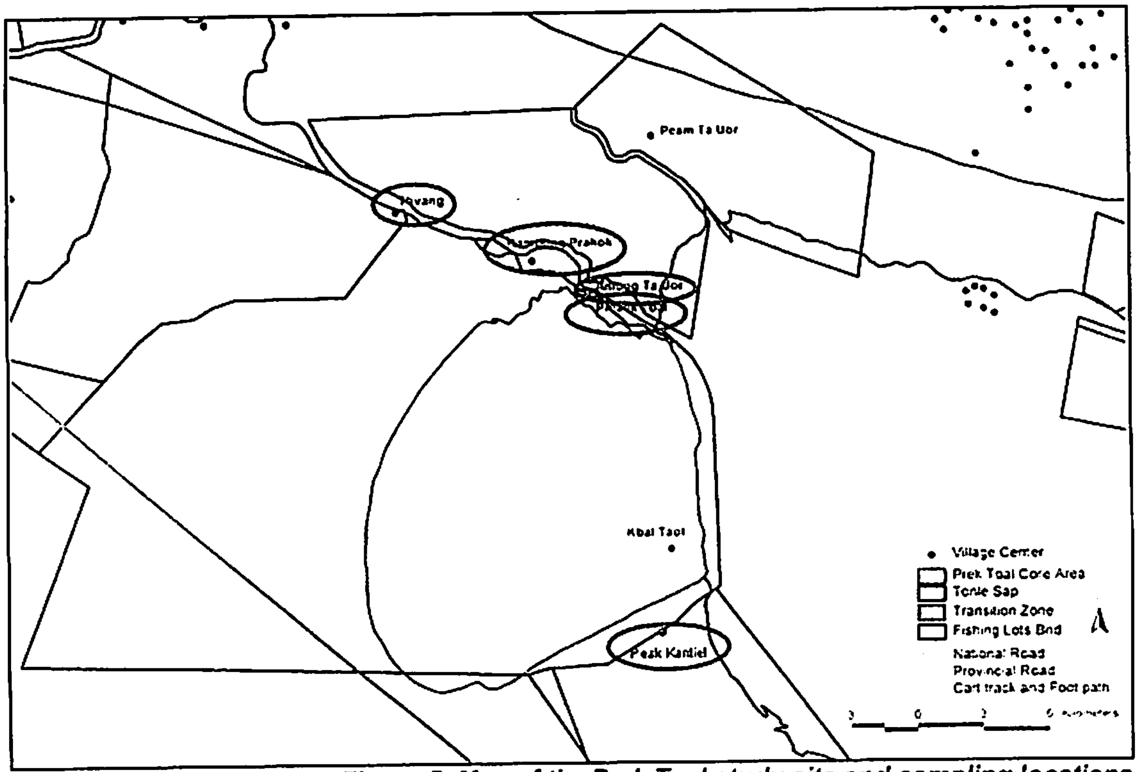

Figure 5: Map of the Prek Toal study site and sampling locations

14.

Integrating the results of all thematic research components. Part of the scientific coordination consisted in making sure that the various components would be clear about the issue they would contribute to or share about, and would have a language in common so that they can ultimately be articulated and integrated. At the local scale, the Sustainable Livelihoods Framework was seen as the one best accommodating inputs from all components, as well as a standardized basis allowing comparisons with other Tonle Sap Initiative projects. At the scale of the Tonle Sap basin, three basic thrusts were identified (hydrology, fish, livelihoods) as the components simple enough to allow for integration of the results. At the scale of the Mekong Basin, focus is on hydrology, water management rules and scenarios, as previously adopted by the Mekong River Commission[2]. Figure 6 summarizes the approach for integration between components.

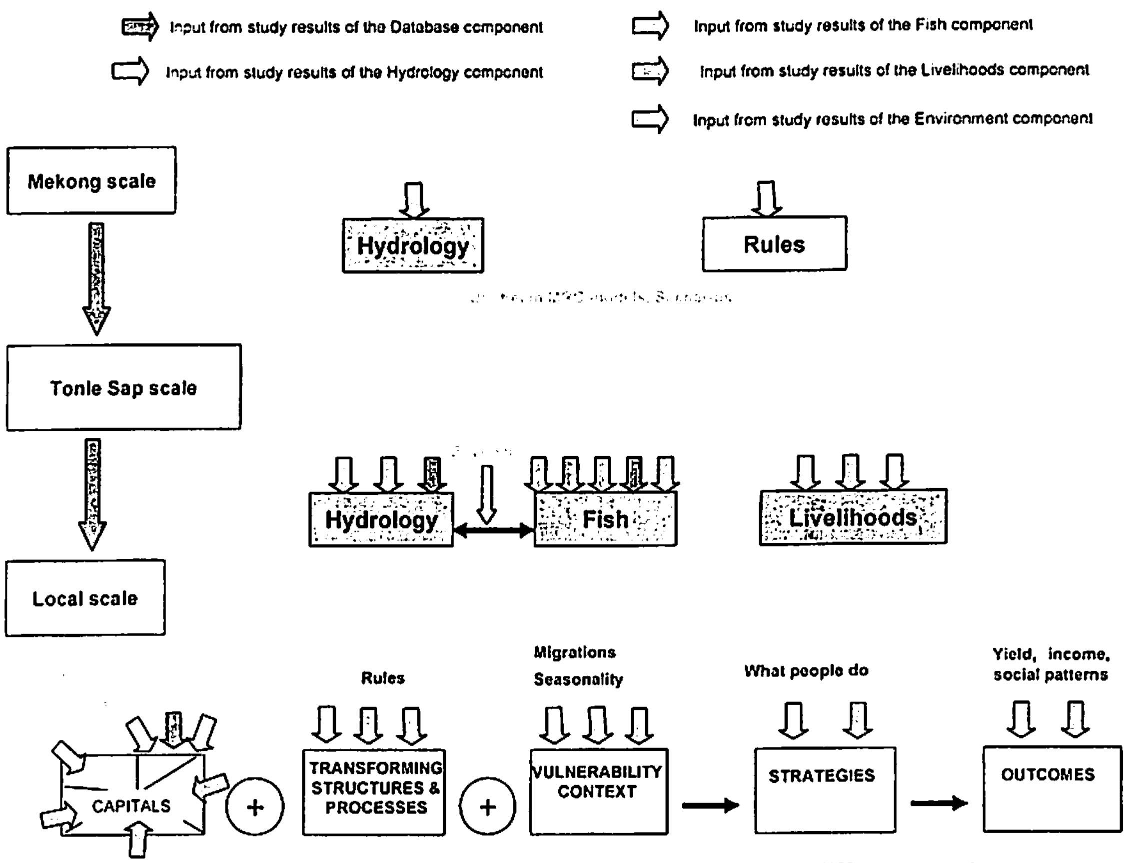

Figure 6: A conceptual framework for integrating components at different scales.

2 • Podger G., Beecham R., Blackmore D., Perry C., Stein R. 2004 Modelled observations on development scenarios in the Lower Mekong Basin. Report of the Mekong Regional Water Resources Assistance Strategy. World Bank, Vientiane, Lao PDR. 122 pp.

• Beecham R., Cross H. 2006. Modelled impacts of scoping development scenarios in the Lower Mekong Basin. Basin Development Planning: draft report of the TSD Modelling Team. Mekong River Commission, Vientiane, Lao PDR. 198 pp.

• MRC 2005 Strategic Directions for Integrated Water Resources Management in the Lower Mekong Basin. Final draft report of the Basin Development Plan (December 2005). Mekong River Commission, Vientiane, Lao PDR. 56 pp.

15. On the practical ground, the interactions between components were worked out, particularly through the identification of variables specific to each component (e.g. road height, water level, fish abundance, income, access rights) and some variables that can be shared among more than one components. This exercise helped each component understand what information the other components need, and assured that each component generated and documented results in a way that could be easily linked with the results of other components, at least logically if not quantitatively.

16. A shared template was developed for preparing the technical report of each component, in order to assure that each component produces the necessary outputs consistent with other components. The concept of integration by the 3 geographic scales was developed into an outline of the synthesis report, and information need for each section was identified through a writing workshop among key IRS and DRS. This process facilitated integration of multiple components results into a consistent framework.

II TA ACCOMPLISHMENTS

A Summary of the TA accomplishments

Table 5: Summary of the project accomplishments

OUTPUTS	ACTIVITIES	MILESTONES ACHIEVED	PROBLEMS FACED	MEASURES TAKEN
1. Creating a database of built structures (Database Output)	1.1 Categories of built structures, focus structures, and the scope of the study are determined	• Report on classification scheme of built structures was prepared • Focus structures for the TA were determined	• Determining the scope of built structures for inclusion in the database was difficult, as there are countless small to medium-scale structures that may have cumulative impacts but are difficult to characterize by remote sensing.	• Built structures that are particularly relevant for the hydrological modeling were prioritized.
	1.2 Existing information on Built Structures of concern is gathered	• Existing data from line agencies were secured. • Supplemental data from alternative data sources were obtained • Data from JICA and MRC were secured • In focus study sites road networks, canals, a irrigation scheme, and fishing fences were digitized using orthophotomaps and ground validation.	• Very little data was available from line agencies. Almost all existing data are outdated because many new structures have been built in recent years.	• Supplemental data were obtained from alternative sources, including conservation NGOs and consultants in other projects. • Detailed features of road networks, irrigation scheme, and fishing fences in study areas were manually digitized with additional field consultant inputs.
	1.3 Ground validation of built structures is conducted in selected locations	• Hi-resolution satellite data sources were evaluated for usefulness for the database. • Ground validation exercises were conducted in Kampong Thom, Siem Reap, Pursat, and Kampong Chhnang provinces	• Ground validation progressed slowly as road condition deteriorated during the rainy season. • Existing orthophotos turned out not very useful for ground-truthing built structures in some areas.	• Additional ground-truthing visits to strategic and selective locations were made in order to improve the overall accuracy of the database. This required additional inputs of field consultant.
	1.4 A database of built structures and the data documentatio n are prepared	• Database of built structures in the Tonle Sap basin was developed, with over 14,000 records, and was refined for faster access and flexible use for the public. Available for public access at: http://www.eia.fi/bs./ • Users' manual for the database was prepared • Summary statistics were generated from the database and presented in an additional report. • Online access to the database was established through TSBR Environmental Database, which became the final repository.	• It was difficult to identify an appropriate host server that allows free online access to the final database. • It took longer than expected to populate the database with built structure information, as the data gathering and validation took longer than expected.	• Open Source servers (in commercial sites) were explored as alternative site for setting up the built structure database • Online access to the database was established through TSBR Environmental Database, which became available towards the end of the TA. • The time allocation of the DRS was extended from 4 to 7 months.
	1.5 Field survey data from other research components are integrated	• Databases with field survey data, reports, and other reference materials were transferred to TSBR Environmental Database.	• Ensuring compatibility with the TSBR-ED web site and interactivity for users of this web site has been challenging	• Programming solutions have been found by the team

2. Modeling the impact of built structures on hydrodynamics and water quality	2.1 Hydrodynamic model of the Tonle Sap is updated integrating large-scale built structures basinwide	• Detailed hydrological models for the sub-catchments that cover the 3 study areas were prepared. • Simplified hydrological models for all Tonle Sap sub-catchments were prepared. • The Tonle Sap water balance model was improved with the MRCS modeling team.	• It was difficult to obtain updated data and information from line agencies. • Delay in the database component delayed the incorporation of built structures data in modeling	• While waiting for the built structure data, the emphasis of modeling work was placed on refining, validating, and analyzing the input data other than built structures. • Tools were developed to facilitate speedy integration of built structure information into the models.
	2.2 Hydrodynamic model of the Tonle Sap is updated integrating small-scale built structures at selected sites	• Fields surveys were conducted to collect hydrological and water quality data at selected sites in Kampong Thom, Pursat, Siem Reap, and Battambang. • Model was developed for small scale embankments and channels. • A scaled-down version of Tonle Sap model was developed for faster analysis of built structures. • A model of the Stung Chinit irrigation system including DEM, channels, gates and embankments was prepared.	• Existing large-scale model was not able to reproduce in detail the functioning of small scale structures. • Description of small scale structures was difficult to achieve with reasonable level of accuracy and computation time .	• To achieve reasonable computation time with the built structure data, a simplified version of hydrological models was created for all sub-catchments. • High-resolution models were developed for selected small/large scale built structures. • Alternative approaches were tested for improved accuracy and decreased computer time.
	2.3 Influence of major fishing gears on hydrodynamics is assessed	• Laboratory experiments of the influence of fishing fences on flood retention was conducted. • Field measurements were taken in Prek Toal area at two different time periods, with and without fishing fences.	• The fishing gears were not in place during the flood season that was covered in the originall workplan. • Impacts of fishing fences are difficult to detect and study especially at large scale.	• Laboratory experiments were conducted to complement the field-based data. • The time coverage of the field surveys was extended to January, allowing the *in-situ* measurements to be taken when fishing fences were in place.
	2.4 Baseline and other scenarios with built structures are evaluated	• Four water development scenarios were developed and the results were compared. • Report on the influence of built structures on hydrology and water quality was prepared.	• The scenario development was delayed due to the delay in the data input from the Database component. • Identifying water development scenarios that are relevant for the Tonle Sap took a lot of time and efforts	• Other TA components helped the hydrological modelers to define distinct scenarios that made sense for the Tonle Sap.
	2.5 Maps and animations summarizing the modeling results are prepared	• Maps and other figures summarizing the results were prepared.	• Resulting quantitative information was complex, and the interpretation of the results into non-technical conclusions was a major challenge	• Other TA components worked with the hydrological modelers and identified specific results that are easily interpreted and have clear environmental or fisheries implications.

3. Assessing the environmental impact of built structures	3.1 A literature review on the main consequences of built structures on tropical floodplains worldwide is conducted	• Over 200 publications were reviewed, and over 30 experts worldwide were consulted. • The final review report was completed, with policy recommendations.	• Too much information of varying quality was available, but not enough time to screen everything. • Much information was available in grey literature but unpublished and thus difficult to access. • Expert questionnaire that was meant to capture unpublished knowledge did not generate much response.	• The focus of literature review was redefined, and the criteria to screen out some information were set. • The questionnaire was re-sent to a fewer number of selected experts.
	3.2 EIAs and IEEs on the projects within Tonle Sap basin are reviewed and findings and recommendations are synthesized	• Evaluation criteria for the review of EIA reports were set. • Report on the evaluation of EIAs/IEEs was prepared. • Recommendations for enhancing the EIA process, impact assessment method and support to the decision-making were identified.	• Significant difficulty in accessing EIAs and IEEs that are scattered across numerous line agencies. • Delay in finalizing the EIAs review report, in order to incorporate additional references and strengthen the results	• Collecting EIAs continued throughout the duration of the experts inputs And not only at the beginning of the task as initially planned • The emphasis of the review was shifted to constraints in implementing EIAs.
	3.3 Contributions, flaws and gaps of Tonle Sap based environmental impact assessments are identified	• Identified and held consultations with key stakeholders in Phnom Penh • Knowledge gaps were identified with reference to existing information worldwide	• The coverage of existing EIAs for Built Structures and for floodplain environment was insufficient for the purpose of the review.	• The scope of review was expanded to include a broader range of Environmental Assessments, not just EIAs.

4. Assessing the impact of built structures on fishery resources	4.1. Field surveys on the influence of Built Structures on fish production and species ecology are conducted in three study areas	• Numerous reference materials with regards to built structure and fisheries were reviewed and shared with other components. • Local fish species were comprehensively reviewed for their ecological characteristics • The survey methodology using a semi-open questionnaire was developed, tested, and finalized • Experienced fishers at each target site were identified, and full surveys were completed at study areas in Pursat, Kampong Thom, and Battambang provinces • Fish larval drift surveys were conducted in 4 sites, and the analyses were conducted	• Existing information on Tonle Sap fish ecology was found insufficient. • Difficulty in identifying the survey sites that accommodate the data need for all components. • Difficulty in developing a methodology that has a suitable balance between practicality and details, and that is flexible enough to accommodate the diversity of the selected sites. • The large amount of time needed for testing questionnaires commanded a slight delay of the full surveys. • Larval migrations consist of intense peaks that last only 1 to 2 days in each tributary and are unpredictable, which made their monitoring almost impossible and results insignificant.	• Stronger emphasis on collecting traditional knowledge from experienced/knowledgeable fishers • Involvement of a specialist in traditional knowledge • The criteria for selecting field sites and target built structures were discussed in details with the other components • The survey methodology was tested at all three study areas and revised so as to ensure its relevance to the local conditions.
	4.2 Fish ecology data and changes in hydrology and water quality predicted by the Tonle Sap hydrodynamic and water quality model are integrated	• A model of Tonle Sap fish production was updated with additional fish bioecology information • A report on the relationship between fish bioecology and hydrology was prepared. • A report on the updated BayFish model of the Tonle Sap fish production was prepared	• Hydrological modeling was delayed and the fish production model was subsequently delayed until February 2007	• Coordination between hydrology and fisheries components was enhanced through additional meetings and other direct interaction among the experts, on how to integrate the data smoothly once hydrological model results become available.
	4.3 Based on best available information, the influence of built structures on Tonle Sap fish productivity is quantitatively assessed	• Potential influence of built structures on the Tonle Sap fish species that are vulnerable to hydrological changes was assessed. • Influence of built structures on local fisheries was assessed at the selected study areas based on traditional knowledge. • Report on the Influence of Built Structures on fisheries was prepared.	• Difficulty in isolating the influence of built structures from other factors that affect fisheries in the specific study areas • Effects of structures on fish have been quantified as much as possible, but knowledge available basinwide does not allow extensive quantification	• All documents and studies allowing a quantification of impacts have been used and combined, and emphasis has been put on dominant commercial species.

5. Assessing the impact of built structures on livelihoods	5.1 A literature review on the main consequences of built structures on the livelihoods of fish-dependant communities in tropical floodplains worldwide is conducted	• A large number of documents was compiled, of which 25-30 key references were used to inform local-scale surveys. • Consultations were conducted with key informants and experts, including local government line agencies, NGOs, donor projects, and consultants.	• Difficulty in obtaining unpublished project reports relevant to the Tonle Sap study areas.	• Contacted relevant agencies and consultants for other TSI projects for unpublished information. • Information was collected through direct consultations with key informants and local experts.
	5.2 A field-based assessment of the impacts of local built structures on livelihood of fish-dependent communities is conducted	• Pre-survey site visits and key informant interviews were conducted in Pursat, K. Thom, and Prek Toal sites. • Participatory survey methods, questionnaires, and materials were developed and tested in all study sites. • Field surveys were conducted at the selected sites. • Report summarizing the methods, analyses, the results, the policy recommendations was prepared.	• Difficulty in identifying the survey sites that accommodate the data need for all components, particularly in Pursat province where a variety of water development schemes are ongoing, including both irrigation structures and floodplain roads.	• The TA team selected a site with floodplain road, based on local diversity of the sites and relevance to all the components.
	5.3 Availability of alternative livelihood is probed	• Focus group discussions were conducted in each of the sites at the Pursat, Kampong Thom, and Prek Toal study areas. • Report on alternative livelihoods was prepared.	• No major problems encountered.	

6. Informing policy makers and decision makers	6.1 Dissemination strategy and plan are prepared	• Communications Strategy for the TA, including a detailed plan for dissemination of publication outputs, was prepared.	• Completion was delayed in order to incorporate the results of the stakeholder workshop in August.	• An experienced consultant was hired to strengthen the communication and dissemination strategy
	6.2 Consultation and dissemination meetings with relevant agencies are conducted	• First Information Workshop held in Phnom Penh, August 2006 with 48 external participants. • Stakeholder Review Workshop was held in January 2007 with 50 external participants. • Final Workshop was held in May 2007 with 98 external participants.	• Identifying relevant agencies to invite was a challenge as they are scattered across numerous Ministries. • Scheduling the workshop dates that accommodate the CNMC's busy schedule in attending/organizing MRC-related meetings was difficult.	• CNMC's membership network was used effectively to secure attendance. • Planning of workshops started well in advance in order to fully engage CNMC and its member ageny.
	6.3 Publication outputs are produced in English and translated into Khmer as appropriate	• Synthesis report was prepared both in English and Khmer and endorsed by CNMC. • Policy brief was prepared both in English and Khmer and endorsed by CNMC. • 7 short educational video clips were prepared in English, Khmer, and French. • Scientific background documents (technical reports) were made available as PDF. • More than 300 PDF files of bibliography have been uploaded in the TSBR-Environmental Database for public access on Internet.	• Securing good quality English-Khmer translation has proven very challenging. • Thorough review process took time and careful coordination.	• The translated manuscripts and the video clips went through several rounds of reviews and revisions, in particular by CNMC and the Fisheries Administration staff.
	6.4 A series of dissemination events (i.e. workshop, briefing) are held	• Press release on the launch of TA was quoted in major Cambodian newspapers, including *Cambodge Soir* and *Rasmei Kampuchea*. • Project information and updates were published in *Tonle Sap Bulletin*, *Cambodia Weekly*, and *South Eastern GLOBE*, a regional business magazine in English. • A paper on the project approach was presented at *International Symposium on Sustainable Development in the Mekong River Basin*, in Phnom Penh in September 2006, and published in its proceedings. • Information on the TA was displayed at an exhibit booth at the Tonle Sap Initiative Forum in March 2007. • Some video clips developed for the TA were shown at a World Wetlands Day event • All the publication outputs were physically delivered to the target audience identified in the Communication Strategy of the TA	• No major problems encountered.	

B Details of the TA accomplishments

1 Creating a database of Built Structures

17. The "Database component" of this project identified and catalogued the built structures of the Tonle Sap Basin, based on existing information from numerous sources such as line agencies and donor projects, validated by extensive ground-truthing exercises around the local study areas. The information compiled in a database was used at first for internal purposes by other research components of the project, facilitating the selection of sites and locations for pre-survey field visits, and later for surveys. The database was then refined further for public access through Internet. More specifically, its objective was to make updated information on built structures available to technicians, managers and decision makers. Key activities carried out include: (i) conducting a scoping study on Built Structure types, identifying the types that are relevant for hydrological modelling and for Tonle Sap, and determining focus Built Structures for the TA; (ii) gathering existing information on Built Structures in the Tonle Sap basin; (iii) ground-truthing the information on Built Structures of concern in selected locations; and (iv) producing a database of the characteristics of Built Structures of concern.

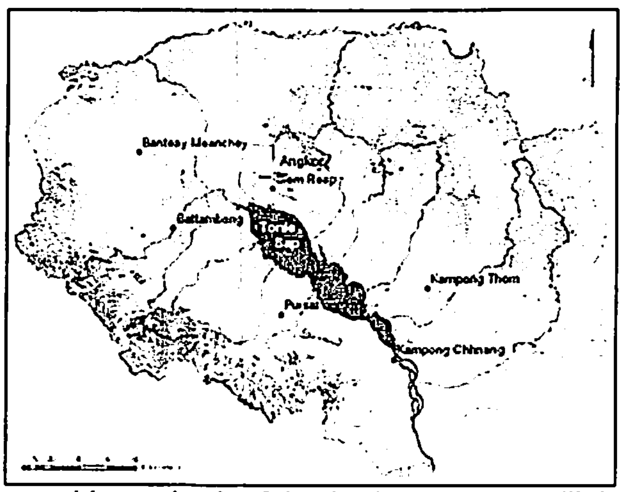

Figure 7: Geographic emphasis of the database contents (light blue colour)

18. Conducting a scoping study on Built Structures. Spatial emphasis was set on the catchment areas through which water flows to the Tonle Sap, and more generally on areas that become inundated during the flood season. The Tonle Sap flooded area shown (in pale blue color) in Figure 4 is mostly confined between national roads n° 5 and 6. The Stung Chinit irrigation project, the project study area in Kampong Thom, is not in the floodplain itself but on the Chinit river, a major tributary flowing into the Tonle Sap.

19. As the first task of the component, The IRS Database Specialist, with support of the DRS, reviewed existing classification schemes of hydraulic structures and prepared a classification scheme for the TA, which groups built structures into a number of broad

categories and rank them based on how they influence water flow and fish movements. An attempt was made to set criteria for identifying built structures that potentially have the most significant influence on fisheries and the environment, for inclusion in the database[3].

20. Structures in the target area were divided roughly to three categories, large, midsize and small structure. Large structures may have catchment-wide impacts, while midsize structures typically have only regional scale impacts, and small scale structures have only local impacts. A hydrological limit for large structure was defined as a structure that can store or transport 2.5 million m^3 water (in a year), or modify existing flows for at least 1 m^3/s on the average, or 4 m^3/s during peak flow time. A limit for midsize structure was here defined as a structure that can store or transports 0.5 million m^3 water (in a year), or modify existing flows for at least 0.5 m^3/s on the average, or 2 m^3/s during peak flow time.

21. Properties for each structure type was defined and incorporated in the database design. Main characteristics of a structure included in the database are: geographical location, physical dimensions of the structure, flow and volume of water affected, validation information. Additional information such as field video footage and photos of the structures, name of owner or management authority, was also included in the database as available.

22. The final database mainly contains large and mid-size structures. Structures classified into the small category may also be included to database in some cases, for example, if the impact of structure is not known or attributes required for assessing the structure size are not available. The total number of records entered to the database is more than 14,000.

23. Gathering information on built structures of concern. Information on existing built structures was compiled from existing paper maps, databases, reports, inventories, and remote-sensing data from various sources. The information gathered was gradually entered into the database as they became available. The Database Specialists visited multiple government agencies and other organizations as potential data and information sources[4]: Consequently, the five major data sets were secured[5].

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[3] **Embankments:** 1) Any embankment potentially catching water for more than 2.5 million m^3 ; 2) Embankments higher than 1 m if longer than 2 km; 3) Embankments lower than 1 m are not mapped; 4) Flood water catching embankments with collected water depth 0-2 m, if area > 2.5 km^2.
Dams & reservoirs: 1) Dams with reservoir volume larger than 2.5 million m^3. For typical reservoir in the area with water depth of 0-2 meters, this would mean an area of at least 2.5 km^2 when 1 m average water depth is used in volume computation.
Channels: 1) Channels with average flow larger than 1m^3/s, or peak flow larger than 10m^3/s; 2) Channels with high water cross section larger than 10 m^2
Irrigation areas: 1) Irrigated areas with field area larger than 2.5 km^2

[4] Namely:
- Department of Hydrology and Rivers Work and Department of Potable Water Supply, MOWRAM
- Department of Geology and Department of Hydropower, Ministry of Industry Mines and Energy
- Ministry of Public Works and Transport
- Department of Fisheries, Ministry of Agriculture, Forestry, and Fisheries
- Basin Development Program, Cambodia National Mekong Committee
- Japan International Corporation Agency, Information Center in Phnom Penh
- Regional Flood Center, Mekong River Commission
- Seila Programme, Ministry of Interior
- Stung Chinit irrigation project office, Kampong Thom

24. Most of the government agencies were reluctant to share the data, despite the official request to these agencies for support and provision of data and information to the TA, issued by CNMC. At the same time, much of the existing data from the government sources turned out to be practically outdated because of the recent developments of new small to medium-scale built structures in the focal areas. Additional data were secured from other data sources, such as NGOs, including Wildlife Conservation Society (WCS), and consultants of other donor projects around the Tonle Sap, to supplement the available data. In addition, built structures for which the information was not readily available, namely floodplain road networks, canals, and fishing fences, were manually digitized based on existing orthophoro maps and entered into the database.

25. Ground-truthinq Built Structures of concern. The built structure information gathered was checked for accuracy through extensive field-based validation exercises in Kampong Thom, Siem Reap, Pursat, and Kampong Chhnang provinces, with an emphasis on selected study areas. Information on flood retention reservoirs prevalent in Kampong Thom province, and on Stung Chinit irrigation scheme was thoroughly validated in particular. Field-based ground-truthing became increasingly difficult especially in remote areas because of the heavy rain and poor road condition, and difficulty in obtaining GPS data points. In addition to field surveys, high-resolution satellite data from IKONOS was evaluated for its usefulness for the ground-truthing, however, no coverage by the satellite was available for the target study areas. Existing orthophotos were also evaluated, but its usefulness turned out to be limited in some areas. Alternatively, the possibility of an airplane fly-over survey was explored for taking new aerial photos for ground-truthing built structures. However, this option was decided to be unpractical due to the overall cost and the time required for photo analysis. Consequently, additional field-based ground-truthing at strategic and selective locations was conducted to improve the overall accuracy of the database.

26. Producinq a database of built structures. The Database Specialists, with inputs from the Hydrological Modeling Specialist, designed and developed a database of the built structures, which is publicly available for online access at EIA Ltd. web site (http://www.eia.fi/bs./) and at the Tonle Sap Biosphere Reserve Environment Information Database (TSBR-ED) web site (http://www.tsbr-ed.org/en/ --- the database access currently limited to registered users of TSBR-ED only) (Figure 8). The database structure went through a few rounds of refinements for faster access and flexible use. The database is now populated with over 14,000 records of built structure information. Discussions were held with the team who are implementing TSBR-ED, and technical solutions were devised to allow easy integration of the built structure database into TSBR-ED. TSBR-ED has been designated as the host of the final database and other associated databases, publications, and reference materials, and its staff will be responsible for making the data publicly available after the life of this TA.

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[5] Namely:

- JICA 1999. Land use map simplified for Tonle Sap floodplain
- MRC Basin Development Plan and recorded infrastructures in the Tonle Sap floodplains
- Ministry of Public Works and Transport, data about bridges and culverts
- Seila program data about construction project locations
- Stung Chinit irrigation scheme data

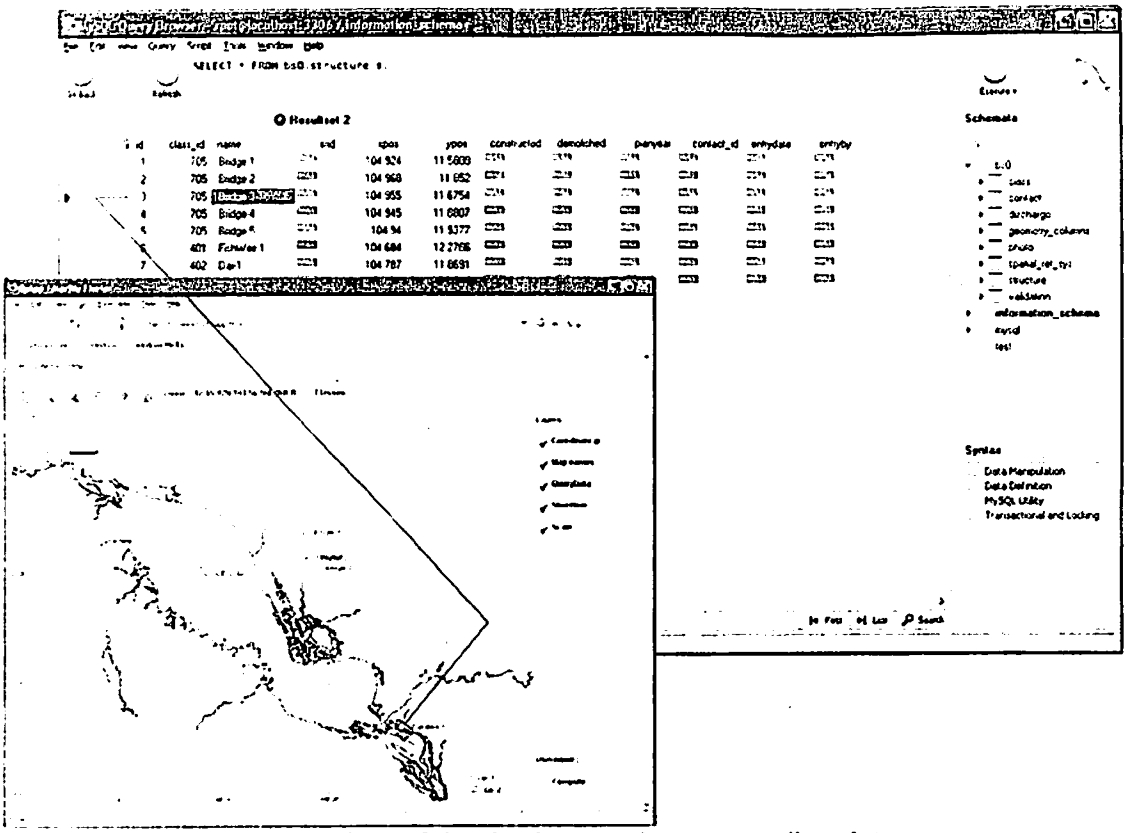

Figure 8 Clickable interface of the database and corresponding data

2 *Modelling the influence of Built Structures on hydrodynamics and water quality*

27. This component uses the Tonle Sap 3D hydrodynamic and water quality model previously developed by WUP-FIN in 2001-2003, supplemented by the Mekong model subsequently developed. The overall objectives of the modeling component was to a) integrate Tonle Sap built structures data into a functional hydrological modeling framework and b) produce information on the influence of built structures on hydrology and water quality. The integrated model framework encompasses topography, land use/ vegetation, water bodies (river channels, lake proper), meteorology, hydrology, monitoring data and built structures. This framework integrates data in a way that corresponds to the naturally occurring functional relationships and thus enables dynamic analysis of the system. The modeling output data was generated for analysis by the Fisheries component of the TA, which included flow and flooding characteristics, sedimentation, water quality, fish larvae drift (particles representing larvae) and habitat conditions. Not only local effects but also influence of upstream developments was studied with the model and was compared to the local effects in terms of its relative significance.

28. Key activities carried out were: (i) integrating large-scale Built Structures, at the basin level, into the Tonle Sap hydrodynamic and water quality model; (ii) integrating relevant small-scale Built Structures into the WUP-FIN Tonle Sap model; (iii) assessing the impact of major fishing gears on hydrodynamics; (iv) conducting quantitative analysis of

hydrodynamic and water quality differences with and without Built Structures; and (v) producing maps of the differences and illustrative animations of the effects.

29. Integrating large-scale built structures into the Tonle Sap model. The Hydrological Modeling Specialists worked with the Database Specialists to specify the attributes and formats of the built structure data so as to facilitate the use of database outputs for the hydrological modeling. Methods for converting the information on large-scale embankment and channel structure into inputs to hydrological models was developed. Time-series hydrological data were evaluated and formatted for input to the Tonle Sap model. The Modeling Specialists prepared detailed hydrological models for the sub-catchments that cover the 3 study areas. However, developing and including built structure data for the detailed models would take so much time that it is neither practical nor necessary for the project purposes. Instead simplified version of hydrological models were developed and used together with MRC Secretariat development scenario data. Because of the delay in populating the built structure database, the hydrodynamic and water quality model implementation with actual built structures was delayed. However, while waiting for the built structure data, the emphasis of modeling work was placed on refining, validating, and analyzing the model data other than built structures. Tools were also developed to facilitate speedy integration of built structure information into the models. Carrying out these exercises compensated for the delays. The built structure information was fully integrated into the large-scale model before the scenarios were evaluated. (*See paragraphs below on scenarios*).

30. Integrating relevant small-scale built structures into the Tonle Sap model. The small-scale structures that are relevant to the hydrodynamics of the selected study sites were integrated into the Tonle Sap model. To parameterize the influence of those small structures in the large-scale model, high resolution models of local small structures were prepared. A model for Stung Chinit irrigation system, including DEM, channels, gates and embankments, was prepared with, and without the structures for comparison. In addition, models were also prepared for small scale embankments and channels, and a floodplain irrigation structure in Kompong Thom province.

31. Field surveys were conducted to collect hydrological and water quality data at selected locations in Kampong Thom, Pursat, Siem Reap, and Battambang, covering the early stage, peak, and end of the flood cycle. The data collection and laboratory analyses were designed to detect characteristics in different phases of the flood cycle. Hydrological modelling parameters were upgraded subsequently as new data became available. Data were collected on parameters that form the basis of the functioning of the fisheries in lake-floodplain ecosystems: water levels; currents and inundation; hydrodynamic connectivity of channels and ponds; sediment transport and sedimentation; and water quality (TSS, DO, inorganic nutrients). Standard sediment and water quality sample analyses were conducted in Ministry of Water Resources and Meteorology (MOWRAM) laboratory, complemented by analyses done by the laboratory of the Research Development International Cambodia (RDIC) for inorganic nutrients. Specialized sediment nutrient bioavailability analyses were also conducted in Finland from the Tonle Sap sediment samples.

32. Assessing the impact of major fishing gears on hydrodynamics. In the original plan, the effectiveness of this activity was constrained by the fact that the time period available for field-based data collection during the TA implementation did not cover the fishing season in Cambodia, when large-scale fishing fences are in place. The scope and duration of

the field work was later extended to assure that the field measurements were taken with the fishing fences, enabling on-site assessment of the influence of fishing gear on local hydrology. In addition, laboratory experiments were conducted using bamboo fences and nets typically found in Tonle Sap fisheries, to recreate the condition similar to that created by fishing gears in a controlled environment. The results of preliminary experiments tend to indicate contrary to the local belief that the fences play a significant role in the lake's hydrology, i.e. slowing down the receding flood. Additional field work during the receding flood yielded results that are generally supportive of the laboratory-based work.

33. Analysis of the hydrodynamics and water quality differences with and without Built Structures. Four water development scenarios described below were developed, using the MRCS development scenario simulation outputs, and evaluated for their potential implications on a number of hydrological parameters for the Tonle Sap, including water level, flood regime, hydrodynamics, and water quality. The results of each scenario were compared for the relative importance at basin and sub-basin scales.

- **Baseline scenario**---represents the existing level of water storage based on the actual situation in 2000 when there was only one hydro-electric dam in the Upper Mekong Basin with a relatively small water-storage capacity of less than one cubic kilometer.
- **Intensive basin development scenario**---represents a combined water-storage capacity of 55 cubic kilometers, assuming that seven more hydro-electric dams are built across the mainstream by 2025 in the Upper Mekong Basin. This assumes that China and Lao PDR will each have a water-storage capacity of about 23 cubic kilometers, including almost five cubic kilometers for the Nam Ngum 1 reservoir alone. Thailand and Viet Nam would account for the remaining nine cubic kilometers.
- **Extreme basin development scenario**---adds to the second scenario seven more dams on the Mekong mainstream in Lao PDR, Cambodia and Thailand, boosting the total storage capacity to 140 cubic kilometers. The additional 85 cubic kilometers would come from dams in Lao PDR (Luang Prabang, Pa Mong, Thakek and Pa Mong), Cambodia (Stung Treng and Sambor) and Thailand (Sayabouri).
- **Limited development scenario for the Tonle Sap watershed**---assumes a combined storage capacity of 5.5 cubic kilometers. This adds to the baseline scenario the hydro-electric and irrigation dams on seven tributaries that flow into the lake, notably Stung Sen.

34. Producing maps and illustrative animations. A series of team meetings in October – November 2006, and a synthesis workshop among the TA components held in January 2007 resulted in guidance to each component in terms of how to summarize their results so that they can be integrated with the results from other components in meaningful way. Numerous maps, figures, and tables were prepared, summarizing the results of the scenarios in a simple manner. The figures below are some examples comparing the results of different water development scenarios for the Tonle Sap.

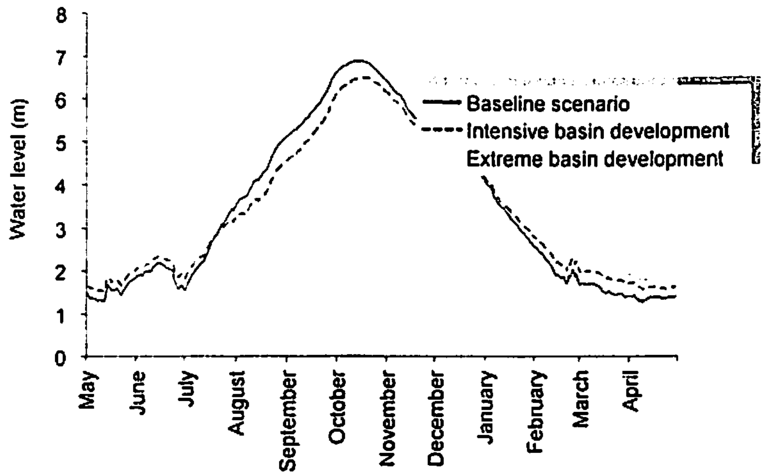

Figure 9: Tonle Sap water levels under Baseline, Intensive Development, and Extreme Development scenarios.

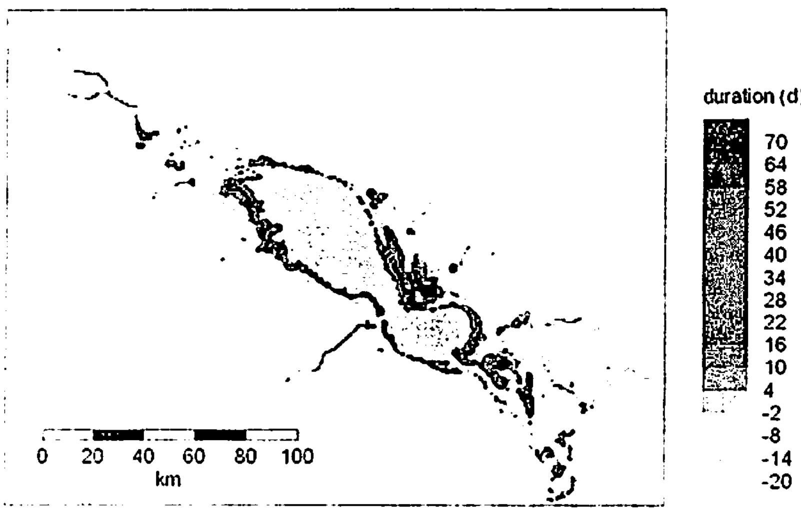

Figure 10: Upstream developments result in floods ending sooner. The legend indicates the change in the duration of flood between the Baseline and Intensive Development scenarios. Longer period of inundation near the lake edge (highlighted in graduation from red to blue) is caused by increased water levels during the dry season.

3 *Assessing the influence of Built Structures on the environment*

35. This component reviewed scientific literature and local impact assessments on the known effects of Built Structures of concern. on the environment. The resulting recommendations were derived from information regarding experiences on a world-wide scale with specific findings from the Tonle Sap. Its specific objective was to analyze lessons learnt from tropical floodplain ecosystems worldwide and from Tonle Sap Environmental Impact Assessments to produce useful guidance for further development of built structures in the Tonle Sap basin.

36. Key activities conducted were: (i) reviewing the documented short-term and long-term influence of Built Structures in tropical floodplains worldwide; (ii) synthesizing the findings and recommendations from environmental impact assessments (EIAs) and initial environmental examinations (IEEs) conducted for development projects in the Tonle Sap basin, existing EIA guidelines, and other secondary literature on the EIA processes, from environmental and social safeguard perspectives; and (iii) providing recommendations about the approaches, methods, and processes followed by EIAs and IEEs in the Tonle Sap basin.

37. Reviewing the documented short-term and long-term influence of built structures in tropical floodplains worldwide. Lessons learnt worldwide on the consequences of built structures on the ecosystem as a whole was reviewed and the general conclusions and recommendations drawn from other tropical floodplains to the Tonle Sap were assessed. To screen the wide variety of information available on the subject and to filter out the information that are not well documented or substantiated, this assessment concentrated on information of quantitative nature, and on lessons learnt in other countries with environmental or social similarities to the Tonle Sap.

38. The Environment Impact IRS conducted literature search using internet as well as university library databases and resources; over three hundred documents were reviewed, including journal articles, reports, and books on the subject. In addition, over 60 key experts and institutions working on floodplain environment conservation/management issues were contacted to gather information that were not readily available in published literature. All the data and information collected were systematically reviewed and synthesized, including the creation of a table specifying, for each significant study, the location, references, type and size of structure, and the recorded impact. Key tropical floodplains reviewed include: the Amazon and the Parana River systems in South America, the Senegal and the Niger in Africa, the Brahmaputra and the Mekong in Asia, and Australian floodplains. Initial analyses highlighted the fact that there are a large number of papers vaguely addressing this issue, without providing any quantitative evidence of changes; hence the need to focus primarily on post-development studies including a quantified approach was identified. A technical report was prepared documenting the findings, list of literature reviewed and the experts consulted, and also with the policy recommendations which were integrated into the synthesis report summarizing the research results of the TA.

39. Main findings of the worldwide review are the following:

- Information on the influence of built structures on tropical floodplain ecosystems are very limited
- Little quantitative and published information is available on impacts of built structures other than large dams
- Large dams have caused hydrological alteration, changes in biogeochemical processes, impacts on biodiversity, and pollution, and can also affect downstream floodplain environments strongly
- Smaller, but numerous built structures such as embankments, channels and dykes, have more localised effects on flood plains, but most probably lead to significant cumulative impacts
- Regardless of continent, disruption of flood pulse and lateral and longitudinal connectivity of floodplains by built structure generally result in loss of ecological services of floodplains

- Compensating for lost floodplain ecosystem services is hard, if not impossible, through conversion of the floodplains to other land use such as crop cultivation and livestock grazing
- It is possible to partially recover the lost floodplain ecosystem services through rehabilitation efforts, while restoring the complete variety of floodplain ecosystem services is extremely difficult and costly

40. Synthesizing the findings and recommendations from Tonle Sap EIAs and IEEs. The Aquatic Impact IRS and the Environment Impact DRS conducted a review, from a fisheries perspective, of the environmental impact assessments of existing and planned built structure projects in the Tonle Sap area. After initial efforts in identifying and compiling the relevant Environmental Impact Assessments (EIA) and Initial Environmental Examinations (IEE) reports, the scope of the review was expanded to include CEA (Cumulative Effects Assessments) and SEA (Strategic Environmental Assessments), due to the general paucity of the EIA and IEE reports referring to the Tonle Sap area. Inclusion of SIA (Social Impact Assessments) was initially considered for the review, however, no SIA was found within the timeframe of the review. Difficulty in identifying and accessing EIAs and IEEs that are scattered across numerous line agencies at different levels of authority also resulted in some delay in securing the relevant documents in time.

41. The original focus of the review was to evaluate the quality of impact assessments in terms of its analytical and predictive capability of impacts of built structures on the fisheries of the Tonle Sap. In face of the paucity of the EIA reports, an adjustment was made to shift the emphasis from evaluating impact assessments *per se* to improving understanding of the reasons underlying this lack of EIA reports, namely, the EIA process. To this end, increased efforts were made to compile secondary information on EIAs with regards to its approaches, methods, and recommendations, and to review this information in order to define the best working alternatives for conducting effective EIAs for floodplain ecosystems in the future. Unpublished secondary literature was identified, and understanding of the transparency of EIA processes and the accessibility of the related information to civil society groups in general was enhanced through stakeholder consultations. The IRS and DRS identified 10 key stakeholders and conducted meetings with them, including Fisheries Action Coalition Team, NGO Forum on Cambodia, EIA Department of Ministry of Environment, Tonle Sap Initiative Coordination Unit of ADB, TSBR Secretariat, Public Works Research Center of Ministry of Public Works and Transport.

42. The EIA and IEE reports and relevant secondary information were collected from various institutions and organizations such as the Ministry of Environment, donor government agencies, and local NGOs. Key official documents and grey literature in Khmer language were translated and summarized in English. The key documents reviewed include:
    - ADB 2005. *Summary Initial Environmental Examination Report for Tonle Sap Sustainable Livelihoods Project in Cambodia.*
    - ADB 2005. *Cumulative Impact Analysis and Nam Theun 2 Contributions,* Nam Theun 2 Hydropower Project.
    - ADB 1998. *Environmental Assessment Requirements of the Asian Development Bank.*

- ADB, AFD, MOWRAM 2005. Stung *Chinit Irrigation and Rural Infrastructure Project: Environmental Impact Assessment*. Pre-Impoundment report.
- DOF 2001. *Fisheries and Aquaculture Development and Environment Impact Review*, Agriculture Productivity Improvement Project (APIP)
- SEI and ADB, 2002. *Strategic Environmental Framework for the Greater Mekong Subregion*.
- SMEC 1998. *Initial Environmental Examination and Social Impact Report*, T.A. 2722-CAM Transport Network Improvement Project
- T.P. Whitington 2005. *Final report volume 6 and Initial Environmental Evaluation Link Canal Sub project*, Northwest Irrigation Sector Project.

43. Data and information from the available reports were analyzed for the evaluation of EIAs and IEEs, based on the following criteria:
    - scope: consideration of fisheries (Y/N)
    - methodology for impact assessment: rapid and/or detailed, before-after or impact-control assessment; quantitative and/or qualitative; participation of stakeholders (Y/N); interdisciplinary and/or inter-sectoral; use of precautionary approach (Y/N)
    - results: quantitative and/or qualitative; support to management recommendations
    - recommendations: adequacy of mitigation and/or enhancement measures, feasibility, cost-efficiency, monitoring of implemented measures.

44. The results on EIA review have been summarized into a technical report, highlighting key constraints (e.g. institutional arrangements, local resources), quality of impact assessment, adequacy of compensation measures, and lessons learnt.

    Main findings of the EIA review are the following:
    - Lack of coordination among relevant agencies with regards to EIA implementation, and limited influence of MOE in the process
    - Insufficient coverage of EIAs – many large to medium-scale built structures have never gone through EIA
    - Gap between the recommendations of EIA/IEE and actual implementation of the projects
    - Quality of impact assessment widely varies in terms of scope, predictive capability, and adequacy of the recommendations
    - Lack of monitoring and evaluation of implemented measures

45. <u>Providing recommendations about the approaches, methods, and processes followed by EIAs and IEEs in the Tonle Sap basin</u>. Based on the main lessons from the two reviews conducted, main strengths and limitations of Tonle Sap EIAs, and key recommendations for conducting environmental impact assessments of projects, including built structures, were identified. A particular emphasis was placed on the need for assessing cumulative impact and the way to overcome their absence in individual project-based impact assessments. The scope was broadened to include EIA implementation process in general, not just methods for built structure projects, drawing from the knowledge and experience of stakeholders gained through informal consultation and documented in secondary literature.

4 Assessing the influence of Built Structures on fishery resources

46. This component assessed the consequences of Built Structures on fishery resources, and their weight in relation to other environmental factors using a variety of tools (questionnaires, biological surveys, modelling). The study was three-fold: one sub-component identifies the changes in composition and abundance of the catch between sites under the influence of built structures or outside their influence. The second sub-component matched this ecological and historical information with the changes in hydrology and water quality derived from the work of the Hydrology component. In a third sub-component, the conclusions of the previous studies were integrated into the BayFish model of Tonle Sap fish production, previously produced during the TA projects "Capacity building of IFReDI", Phases I and II[6], so that the influence of hydrological changes resulting from built structures on fishery resources can be quantified and the influence of these structures compared to that of other environmental parameters can be weighted.

47. Key activities included (i) surveying local knowledge on the influence of built structures on fish production and species ecology in specific study sites; (ii) matching changes in fish resource to changes in hydrology; (iii) forecasting the influence of hydrological changes on fishery resources; and (iv) quantifying, based on available information, the influence of Built Structures on Tonle Sap fishery resources.

48. Influence of built structures on species and catch. Numerous reference materials with regards to built structure and fisheries were collected from a variety of sources and the information in these documents were reviewed for its usefulness for the TA. While much information is available for the Stung Chinit and Prek Toal areas, lack of information on built structures in Pursat presented considerable challenge in selecting specific sites. To overcome this problem, the team conducted extensive consultations with key local informants, including governments and NGOs.

49. Literature review was conducted for Tonle Sap fish species diversity and ecology. 192 local fish species were comprehensively reviewed for their ecological characteristics, such as length and trophic level, and selected into groups of indicator species for assessing specific element of the influence of built structures on fisheries:
    - 30 fish species selected for documenting the change in fish catch and fishing effort;
    - 9 species selected for studying migration patterns; and
    - 20 species for collecting new ecological information.

50. During the process of the review, it was discovered that the Tonle Sap has almost 300 species, making it the third-richest lake in the world in terms of fish specie diversity. 296 fish species are actually found in the Tonle Sap, more than twice the number recorded before. That ranks the Tonle Sap just after Lake Malawi (433 species) and Lake Tanganyika (309 species) Overall, the Tonle Sap has 23 species whose annual migrations are triggered by changes in water levels, and another 3 species triggered by changes in water flows. These fishes, accounting for about 10 percent of the species documented for the Tonle Sap, are particularly sensitive to the hydrological

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[6] • ADB. 2002. *Technical Assistance to the Kingdom of Cambodia for capacity building of the Inland Fisheries Research and Development Institute.* Manila (TA 4025–CAM).
• ADB 2005 Technical Assistance to the Kingdom of Cambodia for capacity building of the Inland Fisheries Research and Development Institute Phase II (TA 36634-CAM)

consequences of infrastructure development such as delays in the arrival of floodwaters, increased water levels in the dry season and changes in the speed of the current. The impact of changing water levels on the remaining 90 percent of Tonle Sap species is still unknown.

51. Because existing information on fish ecology---particularly feeding, spawning, nursing habitats, and migration patterns of some local fish species---is generally poor, and the limited seasonal coverage of the TA period does not allow for effective field-based data collection on fish ecology, a stronger emphasis has been placed on collecting traditional knowledge from experienced/knowledgeable fishers.

52. The surveys of traditional knowledge on fisheries and fish ecology were designed to collect qualitative information from carefully selected knowledgeable informants, fishers, as opposed to the Livelihoods component's approach that covers all social groups present. A survey methodology using a semi-open questionnaire was developed and tested at all three of the study areas to ensure its relevance to the local conditions. Initially, the team encountered some challenges in developing a methodology that has a suitable balance between methods that engage the fishers, are easy to use and that can produce data with the necessary level of detail in the available time. The diversity of selected sites---in terms of biophysical environment and fish species compositions---also raised some issues relating to the identification of what type of impacts of built structures can be documented at each site and how. For example, at Stung Chinit the structure was very new and it was therefore difficult to identify the actual changes in the fishery that can be attributed to the structure itself; at Prek Toal many of the impacts were due less to the structure itself (i.e. the fencing) than to the associated institutional arrangements and it was hard to disentangle these in practice.

53. Acknowledging the importance of getting the survey method right, a few additional rounds of field testing of the questionnaire were conducted, including testing at each of all three study sites. Thanks to this additional effort it was ensured that the methodology was sufficiently flexible to be used in the three very different sites. The increase in the time needed for testing meant that the survey schedule was slightly delayed. However, the information generated during the testing was shared with other components, yielding some useful insights for their surveys and helping define the scope of each component more clearly. The survey methodology was finalized with the revised questionnaire and visual tools with which both the surveyors and the fishers were comfortable.

54. 60-80 experienced/knowledgeable fishers were selected at each target area (about 12 per village) based on a set of criteria, by provincial fisheries officers and village/commune heads. The selection criteria were: between the age of 40-60 years old; with 10-15 years experience fishing; currently active in fishing; well-known for fishing skills in the village; and the fishers selected from same village fish at different location from each other. Using the finalized survey tools, full surveys were completed at the sites in Pursat, Stung Chinit, and Prek Toal. The survey collected a variety of information, including fish catch by gear and species in each season, changes in catch---i.e. fish size and species composition---local fish migration, fish price, flooding areas, fish habitat and fishing location. All the survey data was entered into a database so that systematic analyses can be conducted.

55. In addition to collecting traditional knowledge of fishers, fish larval drift surveys were conducted in 5 locations---Stung (means river) Pursat, Stung Chinit, Stung Stoung, and

Stung Sangkae and the Prek Toal floodplain---to strengthen the bioecological information on Tonle Sap fishes. The sites were selected to compare the patterns of larval drift at locations where influence of built structure is present or absent. For example, the team collected fish larvae drifting down the river with a net at two sites (i.e. Stung Stoung and Stung Sangkae) where there is no apparent influence of a major built structure. Initial analysis of the larvae sampling indicate that significant amount of fish larvae drift from far upstream of Tonle Sap tributaries into the lake at the onset of rainy season, highlighting the importance of connectivity between the upper reach of tributaries and the lake proper. The larval field survey was completed in September and the laboratory analysis of specimens was conducted for species identification and calculating dry and wet weight. Overall the results of this survey have been quite disappointing; the lesson being i) fish larvae migrate during intense and very brief peaks of 1-2 days, the date of these peaks being unpredictable; ii) the expertise available in Cambodia does allow proper locally-driven surveys and studies of fish larvae.

56. Matching changes in fish resource to changes in hydrology. The information on changes in the fishery resources collected during the surveys was interpreted by comparing them to changes in hydrological regime, as synthesized and quantified by the work of the Hydrology component. A series of technical discussions about variables in common between both models were held for bridging hydrological and fisheries models together. Parameters such as water level, changes in flows, extent and length of flooding, were identified as having strong relevance to at least 26 species, which account for about 10 percent of the species documented for the Tonle Sap.

57. Forecasting the influence of hydrological changes on fishery resources. The above results were integrated into a broader framework encompassing other environmental and fishery parameters, and upgraded the model of fish production for the Tonle Sap. A technical documentation for this upgrade was prepared, in addition to the report summarizing the information linking fish bioecolgy and hydrology for the Tonle Sap.

58. Quantifying the influence of built structures on Tonle Sap fishery resources. An analysis of the literature and integration of results of previous projects demonstrated clearly the important impact of upstream dams on Tonle Sap fish resources. This impact was quantified as much as possible but overall the quantification remains limited and disappointing; this is due to the very limited number of scientific studies available despite significant awareness raised by the MRC and other players over the last decade. At the local level the relative importance of potential hydrological impacts and water quality impacts of Built Structures on Tonle Sap fisheries was compared, based on the existing literature as well as bioecological information collected for the TA. It was not possible to quantitatively weigh these different types of hydrological impacts on fisheries, as there is still large information gap in terms of potential habitat change caused by hydrological changes. Effect of change in hydrological triggers of fish migration on fisheries productivity are still unclear. For example, reduced sediment inputs to certain areas of the lake, prolonged inundation of areas with flooded forests, which may cause loss of flooded forests. Another uncertainty lies in the implication of changes in oxygen load to the lake's water on survival rate of fish larvae and eggs. Further scientific investigation on these issues need to be explored to estimate true influence of hydrological changes on the lake's fisheries.

5 Assessing the influence of Built Structures on livelihoods

59. The study conducted under the Livelihoods component was two-fold: i) assessing the influence of Built Structures on the livelihoods of Tonle Sap communities and ii) examining the availability of alternative livelihoods for aquatic resource-dependent communities. The first sub-component assessed changes in the people's livelihood strategies and outputs derived from fisheries, in terms of changes in activity patterns, vulnerability, resource access, diet and food security, and income. It also captured people's perception of the interconnectivity between hydrology, built structures, environment, fisheries and livelihoods, as well as their viewpoints on best practices for built structures. In absence of alternatives, loss of natural capital to the people living in and around Tonle Sap areas can hamper their ability to sustain their livelihood, thus increasing their vulnerability to poverty. In the second sub-component, alternative livelihood options and strategies as well as constraints were probed, and recommendations on enhancing other elements of livelihood assets were developed, such as human, physical, and financial capitals, and relevant transforming structures and processes that enable such enhancements.

60. Assessing the influence of Built Structures on the livelihoods of Tonle Sap communities. A literature review was conducted to gather information on the consequences of built structures on fisheries-dependent livelihoods in tropical floodplains around the world and from the region, including reports from particular donor projects around Tonle Sap. The purpose of this activity was to identify key issues that need to be addressed in the assessment of potential influence on fisheries-dependent communities in the Tonle Sap area. A large number of existing reference materials were compiled, and of those, 25-30 were used to inform the development of survey methodologies. Obtaining unpublished project reports from the past was particularly difficult. Thus the information was also gathered through consultation with government agencies and consultants working on relevant donor projects around Tonle Sap, such as the Sustainable Livelihood Project, the Participatory Poverty Assessment, and the Lowland Stabilization Project of ADB, and the Tonle Sap Conservation Project of UNDP.

61. A series of pre-survey interviews and consultations were held at various locations in Kampong Thom, Pursat, and Battambang provinces, to identify specific field survey sites and to collect background information to guide the design of survey questionnaire. The key informants and stakeholders consulted during the pre-survey activities included: Provincial Departments of Agriculture, Fisheries, Rural Development, and Water Resources; District officials of Rural Development; GRET (a French NGO); Centre d'Etude et de Dévelopement Agricole Cambodgien (CEDAC), Osmose, KNC, and FACT (Cambodian NGOs); and Leucaena (a Japanese NGO). All these NGOs implement projects locally in the three selected provinces.

62. Through extensive field visits and discussions with other research components of the TA, especially the Fisheries component, the team achieved a compromise where both components can generally meet their needs. In Kampong Thom, The Livelihoods team visited 8 places/villages and selected 2 villages, Snao and Sa'ang. In Battambang, the team visited 5 places/villages and selected 2 villages, namely Prek Toal and Thvang villages in Koh Chivang commune. In Pursat, the team visited 10 sites/villages and selected Chong Khlong and Ou Ta Prok.

63. The main compromise made during the site selection was the new Stung Chinit irrigation scheme, as the irrigation scheme had been operational only for a few months and the benefit was unlikely to be reflected in the survey results. However, this challenge was addressed by some modifications to the survey methods. For the survey areas with relatively new built structures, the Livelihood component included ex-ante analysis and assessment of anticipated benefits/negative change caused by the structure based on the local perceptions and operational plans for the built structure.

64. The sites were selected with an aim of capturing diversity of experiences with regards to built structures, which inevitably lead to difficulty in developing a standardized survey format that was flexible enough to collect site-specific information. Another challenge faced by the team was the difficulty in crafting the questions so that they can isolate the influence of built structures among many other factors that affect livelihoods. Draft questionnaires and checklist for interviews and surveys were tested in Pursat and Kampong Thom by the socioeconomic survey team. It took several rounds of testing and revisions to refine the tools so that they were easily used by the enumerators, easily understood by the interviewees, and focused enough to gather information specific to the influence of built structures.

65. Full set of data collection activities---community surveys, household surveys, and participatory village surveys, including group discussions and in-depth interviews of key stakeholders---were conducted at the selected sites in K. Thom, Pursat, and Prek Toal study areas. The results of household surveys were entered into the database and quantitatively analyzed using stratified grouping of households by the main income generating activity and wealth status, with emphasis on changes in livelihood activities, income, income sources and income portfolio, and the role of assets endowments. Inconsistencies in the results of quantitative and qualitative assessments were identified for and possible explanations for the inconsistencies were explored during the process of synthesizing the results from all the research components. The data interpretation and entry into the database was particularly time-consuming, and required additional support personnel to be hired to speed up the process.

66. Examining the availability of alternative livelihoods for aquatic resource-dependent communities. The data collected through the field surveys were analyzed specifically to identify issues for focus group discussions among selected survey participants, with regards to alternative livelihoods strategies. Focus group discussions were organized in two villages in each of the three study sites, with participants selected to have a balance in gender, wealth groups (poorer, medium, and richer). The village chief and vice-chief were also included in each focus group, for a total of 10-12 people per group. Existing and alternative livelihoods scenarios were discussed and evaluated by the focus group participants. Constraints to livelihood diversification were identified and ranked, as well as suggestions about addressing these constraints. The results of these discussions have been integrated into recommendations of the main technical report documenting the overall results of the Livelihoods component. A supplemental report on alternative livelihoods was also prepared, detailing the results of this particular activity.

6 *Informing policy makers and decision makers*

67. The purpose of this TA was to improve the awareness and understanding of Government agencies and policy makers regarding the influence of built structures on the lake's hydrological regime, fisheries, and livelihoods. This required that key findings were translated into products appropriate for target audiences and readily accessible. As the other components of the TA were primarily about generation of new knowledge, the sixth output of this TA focused on the dissemination of research results in a form that was accessible to decision-makers in particular[7].

68. Key activities included: (i) A synthesis of lessons learned culminating in a policy brief; ii) preparing a set of guidelines about approaches and methods that would minimize the negative influence of built structures while maximizing their beneficial outcome; and (iii) disseminating the policy brief and guidelines.

69. A communication strategy was developed to guide the overall approach of this component, in close collaboration with CNMC. This strategy characterizes the different stakeholders, defines the format and content of the appropriate communication products, and evaluates the possible delivery systems or communication channels. The completion of the communication strategy was slightly delayed from the end of July to mid August, in order to reflect the results of the first stakeholder workshop on August 2nd. CNMC took a lead in implementing the plans outlined in the strategy, with support from the TA consultants. The main role CNMC played during the TA implementation was to communicate to relevant government agencies about the plans and activities of the TA and seek their feedback and support. An official letter of request for support signed by the Chairman of CNMC was issued to relevant government agencies, in terms of facilitating access to information and documents, as well as supporting the field work in provinces.

70. As identified in the Communication Strategy, a number of publication products were developed toward the end of the TA, in order to communicate the results and the recommendations of the TA to different set of target audiences. Two main publications are: a Synthesis Report, which integrates the key scientific findings of the thematic studies described above, into a coherent narrative with conclusions and recommendations; and a Policy Brief, which presents the conclusions and recommendations in a much shorter, less technical narrative. The contents of these reports were informed by the stakeholder feedbacks during the two consultation workshops organized by the CNMC and WorldFish, as described below. The original draft contained a set of "guidelines" aiming to inform decision-makers for planning built structures that potentially affect Tonle Sap fisheries. The draft was officially reviewed by the CNMC, and upon CNMC's request, the term "guideline" was replaced with "recommendation", which does not have connotation of a binding agreement. After full endorsement by CNMC, both documents were translated into Khmer language, and went through another round of thorough editing and review by WorldFish scientist and CNMC in order to assure the accuracy of translation. (*See Section III: Communication Products for more details. Also see* Table 6: Products and Dissemination Targets Achieved *in Section VI: Dissemination of Publication Outputs*).

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[7] Advice on linking research to practice is provided at http://www.adb.org/Projects/Tonle_Sap/.

71. The progress of the TA was presented to key stakeholders at different phases of the implementation, as planned in the communication strategy. The First Information Workshop was held on August 2nd in Phnom Penh, to introduce the TA to key stakeholders and to seek their support and feedback. It was organized jointly by WorldFish and CNMC, and chaired by H.E. Sin Niny, the Vice Chairman of CNMC. About 48 external participants---27 representing government agencies in Phnom Penh, 7 from provincial departments of agriculture, fisheries, or water resources, and 14 NGOs---attended the workshop. Presentations were given on the overview and the objectives of the TA and the on-going and planned activities under each research component, followed by Q&A and open discussion. In his opening address, H.E. Sin Niny highlighted the importance of addressing the issues associated with built structures and the needs for a clear legal framework and collective efforts among all parties concerned, including government institutions, local authorities, international organizations as well as civil society organizations. His contribution was instrumental in setting a positive tone for the presentations that followed. In his closing remark, H.E. also gave a strong endorsement to the TA and urged all the participants for assistance and close cooperation during the course of the TA implementation.

72. There was active participation and strong interests from the participants, especially from those who were representing provincial line agencies. This was very encouraging because these provincial officials are the ones dealing with day-to-day decisions associated with built structures. Emphasizing the scientific nature of the TA and its balanced, inter-disciplinary approach to look at both negative and positive influence of the built structures, generally ensured that the feedback was positive and constructive. The key comments repeatedly expressed by the participants during the Q&A and discussion were the following:
    - A study of the influence of built structures is appropriate and timely, and its results would be useful to policy-makers as new privately-owned built structures (i.e. irrigation reservoirs) are mushrooming in Kampong Thom and Pursat provinces in particular. These structures have become a concern for several line agencies because they are constructed and operated out of any formal regulatory framework;
    - The TA, with its emphasis on *trade-offs* between positive and negative aspects of built structures, is much welcome;
    - Results of the study should be made widely available, particularly at the provincial level, since province agencies typically never get any information back from projects they contribute to;
    - Scientific rigor of the TA is compromised because the duration of the study does not cover a full one-year cycle despite the seasonal variability in fishing activities and livelihoods that is characteristic in Cambodia; and
    - A follow-up study or at least an extension of the current study will be desirable in order to cover the full fishing season.

73. The Stakeholder Review Workshop was held in January 2007, in Phnom Penh, to present the preliminary results of the TA to key stakeholders and to seek their feedback and suggestions. It was organized jointly by WorldFish and CNMC, and chaired by H.E. Sin Niny, the Vice Chairman of CNMC. Approximately 50 external participants---30 representing government agencies in Phnom Penh, 5 from provincial departments of agriculture, fisheries, or water resources, and 15 NGOs and donor agencies---attended the workshop. Each research component gave a presentation on the activities and the preliminary results, and draft recommendations, followed by Q&A and open discussion.

Level of participation was active, but was relatively concentrated on a few individuals, mostly from the government agencies. Key comments expressed by the participants include:

- Clear action guidelines are needed rather than vague and unrealistic recommendations that are typically found in other similar studies;
- Specific recommendations need to be made for different stakeholders and decision-makers;
- Scope and limitations of the study need to be clearly stated;
- Use extra caution in generalizing the conclusions and messages based on the limited scope of the study;
- Need for follow-up studies or related studies should be identified; and
- Dissemination of final results is important, especially at provincial level.

74. The Final TA Workshop was held on 2 May 2007 in Phnom Penh. The purpose of the workshop was to present the final conclusions and recommendations of the study and seek the participants' endorsement and suggestions on implementation, especially from the representatives of 10 Ministries under the CNMC, and their line agencies in the provinces. As were the previous two stakeholder workshops, the final workshop was chaired by H.E. Sin Niny, Vice-Chairman of CNMC. 98 participants attended the workshop: 43 from government agencies in Phnom Penh; 29 government officials from 10 provinces around the Tonle Sap lake and the Mekong river downstream; and 26 representing NGOs and development partners.

75. A pre-publication draft of the Policy Brief with the TA findings and recommendations was disseminated to the participants in advance of the workshop, allowing them enough time to consider these recommendations. The pre-publication draft of the Synthesis Report, which contains more details on the scientific results of the TA, was also distributed to the participants at the workshop. The participation to the Q&A and open discussions were active, and many comments were made by representatives of provincial agriculture departments and NGOs in particular. Key points that came across from the questions and comments raised by the participants are:

- There is high demand from provincial-level stakeholders for more specific guidance on how to implement the TA recommendations into practice at local scale
- Many stakeholders want to know more precise quantitative information on the impacts of dams upstream in the Mekong river on the Tonle Sap fisheries, so that the information can be used for future planning of built structures
- More detailed, follow-up studies are needed in order to address the two points above
- The participants are concerned about how Cambodia can address the potential impact of water development projects in upstream countries within the Mekong river basin
- Dissemination of the recommendations not only in Cambodia but also in other Mekong countries are needed
- Dissemination of the reports and implementation of the principles outlined in the reports to provinces are needed

76. In response to some of the questions raised, H.E. Sin Niny expressed his strong intention to disseminate the findings at regional fora, particularly the impact of upstream infrastructure development on Tonle Sap fisheries. Ms Mio Oka, the ADB representative,

also assured that the results of the TA will be shared with other relevant ADB projects in the region, which will help some of the recommendations to be put into practice. H.E. Sin Niny and the WorldFish research team members also responded to some of the more technical comments, pointing out that the scope and timeframe of the TA was limited for producing the kind of detailed guidelines needed at local scale, and that instead, the TA identified many areas that require further studies. H.E. added that CNMC cannot endorse specific guidelines aimed at local scale decision-making, however, will explore opportunities for conducting follow-up studies on the issue with ADB and other potential donor agencies. The workshop concluded with an endorsement from the chairperson to officially publish both publication outputs of the TA (i.e. Synthesis Report and Policy Brief) under CNMC. (*See Section VI Dissemination of Results for details on distributing the final publication outputs.*)

77. Other opportunities to disseminate information from the TA were actively pursued throughout the TA implementation, as outlined in the communication strategy. Reporters from major news papers were invited to the stakeholder workshops, which resulted in the following coverage:
    - *Cambodge Soir*, 3-08-2006 --- "The ADB finances a study of the impact of the infrastructures on the fisheries" (in French)
    - *Rasmei Kampuchea*, 4-08-2006--- "Three sites is selected for a new research project on fishery resources of Tone Sap basin" (in Khmer)
    - *Cambodge Soir*, 10-01-2007 --- "Tonle Sap - effects of development on the fisheries" (in French)

78. A short, non-technical article introducing the TA activities was also published in news letters in Khmer language, one issued by Save Cambodia's Wildlife and another by Tonle Sap Environmental Management Project, and was distributed in provinces. Similar article was also published in *Cambodia Weekly*, a newly established English-language news paper, and in *South Eastern GLOBE*, a regional business magazine in English (March 2007). Posters on the TA approach and video clips on built structures that were prepared as the TA product were also displayed at a joint CNMC/WorldFish exhibit booth at the *Tonle Sap Initiative Forum* organized by ADB and CARD in March 2007. Over 300 people attended this event, and the exhibit area also received much attention from the participants.

79. In addition, technical papers describing the research approach of the TA or built structures were presented in two international meetings: *The 2nd International Symposium on Sustainable Development in the Mekong River Basin*, organized by the National Institute for Rural Engineering of Japan and the Institute of Technology of Cambodia, with participants from four Mekong countries as well as Japanese researchers; and *the Southeast Asia Regional Meeting on Integrated Water Resources Management*, organised by the United Nations Development Program, in Thailand. The titles of the papers are:
    - Baran E., Arthur R., Chuenpagdee R., Keskinen M., Koponen J., Kruskopf M., Kura Y., Lauri H., Nguyen Khoa S., Ratner B., Sarkkula J., So S. 2006. "Influence of built structures on the fisheries of the Tonle Sap: a multidisciplinary approach." P. 59-66, *Proceedings of the 2nd International Symposium on Sustainable Development in the Mekong River Basin. Phnom Penh, 16 – 18 September 2006.* Japan Science and Technology Agency. 240 pp.

• Baran E., Munro J. 2006. "Maximizing water productivity in Southeast Asia: what fish can do." Keynote speech at the Southeast Asia regional meeting on Integrated Water Resources Management organised by the United Nations Development Program, 10-13 September 2006, Rayong, Thailand.

80. Khmer-language translation of the first paper on the approach of the study was made available to the Deputy Chairman of the National Assembly Commission on Economy, Planning, Investment, Agriculture, Rural Development, Environment and Water Resources. Some of the TA team helped him prepare the National Assembly delegation for the upcoming *Asia-Pacific Parliamentarians Conference on Environment and Development* by providing copies of several relevant documents.

81. As part of dissemination activity, the reference materials and maps gathered by the various components from partners (e.g. EIA reports, site-specific studies, etc.) were scanned and catalogued as PDF files so that they can be shared electronically. Thus more than 300 documents have been posted as pdf files at the TSBR bibliographic database, and are accessible through the TSBR-ED web site.

III COMMUNICATION PRODUCTS

A Technical Reports

82. Thirteen technical reports documenting specific aspect of the project activity and the results were prepared, which serve to substantiate the conclusions and recommendations summarized in the Synthesis Report, and Policy Brief (*see Section III-B and C below*). The titles of the reports are as below:

- H. Lauri. *Built structures database – documentation.*
- H. Lauri. *Built structures database – user's manual.*
- H. Lauri. *Built structures database - structure statistics.*
- J. Koponen, S. Tes, and J. Mykkänen. *Impact of built structures on Tonle Sap hydrology and related parameters.*
- M. Kruskopf. *Review of impacts of built structures on tropical floodplains worldwide.*
- S. Nguyen Khoa and P. Chet. *Review of built structure Environmental Impact Assessments (EIA) with regard to the fisheries of the Tonle Sap.*
- E. Baran, N. So, S. Leng, R. Arthur, and Y. Kura. *Relationships between bioecology and hydrology among Tonle Sap fish species.*
- E. Baran E., N. So, R. Arthur, S.V. Leng, and Y. Kura. *Bioecology of 296 fish species of the Tonle Sap Great Lake (Cambodia).*
- T. Jantunen. *Integration of databases to the BayFish – Tonle Sap fish production model*
- E. Baran, T. Jantunen, P. Chheng, and M. Hakalin. *"BayFish-Tonle Sap", a model of the Tonle Sap fish resource.*
- R. Arthur, E. Baran, N. So, S. Leng, S. Prum, and S.H. Pum. *Influence of built structures on Tonle Sap fish resources.*
- B.D. Ratner, D.B. Rahut, M. Käkönen, N. Hap, M. Keskinen, S. Yim Sambo, L. Suong, and R. Chuenpagdee. *Influence of built structures on local livelihoods: case studies of roads, irrigation, and fishing lots.*
- D.B. Rahut, N. Hap, and B.D. Ratner. *Enabling alternative livelihoods for aquatic resource dependent communities of the Tonle Sap.*

These reports are published as PDF documents, made available online at the WorldFish Center web site, and as CD-ROM.

B Synthesis Report (Guidelines)

83. A "Synthesis" report was prepared as the main publication output of the TA. The report is based on the results of technical reports listed above, and combines the hydrological, ecological, fisheries, and livelihood consequences of built structures into a coherent narrative, including recommendations to decision-makers at national and sub-national levels. The full reference is:

E. Baran, P. Starr, and Y. Kura, editors. 2007. *Influence of built structures on Tonle Sap fisheries.* Cambodian National Mekong Committee and the WorldFish Center, Phnom Penh, Cambodia. ISBN 978-983-2346-59-3

The hard copy report is published jointly by CNMC and WorldFish Center in English and Khmer languages.

C Policy Brief

84. This report summarizes conclusions and recommendations of the overall study as described in the Synthesis Report into a comprehensive, short narrative, and integrates elements of the policy context in Cambodia. The full reference is:

E. Baran, S. So, Y. Kura, and B. Ratner. 2007. *Infrastructure and Tonle Sap fisheries: How to Balance Infrastructure Development and Fisheries Livelihoods?* Cambodian National Mekong Committee and the WorldFish Center, Phnom Penh, Cambodia.

The hard copy report is published jointly by CNMC and WorldFish Center in English and Khmer languages.

D Scientific and Academic Articles

- Baran E., Arthur R., Chuenpagdee R., Keskinen M., Koponen J., Kruskopf M., Kura Y., Lauri H., Nguyen Khoa S., Ratner B., Sarkkula J., So S. 2006. "Influence of built structures on the fisheries of the Tonle Sap: a multidisciplinary approach." P. 59-66, *Proceedings of the 2nd International Symposium on Sustainable Development in the Mekong River Basin. Phnom Penh, 16 – 18 September 2006.* Japan Science and Technology Agency. 240 pp.
- Baran E., Munro J. 2006. "Maximizing water productivity in Southeast Asia: what fish can do." Keynote speech at the Southeast Asia regional meeting on Integrated Water Resources Management organised by the United Nations Development Program, 10-13 September 2006, Rayong, Thailand.

E Newspapers and Magazine Articles

- *Cambodge Soir*, 3 August 2006 --- "The ADB finances a study of the impact of the infrastructures on the fisheries" (in French)
- *Rasmei Kampuchea*, 4 August 2006--- "Three sites is selected for a new research project on fishery resources of Tone Sap basin" (in Khmer)
- *Cambodge Soir*, 10 January 2007 --- "Tonle Sap - effects of development on the fisheries" (in French)
- *Cambodia Weekly*, 4 March 2007 --- "Tonle Sap in Focus: Heart of Cambodia" (in English)
- *SE Globe*, March 2007 --- "Net values – a study to be released underscores the economic importance and vulnerability of fisheries of the Mekong" (in English)
- *Tonle Sap Biosphere Reserve Bulletin*, December 2006 --- "Three sites chosen for important new study on Tonle Sap fisheries" (in English and Khmer)

F Multimedia products

85. WorldFish commissioned the production of seven short video clips (8 minute-long each). These clips are for educational purposes, aiming to increase awareness of general, non-technical audience about natural resources, fisheries, fishing communities, and influence of infrastructure development around the Tonle Sap and in Cambodia in general. The themes covered by the video clips include: livelihoods of fishing communities on the lake; Cambodian fisheries; and Built Structures around the Tonle Sap. All clips are packaged as *Lands of the Lake*, a single VCD/DVD including English, Khmer and French versions.

IV KEY FINDINGS

The main findings of the four research components of the TA are listed below.

A Modelling the influence of Built Structures on hydrodynamics and water quality

Based on the Mekong basin-scale modelling of water development scenarios:

- Upstream developments in the Mekong basin will delay the onset of the annual flood in the Tonle Sap and shorten its duration. Under the intensive scenario in a dry year, the flood would be delayed by up to 12 days depending upon the location and altitude, and its duration would be a week shorter. Under the extreme development scenario, the flood would be delayed by one month and its duration would be two weeks shorter.

- Upstream developments will also decrease the height and surface area of the flood. Under the intensive development scenario in a dry year, the maximum height will be about half a meter lower and the surface area about 10 percent smaller. The main losses will occur in very high areas that are flooded for short periods.

- Dams upstream will also sharply reduce the input of sediments into the Tonle Sap, adversely affecting the recycling of nutrients and possibly threatening dry-season habitats, especially in areas with high fish productivity. The Upper Mekong Basin is the source of more than 50 percent of the suspended sediments in downstream areas in the Lower Basin. The planned cascade of eight dams in the extreme development scenario has the potential to trap nearly all of these sediments. Loss of sediments in flood water would result in a loss of natural soil fertility.

Based on the small-scale modelling of study areas and the field-based assessment:

- The velocity of water flows on the floodplain is generally very slow compared to the lake so the impact of roads depends on where they are placed, and whether they have culverts and gates as mitigation measures.

- Small-scale private reservoirs in the floodplain so far have had a relatively limited influence on the flow and quality of water around the Tonle Sap. The overall storage capacity of existing private irrigation structures on the floodplain is quite limited as the depth of water trapped is only about one and a half meters. Existing reservoirs in the Tonle Sap floodplain have a surface area of less than 100 square kilometers with a storage capacity of about one-tenth of a cubic kilometer, a small fraction of the annual inflows into the Tonle Sap ranging from 44 to 107 cubic kilometers.

- Laboratory experiments demonstrated that fishing fences made of bamboo and nets typical used on the Tonle Sap cause only minimal resistance to water flows and do not slow down water recession, whereas it is clear that the fences and the attached nets obstruct fish movements.

B Assessing the influence of Built Structures on the environment

Findings based on the worldwide literature review of the built structures in floodplain environment:

- In terms of ecological and social benefits, floodplains are among the most valuable landscapes in the world. A global review of tropical floodplains completed during the study found that fish and other natural resources are the primary benefits, followed by the replenishment of nutrients and fertile soils for farmlands and pastures. However, much is still unknown about the ecological functions of floodplains and how to value them properly.

- Modifying water flows and flood patterns are the biggest threats to the ecology of floodplains. Once lost, the costs of rehabilitating the ecological functions of floodplains are very high. Any structure affecting water within a floodplain or in rivers upstream is assumed to have some influence on the floodplain environment and should be treated with caution. Most declines in fisheries production in tropical floodplains are either directly or indirectly related to changes in water flows. Seasonal flooding and connectivity are essential for maintaining the ecology of floodplains.

- Large infrastructure projects increasingly require cumulative-impact and strategic-environmental assessments. Most structures are not isolated from the surrounding environment. The cumulative impact of many structures can be assessed, although this is complicated as it is more than simply adding up the individual impacts of each structure. In general, impact assessments rarely quantify benefits that might be lost. Existing guidelines and recommendations on how to implement EIAs typically do not include instructions on how to consider specific environmental characteristics of floodplain and how to assess impacts of a project on floodplain ecosystems, or how to include economic valuation of lost benefits of floodplains.

Findings based on the review of the Environmental Assessment reports and the EIA processes around the Tonle Sap:

- Environmental Impact Assessments (EIAs) for Tonle Sap infrastructure projects that may have a significant impact on water resources and fish are not systematically implemented. Access to Environmental Impact Assessments of Tonle Sap development projects is difficult, reports being scattered across various ministries and provincial and district government offices or with project developers. Very few are available at the Ministry of Environment or other relevant ministries. Assessments are not systematically recorded or classified.

- The quality of the Environmental Impact Assessments (EIAs) of Tonle Sap projects that might have a significant impact on water resources and fish is insufficient. The EIA process refers to the overall mechanism in place to request, submit, accept and monitor project EIA. Increased awareness of the importance of EIA practice should be supported.

- Stakeholder participation in planning of built structure development and environmental impact assessments is generally very limited. There is no systematic mechanism for involving local communities, provincial and district authorities, and non-governmental organizations. This raises issues of transparency and the need to allocate resources to communications at the local and national levels.

C Assessing the influence of Built Structures on fishery resources

Findings at the Mekong basin scale include:

- Dams are the main type of structure having an impact on fisheries production in the Mekong river systems, through their negative impact on fish migrations. In the Mekong Basin, 87 percent of fish species, for which the information is available, are migrant species. Sixteen percent of these species are known to be sensitive to hydrological migrations triggers that will be modified by dam construction. Since the bulk of the catch is actually due to a small number of species groups that are in majority sensitive to hydrological migration triggers, a very large proportion of the total catch is likely to be affected by river modifications (for example, 96% of the catch in Khone Falls, Southern Laos).

- The study found no examples of positive long-term impacts of dams on fisheries, nor any effective mitigation measures. Reservoirs are sometimes presented as a way to create new fisheries upstream, but this usually does not compensate for the loss of downstream fisheries. Similarly, fish passes are often proposed to help fish migrate. However, there are no examples of fish passes that work in the Mekong Basin. This is mainly due to ecological factors and the intensity of migrations which fish passes cannot accommodate. Out of the hundreds of species in the Mekong Basin, only nine are known to breed in reservoirs. The effectiveness of the new fish pass at Stung Chinit completed in 2006 has not yet been assessed.

- The Tonle Sap has almost 300 species, making it the third-richest lake in the world in terms of fish diversity. A review of scientific literature identified 296 species, more than twice the number recorded before. That makes the lake the richest in the world only after Lake Malawi (433 species) and Lake Tanganyika (309 species), both in Africa.

- Changes in water levels affect the annual migrations of some sensitive species which account for 13 percent of the Tonle Sap catch, or between 38,000 tonnes and 56,000 tonnes a year. In addition, if the two species of trey riel (*Henicorhynchus* genus)---that are also suspected to be sensitive---are included, the proportion of the catch whose migration is triggered by changing water levels jumps to 38 percent, amounting to between 110,000 tonnes and 164,000 tonnes a year. How this effect on migration translates to fish productivity is still unclear.

Findings at the Local study sites include:

- Road-management committees have an important role to play in fisheries protection by instituting rules that prohibit road culverts from being blocked by fishing gear. This is a commendable practice at the Pursat study site that should be encouraged elsewhere in the country. But these rules are not always followed and more intensive fishing gear is being deployed.

- Maintaining downstream flows and migration upstream is important to the sustainability of fish catches. Villages downstream seem to have borne several costs and received fewer benefits from the irrigation scheme. All people interviewed downstream blamed flow changes for reduced fish abundance and smaller catches from the river. Rice-field fisheries also seem to have suffered. Respondents mentioned that local fish abundance was closely linked to the seasonal flooding of the lake with bigger floods leading to more fish.

- Both fisheries management systems (fishing lots and community fisheries) suffer from a prevalence of highly destructive fishing practices, such as electro fishing, damming and pumping water out of streams. But there are trade-offs between productivity, equity and possibly sustainability between the two management systems in operation at the site.

D Assessing the influence of Built Structures on livelihoods

Findings at the Local study sites include:

- In both planning and maintaining roads, commune councils have a natural coordinating role to play with local bodies, such as community-fishery and road-maintenance committees as well as Buddhist and Islamic institutions that can mobilize collective action.

- Getting villagers to take part in infrastructure planning is a key factor in shaping their perceptions of a scheme's suitability and their willingness to invest in its long-term maintenance.

- All the case studies show clearly that management and social issues associated with built structures, such as access to benefits, use rights and regulations, and operations, can be perceived at the local level as much more crucial than the technical design of the structure itself.

- The case studies found that coordination between fishing communities, local authorities, management committees and fisheries officers was either limited or absent at all three study sites.

- The study found that most people's livelihoods were diversifying as new opportunities and risks arose from new infrastructure. However all case studies showed that fishing and related activities were still the main source of income.

- Infrastructure development is generally benefiting richer households. Many poor households are also benefiting but not at the same rate. The three case studies found that rural households had different capacities to benefit from opportunities arising from infrastructure development.

- The three case studies showed strong ties between household assets, especially education, and the ability to take advantage of new opportunities. After education, the next most significant asset explaining the ability of households to get out of poverty was livestock, a form of savings.

V RECOMMENDATIONS TO DECISION MAKERS

86. A set of recommendations were drawn from the results of the TA research components. The recommendations below point to key principles and actions needed that are meant to help decision-makers in maximizing the economic and social returns from investments in infrastructure while minimizing adverse impacts on the environmental sustainability of the Tonle Sap or the people who live around the lake.

1. When planning infrastructure development, avoid irreversible changes to water flows, especially those affecting seasonal flooding or breaking the natural "connectivity" between various water bodies around the Tonle Sap.

2. In assessing plans for dams and other water developments upstream on the Mekong mainstream, highlight the significant impacts on flooding in the Tonle Sap Lake.

3. In addition to considering the seasonal impact on water flows, planning of upstream water developments should specifically take into account possible ecological consequences of the changes in flooding, including loss of flooded forests, reduced inflows of sediments, lower oxygen levels, and changes in the drift of fish larvae and juvenile fish.

4. The livelihood benefits of floodplains should be properly evaluated and integrated into basin-wide water development planning, with particular focus on the impact of dams on fisheries.

5. Adopt regional guidelines such as the Strategic Environmental Framework for the Greater Mekong Sub-region (GMS), which promote strategic environmental assessments addressing the cumulative impacts of multiple development projects in order to improve EIA processes.

6. Give special attention to infrastructure developments within the Tonle Sap basin, because these have direct impacts on fisheries, and because they can magnify the influence of upstream changes in water flows.

7. Improve the Environmental Impact Assessment process, particularly the coverage of fisheries, coupled with capacity-building for EIA practitioners.

8. Impact assessments and regional negotiations over water allocation should take into account the unique importance of the Tonle Sap Lake for fisheries productivity and fish diversity not only in Cambodia but throughout the Mekong system.

9. When assessing the impact of infrastructure development on Tonle Sap fisheries, focus on species that are both economically important and which depend on hydrological triggers for migration. In particular, prioritize trey sleuk russey (Paralaubuca typus), trey chhkok and trey sraka kdam (two species from the Cyclocheilichthys genus) and trey pra (species from the Pangasius genus) as indicator species.

10. In designing fisheries management strategies and conducting impact assessments, consider three – rather than the traditional two – major ecological groups of fish. This highlights the importance of species which rely on tributaries as dry season refuges.

11. Explicitly take water flows and fish-migration routes into account when planning and building roads in floodplains, using culverts and bridges to avoid blocking complex networks of channels. Also ensure that planning addresses how these structures will be managed and maintained.

12. Coordinate road development among ministries and also with local institutions, particularly Commune Councils, to ensure proper planning and maintenance.

13. Ensure that road planning takes into account the poorest groups by clarifying who will benefit and how. Provide alternative livelihoods support services targeted to poorer families to help them accumulate household assets, such as education, cattle and savings.

14. Assess the ecological impacts of dams and reservoirs at the planning stage. Determine the pros and cons in the long run so that informed decisions can be made and mitigation measures taken.

15. Analyze the social and economic costs and benefits of irrigation projects for different social groups at the planning stage. Make complementary investments to make sure poorer households can take advantage of new opportunities.

16. Provide training to commune councils to build effective communication channels between local officials, engineers and villagers. Support the establishment of water-user committees to promote equitable distribution of water and avoid conflicts over operating and maintaining the system.

17. Promote future studies on how large-scale fishing fences affect the movement of fish and longer-term fish recruitment, and appropriate mitigation measures.

18. Decisions on where and how large-scale lot systems are implemented should take into account economic, social, and ecological trade-offs as compared to other management options such as community fisheries.

19. When fishing lots are released and access opened to local communities, there are high incentives for relatively wealthier households to capture more of the benefits. Pay specific attention to institutional mechanisms to ensure equity and manage conflicts.

20. Ensure that negative impacts of built structures are addressed through management and operational aspects of the projects, in addition to technical and engineering measures.

21. Improve management of fisheries around built structures adapted to the newly created social dynamics and fishing environment, through better enforcement of regulations and coordination of stakeholders, including community fisheries, government agencies, donors, and non-governmental organizations.

22. Hold systematic consultations between national and local stakeholders throughout project development and help local people articulate their needs and concerns. Evaluate and publicly debate the social, economic and ecological trade-offs arising from different development scenarios before deciding on a specific option.

23. Link infrastructure planning to the decentralized institutions for rural development and natural resource management (commune, district, and provincial councils).

24. Analyze how the costs and benefits of a project affect different social groups, taking the role of local institutions and differences in household assets into account. Considering the importance of poverty alleviation in Cambodia's development agenda, make special provisions to involve the poorest groups in project planning.

25. Complement infrastructure projects with investments in basic education, training and technical support.

VI DISSEMINATION OF PUBLICATION OUTPUTS

87. After the Final Workshop of TA, the Synthesis Report and the Policy Brief were published both in English and Khmer languages. The set of video clips was reproduced as DVD and also as VCD, which is more popular in provinces (*see Table 6 below*). The full set of publication products was packaged and distributed to relevant line agencies under CNMC, as well as key national decision-makers in the National Assembly, Senate, Council for the Development of Cambodia, as identified in the Communication Strategy. At provincial level, provincial departments of relevant line agencies, provincial governors, district governors, Chamber of Commerce are the main target for dissemination of the publication products in Khmer version. Over 900 sets of publications were manually couriered to provincial line agency offices and the offices of key decision-makers. Similarly, around 700 sets were distributed to key target audience in Phnom Penh through CNMC's dissemination channels at member Ministries, and also through courier services hired by WorldFish.

Table 6: Products and Dissemination Targets Achieved

	Planned as in Communication Strategy of August 2006					Implemented as of May 2007			
Product	No	Medium	Content	Lang	Copies	No	Copies	Note	Achieved
Synthesis Report	1	Print	Hydrological, ecological, fishery and livelihood impacts (10 to 30 pages, 5,000-15,000 words).	Eng. Khmer	600	1	**Eng. 1,000 Khmer 2,000**	Number of copies increased for wider distribution in provinces	*Yes*
Policy brief	1	Print	National issues relating to hydrological, ecological, fishery impact of built structures (8 to 12 pages, 4,000-6,000 words)	Eng. Khmer	2,000	1	**Eng. 1,000 Khmer 2,000**	Number of copies increased for wider distribution in provinces	*Yes*
Guidelines*	1	Print	Design, number and operation of built structures (4-8 pages, 2,000-4,000 words)	Eng. Khmer	5,000	0	-	Included as general recommendations in both Synthesis Report and Policy Brief	*No*
Meetings	2	DVD, PDF	Project activities, results	Eng. Khmer	x	5	x	Includes stakeholder workshops and external conferences	*Yes*
News releases	4	Print media	Newsworthy developments and findings as they emerge including background material from inception and mid-term reports	K (E)	x	6 (4 press releases, 2 magazine articles)	x		*Yes*
Multimedia	1 (4 video clips)	CD/DVD	Multimedia CD/DVD including i) 40 mn of video clips on Built structures, BS and water, BS and fisheries, BS and livelihoods; ii) 4 audio interviews of scientists, and iii) 3D didactic animations	K (E)	300	1 (7 video clips)	**1,000 DVDs 500 VCDs**	Number of copies increased for wider distribution in provinces	*Yes*
Raw technical reports	9	PDF	Classification of structures Hydro-dynamics, water quality Envir. impact assessments Review of tropical floodplains Hydro changes and fish ecology Influence on fisheries Influence on communities Alternative livelihoods Influence of fishing gear	Eng.	x	13	x	Available online as PDF at WorldFish and IFReDI web sties	*Yes*

* It was agreed by CNMC and ADB during the TA implementation stage that guidelines are no longer required as their elements are already included in the Synthesis Report.

The documents presented here as Appendices are available on Internet at

http://www.ifredi.org/BS_project.asp

The Built Structures Database is accessible online at

http://www.eia.fi/bs/

Appendix 1 Built Structures Database Technical Reports

- Built Structures Database Tonle Sap Built Structures Statistics
- Database Documentation
- Built Structures Database User Manual

Asian Development Bank
TA 4669-CAM

Technical Assistance to the Kingdom of Cambodia
for the Study of the Influence of Built Structures
on the Fisheries of the Tonle Sap
(financed by the Government of Finland)

Database Component

BUILT STRUCTURES DATABASE
TONLE SAP BUILT STRUCTURES STATISTICS

Prepared by

Hannu LAURI

Environmental Impact Assessment Center of Finland Ltd

April 2007

CONTENTS

INTRODUCTION

This document contains summary statistics of the Tonle Sap Basin built structures database. Data sets used to identify structures are detailed in the database documentation. In short this census is based on the best available GIS information covering the whole basin, with a specific focus on floodplains and the three project study areas: Stung Chinit, Prek Toal and Pursat. For these study areas, more detailed information has been sought, maps of higher resolution have been used and details of these maps have been digitized (e.g. fishing gear in Prek Toal) to be better quantified.
More than fourteen thousand built structureshave been identified during the studying the Tonle Sap Basin. However counting all existing structures in the Tonle Sap Basin (i.e. over 44 percent of the whole country) is a titanic undertaking; during this project only 3 study areas could be covered in detail. Roads cannot be easily counted (their length, width or design might be more important than their number). Counting structures also relies on automatic mapping (e.g. to identify rice fields), with subsequent uncertainties. Categorizing them into simple, distinct groups is often tricky (e.g. difference between weirs, dykes and embankments). Fishing fences can be identified as long as they are not under vegetation cover nor underwater (which is often the case with extensive nylon barriers). Canals are many but include a large majority of canals from the Khmer Rouge period that are not actually operational. Major pollution sources (mines, factories, etc.) can be counted, but not diffuse pollution sources due to agriculture or human settlements. Last, the influence of many structures depends on how they are designed and operated. For instance a sluice gate in an irrigation scheme counts as one structure, but its role depends whether it is open or closed, and when; similarly a floodplain road that counts as one structure will have a different influence depending upon the number and size of its culverts.

1. STATISTICS BY SUB-CATCHMENT

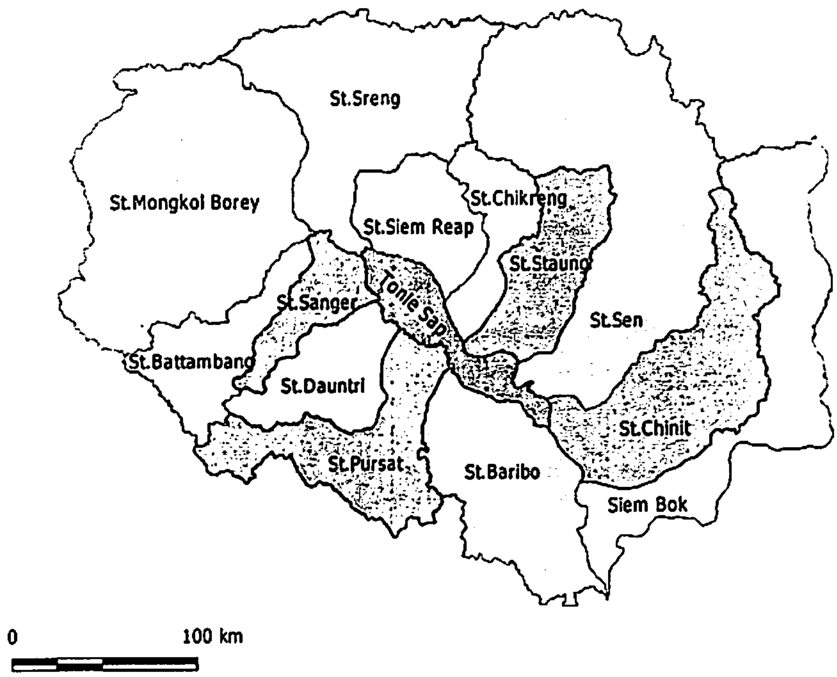

Figure 1: Tonle Sap subcatchments

Tonle Sap subcatchment statistics

Subcatchment	Area (km2)	Flooded (km2) medium flood	Flooded (%) in medium flood
Siem Bok	8851.22	2171.99	24.54
St. Baribo	7153.78	1032.37	14.43
St. Battambang	3708.31	431.79	11.64
St. Chikreng	2713.90	700.19	25.80
St. Chinit	8236.86	1983.23	24.08
St. Dauntri	3695.97	1174.30	31.77
St. Mongkol Borey	14966.42	1834.95	12.26
St. Pursat	5964.77	687.25	11.52
St. Sangker	2344.47	1548.73	66.06
St. Sen	16359.58	1773.03	10.84
St. Siem Reap	3618.98	1017.23	28.11
St. Sreng	9986.27	1430.55	14.33
St. Staung	4357.39	1186.82	27.24
Tonle Sap	2743.80	2743.80	100.00
Sum	94701.70	19716.23	20.82

Lake dry season and medium flood (year 2001) statistics

Dry season lake from MRC shoreline data (50m resolution):

Lake shoreline length	1059	km
Main islands shoreline length	1309	km
Together	2368	km
Lake area (islands subtracted)	2767	km2

Medium flood lake shoreline length from MRC 2001 flood level data (50m resolution):

Total shoreline length	7007.8	km
Area under flood	19718.7	km2

Dry season and medium flood shoreline lengths by catchment area

Catchment	Dry season (km)	Flooded (km)
Siem Bok	0	736.24
St. Baribo	368.1	554.33
St. Battambang	0	267.85
St. Chikreng	298.5	162.42
St. Chinit	181.2	379.19
St. Dauntri	133.9	725.48
St. Mongkol Borey	0	1626.26
St. Pursat	109.7	351.88
St. Sangker	176.5	89.5
St. Sen	106.4	531.38
St. Siem Reap	69.4	449.58
St. Sreng	41.7	814.25
St. Staung	482.8	319.42
Tonle Sap	400.8	0
Sum	2368.1	7007.78

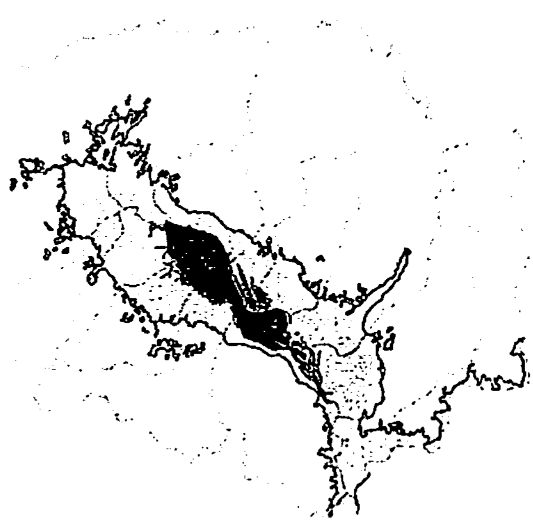

Figure 2: Data used in shoreline length and area computation, dry season lake area in blue, medium flood area in light blue, and catchment boundaries in red.

Dry season lake shoreline length during low water level, computed from subcatchment boundary data:

Catchment	Length (km)
Siem Bok	0
St. Baribo	80.5
St. Battambang	0
St. Chikreng	22.2
St. Chinit	15.5
St. Dauntri	30.0
St. Mongkol Borey	0
St. Pursat	83.7
St. Sangker	33.6
St. Sen	46.6
St. Siem Reap	56.6
St. Sreng	11.9
St. Staung	40.5
Tonle Sap	0
Sum	421.1

2. STATISTICS BY PROVINCE

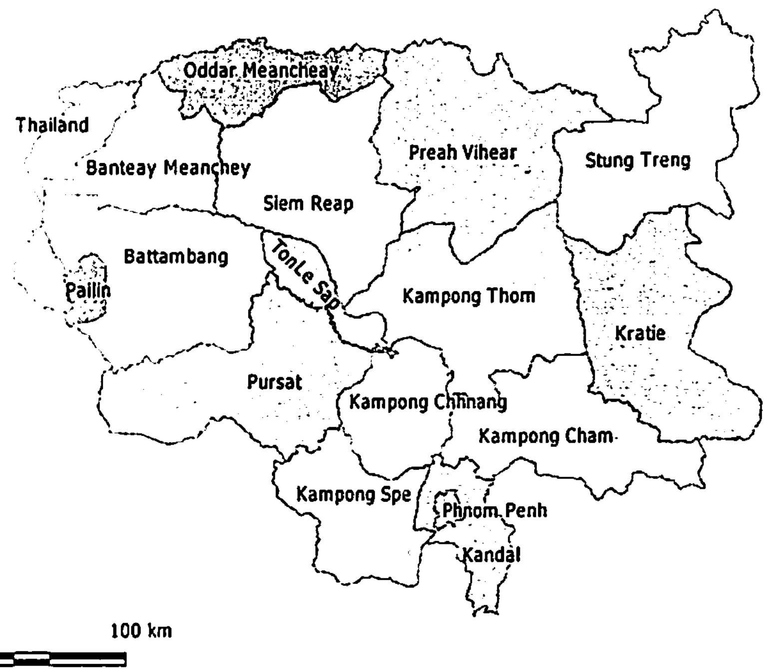

Figure 3: Cambodian provinces intersecting Tonle Sap catchment area

Area data for provinces in the Tonle Sap catchment, including flooded area of provinces within the Tonle Sap catchment boundary (see Figure 4).

Province	Area (km2)	Flooded (km2) in medium flood and within Tonle Sap catchment
Stung Treng	12016.42	0
Oddar Meancheay	5211.71	30.90
Preah Vihear	14030.75	0
Banteay Meanchey	6148.69	1347.75
Siem Reap	11963.74	2825.36
Thailand	4102.97	0
Battambang	11857.86	3331.61
Kampong Thom	12446.57	3625.73
Kratie	11972.83	268.88
Tonle Sap	2524.603	2524.603
Pailin	1090.97	0
Pursat	11576.90	1612.47
Kampong Chhnang	5327.54	1964.28
Kampong Cham	9482.88	1642.04
Kampong Spe	6964.62	0.2
Kandal	3563.69	506.35
Phnom Penh	373.72	56.06

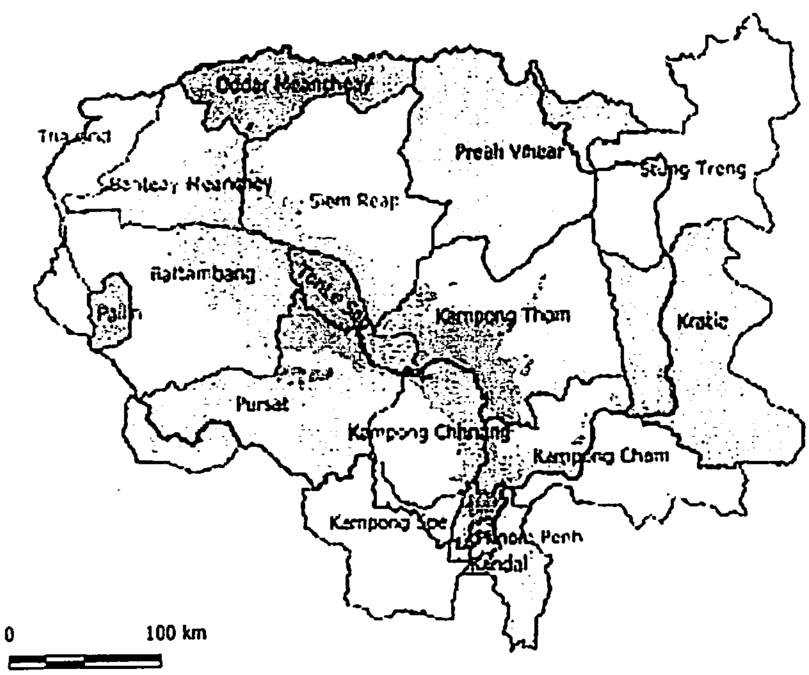

Figure 4: Medium flood area with provinces and Tonle Sap catchment boundary (wide blue line).

3. NUMBER OF STRUCTURES BY CLASS

Class ID	Class name	Count
110	Reservoir	55
211	Irrigation canal	3992
220	Bridge	1311
230	Culvert	323
310	Dam	38
320	Embankment	908
321	Road embankment primary	45
322	Road embankment other	2149
323	Railroad embankment	20
324	Reservoir dike	3
340	Weir	2
371	Hydrological station	44
372	Meteorological station	85
411	Dai fishery	11
413	Fence system	163
414	Fence trap	258
415	Fence pen	51
440	Fishing lot	41
450	Fish sanctuary	7
610	Rice field	1597
620	Field crops	473
630	Plantation	77
640	Other agriculture	2961
650	Irrigated area	159
710	Docks/Harbour	4
730	Ferry	4
814	Mine	62
Sum		14843

4. STRUCTURE STATISTICS BY SUBCATCHMENT

Length of primary roads (km)

Catchment	Count	Length (km)
Siem Bok	8	138.47
St. Baribo	16	188.79
St. Battambang	1	18.89
St. Chikreng	1	19.88
St. Chinit	2	68.72
St. Dauntri	2	51.26
St. Mongkol Borey	5	155.61
St. Pursat	1	29.31
St. Sangker	1	20.63
St. Sen	1	50.32
St. Siem Reap	1	77.83
St. Sreng	2	35.6
St. Staung	2	44.49
Sum	43	899.81

Length of other roads (km)

Catchment	Count	Length (km)
Siem Bok	106	657.27
St. Baribo	225	844.73
St. Battambang	152	443.27
St. Chikreng	8	41.97
St. Chinit	129	600.12
St. Dauntri	85	208.99
St. Mongkol Borey	509	1604.24
St. Pursat	191	588.8
St. Sangker	6	49.73
St. Sen	212	1013.28
St. Siem Reap	228	678.61
St. Sreng	243	1091.97
St. Staung	54	215.56
Sum	2148	8038.54

Length of railroad embankments (km)

Catchment	Count	Length (km)
Siem Bok	0	0
St. Baribo	9	143.07
St. Battambang	1	21.53
St. Chikreng	0	0
St. Chinit	0	0
St. Dauntri	2	51.97
St. Mongkol Borey	3	111.34
St. Pursat	1	31.72
St. Sangker	1	20.15
St. Sen	0	0
St. Siem Reap	0	0
St. Sreng	0	0
St. Staung	0	0
Sum	17	379.78

Length of embankments (km)

Catchment	Count	Length (km)
Siem Bok	232	363.88
St. Baribo	108	197.61
St. Battambang	15	24.72
St. Chikreng	17	57.36
St. Chinit	67	117.92
St. Dauntri	62	168.09
St. Mongkol Borey	124	347.11
St. Pursat	4	8.62
St. Sangker	12	34.86
St. Sen	33	64.82
St. Siem Reap	167	418.73
St. Sreng	44	144.82
St. Staung	23	89.56
Sum	908	2038.11

Length of irrigation channels (km)

Channels selected for a catchment if the channel mid-point is within the catchment.

Catchment	Count	Length (km)
Siem Bok	264	259.49
St. Baribo	133	285.81
St. Battambang	94	108.77
St. Chikreng	30	65.56
St. Chinit	493	626.94
St. Dauntri	282	479.58
St. Mongkol Borey	1622	2039.92
St. Pursat	249	405.84
St. Sangker	86	154.17
St. Sen	161	215.69
St. Siem Reap	63	155.73
St. Sreng	373	429.15
St. Staung	142	187.98
Sum	3992	5414.63

Length of reservoir dikes (km)

Catchment	Count	Length (km)
Siem Bok	0	0
St. Baribo	0	0
St. Battambang	0	0
St. Chikreng	0	0
St. Chinit	3	25.89
St. Dauntri	0	0
St. Mongkol Borey	0	0
St. Pursat	0	0
St. Sangker	0	0
St. Sen	0	0
St. Siem Reap	0	0
St. Sreng	0	0
St. Staung	0	0
Sum	3	25.89

Length of fish fences (km)

Data was available from Preak Toal area only, see figure 5.

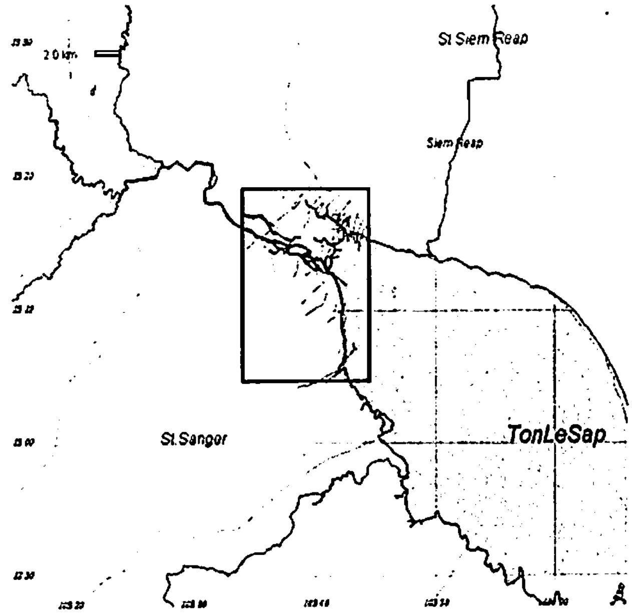

Figure 5: Area from where fishing fences, pens and traps data have been digitized.

Catchment	Count	Length (km)
Siem Bok	0	0
St. Baribo	0	0
St. Battambang	0	0
St. Chikreng	0	0
St. Chinit	0	0
St. Dauntri	0	0
St. Mongkol Borey	0	0
St. Pursat	0	0
St. Sangker	54	55.66
St. Sen	0	0
St. Siem Reap	1	4.1
St. Sreng	74	56.45
St. Staung	34	8.16
Sum	163	124.37

Number of traps (km)

Catchment	Count
Siem Bok	0
St. Baribo	0
St. Battambang	0
St. Chikreng	0
St. Chinit	0
St. Dauntri	0
St. Mongkol Borey	0
St. Pursat	0
St. Sangker	83
St. Sen	0
St. Siem Reap	0
St. Sreng	105
St. Staung	70
Sum	258

Number of pens (km)

Catchment	Count
Siem Bok	0
St. Baribo	0
St. Battambang	0
St. Chikreng	0
St. Chinit	0
St. Dauntri	0
St. Mongkol Borey	0
St. Pursat	0
St. Sangker	17
St. Sen	0
St. Siem Reap	0
St. Sreng	24
St. Staung	10
Sum	51

Area of reservoirs (km2)

Catchment	Count	Area (km2)
Siem Bok	2	1.74
St. Baribo	0	0
St. Battambang	0	0
St. Chikreng	2	3.64
St. Chinit	1	0.85
St. Dauntri	0	0
St. Mongkol Borey	6	27.36
St. Pursat	0	0
St. Sangker	0	0
St. Sen	4	6.83
St. Siem Reap	3	14.27
St. Sreng	5	12.03
St. Staung	32	35.56
Sum	55	102.28

Area of paddy fields (km2)

Catchment	Count	Area (km2)
Siem Bok	206	1196.25
St. Baribo	167	2656.31
St. Battambang	29	539.88
St. Chikreng	51	402.85
St. Chinit	109	1607.71
St. Dauntri	48	1349.02
St. Mongkol Borey	139	4476.1
St. Pursat	45	674.7
St. Sangker	12	427.61
St. Sen	370	1624.11
St. Siem Reap	40	1347.38
St. Sreng	289	1988.98
St. Staung	89	790.19
Sum	1594	19081.11

Area of field crops (km2)

Catchment	Count	Area (km2)
Siem Bok	37	209.43
St. Baribo	46	53.51
St. Battambang	28	70.33
St. Chikreng	3	2.57
St. Chinit	99	387.8
St. Dauntri	1	10.11
St. Mongkol Borey	160	742.31
St. Pursat	2	17.42
St. Sangker	0	0
St. Sen	40	65.51
St. Siem Reap	17	23.31
St. Sreng	27	31.15
St. Staung	13	10.52
Sum	473	1623.98

Area of plantations (km2)

Catchment	Count	Area (km2)
Siem Bok	8	111.92
St. Baribo	0	0
St. Battambang	9	2.52
St. Chikreng	0	0
St. Chinit	37	218.37
St. Dauntri	0	0
St. Mongkol Borey	22	85.54
St. Pursat	0	0
St. Sangker	0	0
St. Sen	1	0.17
St. Siem Reap	0	0
St. Sreng	0	0
St. Staung	1	0.5
Sum	78	418.90

Area of other agriculture (km2)

Catchment	Count	Area (km2)
Siem Bok	450	826.83
St. Baribo	422	362.74
St. Battambang	100	172.51
St. Chikreng	61	123.65
St. Chinit	316	338.2
St. Dauntri	90	96.1
St. Mongkol Borey	325	354.58
St. Pursat	62	83.54
St. Sangker	26	14.2
St. Sen	354	278.09
St. Siem Reap	201	865.59
St. Sreng	391	693.68
St. Staung	159	132.35
Sum	2957	4342.06

Area of irrigation (km2)

Catchment	Count	Area (km2)
Siem Bok	12	186.42
St. Baribo	27	146.01
St. Battambang	0	0
St. Chikreng	2	259.54
St. Chinit	5	48.86
St. Dauntri	17	562.49
St. Mongkol Borey	5	965.03
St. Pursat	14	139.24
St. Sangker	1	356.29
St. Sen	19	141.78
St. Siem Reap	14	297.2
St. Sreng	13	109.84
St. Staung	30	313.37
Sum	159	3526.08

Number of dams

Catchment	Count
Siem Bok	1
St. Baribo	0
St. Battambang	0
St. Chikreng	0
St. Chinit	0
St. Dauntri	0
St. Mongkol Borey	23
St. Pursat	0
St. Sangker	0
St. Sen	11
St. Siem Reap	0
St. Sreng	2
St. Staung	1
Sum	38

Number of bridges

Catchment	All bridges	Bridges on primary roads
Siem Bok	132	39
St. Baribo	147	68
St. Battambang	60	10
St. Chikreng	13	4
St. Chinit	41	23
St. Dauntri	65	24
St. Mongkol Borey	202	67
St. Pursat	164	23
St. Sangker	21	18
St. Sen	204	16
St. Siem Reap	79	30
St. Sreng	162	22
St. Staung	21	10
Sum	1311	354

Number of culverts

Includes only bridges on primary roads (no data on culvers elsewhere)

Catchment	Count
Siem Bok	5
St. Baribo	43
St. Battambang	5
St. Chikreng	2
St. Chinit	9
St. Dauntri	13
St. Mongkol Borey	46
St. Pursat	8
St. Sangker	5
St. Sen	12
St. Siem Reap	78
St. Sreng	56
St. Staung	41
Sum	323

5. STRUCTURE STATISTICS BY PROVINCE

In that section, statistics about built structures are detailed by province. Two special cases are to be mentioned:
- the tables below include a "Tonle Sap" category, that corresponds to the permanent water body that includes structures but does not pertain to any province in particular;
- the tables also include a "Thailand" category; as a matter of fact a small fraction of the Tonle Sap basin lies in Thailand, and this area includes built structures that have also been recorded in the database.

Length of primary roads (km)

Province	Count	Length
Stung Treng	0	0
Oddar Meancheay	0	0
Preah Vihear	0	0
Banteay Meanchey	4	121.36
Siem Reap	4	131.66
Thailand	1	0.94
Battambang	4	111.65
Kampong Thom	3	141.78
Kratie	0	0
Tonle Sap	0	0
Pailin	0	0
Pursat	3	88.04
Kampong Chhnang	1	93.34
Kampong Cham	6	109.76
Kampong Spe	3	1.07
Kandal	16	100.47
Sum	45	900.08

Length of other roads (km)

Province	Count	Length
Stung Treng	4	42.28
Oddar Meancheay	188	799.99
Preah Vihear	118	602.74
Banteay Meanchey	228	848.73
Siem Reap	288	1029.28
Thailand	91	161.03
Battambang	292	1032.8
Kampong Thom	208	960.53
Kratie	49	401.46
Tonle Sap	2	1.08
Pailin	90	148.35
Pursat	308	907.66
Kampong Chhnang	97	449.99
Kampong Cham	93	367.79
Kampong Spe	24	107.55
Kandal	65	171.07
Sum	2145	8032.33

Length of railroad embankments (km)

Province	Count	Length
Stung Treng	0	0
Oddar Meancheay	0	0
Preah Vihear	0	0
Banteay Meanchey	1	70.78
Siem Reap	0	0
Thailand	1	0.73
Battambang	4	113.74
Kampong Thom	0	0
Kratie	0	0
Tonle Sap	0	0
Pailin	0	0
Pursat	3	80.14
Kampong Chhnang	2	75.17
Kampong Cham	0	0
Kampong Spe	1	14.83
Kandal	8	24.39
Sum	20	379.78

Length of irrigation channels (km)

Province	Count	Length
Stung Treng	1	0.55
Oddar Meancheay	13	13.71
Preah Vihear	41	24.91
Banteay Meanchey	964	1255.68
Siem Reap	431	566.49
Thailand	0	0
Battambang	1047	1455.06
Kampong Thom	507	750.74
Kratie	20	14.23
Tonle Sap	0	0
Pailin	0	0
Pursat	403	670.24
Kampong Chhnang	77	147.94
Kampong Cham	452	459.97
Kampong Spe	6	12.27
Kandal	30	42.84
Sum	3992	5414.63

Length of embankments (km)

Province	Count	Length
Stung Treng	0	0
Oddar Meancheay	3	7.3
Preah Vihear	7	25.21
Banteay Meanchey	90	245.04
Siem Reap	224	587.44
Thailand	1	4.2
Battambang	106	300.25
Kampong Thom	56	137.4
Kratie	4	8.08
Tonle Sap	0	0
Pailin	0	0
Pursat	31	80.93
Kampong Chhnang	122	255.12
Kampong Cham	173	265.12
Kampong Spe	11	14.43
Kandal	80	107.58
Sum	908	2038.11

Length of reservoir dikes (km)

Province	Count	Length
Stung Treng	0	0
Oddar Meancheay	0	0
Preah Vihear	0	0
Banteay Meanchey	0	0
Siem Reap	0	0
Thailand	0	0
Battambang	0	0
Kampong Thom	3	25.89
Kratie	0	0
Tonle Sap	0	0
Pailin	0	0
Pursat	0	0
Kampong Chhnang	0	0
Kampong Cham	0	0
Kampong Spe	0	0
Kandal	0	0
Sum	3	25.89

Length of fish fences (km)

Province	Count	Length
Stung Treng	0	0
Oddar Meancheay	0	0
Preah Vihear	0	0
Banteay Meanchey	0	0
Siem Reap	41	45.49
Thailand	0	0
Battambang	115	76.67
Kampong Thom	0	0
Kratie	0	0
Tonle Sap	7	2.2
Pailin	0	0
Pursat	0	0
Kampong Chhnang	0	0
Kampong Cham	0	0
Kampong Spe	0	0
Kandal	0	0
Sum	163	124.37

Number of traps (km)

Province	Count
Stung Treng	0
Oddar Meancheay	0
Preah Vihear	0
Banteay Meanchey	0
Siem Reap	60
Thailand	0
Battambang	171
Kampong Thom	0
Kratie	0
Tonle Sap	27
Pailin	0
Pursat	0
Kampong Chhnang	0
Kampong Cham	0
Kampong Spe	0
Kandal	0
Sum	258

Number of pens (km)

Province	Count
Stung Treng	0
Oddar Meancheay	0
Preah Vihear	0
Banteay Meanchey	0
Siem Reap	12
Thailand	0
Battambang	34
Kampong Thom	0
Kratie	0
Tonle Sap	5
Pailin	0
Pursat	0
Kampong Chhnang	0
Kampong Cham	0
Kampong Spe	0
Kandal	0
Sum	51

Area of reservoirs (km2)

Province	Count	Area
Stung Treng	0	0
Oddar Meancheay	1	8.94
Preah Vihear	1	0.64
Banteay Meanchey	6	16.11
Siem Reap	8	28.27
Thailand	0	0
Battambang	1	12.89
Kampong Thom	36	42.6
Kratie	0	0
Tonle Sap	0	0
Pailin	0	0
Pursat	0	0
Kampong Chhnang	0	0
Kampong Cham	2	1.74
Kampong Spe	0	0
Kandal	0	0
Sum	55	111.2

Area of paddy fields (km2)

Province	Count	Area
Stung Treng	41	28.69
Oddar Meancheay	136	624.76
Preah Vihear	334	369.19
Banteay Meanchey	146	3350.5
Siem Reap	191	2927.83
Thailand	15	38.77
Battambang	102	2983.65
Kampong Thom	174	2841.25
Kratie	57	189.7
Tonle Sap	0	0
Pailin	9	6.85
Pursat	80	1650.73
Kampong Chhnang	124	1592.3
Kampong Cham	113	1498.17
Kampong Spe	21	573.14
Kandal	52	405.51
Sum	1595	19081.02

Area of field crops (km2)

Province	Count	Area
Stung Treng	0	0
Oddar Meancheay	3	4.5
Preah Vihear	14	18
Banteay Meanchey	79	159.93
Siem Reap	35	43.16
Thailand	46	10.29
Battambang	45	509.97
Kampong Thom	90	163.66
Kratie	3	1.04
Tonle Sap	0	0
Pailin	27	144.09
Pursat	3	27.53
Kampong Chhnang	37	34.91
Kampong Cham	76	481.89
Kampong Spe	8	6.74
Kandal	4	18.27
Sum	470	1623.97

Area of plantation (km2)

Province	Count	Area
Stung Treng	0	0
Oddar Meancheay	0	0
Preah Vihear	0	0
Banteay Meanchey	2	24.71
Siem Reap	0	0
Thailand	19	60.71
Battambang	7	1.47
Kampong Thom	6	9.51
Kratie	0	0
Tonle Sap	0	0
Pailin	2	1.05
Pursat	0	0
Kampong Chhnang	1	0.2
Kampong Cham	39	321.26
Kampong Spe	0	0
Kandal	0	0
Sum	76	418.9

Area of other agriculture (km2)

Province	Count	Area
Stung Treng	86	21.23
Oddar Meancheay	97	271.75
Preah Vihear	156	50.8
Banteay Meanchey	237	191.69
Siem Reap	522	1459.43
Thailand	23	7.83
Battambang	295	382.52
Kampong Thom	491	454.24
Kratie	56	78.44
Tonle Sap	16	1.07
Pailin	3	3.83
Pursat	149	162.09
Kampong Chhnang	297	501.55
Kampong Cham	247	509.7
Kampong Spe	85	23.2
Kandal	202	222.7
Sum	2962	4342.06

Area of irrigation (km2)

Province	Count	Area
Stung Treng	0	0
Oddar Meancheay	6	31.53
Preah Vihear	0	0
Banteay Meanchey	2	235.56
Siem Reap	22	614.5
Thailand	0	0
Battambang	10	1507.42
Kampong Thom	50	461.83
Kratie	0	0
Tonle Sap	0	0
Pailin	0	0
Pursat	34	334.23
Kampong Chhnang	10	63.58
Kampong Cham	12	192.95
Kampong Spe	7	24.43
Kandal	6	60.05
Sum	159	3526.08

Number of bridges

Province	All bridges	Bridges on primary roads
Stung Treng	17	0
Oddar Meancheay	106	0
Preah Vihear	138	0
Banteay Meanchey	118	42
Siem Reap	158	51
Thailand	0	0
Battambang	187	77
Kampong Thom	99	40
Kratie	36	0
Tonle Sap	0	0
Pailin	14	0
Pursat	242	52
Kampong Chhnang	87	39
Kampong Cham	53	16
Kampong Spe	6	0
Kandal	50	37
Sum	1311	317

Number of culverts

Province	Count
Stung Treng	0
Oddar Meancheay	0
Preah Vihear	0
Banteay Meanchey	34
Siem Reap	126
Thailand	0
Battambang	42
Kampong Thom	58
Kratie	0
Tonle Sap	0
Pailin	0
Pursat	17
Kampong Chhnang	20
Kampong Cham	9
Kampong Spe	4
Kandal	13
Sum	323

Number of dams

Province	Count
Stung Treng	0
Oddar Meancheay	2
Preah Vihear	10
Banteay Meanchey	23
Siem Reap	0
Thailand	0
Battambang	0
Kampong Thom	2
Kratie	1
Tonle Sap	0
Pailin	0
Pursat	0
Kampong Chhnang	0
Kampong Cham	0
Kampong Spe	0
Kandal	0
Sum	38

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Database Component

DATABASE DOCUMENTATION

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CONTENTS

PURPOSE OF THE DATABASE COMPONENT OF THE PROJECT

The main task of the database component of the Built Structures project is to prepare a database of existing surface water and surface water quality related structural works in the Tonle Sap Basin. The database should contain the geographic extent and characteristics of these structures.

The database will be used in the assessment of the consequences of built structures on the environmental and human components of the lake ecosystem.

A built structure is defined here as a structure that

(i) opposes water outflow (e.g. dams, weirs, irrigation schemes, levees, embankments);

(ii) prevents water inflow (e.g. . roads, railways, flood control works, polders, dykes, wharves and quays);

(iii) alters water inflow or outflow (e.g. drainage canals, diversion structures, agricultural works, and flow modifications);

(iv) may degrade water quality (e.g. plants with aqueous effluents, mining and mineral processing facilities, petroleum storage facilities, sewerage systems, and dredges); and

(v) Fishing gears that can alter hydrological flows and obstruct fish movement.

The main emphasis of the database is on structures of type (i), (ii) and (v).

CLASSIFICATION OF BUILT STRUCTURES

The structures are grouped in the database using structure type classification, derived from structure type and usage. The type classification

1. Assigns exactly one type class for each existing structure in the target area,
2. Determines what characteristics of a given structure are stored in the database,
3. Aids database users in searching for structures that have specific impacts,
4. Is easy to understand for the database user.

STRUCTURE TYPE CLASSIFICATION

1 Storage
110 Reservoir
120 Floodwater storage

2 Flow route
210 Canal
211 Irrigation canal
210 Bridge
230 Culvert
240 Spillway

3	**Flow control**
310	Dam
320	Embankment
321	Road embankment primary road
322	Road embankment other
323	Railroad embankment
324	Reservoir dike
330	Gate
340	Weir
350	Pumping station
360	Hydropower station
370	Measurement station
371	Hydrological station
372	Meteorological station
4	**Fish and aquaculture**
410	Fishing gear
411	Dai fishery
412	River barrage with bagnet or trap
413	Fence system fence
414	Fence system trap
415	Fence system pen
420	Fishway
430	Aquaculture
431	Fish pond
432	Fish cage
440	Fishing lot
450	Fish sanctuary
5	**Erosion prevention**
510	Reinforced bank
520	RipRap
6	**Agriculture**
610	Rice field
620	Field crops
630	Plantation
640	Other agriculture
650	Irrigated area
7	**Transportation**
710	Docks/Harbour
720	Breakwater
730	Ferry
8	**Discharge**
810	Point source
811	Sewage treatment plant
812	Sewage outlet
813	Industrial sewage outlet
814	Mine
820	Diffuse source
821	Scattered population

STRUCTURE ATTRIBUTES

Structure attributes are values that describe a given structure and are stored in the database. The following data is stored:

- Structure name
- Structure position (mid-point position), UTM (Universal Transverse Mercator, zone 48N with false easting of 500000, and WGS84 datum)
- Structure outline, mid-line or point location, coordinate system as above
- Structure creation (and demolition) date
- Database diary data; entry date and user ID
- Main physical dimensions of the structure
- Main hydrological characteristics of the structure
- Photographs of the structure

Below is a table of attributes based on the above structure classification.

Attributes for all classes

Field	Type	Unit	Explanation
id	Int	-	Structure identifier
class_id	Int	-	Structure class identifier
name	String	-	Name of structure
info	String	-	Additional information in text format
xpos	Real	m	x-coordinate of mid-point (UTM)
ypos	Real	m	y-coordinate of mid-point (UTM)
boundary	Geom	-	Boundary/mid-line/mid-point data
constructed	Date	-	Construction date (when taken to use)
demolished	Date	-	Demolition date (when taken out of use)
entrydate	Date	-	Date when entered into database
entryby	String	-	Userid of user who created this entry
datasource	String	-	Datasource acronym
srid	Int	-	Coordinate system identifier
boundary	Geom	-	Mid-point/boundary/mid-line geometry data

Class-dependent attributes

Field	Type	Unit	Explanation
width	Real	m	Width of structure
height	Real	m	Height of structure
length	Real	m	Length of structure
area	Real	m^2	Area or structure (at the maximum water level)
activestorage	Real	m^3	Storage volume between minimum and maximum water levels
minlevel	Real	m	Water level at which flow out or through a structure stops
maxdepth	Real	m	Maximum water level for a structure
crestlevel	Real	m	Minimum water level for flow to occur over structure
maxflow	Real	m^3/s	Maximum flow on maximum water level
crsection	Real	m^2	Channel/opening cross section area at maximum water level
wldrop	Real	m	Water level drop over structure
material	String	-	Construction material, e.g. timber/earth/stones/concrete/metal

production	Real	kg/a	Approximate production per year

SELECTION CRITERIA FOR STRUCTURES

SPATIAL EXTENT

The database contains structures in the Tonle Sap Basin as defined by the watershed boundary. Spatial emphasis is on the areas through which water flows to the Tonle Sap, and more generally on areas that are or have been under water during the flood season. The Tonle Sap flooded area is shown in Figure 1 and is mostly limited by National Roads n° 5 and 6. The project target sites in Preak Toal, Pursat and Chinit are included in the database with some more detail.

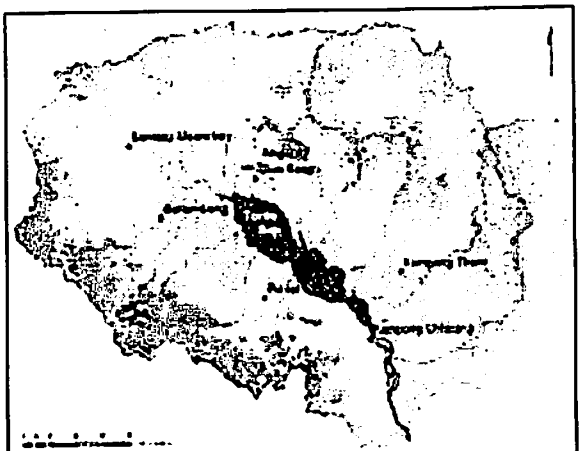

Figure 1: Geographic boundary for database contents

FLOW IMPACT CLASSIFICATION

Structures in the area are divided roughly into three categories according the impact of the structure on water flow. The classes are large, mid-size and small structure. Large structures may have catchment scale impacts, mid-size structures have regional scale impacts, and small-scale structures have only local impacts.

A limit for large structures is here defined as a structure that can store at least 2.5 million m^3 water (in a year), or modify existing flows for at least 1 m^3/s on average, or 4 m^3/s during peak flow time.

A limit for mid-size structures is defined as a structure that can store at least 0.5 million m^3 water (in a year), or modify existing flows for at least 0.5 m^3/s on average, or 2 m^3/s during peak flow time.

Structures that store water modify flows less than mid-size structures that belong to the small category.

The database mainly contains large and mid-size structures. Structures classified as small may also be included in the database in some cases, for example, if the impact of a structure is not known or the attributes required for assessing the structure size are not available.

DATABASE

The data is put into a relational database with the capability to store geometry types MySQL database version 5.0.21 is used here. The MySQL database is free, and contains user friendly tools for installation, database management, and queries. Also, tools for data import from shapefile to the database are available.

A map-based data viewer Java applet was constructed to allow remote access to the database data using an Internet browser.

Export of data to and from the database to GIS programs can be done by writing selected database contents to an ESRI shapefile. The shapefile attribute table will contain selected structure properties.

DATABASE TABLES

The database contains the following tables:

- Structure table – table for storing structure attributes
- Class table – table for storing structure classification data
- Photo table – table for storing photographs of structures
- Contact table – table for storing contact information for structure managers, database users and data sources
- Validation table – table for storing validation data
- Discharge table – table for storing point load data
- Area table – geographic data that can be used to geographically select structure data, for example, catchment boundaries, main rivers, districts and province boundaries, and main settlement locations.

Structure table

Since many types of structures have common attributes, all structures are put in to a single table that has a set of attributes shown below. The list of attributes can be extended if required. Not all attributes are relevant to all structures, so only the relevant attributes, defined by the structure class, will be set for each structure. The irrelevant attributes will have undefined (null) values.

Field	Type	Unit	Explanation
id	Int	-	Structure identifier
class_id	Int	-	Structure class identifier
name	String	-	Name of structure
info	String	-	Additional information in text format
xpos	Real	m	x-coordinate of mid-point (UTM)
ypos	Real	m	y-coordinate of mid-point (UTM)
boundary	Geom	-	Boundary/mid-line/mid-point data
constructed	Date	-	Construction date (when put into use)
demolished	Date	-	Demolition date (when taken out of use)
entrydate	Date	-	Date when entered into database
entryby	String	-	Userid of user who created this entry
datasource	String	-	Datasource acronym
srid	Int	-	Coordinate system identifier
boundary	Geom	-	Mid-point/boundary/mid-line geometry data
width	Real	m	Width of structure
height	Real	m	Height of structure
length	Real	m	Length of structure

area	Real	m^2	Area of structure (at the maximum water level)
activestorage	Real	m^3	Storage volume between minimum and maximum water levels
minlevel	Real	m	Water level at which flow out or through a structure stops
maxdepth	Real	m	Maximum water level for a structure
crestlevel	Real	m	Minimum water level for flow to occur over structure
maxflow	Real	m^3/s	Maximum flow on maximum water level
crsection	Real	m^2	Channel/opening cross section area at maximum water level
wldrop	Real	m	Water level drop over structure
material	String	-	Construction material, e.g. timber/earth/stone/concrete/metal
production	Real	kg/a	Approximate production per year

Class table

The class table contains data on structure classes.

Field	Type	Unit	Explanation
id	Int	-	Structure class identifier
name	String	-	Name of class
parent	Int	-	Identifier of parent class
description	String	-	Description of the class
shapetype	tinyint	-	Shape type point/polyline/polygone
linecolor	Integer	-	RGB linecolor (256*R+256*(G+B))
linestyle	tinyint	-	Line style: 0=thin, 1=medium, 2=thick, 3=dashed
fillcolor	integer	-	RGB fillcolor (256*R+256*(G+B))
fillstyle	tinyint	-	Fill style, 0=solid, 1-28 hatch: 1: ' ', 4: '\\\', 7: '///', 10: '|||', 13:'xx' , 16:'++'; +0=dense, +1=medium, +2=sparse

Photo table

The photo table contains photos that can be added to structure descriptions. Photos are stored using a maximum size of 1600x1200 pixels and in .jpeg format.

Field	Type	Unit	Explanation
id	Int	-	Photo identifier
structure_id	Int	-	Structure identifier
image	BLOB	-	Photograph data (.jpeg 1600x1200)
description	String	-	Photo description
priority	Int	-	Photo presentation order, smaller first
date	date	-	Date photo was taken
ypos	Real	m	Photo position X-coordinate (UTM)
ypos	Real	m	Photo position Y-coordinate (UTM)
direction	Int	degr.	Direction from structure to photographer, 0=from north, 90=from east side
distance	Real	m	Distance from structure to photographer

Contact table

Table for contact information of database users, data sources and structure managers.

Field	Type	Unit	Explanation
id	Int	-	Contact identifier
acronym	String	-	Acronym
firstname	String	-	Firstname
lastname	String	-	Lastname
userid	String	-	Database userid, if exist
institute	String		Institute
department	String		Department
address1	String	-	Street address
address2	String	-	Post number and city
phone1	String		Phone number
phone2	String	-	Mobile phone number
fax	String	-	Fax number
email	String	-	Email address
date	Date	-	Date of last update

Validation table

Table for structure validation data.

Field	Type	Unit	Explanation
id	Int	-	Validation identifier
structure_id	Int	-	Structure identifier
contact_id	Int	-	Validator identifier
validated	Date	-	Date of validation
method	String	-	Validation method; visit/indirect
description	String	-	If anything was changed

Discharge table

Table for discharge data.

Field	Type	Unit	Explanation
id	Int	-	Load identifier
structure_id	Int	-	Associated structure
substance	String	-	Load variable, e.g. PTOT, NTOT
amount	Real	kg/d	Amount of load per day
dyear	Int	-	Year for discharge

Area table

Table for selection data.

Field	Type	Unit	Explanation
id	Int	-	Area identifier
name	String	-	Area name
type	String	-	Catchment/district/river/settlement/road
area	Double	m^2	Area of boundary
boundary	Geometry	-	Area boundary

110 Reservoir

Class-dependent attributes

Attribute	Type	Unit	Explanation
*info	String	-	Reservoir owner (owner: name)
width	Real	m	Reservoir extent (bounding box width) in east-west direction
length	Real	m	Reservoir extent (bounding box height) in north-south direction
area	Real	km2	Area of reservoir at the maximum water level
activestorage	Real	m3	Active storage of the reservoir
minlevel	Real	m	Water level at which outflow from the storage stops
maxdepth	Real	m	Difference from minlevel to activestorage level

Selection criteria

Large: Reservoirs with a volume larger than 2.5 million m^3. For typical reservoirs in the area with a water depth of 0-2 meters, this would mean an area of at least 2.5 km^2 when 1 m average water depth is used in volume computation.
Midsize: Reservoirs with a volume 0.5-2.5 million m^3. For typical reservoirs in the area with a water depth of 0-2 meters, this would mean an area of at least 0.5 km^2 when 1 m average active depth is used in volume computation.

Reservoirs that are next to each other are included in the database if the combined estimated volume exceeds the above criteria.

Source data

- source data JICA reservoirs (ts_reservoir2.shp),
    - attributes: boundary, name and area

Data processing

- reservoirs with area smaller than 0.5 km^2 dropped out
- selection criteria applied to original data

120 Floodwater_storage

Class-dependent attributes

Attribute	Type	Unit	Explanation
*info	String		Storage owner (owner: name)
width	Real	m	Storage extent (bounding box width) in east-west direction
length	Real	m	Storage extent (bounding box height) in north-south direction
area	Real	km2	Area of storage at the maximum water level
activestorage	Real	m3	active storage of the reservoir
minlevel	Real	m	Water level at which flow to/from the storage stops
maxdepth	Real	m	Difference from minlevel to water level at activestorage volume

Selection criteria

- same as for reservoirs (class 110)

Source data

- source data Kampong Thom private reservoirs, Agriculture Office Kampong Thom Province (kt_reservoir.shp)
  - attributes: boundary, owner, area

Data processing

- no addition processing

210 Canal

Class-dependent attributes

Attribute	Type	Unit	Explanation
width	Real	m	Channel/opening width perpendicular to flow direction
length	Real	m	Channel/opening length along flow
minlevel	Real	m	Channel bottom level
maxdepth	Real	m	Channel depth from minlevel to bank level
crsection	Real	m2	Channel cross section area at maxlevel
material	String		

Selection criteria

Large: Canals with an average flow larger than 1m^3/s, or a peak flow larger than 10m^3/s. Channels with high water cross section larger than 10 m^2
Midsize: All channels wider than 2 meters

Source data

- no data

Data processing

- no addition processing

211 Irrigation canal

Class-dependent attributes

Attribute	Type	Unit	Explanation
width	Real	m	Channel width perpendicular to flow direction
length	Real	m	Channel length along flow
minlevel	Real	m	Channel bottom level
maxdepth	Real	m	Channel depth from minlevel to bank level
crsection	Real	m2	Channel cross section area at maxlevel
material	String	-	Bank material, if not earth

Selection criteria

- same as canal (class 210)

Source data

- source data JICA irrigation channel data (ts_irr_canal2.shp)
  - all data included
  - attributes: mid-line, small/large size classification
- source data Chinit irrigation project channel data (added ts_reservoir2.shp)
  - all data included
  - attributes: mid-line, size: main/secondary/tertiary canal/drain

Data processing

- simplified data to 10 meter resolution
- split with catchment boundaries

220 Bridge

Class-dependent attributes

Attribute	Type	Unit	Explanation
width	Real	m	Channel/opening width perpendicular to flow direction
height	Real	m	Height of bridge bottom from dry-season water level
length	Real	m	Channel/opening length along flow
minlevel	Real	m	Bridge opening bottom level
maxdepth	Real	m	Typical maximum water depth under bridge
crsection	Real	m2	Channel/opening cross section area at maxlevel
material	String	-	Material

Selection criteria

Large: Bridges longer than 30 meters
Midsize: Bridges longer than 5 meters

Source data

- source data JICA map road bridges (ts_rd_bridge.shp)
  - all bridges included
  - attributes: location

- source data JICA map railroad bridges (ts_rr_bridge.shp)
    - all bridges included
    - attributes: location

Data processing

- no additional processing

230 Culvert

Class-dependent attributes

Attribute	Type	Unit	Explanation
*info	String		Culvert type, pipe/box
width	Real	m	Width perpendicular to flow direction
height	Real	m	Height of culvert opening
length	Real	m	Length along flow
minlevel	Real	m	Culvert bottom level
maxdepth	Real	m	Culvert maximum water depth
crsection	Real	m2	Cross section area at maxdepth
wldrop	Real	m	Difference of height from start to end of culvert
material	String		Material, if not earth

Selection criteria

- all culverts included

Source data

- source data (ts_culvert2.shp)
    - attributes: location, culvert type box/pipe, construction year

Data processing

- Culverts with no completion year dropped out

240 Spillway

Class-dependent attributes

Attribute	Type	Unit	Explanation
width	Real	m	Channel/opening width perpendicular to flow direction
length	Real	m	Channel/opening length along flow
minlevel	Real	m2	Minimum water level for flow to occur over structure
maxdepth	Real	m2	Typical maximum water depth
crsection	Real	m2	Cross-section area
wldrop	Real	m	Water level drop over the length of structure
material	String		Bank material, if not earth

Selection criteria

- all data included

Source data

- field visit data from Chinit
    - attributes: width, length, wldrop

Data processing

- no additional processing

310 Dam

Class-dependent attributes

Attribute	Type	Unit	Explanation
width	Real	m	Width of structure/opening perpendicular to flow direction
height	Real	m	Largest height of dam
length	Real	m	Length of flow path in structure along flow direction
crestlevel	Real	m	Minimum water level for flow to occur over structure
material	String	-	Timber/earth/stone/concrete/metal

Selection criteria

Large: Dams with active reservoir volume larger than 2.5 million m3
Midsize: Dams with active reservoir volume between 0.5-2.5 million m3

Source data

- source data JICA map (ts_dam_earth2.shp)
    - attributes: boundary, material

Data processing

- all data included
- joined lines
- simplified to 10 m resolution

320 Embankment

Class-dependent attributes

Attribute	Type	Unit	Explanation
width	Real	m	Width of structure
height	Real	m	Average height of embankment from ground level
length	Real	m	Length of embankment
crestlevel	Real	m	Minimum water level for flow to occur over structure
material	String	-	Timber/soil/concrete/metal

Selection criteria

Large: Any embankment potentially catching water for more than 2.5 million m^3, or, an embankment longer that 10 km.
Midsize: Embankments higher than 1 m if longer than 2 km. Also, other embankments that potentially trap more than 0.5 million m^3 of water.

Source data

- source data JICA embankments (ts_levee3.shp)
    - attributes: boundary, material, length

Data processing

- joined lines
- dropped out embankments shorter than 0.8 km, and not within distance of 0.5 km of a selected embankment
- simplified to 10 m resolution
- split with catchment boundaries

321 Road embankment (primary)

Class-dependent attributes

Attribute	Type	Unit	Explanation
width	Real	m	Width of structure
height	Real	m	Average height of embankment from ground level
length	Real	m	Length of embankment
crestlevel	Real	m	Minimum water level for flow to occur over structure
material	String	-	Timber/soil/concrete/metal

Selection criteria

- all data included

Source data

- source data JICA primary roads (ts_rdprimary2.shp)
    - attributes: boundary, length

Data processing

- split with catchment boundaries
- set the crestlevel to 12 meters (equal to above flood)

322 Road embankment (other)

Class-dependent attributes

Attribute	Type	Unit	Explanation
width	Real	m	Width of structure
height	Real	m	Average height of embankment from ground level
length	Real	m	Length of embankment
crestlevel	Real	m	Minimum water level for flow to occur over structure
material	String	-	Timber/soil/concrete/metal

Selection criteria

- all data included (no knowledge on embankment heights available)

Source data

- source data JICA secondary roads (ts_rdsecondary2.shp)
    - attributes: boundary, length

Data processing

- simplified data to 25 meter resolution
- split with catchment boundaries

323 Railroad embankment

Class-dependent attributes

Attribute	Type	Unit	Explanation
width	Real	m	Width of structure
height	Real	m	Average height of embankment from ground level
length	Real	m	Length of embankment
crestlevel	Real	m	Minimum water level for flow to occur over structure
material	String	-	Timber/soil/concrete/metal

Selection criteria

- all data included

Source data

- source data JICA railroads (ts_railway2.shp)
    - attributes: boundary, length

Data processing

- joined lines
- simplified data to 25 meter resolution
- split with catchment boundaries
- set crestlevel to 12 (above flood)

324 Reservoir dike

Class-dependent attributes

Attribute	Type	Unit	Explanation
width	Real	m	Width of structure
height	Real	m	Largest height of dike from ground level
length	Real	m	Length of dike
crestlevel	Real	m	Minimum water level for flow to occur over structure
material	String	-	Timber/earth/stone/concrete/metal

Selection criteria

- see reservoir

Source data

- source data Chinit irrigation project data (chinit_embankment.shp)
    - attribute: boundary, width, length

Data processing

- no additional processing

330 Gate

Class-dependent attributes

Attribute	Type	Unit	Explanation
width	Real	m	Width of gate perpendicular to flow direction
height	Real	m	Height of gate from bottom to max water level
length	Real	m	Length of flow path in gate along flow direction
minlevel	Real	m	Min water level on which flow can occur through the gate
maxdepth	Real	m	Typical maximum water depth for gate
crsection	Real	m2	Cross section though which water can flow at maxdepth
material	String	-	Timber/earth/stone/concrete/metal

Selection criteria

Large: Gate with width of at least 3.0 meters
Midsize: Gate with width of 1.0 to 3.0 meters

Source data

- field survey data

Data processing

- no additional processing

340 Weir

Class-dependent attributes

Attribute	Type	Unit	Explanation
width	Real	m	Width of weir perpendicular to flow direction
height	Real	m	Height of weir
length	Real	m	Length of weir flow path in flow direction
crestlevel	Real	m	Minimum water level for flow to occur over structure
wldrop	Real	m	Water level drop (typical)
material	String	-	Timber/earth/stone/concrete/metal

Selection criteria

Large: Weir with width of at least 30 meters
Midsize: Weir with width of 2.0 to 30 meters

Source data

- source data Chinit irrigation project data (chinit_weir.shp)
    - attributes: length, wldrop, material

Data processing

- no additional processing

350 Pumping station

Class-dependent attributes

Attribute	Type	Unit	Explanation
minlevel	Real	m	Minimum water level where the station can work
production	Real	m3/s	Maximum pumping capacity

Selection criteria

Large: Station with capacity of at least 2 m3/s
Midsize: Station with capacity over 0.5 m3/s

Source data

- no data

Data processing

- no additional processing

360 Hydropower station

Class-dependent attributes

Attribute	Type	Unit	Explanation
minlevel	Real	m	Min water level on which flow can occur through the structure
maxdepth	Real	m	Typical maximum water depth from minlevel
maxflow	Real	m3	Maximum flow though structure on maximum water level
wldrop	Real	m	Water level drop (maxlevel to bottom of structure)
production	Real	Gwh	Annual hydropower production

Selection criteria

Large: Station with production over 50 Gwh
Midsize: Station with production less than 50 Gwh

Data processing

- no additional processing

370 Measurement station

Class-dependent attributes

Attribute	Type	Unit	Explanation
*info	Real	m	Type of station: automatic/manual, measured variable(s)

Selection criteria

- all data stations included

Data processing

- no additional processing

371 Hydrological station

Class-dependent attributes

Attribute	Type	Unit	Explanation
*info	Real	m	Type of station: automatic/manual, measured variable(s)

Selection criteria

- all data stations included

Source data

- source data MOWRAM water level stations (river_station.shp)
    - attributes: location, station id code, measured variables

Data processing

- no additional processing

372 Meteorological station

Class-dependent attributes

Attribute	Type	Unit	Explanation
*info	Real	m	Type of station: automatic/manual, measured variable(s)

Selection criteria

- all data stations included

Source data

- source data MPWT rainfall stations (rainfall_st.shp)
    - attributes: location, station id, measured variables

Data processing

- no additional processing

410 Fishing gear

Class-dependent attributes

Attribute	Type	Unit	Explanation
production	Real	kg/a	Approximate production in one year

Selection criteria

- stationary gears included

Data processing

- no additional processing

411 Dai fishery

Class-dependent attributes

Attribute	Type	Unit	Explanation
width	Real	m	Number of nets
production	Real	kg/a	Approximate production in one year

Selection criteria

- all known dai fisheries included

Source data

- satellite picture from Google Earth
  - attributes: boundary, number of nets

Data processing

- no additional processing

412 River barrage with bagnet or trap

Class-dependent attributes

Attribute	Type	Unit	Explanation
width	Real	m	Width of barrage
production	Real	kg/a	Approximate production in one year

Selection criteria

Large: Barrages longer than 50 meters
Midsize: Barrages between 10-50 meters

Data processing

- no additional processing

413 Fence system fence

Class-dependent attributes

Attribute	Type	Unit	Explanation
length	Real	m	Length of associated fence system (main fence part only)
production	Real	kg/a	Approximate production in one year

Selection criteria

- all fences, traps and pens

Source data

- digitized from aerial photos (fence_pen.shp, fence_trap.shp, fish_fence.shp), Preak Toal area only
  - attributes: boundary, length

Data processing

- no additional processing

414 Fence system pen

Class-dependent attributes

Attribute	Type	Unit	Explanation
length	Real	m	Length of associated fence system (main fence part only)
production	Real	kg/a	Approximate production in one year

Selection criteria

- all fences, traps and pens

Source data

- digitized from aerial photos (fence_pen.shp, fence_trap.shp, fish_fence.shp), Preak Toal area only
    - attributes: boundary, length

Data processing

- no additional processing

413 Fence system rap

Class-dependent attributes

Attribute	Type	Unit	Explanation
length	Real	m	Length of associated fence system (main fence part only)
production	Real	kg/a	Approximate production in one year

Selection criteria

- all fences, traps and pens

Source data

- digitized from aerial photos (fence_pen.shp, fence_trap.shp, fish_fence.shp), Preak Toal area only
    - attributes: boundary, length

Data processing

- no additional processing

420 Fishway

Class-dependent attributes

Attribute	Type	Unit	Explanation
width	Real	m	Channel width perpendicular to flow direction
length	Real	m	Channel length along flow (measured along bank)

crestlevel	Real	m	Minimum water level for flow to occur
crsection	Real	m2	Channel cross section
wldrop	Real	m	Water level drop over the length of structure
material	String		Bank material, if not earth

Selection criteria

- all fishways

Source data

- field trip data from Chinit area
    - attributes: boundary, width, length, wldrop

Data processing

- no additional processing

430 Aquaculture

Class-dependent attributes

Attribute	Type	Unit	Explanation
area	Real	m2	Aquaculture area
production	Real	kg/a	Approximate production in year

Selection criteria

- farms with annual production more than 10 tons per year

Source data

- no data

Data processing

- no additional processing

431 Pond fish farm

Class-dependent attributes

Attribute	Type	Unit	Explanation
area	Real	m2	Aquaculture area
production	Real	kg/a	Approximate production in year

Selection criteria

- same as for aquaculture (class 430)

Source data

- no data

Data processing

- no additional processing

432 Cage fish farm

Class-dependent attributes

Attribute	Type	Unit	Explanation
area	Real	m2	Aquaculture area
production	Real	kg/a	Approximate production in year

Selection criteria

- same as for aquaculture (class 430)

Source data

- no data

Data processing

- no additional processing

440 Fishing lot area

Class-dependent attributes

Attribute	Type	Unit	Explanation
*name	String		Province and number
area	Real	m2	Lot area
production	Real	kg/a	Approximate production in year

Selection criteria

- all fishing lots included

Source data

- source data MRC fishing lots from year 2001 (c_lot2001_commercial_3.shp)
  - attributes: boundary, lot number, area code

Data processing

- extracted commercial lots (type 2) from c_lot2001.shp
- union of lots with same region code and lot number
- simplified to 50 m resolution

450 Fish sanctuary

Class-dependent attributes

Attribute	Type	Unit	Explanation
*name	String		Province and number
area	Real	m2	Lot area

Selection criteria

- all fish sanctuaries included

Source data

- source data MRC fish sanctuaries from year 2001 (c_lot2001_sanctuary.shp)
    - attributes: boundary

Data processing

- extracted sanctuaries (type 3) from c_lot2001.shp
- simplified to 50 m resolution

510 Reinforced bank

Class-dependent attributes

Attribute	Type	Unit	Explanation
width	Real	m	
length	Real	m	
material	String	-	Description of material used

Data processing

- no additional processing

520 RipRap

Class-dependent attributes

Attribute	Type	Unit	Explanation
width	Real	m	Width across flow direction
length	Real	m	Length along flow direction
material	String	-	Description of material used

Selection criteria

- ripraps associated with a structure already in the database

Source data

- field trip data from Chinit area
    - attributes: boundary, width, length, wldrop

Data processing

- no additional processing

610 Rice field

Class-dependent attributes

Attribute	Type	Unit	Explanation
area	Real	km2	Area of structure

Source data

- source data JICA paddy field areas (ts_paddyfield5.shp)
    - attributes: boundary, area

Data processing

- simplified to 50 m resolution
- split to catchment areas
- areas smaller than 0.1 km2 removed

620 Field crops

Class-dependent attributes

Attribute	Type	Unit	Explanation
area	Real	km2	Area of structure

Source data

- source data JICA plantation areas (ts_fieldcrop2.shp)
    - attributes: boundary, area

Data processing

- simplified to 50 m resolution
- areas smaller than 0.1 km2 removed
- split to catchment areas

630 Plantation

Class-dependent attributes

Attribute	Type	Unit	Explanation
area	Real	km2	Area of structure

Source data

- source data JICA plantation areas (ts_plantation2.shp)
    - attributes: boundary, area

Data processing

- simplified to 50 m resolution
- areas smaller than 0.1 km2 removed
- split to catchment areas

640 Other agriculture

Class-dependent attributes

Attribute	Type	Unit	Explanation
area	Real	km2	Area of structure

Source data

- source data JICA agricultural areas (ts_otheragri2.shp)
  - attributes: boundary, area

Data processing

- simplified to 50 m resolution
- areas smaller than 0.1 km2 removed
- split to catchment areas

650 Irrigated area

Class-dependent attributes

Attribute	Type	Unit	Explanation
area	Real	km2	Area of structure

Selection criteria

- Irrigated areas with field area larger than 2.5 km^2

Source data

- source data MRC irrigated areas (ts_irriarea.shp)
  - attributes: boundary, project name, area
- source data Kampong Thom private reservoir areas (kt_irriarea.shp)
  - attributes: boundary, area, owner name

Data processing

- no additional processing

710 Dock/Harbour

Class-dependent attributes

Attribute	Type	Unit	Explanation
length	Real	m	Length of structure

Selection criteria

- all data included

Source data

- no data

Data processing

- no additional processing

720 Breakwater

Class-dependent attributes

Attribute	Type	Unit	Explanation
length	Real	m	Length of structure

Selection criteria

- breakwaters with length of at least 100 meters

Source data

- no data

Data processing

- no additional processing

730 Ferry

Class-dependent attributes

Attribute	Type	Unit	Explanation
length	Real	m	Length of structure

Selection criteria

- all data included

Source data

- source data JICA ferry lines (ts_ferry_line.shp)

Data processing

- no additional processing

810 Point source

Class-dependent attributes

Attribute	Type	Unit	Explanation
production	Real	m3/d	Volume of water coming from outlet

Selection criteria

- waste water flow of at least 100 m3/d, or P load of at least 0.1 kg/d, or N load of at least 1 kg/d, or otherwise non-negligible point source.

Source data

- no data

Data processing

- no additional processing

811 Sewage treatment plant

Class-dependent attributes

Attribute	Type	Unit	Explanation
production	Real	m3/d	Volume of water coming from outlet

Selection criteria

- with waste water flow of at least 100 m3/d

Source data

- no data

Data processing

- no additional processing

812 Sewage outlet

Class-dependent attributes

Attribute	Type	Unit	Explanation
production	Real	m3/d	Volume of water coming from outlet

Selection criteria

- with waste water flow of at least 50 m3/d

Source data

- no data

Data processing

- no additional processing

813 Industrial sewage outlet

Class-dependent attributes

Attribute	Type	Unit	Explanation
production	Real	m3/d	Volume of water coming from outlet

Selection criteria

- with waste water flow of at least 50 m3/d

Source data

- no data

Data processing

- no additional processing

814 Mine

Class-dependent attributes

Attribute	Type	Unit	Explanation
*info	String		Mineral/material, type open-pit/placer/quarry/sub-surface
production	Real	tn	Production of material processed/taken out yearly

Selection criteria

- all data included

Source data

- source data MIME mine data (mine_mime2.shp)

Data processing

- removed points outside Tonle Sap catchment areas

820 Diffuse source

Class-dependent attributes

Attribute	Type	Unit	Explanation
*info	String		Type of source
area	Real	km2	Area of source
width	Real	-	Number of units
height	Real	kg	Production per unit per year
production	Real	units	Total production per year

Source data

- no data

Data processing

- no additional processing

821 Scattered population

Class-dependent attributes

Attribute	Type	Unit	Explanation
*info	String		Type of source, waste produced
area	Real	km2	Area of source
width	Real	-	Number of people
height	Real	kg	Production per person per year
production	Real	units	Total production per year

Selection criteria

- Village ("phum") level division

Source data

- population data from year 1998 (ts_phum2.shp)

- attributes: village position, number of persons

Data processing

- no additional processing

AREA DATA

The area table contains the following data:

- Tonle Sap catchment and subcatchment boundaries
    - Data source: MRC (tls_catchments.shp)
    - Attributes: boundary, name, area
- Medium flood extent boundaries
    - Data source: MRC (tls_catchments.shp)
    - Attributes: boundary, name, area
- Cambodian province boundaries (the provinces intesecting Tonle Sap catchment area)
    - Data source: MRC (tls_provicnes.shp)
    - Attributes: boundary, name, area

SYSTEM COMPONENTS AND SETUP

The database system is based on the following MySQL standard software components

- MySQL database server (version 5.0. community edition)
- MySQL Query browser (version 1.1.20)
- MySQL Administrator (version 1.1.9)

Additional tools were created in the project to enable transfer of GIS file data to and from the database server, and to allow data to be shared in internet. These are:

- BSViv tool to access database locally, and to import and export data from ESRI shapefile format
- BSMap tool (a java applet) to view data in internet
- BSConn program (a www-server cgi-program) to retrieve data from database server to BSMap applet

The MySQL database server stores the database data and provides database services to client applications. The MySQL Query browser is an interactive tool that can be used to view and modify the data in the database in the computer that contains the database. Use of the tool requires knowledge of SQL. The Administrator tool is used to manage the database server, for example, create new users and create data backups. The programs are available at the MySQL www-site www.mysql.com free of charge.

The Local database access tool "BSViv" can be used to view, add, and modify structure data on map-based windows application. Also import and export of data to ESRI shape file is possible. This feature can be used, for example, when larger amounts of structure data need to be moved to GIS system. The BSViv program utilizes an open-source GIS tool package called FWTools (version 1.0.7), which can be downloaded from http://fwtools.maptools.org.

The Internet access interface "BSApp" can be used to view database data remotely using an internet browser. To use BSApp a www-server with system html pages and bsconn- cgi-program needs to be setup.

Installation of the system for local and internet access is described in the chapter 2 of the Built Structures Database User Manual.

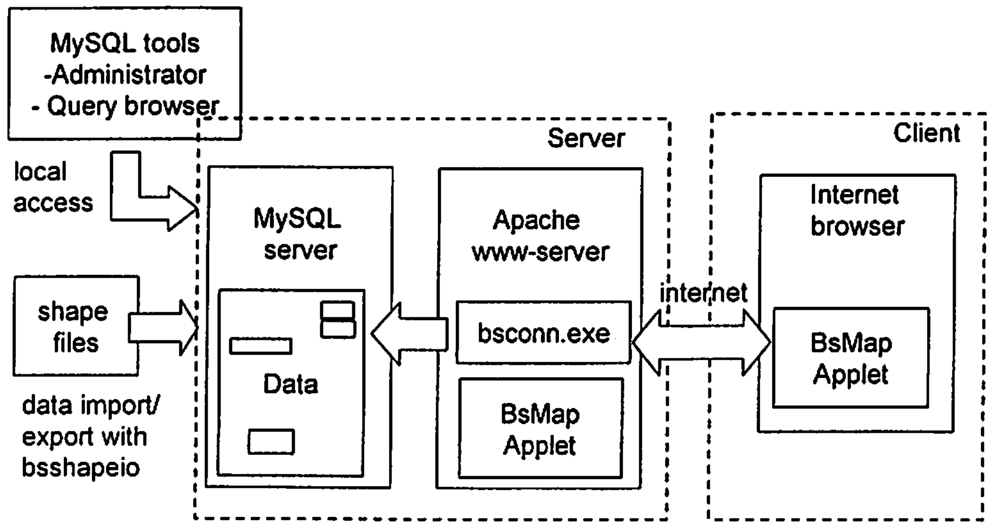

Figure 1: System components and connections

BSVIV APPLICATION FILES

The BSViv application is implemented using a viv-language interpreter, that is developed in EIA Ltd. for simple graphical user interface implementation. The installation will setup the BSViv application under the installation directory to several subdirectories listed below with contents. Starting the program is done by running the "viv.exe" program with the "bs.ip"-file as a parameter.

The viv (=program) subdirectory contains following files:

bs.ip	- program statup file
bsmain.ip	- main program file
common.ip, rl*.ip	- application program files
viv.exe	- ip-file interpreter
vivres.dll, vivbmp.dll	- viv.exe resources and bitmaps, required by viv.exe
rlgis.bmp	- about dialog bitmap file

The map-subdirectory contains following files:

tls_lake.*	- lake and river data for BSViv application
tls_subcatch_utm.*	- subcatchment boundaries for BSViv application

The doc-subdirectory contains following files:

BSApp-help.doc	- BSApp help file
BSDB_manual.doc	- Built structure database system user manual
bsdb_techdoc.doc	- this document

The bsdb-subdirectory contains following files:

bs0.sql	- sql macro to create bs-database tables

bs0create.sql	- sql macro to create bs-database
bs0dump.sql	- database dump file
bs0users.sql	- sql macro to setup default database users
classdata.sql	- sql macro to populate structure class data to database

WWW-SITE FILES

To access the bs-database using internet, the files listed below need to be setup in a www-server directory. The built structures – site contains BSApp java applet, composed of several jar-files, a bsconn – cgi-bin program, and some html pages.
By defatul user authentication is setup using as in the Apache www-server basic authenication using .htaccess file. The bs-www site countains the following files

Main directory: www/bs

.htaccess	- Apache access control file
index.html	- startup page
tlsstart.jpg	- picture in the startup page
bsapp.shtml	- applet window
bsapp.jar	- applet code
openmap.jar	- applet code library
swingset.jar	- applet code library
bsapp_help.html	- help window
exitwindow.html	- file used to exit applet

Help pictures : www/bs/bsapp_help_files

.	- bsapp_help.html pictures

cgi-bin programs: www/bs/cgi-bin

bsconn.exe	- cgi-bin program to connect bsapp to MySQL database
libmysql.dll	- mysql dll-library, used by bsconn

Documentation: www/bs/doc

bsdb_manual.doc	- bsdb user manual
bsdb_techdoc.doc	- this documentation

Apache configuration: wwwconf

.htpasswd	- password file
htpasswd.exe	- password generator program
httpd.conf	- example Apache configuration file

DATABASE AND WWW-SITE USER AUTHENTICATION

The user authentication is setup by default for the Apache www-server using basic authentication. Entering the www/bs directory requires giving a user identification and password, after this no more passwords are asked.

The "bsconn" cgi-bin program uses defult username and password (see user manual/Installation) hard coded in the program for accessing MySQL database server. Therefore, it is necessary to setup the default user to the database server if it is to be used via BSApp – applet. If required, the username and password can be easily changed in the bsconn source code.

SOURCE CODE FILES

The bsconn c++ source files and BSApp java source files are included in the "BSSourceSetup.exe" installation package. The bsconn is compiled with Borland C++ builder 6, and the BsApp with Java 1.5.0_08.

APPENDIX A: GLOSSARY

(Reference: http://www.nalms.org/glossary/glossary.htm)

Channel
A course, such as a trench or aqueduct, through which water is moved or directed; the bed of a river or stream.

Conduit
Any channel or pipe used for conducting the flow of water.

Culvert
A hydraulically short conduit which conveys water e.g. through a roadway embankment or through some other type of flow obstruction below ground level.

Dam
A barrier built across a valley or river for storing water.

Detention basin
A basin or reservoir where water is stored for regulating a flood. It has outlets for releasing the flows during the floods.

Embankment
A man-made earth structure constructed for the purpose of impounding water and/or carrying a roadway.

Fish ladder
An inclined trough which carries water from above to below a dam so that fish can easily swim upstream.

Fishway
A structure allowing fish to pass over vertical impediments. It may include special attraction devices, entrances, collection and transportation channels, a fish ladder, and an exit.

Gauge (gauging station)
Specific locations on a stream where systematic observations of hydrologic data are obtained through mechanical or electrical means.

Intake
A hydraulic structure built at the upstream end of the diversion canal; a tunnel or power plant for controlling the flow and preventing silt and debris from entering the diversion.

Levee
A natural or man-made earthen barrier along the edge of a stream, river, or lake to prevent the flow of water out of its channel.

Reservoir
An artificial lake, pond, tank, or basin (natural or man-made) into which water flows and is stored for future use.

Riprap
A layer of large stones, broken rock, boulders, or precast blocks placed in random fashion on the upstream and downstream faces of embankment dams, on stream banks, on reservoir shores, on the sides of a channel, or on other land surfaces to protect them from erosion caused by current, wind, wave, and/or ice action.

Sluice
An artificial channel for conducting water, with a valve or gate to regulate the flow.

Sluice gate
A valve or gate used in a channel to regulate flow.

Spillway

Section of a dam designed to permit water to pass over its crest; a weir or channel taking overflow from the dam; serves as a safety channel to prevent erosion of the dam.

Weir

A dam, usually small, in a stream to raise the water level or divert its flow.

Weir (measurement)

A notch or depression in a levee, dam, embankment, or other barrier across or bordering a stream, through which the flow of water is measured or regulated.

Weir (fish)

A barrier constructed across a stream to divert fish into a trap.

APPENDIX B: TONLE SAP CATCHMENT STATISTICS

(references. MRC hydrology report, 2005, WUP-FIN Tonle Sap modelling project, www.eia.fi/wup-fin)

Catchment area ~ 95000 km^2
Dry season lake ~ volume 1-2 km^3, depth minimum 0.5 m, area 2500 km^2
Rainy season lake ~ volume 50-80 km^3, depth 6-9 m, area 13000-14500 km^2
Lake retention capacity ~ 80 km^3
80 % of sediments brought to lake by flood retained

Average leaching from lake catchment area ~ 30 km^3/a = 10 $l/s/km^2$
Average volume flowing to lake outside catchment 40 km^3/a

Outflow from lake 7.5-8.5 months, 70.4 km^3, or 3375 m^3/s average for 8 months

Inflow to lake from outside catchment area 40.7 km^3, starting mid-May to mid-June, duration 3.5-4.5 months, 3860 m^3/s average for 4 months

Precipitation ~ 1300 mm/a, typically no rain from December to February
For rainy season, peak precipitation per month is typically over 300 mm/a, or about ¼ of the total yearly precipitation, three times the average precipitation.

Pan evaporation ~ 2100 mm/a = 5.8 mm/d
1 cm water level change in dry season lake level is 2.5 km^3

APPENDIX C: DATA DIRECTORY

JICA data point data

- ts_rr_bridge.shp
- ts_rd_bridge.shp
- ts_culvert.shp
- mine_mime.shp
- ts_hystation.shp

JICA line data

- ts_ferry_line.shp
- ts_railway2.shp
- ts_canal.shp
- ts_levee.shp
- ts_rdprimary2.shp
- ts_dam_earth.shp
- ts_rdsecondary_aw.shp
- ts_rdsecondary_dw.shp

JICA polygon data

- ts_reservoir.shp

MRC data

- Tonle Sap catchment boundary
- Tonle Sap subcatcment boundaries

Asian Development Bank
TA 4669-CAM

Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap (financed by the Government of Finland)

Database Component

BUILT STRUCTURES DATABASE USERS MANUAL

Prepared by

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EIA Ltd., Finland

April 2006

Contents

1. INTRODUCTION

The Built Structures database "BSData" contains data on man-made hydraulic structures on the Tonle Sap catchment. The structures are classified according to the intended use. For each structure position, extent and structure attributes such as structure height and construction material are stored.

Classification of structures

The structures are classified for eight higher level classes that may have one or more subclasses. The detailed classification can be found in the technical documentation. The main classes are:

1. Storages (e.g. reservoirs)
2. Flow routes (e.g. canals)
3. Flow controls (e.g. dams, gates)
4. Fish and aquaculture (e.g. dai fisheries)
5. Erosion prevention (e.g. ripraps)
6. Agriculture (e.g. irrigated areas)
7. Transportation (e.g. docs and harbours)
8. Discharge (e.g. sewage outlets, mines)

Database access

The database can be accessed using three methods (see Figure 1.1):

1. Standard SQL tools (MySQL)
2. Local database access
3. Internet access interface

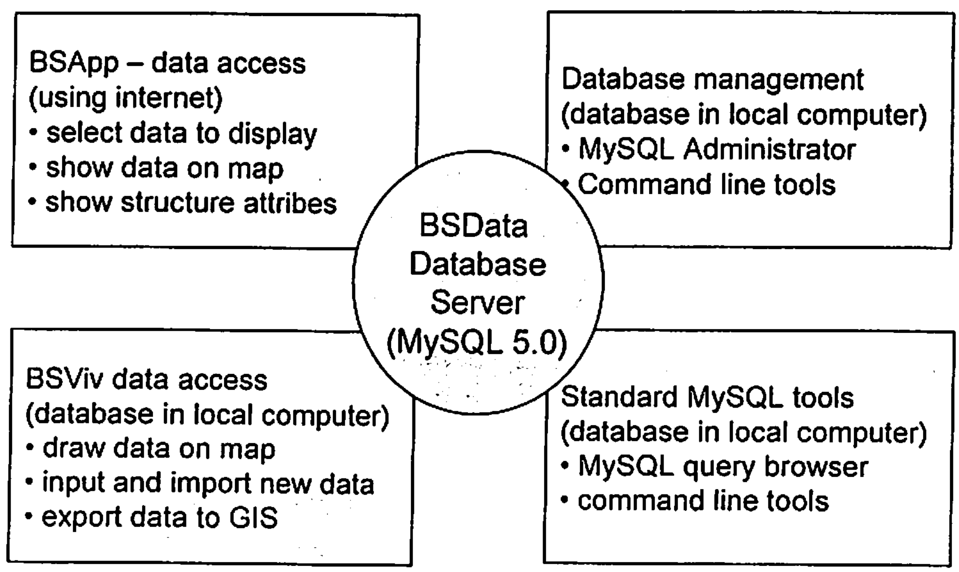

Figure 1.1: Database access and management tools

The standard MySQL tools are:

a. MySQL database server (version 5.0. community edition)
b. MySQL Query browser (version 1.1.20)
c. MySQL Administrator (version 1.1.9)

The MySQL database server stores the database data and provides database services to client applications. The Query browser is an interactive tool that can be used to view and modify the data in the database in the computer that contains the database. Remote access is also possible. Use of the tool requires knowledge of SQL. The Administrator tool is used to manage the database server, for example, create new users and create data backups. The programs are available at the MySQL www-site www.mysql.com free of charge.

Please see the technical documentation on database structure. Chapter 1, "Setting up the database"", explains how to set up the database and access it using Query Browser.

The Local database access tool "BSViv" can be used to view, add, and modify structure data on map-based windows applications. Also, importing and exporting to and from ESRI shape files is possible if larger amounts of structure data need to be moved to or from a GIS system. See Chapter 3 below on how to set up and use this application.

The Internet access interface "BSApp" can be used to view database data remotely using an Internet browser. In order to use this access method, a www-browser installation of the database system needs to be set up. See Chapter 4 below on how to setup and use this system.

Database management, such as adding users and backing up data, can be done using Database standard tools. Some tasks can be done using the "BSViv" applications. See Chapter 5 on database administration and updating.

2. SETTING UP THE BSDATA DATABASE

Running environment

The database system works on PC computers using Windows 2000/XP operating systems. About 150 Mb of disk space is needed to set up the system. Software installation packages can be found on the distribution CD.

Setting up database for local use

To set up the BSData database the following software needs to be installed:

1. MySQL database server (version 5.0.21)
2. MySQL Query Browser (version 1.1.20)
3. BSViv application (version 1.0)
4. FWTools toolset (version 1.1.0)

Detailed installation instructions for the MySQL database server can be found on the MySQL www-site (www.mysql.com). The following instance configuration options seem to work quite well:

- Developer machine
- Multifunctional database
- Tablespace in C: disk and "Installation Path"
- Number of concurrent connections 15 (Manual setting)
- Enable TCP/IP networking (also configure your Firewall, so that access to port 3306 is allowed from localhost ip-address 127.0.0.1 only)
- Standard character set

- Set password to 'tietoa'. If you change this the password in the BSViv application must be changed as well. See below.

To install the Query Browser, BSViv application and FWTools just run the corresponding installation files "mysql-query-browser-1.1.20-win.msi", "BSVivSetup.exe" and "FWTools100.exe". Please use the default installation directories. The database data is in the BSViv setup.

After the database server is installed and working, the database data needs to be imported. This can be done using the BSViv application, or by using MySQL command line client.

If you are using the BSViv, do the following:
- Start the BSViv application (Windows "Start" menu)
- If you changed the database root password, select the Database/Connection setup from the main menu and type in the new password to dbpasswd-field.
- To create to database select the "Database/Create bs0 database" menu item. If the database already exists, this will return an error.
- To import data to the database select the "Database/Import dump file" menu item, then select "bs0dump.sql" from the file list, and click "Open". The dump file is located in "C:\Program Files\BS\bsdb directory".

If you like to use MySQL command line, do as follows:
- Start MySQL command line (from Windows "Start" menu)
- create the database by typing "create database bs0;", then press <Enter>
- import data by typing "source C:/Program Files/BS/bsdb/bs0dump.sql;".

Setting up database remote access

There are two possibilities for accessing the database remotely:
- Access through IP-port 3306, using BSViv and Query Browser.
- Access using www-browser and BSApp

First, access to the database server can be opened to selected remote computers, by configuring the firewall of the server computer to allow access to IP-port 3306 from the remote computers. Note that access to port 3306 should be allowed for friendly ip-addresses only. In this case the BSViv and Query Browser can be used to access the database. Just configure the database server to the remote server computer.

The second way is to set up remote access using a www-server and the BSApp data browsing program. This configuration allows access to anyone with an Internet browser, and knowledge of the correct userid and password.

To setup remote intenet access the following software needs to be installed (in addition to the local database installation):
- Apache 2.2.2 www-server
- BSApp www-pages and cgi-program.

The Apache www-server setup is on the distribution CD. The latest version can be downloaded from http://www.apache.org.

The BSApp system setup can be done by running the BSAppSetup program from the distribution disk. The setup program will put the BSApp www-pages to directory c:\bs\www by default. In addition to running the setup program following task need to be done:

- Set up network access userid's for the MySQL database by running the "bsdb/bs0users.sql" macro using the BSViv "Run SQL macro" command.
- Modify Apache configuration file so that it works with BSApp. After installing the BSApp, an example configuration file "httpd.conf" can be found from the wwwconf-directory. To setup the default configuration for Apache, with local www-server access only, copy the provided example configuration file to Apache configuration directory (typically "C:\Program files\Apache Group\Apache2\conf"). Note that Apache must be restarted after the configuration has been changed. To modify the file by hand, "Includes" must be allowed for bs directory, and "bs/cgi-bin" directory must be defined to contain script files. See the provided "httpd.conf" file for details.

3. USING BSVIV TO ACCESS BSDATA LOCALLY

The BSViv program is used to access BSData locally; that is, the database server containing the data is in the same computer. The program can be configured to access data in remote servers as well.

The BSViv can be used for the following tasks:

- querying database data by class, and showing the results on the map
- moving data from an ESRI shapefile to the BSData database
- exporting data from the BSData database to a shapefile
- modifying single structure attributes
- adding and removing single structures from the database
- importing photos to the database
- modifying class related database data
- creating a database dump file and importing all data from an existing dump file
- creating a database report of the number of structures in each class.

Installation and starting the program

To install the BSViv application, see chapter 2, Setting up the database for local use. The installation program creates a start-menu item "BSViv", that is used to start the program. To start the system from command line, move to the installation directory ("C:\Program Files\BS\viv") and give command "C:\Program Files\BS\viv\viv bs.ip".

Main window, tools and main menu

The BSViv main window displays a menu, toolbar, data layer list, and map window workspace typically containing a single map window.

The top part of the window holds the main menu and toolbar. Main menu commands are used to initiate actions such as querying of the database. Toolbar tools are used to zoom and pan the map window, and select, add and remove structures from the data layers.

The map window displays some base map data (catchment boundaries and main rivers) from which database structure data is drawn. The data in the map window is divided into layers that are listed in the layer list. The map window can be zoomed and panned using the toolbar tools. The UTM coordinates of the current mouse location are shown on the toolbar as well.

On the left side of the window is the layer list containing a list of data layers shown in the map window. A data layer can hold data for one class of structures only. Many data layers can be shown at the same time. Some actions require selecting a data layer from the layer list. This can be done simply by clicking the layer name in the layer list. Clicking a layer name with the right mouse button causes a popup menu to appear. By using this menu the layers can be rearranged or completely removed.

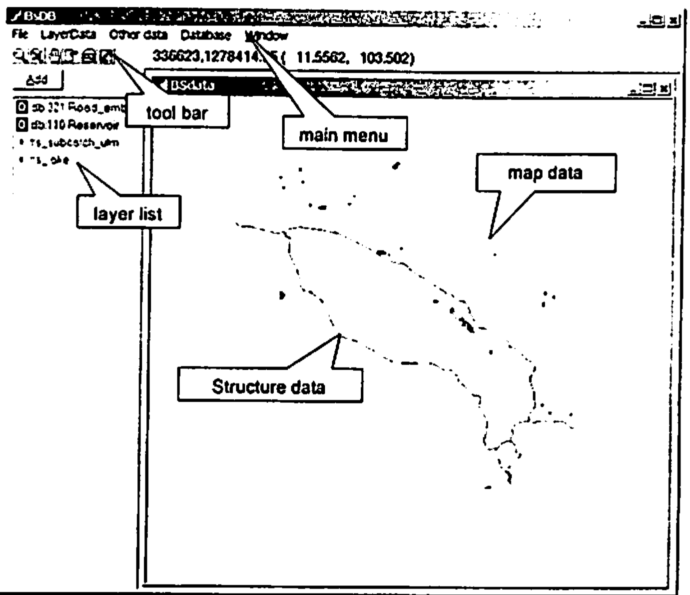

Figure 3.1: BSViv main window

The toolbar has the following tools:

	Zoom in by dragging a rectangle to a model window
	Zoom back to previous zoom setting
	Pan by dragging the mouse
	Copy window contents to the clipboard as a Metafile
	Zoom to selected layer boundaries
	Add a new structure to the selected data layer
X,Y (Lat,Lon)	Current mouse position coordinates: UTM-East,UTM-North, (latitude, longitude) Units: meters and decimal degrees

The main menu has the following commands:

File menu	
New	Create a new map window
Run SQL command	Run a SQL command
Run SQL macro	Select a SQL macro file and run it
Show cmd window	Display viv command window
Exit	Exit program

LayerData menu	
New layer	Create a new empty structure data layer
Query by class	Query data from the database and create a new data layer
Read shapefile	Import graphics and attributes from a shapefile to a structure data layer
Write to shapefile	Write structure graphics and attributes to a shapefile
Import to database	Write structure data from a structure data layer to the database

Other data menu	
Import photo	Read a .jpeg photo to database, convert to standard size and also create an icon file
Edit class data	Select class and edit related data, such as line and fill color

Database menu	
Connection setup	Set database location and userid information
Program path setup	Set MySQL command line and FWTools paths
Report by class	Count and report the number of items in each class
Dump to file	Dump all database data to a SQL-script file
Create bs0 database	Create a database, used when setting up the database
Reset tables	Create database tables, used when setting up the database
Import dump file	Used to import all database data and tables from a SQL dump file

Viewing and updating database data

To view and edit database data, a database query must first be made. The query will then fetch data from the database and create a new data layer in the map window. To perform a query use the "LayerData/Query by class" command from the main menu, select structure class and click OK. After the query is completed a new data layer is added to the layer list, and the structure data is drawn to the window.

To view or modify single structure attributes zoom in on the area of the map where the structure is located, and click the structure graphic with the mouse. This action will create a popup menu showing a list of nearby structures, where the preferred structure can be selected. A dialog box containing the structure data then opens in the window, shown in Figure 3.2 below.

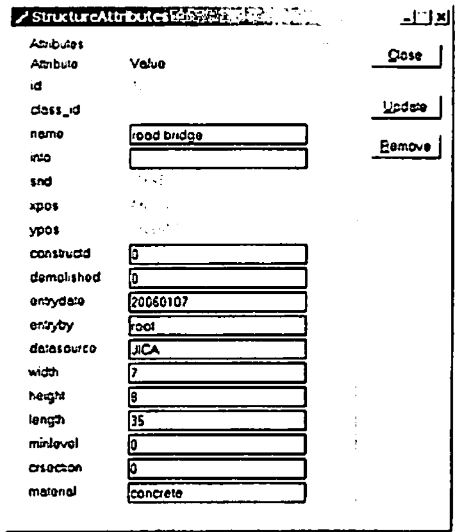

Figure 3.2: Structure data dialog box

The dialog box allows editing of structure attribute data. Attribute fields visible in the window depend on the structure class. To modify and update the data to the database first modify the desired fields, and then click the "Update" button. To close the window with no update click "Close". To remove the structure from the database click "Remove".

Graphical structure data cannot for now be modified in the BSViv application. If graphical data needs to be modified, the old structure must be removed, and a new structure with the modified data must then be created.

Importing data from ESRI shapefile to the BSData database

To move data from the ESRI shapefile to the database, first the shapefile must be imported to BSViv, and then from BSViv to the database.

To import shapefile contents to BSViv, use the "LayerData/Read shapefile" menu command. After giving the command two things need to be selected. First the shapefile to import, and then the structure class for the objects in the shapefile. Each shapefile may contain only structures belonging to same structure class. After selecting these an attribute selection window opens, in which the shapefile attribute data can be mapped to BS database structure attributes. (See Figure 3.3 below).

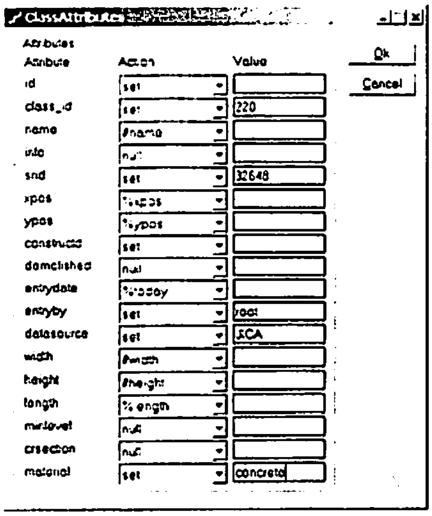

Figure 3.3: Setting class attributes during shapefile import

For each structure attribute there are the following options: "set to given value", "use attribute from shapefile", or "compute from geographic data". The dialog box "Action" column pull-down menus define how to set the field value. Items staring with "%" are values that are computed from geographical data ("%length", "%xpos", "%ypos"). The items starting with "#" are attributes from the shapefile. If the action column value is "set" then the value in the "Value" column is set for all imported structures.

After pressing OK the shapefile data is imported to BSViv and displayed on the map. The structures are, however, not yet in the database, (structure "id" values are set to zero to show that the structures are not yet in the database). To copy the data from the new shapefile layer to the database, first select the new layer from the layer list, and then use the "LayerData/Import to database" command.

Exporting data from BSData database to shapefile

To export data from the database to a shapefile, first query the preferred structure from the database using the "LayerData/Query by class" command. After the query is done and a new data layer is created in the map window, select the data layer from the layer list and select the "LayerData/Write to shapefile" command from the main menu. Select a new name for the new shapefile and press OK:

Adding and removing single structures from the database

Adding new structures to the database can be done by importing shapefile data as described above, or by creating new structures manually.

To create a new structure, a data layer for the structure data must first be created using the "LayerData/New Layer" command. The command asks for the structure class of the new layer, after which it creates a new empty layer in the layer list.

To add a new structure to the created data layer, click the "Add new structure" tool from the toolbar, and the use the mouse to click a location on the map for the new structure. If the structure is a point, one mouse click is sufficient. If the structure is a line-type of polygon, draw the structure on the map with a sufficient number of mouse clicks, and finish the drawing by double clicking. After the geographic data is clicked to the map, a dialog box asking for structure attributes opens. Fill the structure data and press "Create" to create the structure in the database.

Importing photos to the database

Photos can be put into the database and associated with structures that are already in the database. The imported photos must be in .jpeg format. Photos can be imported using the "Other data/Import photo" command, which will open a dialog box asking for the photo file name, photo location and associated structure id. After the information is given, the command creates a 800x600 pixel size version of the photo and copies it to the database. Also, a 80x60 pixel size icon is made and put into the database as well. The www-interface is able to show the photos along with structure data. The BSViv cannot display photos.

Modifying class related database data

Class related data, such as drawing line color and fill color, can be modified using "Other data/Edit class data". After selecting the class to edit, a class data edit dialog box opens. The drawing attributes and class description can be changed. Class identifiers and shapetype cannot be changed, since other applications use the defined values.

Creating database dump file and importing all data from an existing dump file

Database dump files can be used to move the whole database to another computer, or to backup the database before making changes to the data content. To create a database dump use the menu command "Database/Dump to file", select a new name for the database dump, and click OK.

To restore the database from a dump file, use the menu command "Database/Import dump file", select the database dump file from the file window, and click OK.

Creating a database report

A simple report listing number of items in each structure class can be created using the menu command "Database/Report by Class". The command will create a new text window containing the generated report.

class	items	class name
110	55	Reservoir
211	3732	Irrigation canal
220	1278	Bridge
230	323	Culvert
310	38	Dam
320	892	Embankment
321	28	Road embankment primary
322	1848	Road embankment other
323	14	Railroad embankment
324	3	Reservoir dike
340	2	Weir
371	44	Hydrological station
372	85	Meteorological station
411	11	Dai fishery
413	472	Fence system
440	41	Fishing lot
450	7	Fish sanctuary
610	1323	Rice field
620	372	Field crops
630	77	Plantation
640	2708	Other agriculture
650	157	Irrigated area
710	4	Docks/Harbour
730	4	Ferry
814	62	Mine

Figure 3.4: Database Report by class

4. USING BSAPP TO ACCESS BSDATA REMOTELY

The BSApp interface can be used to connect to the BSData database using an Internet browser, such as IE 6.0 or Firefox 1.5. The Internet server should have BSData database installed for remote access.

The BSApp can be used for the following tasks:

- querying database data by class and geographical area, and showing the results on the map
- Viewing structure attribute data for selected structures
- Viewing structure attribute data in table format

Installation and starting the program

The BSApp runs in any modern Internet browser that can run Java applets. To run the program an Internet browser should be installed. The BSApp also uses Java Runtime Environment 5 or later, which should be installed on the client computer (JRE download: http://java.sun.com/javase/downloads/index.jsp).

To start the BSApp, start your browser program and type the address of the BSData server into the address bar of the browser. A test version of the database is available during 2007 at http://www.eia.fi/bs, userid "bsclient" and password "gh4ntx89". On the welcome page there is a button where the BSApp can be started.

After clicking the start button the application downloads from the www-server, which can take some time, since a few megabytes of data program code need to be downloaded. The application code is cached to the accessing computer, so next time the program is started the start time will be shorter.

Main window, tools and main menu

The main window of the BSApp applet is shown in Figure 4.1. The window displays a base map with main rivers and catchment boundaries, a coordinate grid and a scale bar. On the right side of the window is a data layer list displaying all data layers shown in the window. The top part of the window contains the menu and toolbar.

The map window can be zoomed and panned using the toolbar tools. Also, the Zoom, Query, Classes and Areas commands are located on the toolbar for fast access. The geographic coordinates of the current mouse location are shown on the toolbar as well.

On the right side of the window the layer list containing a list of maps and data layers in shown in the window. A data layer holds data that results from one database query. Many data layers can be shown at the same time. Some actions require selecting data layers from the layer list. This is done simply by clicking the layer name in the layer list. By clicking a layer name with the right mouse button, a popup menu appears. Using this menu the layers can be rearranged or completely removed.

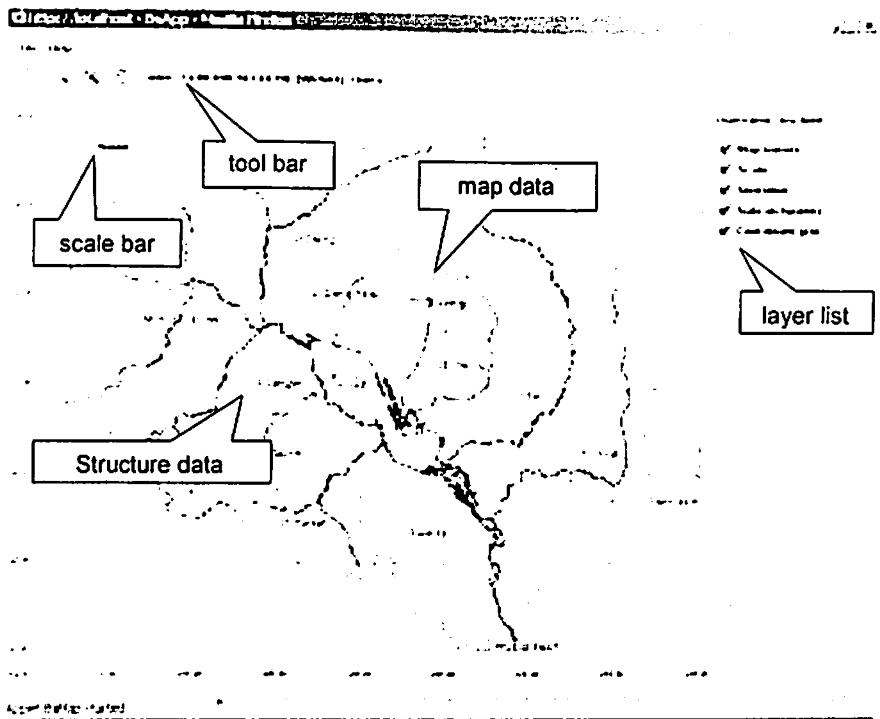

Figure 4.1: BSApp main window

The toolbar has the following tools and buttons:

	Arrow tool: Show structure data (point and click), Zoom (drag) and Pan (Shift+drag)
	Zoom in by dragging a rectangle to model window
	Zoom back to previous zoom setting
	Pan by dragging with the mouse
Zoom	Zoom to preset area
Lat N, Lon E	Mouse position geographical coordinates in degrees and decimal minutes
Query	Query data from the database

The window menu contains the following commands:

File menu	
Print	Print window contents
Exit	Exit program

Help menu	
Help	Open up a help window
About	Application version etc. information

Querying database data

To view database data a database query must be made. The query will then fetch data from the database and create a new data layer in the map window. To perform a query click the "Query" button on the toolbar, which opens a query dialog box (Figure 4.2). In the query dialog box select a structure class and area and click OK. After the query is completed a new data layer is added to the layer list, and the structure data is drawn in the window.

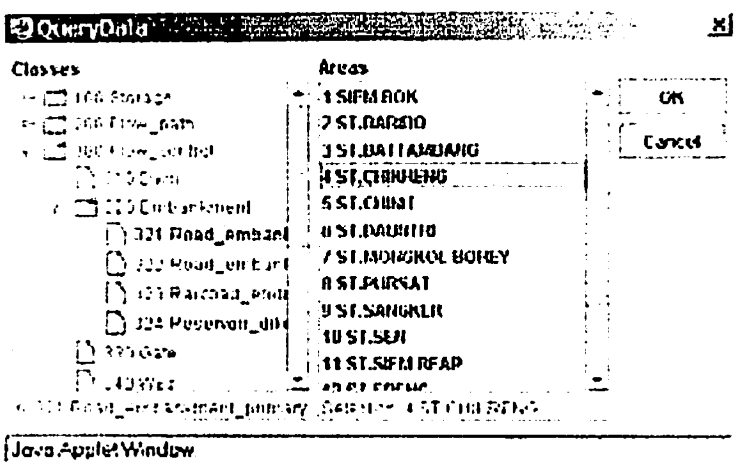

Figure 4.2 Query data window

Viewing structure data

To view structure attribute data zoom the map to the area where the preferred structure is located and click the structure graphic with the mouse (when the Arrow tool is active). This will open a dialog window showing the structure data (Figure 4.3). The displayed attributes depend on structure class.

To view all the attribute data of a data layer in table format, click the layer title in the layer list with the right button, and select "Show table" from the popup menu. This will open a table view of all structure attribute data (Figure 4.4). The table rows can be selected using the mouse and copied to Clipboard by pressing Ctrl-C on the keyboard.

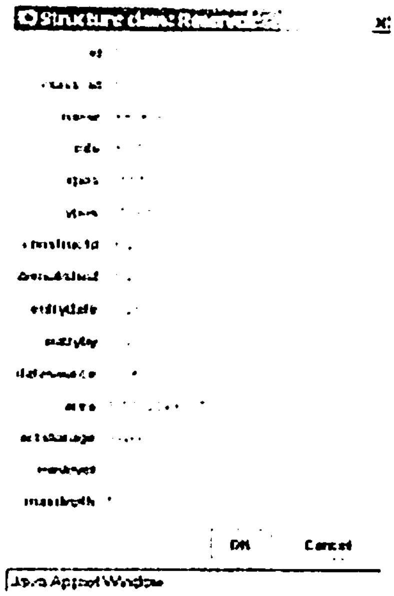

Figure 4.3 Structure data dialog box

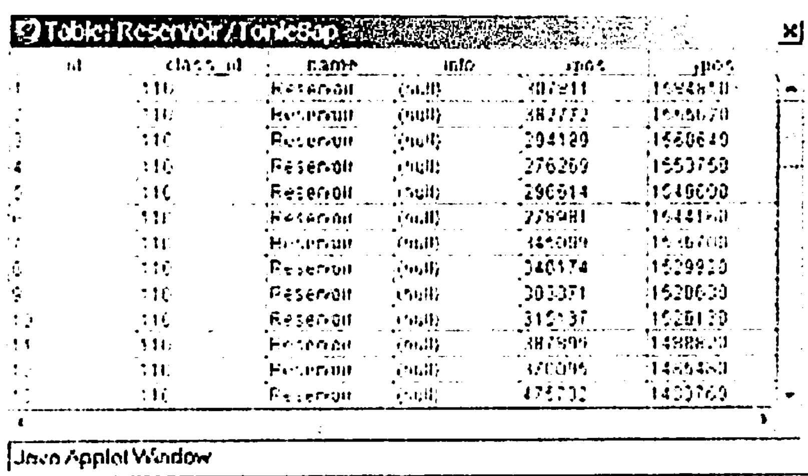

Figure 4.4 Table view of layer attribute data

Other functionality

"Zoom" – toolbar button has some zoom shortcuts, including, "TonleSap river", "TonleSap lake" and "Full extent".
"Areas" – toobar button can be used to draw selection areas to map window. This includes subcatchments, provinces and mediumflood boundary

Appendix 2 Hydrology Component Technical Report

- Influence of Built Structures Tonle Sap Hydrology And Related Parameters

Asian Development Bank
TA 4669-CAM

Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap (financed by the Government of Finland)

Hydrology Component

INFLUENCE OF BUILT STRUCTURES ON TONLE SAP HYDROLOGY AND RELATED PARAMETERS

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Environmental Impact Assessment Center of Finland Ltd

February 2007

CONTENTS

EXECUTIVE SUMMARY

A set of tools and analyses has been applied to assess the impacts of built structures on Tonle Sap hydrology, hydrodynamics, sediments, water quality and conditions for fish. Three scales of impacts have been studied: (i) upstream basin-wide development impacts, (ii) Tonle Sap catchment development impacts, and (iii) local scale individual structures.

Four scenarios have been studied. The (i) baseline scenario represents the current development level of the Mekong Basin. Two additional basin-wide scenarios have been studied: (ii) upstream tributaries' intensive irrigation and hydropower dam development, and (iii) mainstream dams + upstream tributaries' intensive development as in (ii). For the Tonle Sap scale (iv) the impact of catchment irrigation and hydropower dam development has been modeled.

The different tools and methodologies used in the study include:

- Hydrological, hydrodynamic, sediment and water quality field measurements
- Laboratory experiments for fishing gears
- Hydrological water balance studies
- Tonle Sap Lake, River and floodplain three-dimensional hydrodynamic, sediment and water quality model
- Stung Chinit irrigation system three-dimensional hydraulic, hydrodynamic, sediment and water quality model
- Model applications for floodplain structures including roads and irrigation reservoirs
- Water resources allocation model for irrigation and hydropower.

NATURAL VARIABILITY AND BUILT STRUCTURE IMPACTS

The human impact is relatively small compared with the high natural variability of the floods. Fish have adapted to the varying conditions and consequently, at least to a degree, are resistant to the human impacts. However, dry years can be critical because built structure impacts are most pronounced then and fish are most vulnerable to additional stress.

BASIN-WIDE DEVELOPMENT IMPACTS

The upstream development impacts can be summarized as:

- Increased dry season water levels that will probably permanently inundate and destroy the lake edge flooded forest that functions as an important habitat and buffer between the Tonle Sap Lake and its floodplain
- Decreased sediment input and consequently impacts on primary productivity
- Delay of flooding and accompanied adverse impact on larvae drift and floodplain habitat oxygen conditions
- Decreased flood season flooded area and volume resulting in less primary production and habitat for fish.

The cumulative impact of the individual impacts may result is serious consequences for Cambodia's fisheries.

TONLE SAP CATCHMENT DEVELOPMENT IMPACTS

Implementation of the planned Tonle Sap catchment large-scale dam development plans would result in impacts similar to those in the basin-wide intensive development scenario. The impact on maximum water levels would be similar, but the floods would be delayed longer. Also, the sediment input into the lake would be diminished.

Local developments will considerably strengthen the impacts of upstream developments because both act in a similar way.

STUNG CHINIT RESERVOIR

- The conditions in the reservoir are favorable for fish – good oxygen conditions and sedimentation for primary productivity. However, the structure hinders natural fish migration.
- Positive influence on oxygen concentrations of the river, values increasing by approximately 20% downstream of the structure.
- Slight flushing effect of the reservoir during the flood season, total nutrient and suspended sediment concentrations have to some extent increased and visibility value decreased downstream of the structure.
- Drainage water from irrigation canals is slightly loading the river downstream.
- Data on the full hydrological cycle is required to see total changes in nutrient and sediment dynamics.
- Generalizations about the impacts of other reservoirs should be cautious because local hydrological, water quality, soil and land use conditions influence the impacts.

FISHING GEARS

- Slight opposing influence of bamboo fences on flow velocity can be observed when velocity is higher than 10 cm s^{-1}
- Opposing influence of nylon nets is slight and appears only when velocity is higher than 20 cm s^{-1}
- Flow velocities in the Tonle Sap Lake on the Prek Toal area were principally under 10 cm.s^{-1} in August 2006 and January 2007; consequently, the hydrological and hydrodynamic impacts are small.

PRIVATE IRRIGATION RESERVOIRS ON THE FLOODPLAIN

- The reservoirs trap only a small portion of the flood waters and have a small impact on the large-scale hydrology.
- No major changes in water quality inside and outside of the reservoir.
- Significant changes in water quality can bee seen only in the values of chemical oxygen demand. Oxygen demand is increased because of trapped organic matter, sediment and the detritus of biomass production in the reservoir.

FLOODPLAIN ROADS

- In general, roads do not have a major impact on hydrology as long as enough bridges and other openings are built.
- In certain places roads may block main flood flow routes that supply fresh water, sediments and larvae/fish to the floodplain. It is important to understand the hydrodynamic behavior of the floodplain before road construction.

SUMMARY OF THE IMPACTS AND RECOMMENDATIONS

The large-scale basin and catchment irrigation and hydropower dams have the most significant impact on the Tonle Sap's hydrological and related conditions. However, the cumulative impact of a large number of small structures can be significant and should be clarified.

If intensive basin-wide and local development is realized, the impacts could be critical for the Tonle Sap fisheries. It is recommended that precautionary principles are applied in basin and catchment development until solid knowledge is accumulated on these impacts.

I INTRODUCTION

I.1 STUDY AREA AND BACKGROUND

Importance of the Tonle Sap

1. The Tonle Sap Lake and floodplains in Cambodia contain the largest continuous areas of natural wetland habitats remaining in the Mekong system, while being the largest permanent freshwater body in Southeast Asia. Tonle Sap is a crucially important source for food and livelihoods in Cambodia. More than one million people live in the immediate surroundings of the Tonle Sap Lake and wetlands. These are the poorest people in Cambodia, and they are highly dependent on agriculture and fisheries. Tonle Sap fisheries provide 60% of the animal protein in Cambodia. The lake also operates as a natural reservoir for the Lower Mekong Basin, offering flood protection and contributing significantly to the dry season flow to the Mekong Delta.

Tonle Sap ecosystem

2. The Tonle Sap is among the most productive freshwater ecosystems in the world (e.g. Bonheur, 2001; Lamberts, 2001; van Zalinge *et al.*, 2003). Its high productivity depends on the flood pulse from the Mekong which transfers terrestrial primary products into the aquatic phase during flooding (e.g. Lamberts, 2001). For many of the Mekong fish species, the floodplain of the lake, and particularly the riparian flooded forest and shrublands, offers good conditions for feeding, breeding and rearing their young (Poulsen *et al.*, 2002).

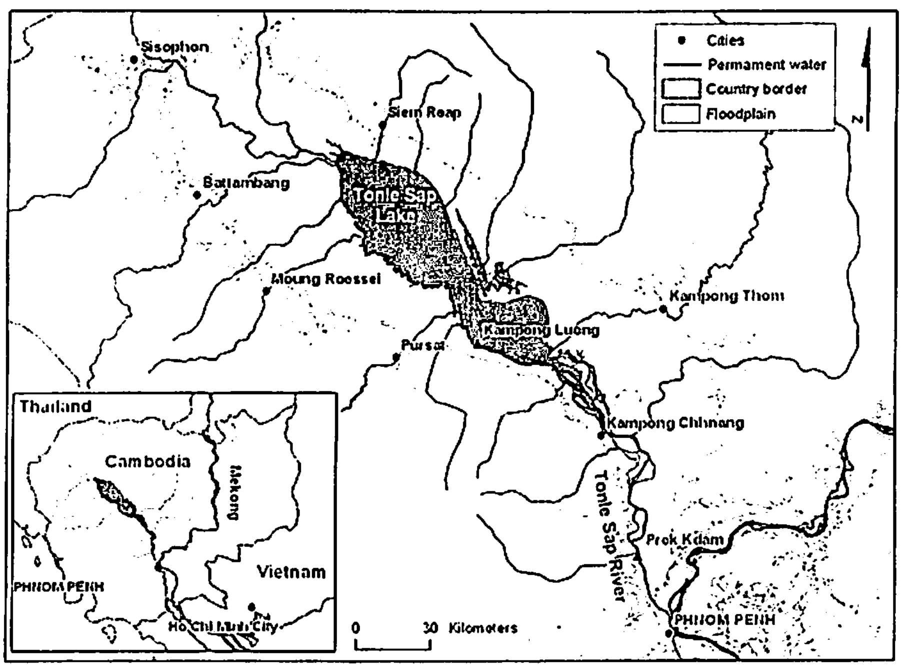


Figure 1. Tonle Sap Lake and its floodplains.

3. The basic hydrological and limnological processes, such as sediment transport and dissolved oxygen levels, are now relatively well documented (e.g. Bonheur, 2001; Carbonnel and Guiscafre, 1963; Koponen *et al.*, 2004; Kummu *et al.*, 2005; Lamberts, 2001; Penny *et al.*, 2005; Sarkkula *et al.*, 2004; Sarkkula *et al.*, 2003; Tsukawaki, 1997;

van Zalinge *et al.*, 2003; WUP-FIN, 2003), but the status and dynamics of biological productivity within the lake are not well studied. This is a major shortcoming in the understanding of the lake's ecological system (Kummu *et al*, 2006). Nonetheless, what is well identified about the Tonle Sap ecosystem is the concept of flood pulse (Lamberts, 2001). The concept was developed in Amazon Basin by Junk (1997), and should be utilized in Tonle Sap studies.

Flood pulse

4. On floodplains, the fluctuation of water level over time is the principal factor that causes the biota to adapt and produce characteristic community structures (Junk, 1997). Ecosystems that experience fluctuations between terrestrial and aquatic conditions are called pulsing ecosystems, and fall within the domain of the flood pulse concept. Junk's (1997) flood pulse concept has been widely accepted as describing highly productive floodplain environments and the ecology of pulsing systems. This information can be applied in basins with similar characteristics, such as the Lower Mekong Basin that, like the Lower Amazon, experiences large water level variation and one flood pulse per year. The importance of the flood pulse concept has been recognised by many authors working on the Mekong River/Tonle Sap system (see, for example, Bonheur and Lane, 2002; Fox, 2004; Lamberts, 2001; Poulsen *et al.*, 2002; Sverdrup-Jensen, 2002).

II METHODS, TOOLS AND STUDY LOCATIONS

II.1 FIELD STUDIES

II.1.1 Introduction

5. Hydrological field measurements support the validation of the Tonle Sap hydrodynamics and water quality model and the assessment of the influence of built structures. The field measurements were performed at the irrigation system on the Stung Chinit River, fishing lot area in Prek Toal and private irrigation reservoir on the floodplain in Stung Staung district. Measurements consisted of flow velocity and direction, discharge, water level and water quality analyses at the study sites. The period of field activities coincided with the annual hydrological cycle from August 2006 to January 2007.

II.1.2 Stung Chinit

6. The goal of field measurements at the Stung Chinit irrigation system was collecting hydrological and water quality data for model calibration, assessing how the structure is changing discharges and water quality and what kind of new habitat the reservoir and canal network is creating for the fish population. Measurements were performed every second week from August 2006 to January 2007.

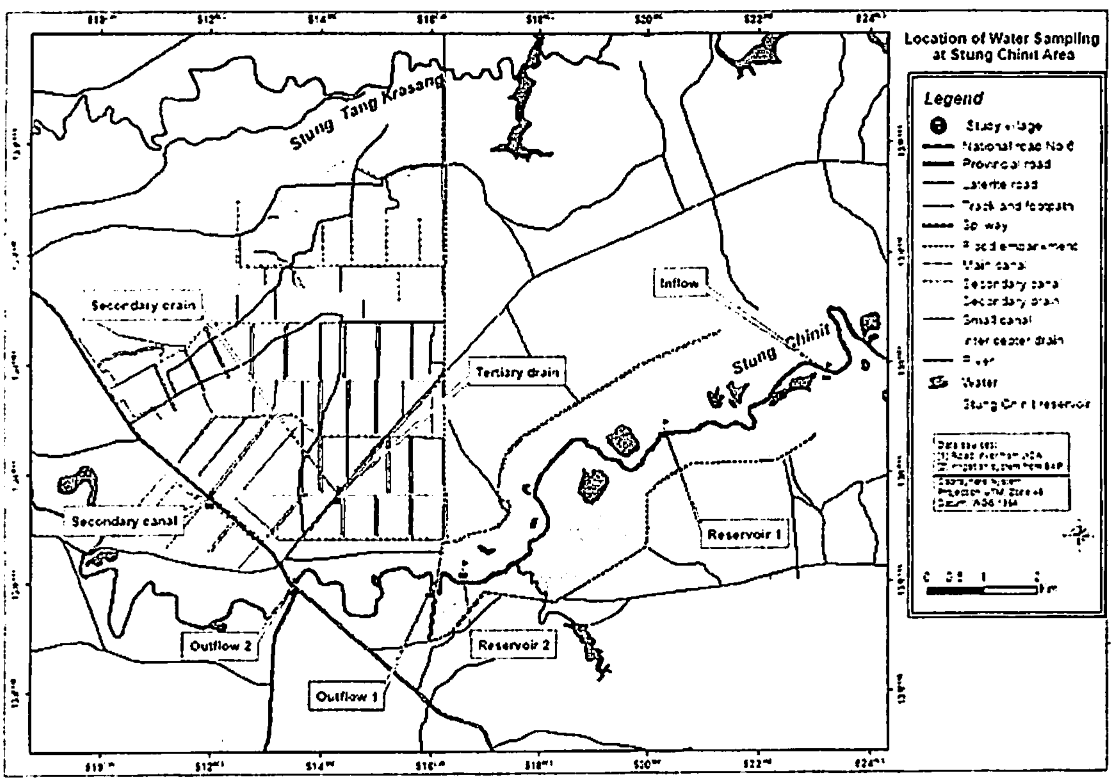


Figure 2. Measurement locations in the Stung Chinit irrigation scheme.

7. Hydrological measurements consisted of discharge and water level measurements. Discharge into the reservoir upstream of the reservoir and discharge from the reservoir right after the dam and next to the national road bridge were measured by an ADCP-device (Acoustic Doppler Current Profiler) (Figure 2.). Water levels were recorded in the reservoir next to the fish pass, downstream under the national road bridge and temporarily upstream at the discharge measurement location.

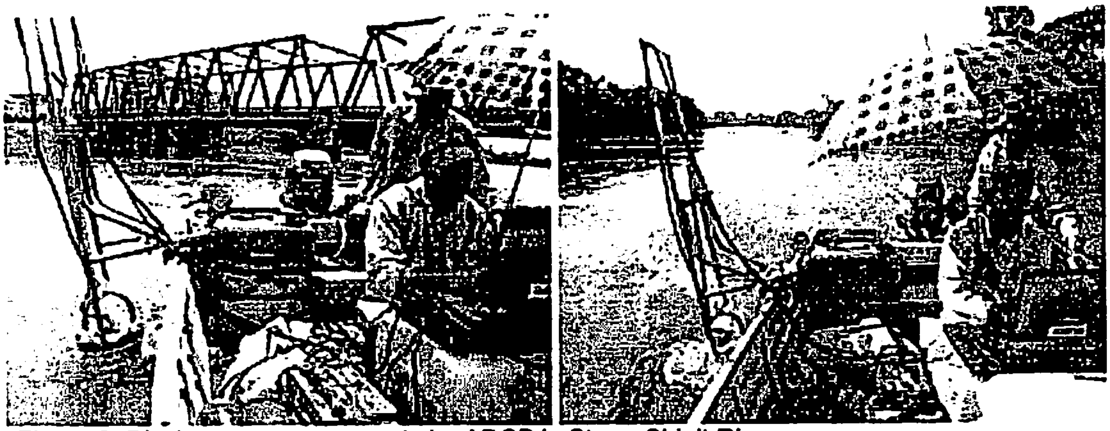


Figure 3. Discharge measurements by ADCP in Stung Chinit River.

8. Water quality measurements were carried out by water sampling in the locations where discharges were measured to find out possible changes in the river water quality caused by the structure. In addition to the river water analyses, samples were taken from the reservoir and from the irrigation canals. Water quality of the reservoir was sampled in the middle and near the outlet of the reservoir. Water quality in the irrigation canals was sampled in the secondary and tertiary drainage canals and in the secondary irrigation canal (Figure 3.). All water samples were analysed in the water quality laboratory of the Ministry of Water Resources and Meteorology in Phnom Penh. Analysed parameters were DO (dissolved oxygen), COD (chemical oxygen demand), TSS (total suspended solids), TDS (total dissolved solids), pH, conductivity, alkalinity, TOT-N (total nitrogen), NO3 (nitrate), NH4 (ammonium), TOT-P (total phosphorus) and PO4 (phosphate).

II.1.3 Prek Toal

9. Fieldwork in the Prek Toal area aimed at finding out the impacts of fishing gears on the lake's hydrology. The major impacts of fishing gears on the flow fields of the lake are caused by thick bamboo fences which are used on fishing lot fence systems. The fences are assembled with bamboo mats attached to wooden poles placed at a distance of 50 to 70 cm from each other. The distance between the bamboo slats is 10 to 15 mm (Deap et. al. 2003). The impacts of bamboo fences on flow velocity and direction were studied by field measurements and laboratory experiments. The lake flow field without fences was studied by point measurements in the Prek Toal area in August 2006. Measurements were carried out by recording current meter (RCM9). Measurements were repeated in January 2007 when bamboo fences were installed on the lake.

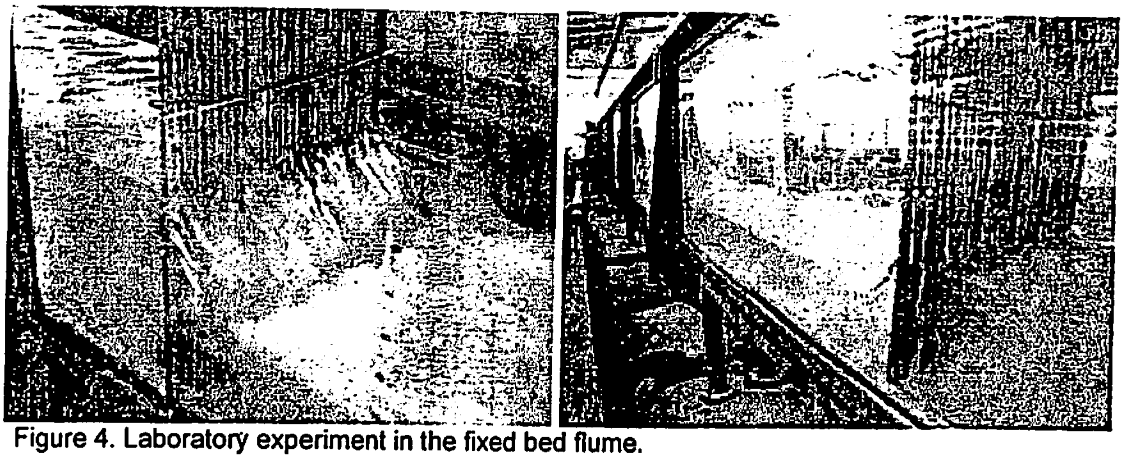


Figure 4. Laboratory experiment in the fixed bed flume.

10. Laboratory experiments were performed in the laboratory of hydraulics in the Asian Institute of Technology (AIT) in Bangkok. Bamboo fences were installed to a fixed bed flume where flow velocity and discharge were controlled by setting the power of pumps. Water level was kept at approximately the same level in each measurement in the flume by setting the level of the tail gate at the end of the flume. The experiment was carried out with seven different flow velocities from 5 cm s^{-1} to a maximum velocity of 68 cm s^{-1}. Three different pieces of bamboo fence were installed on the flume one by one for measurement at each flow velocity. Water level was recorded on both sides of the fence to find out the possible trapping effect of the fence. In addition to bamboo fence measurements the experiment was carried out with a piece of nylon net (net size 5 mm), which is replacing fences on the lake. Bamboo fences last only two years on the lake while cheaper nylon net lasts three years longer. Bamboo fences have therefore replaced nylon nets at several locations.

Figure 5. Bamboo fence on the lake, flow velocity and direction measurement by Acoustic Doppler Current Profiler.

11. In addition to the laboratory measurements, the impacts of bamboo fences were studied on the lake in the Prek Toal area. Flow velocity was measured by an Acoustic Doppler Current Profiler (ADCP, Figure 5.) on both sides of the bamboo fence of Fishing Lot No. 2 at the end of January 2007. Cross sections were measured at a distances of 2 m, 10 m, 50 m and 100 m of the fence both inside and outside of the fenced area.

II.1.4 Private irrigation reservoir in Stung Staung District

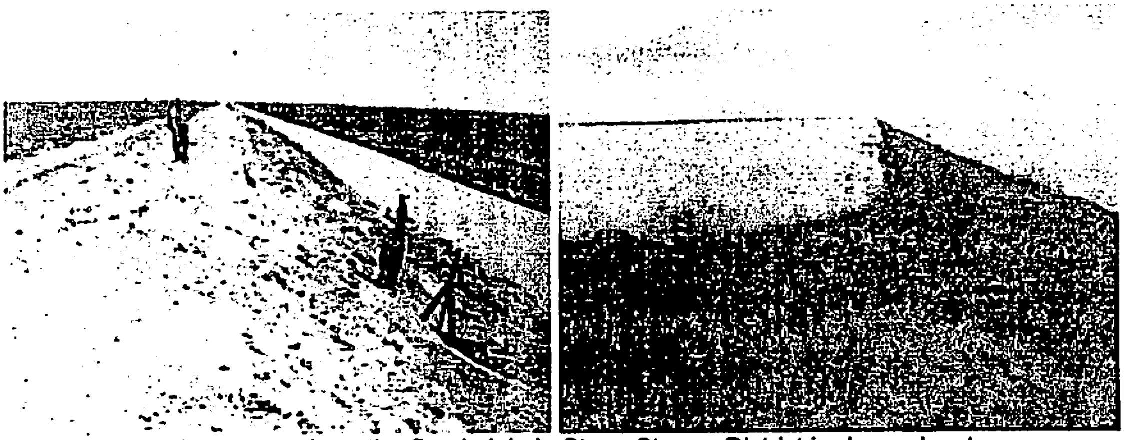


Figure 6. Irrigation reservoir on the flood plain in Stung Staung District in dry and wet season.

12. Development of the Tonle Sap floodplain is most dramatically shown in the building up of huge private irrigation reservoirs. Reservoir banks are simply made by heaping up soil (Figure 6) to a sufficient height to trap rising floods. The height of embankments varies normally between 1.5 and 3 meters. When the flood level decreases and the area nearby the reservoir dries, the water in the reservoir is used to irrigate surrounding rice fields. Almost 40 reservoirs can be found in the Kampong Thom area. To study the impacts of private irrigation reservoirs, one of the reservoirs in Stung Staung district was chosen (Figure 6). The field measurement results indicate reservoir impacts on the floodplain hydrology and water quality. Water quality was measured by water sampling inside and outside of the reservoir (Figure 7.) when (i) the flood level was high, (ii) the water level was decreasing and the floodplain on the north side of the reservoir was already dry and (iii) all surrounding areas were dry and rice growing was started. Water samples were analysed in the water quality laboratory of the Ministry of Water Resources and Meteorology in Phnom Penh. Analysed parameters were DO, COD, TSS, TDS, pH, conductivity, alkalinity, TOT-N, NO3, NH4, TOT-P and PO4. In addition to the water sampling, water level was measured daily inside and outside of the reservoir by the reservoir staff.

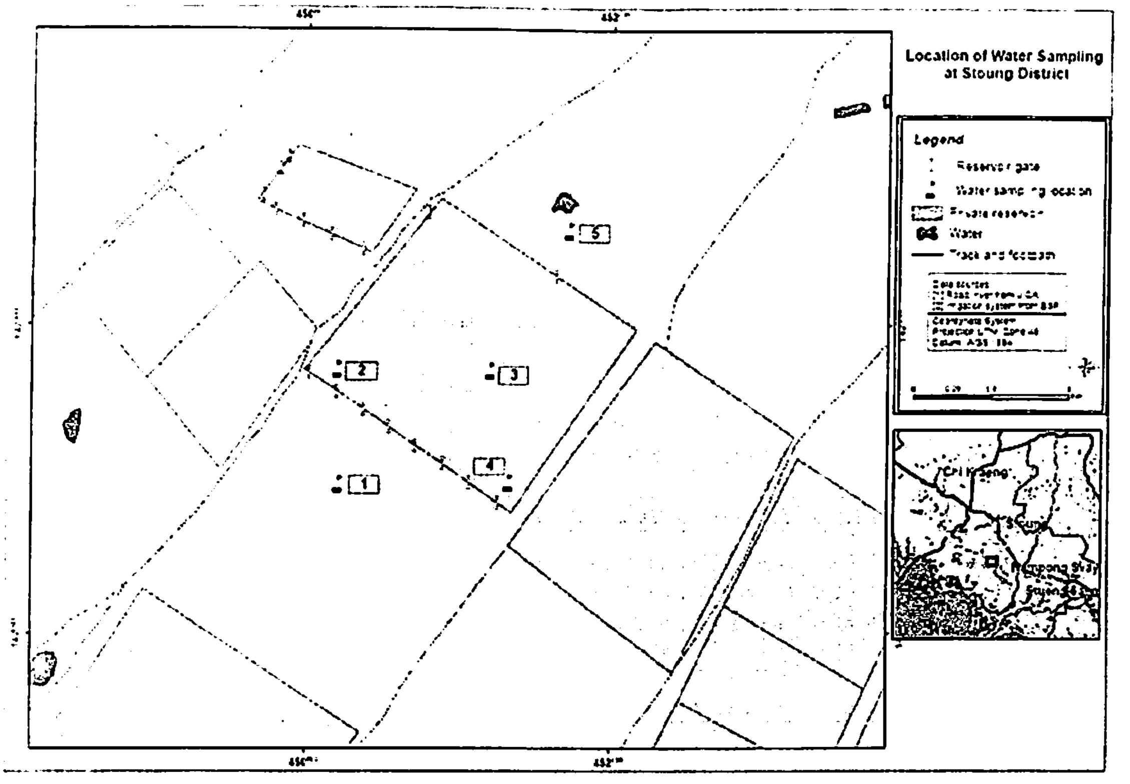


Figure 7. Sampling locations at the private irrigation reservoir in Stung Stoung district.

II.2 MODELS

II.2.1 Modeling requirements

13. Modeling is a powerful tool to integrate heterogeneous data, fill in spatial and temporal data gaps, study dynamic processes and illustrate natural processes. In many cases, modeling is also the only practical tool to assess impacts of planned developments in a systematic and quantitative way. In the Tonle Sap built structures case, models have been used to study the different types of structures and impacts from the basin-wide to the very local scale. A 3D hydrodynamic and water quality model has been used. Three dimensionality means that both the horizontal and vertical differences in the water properties are modeled. The Tonle Sap system and reservoirs are highly three dimensional. That is, their properties vary significantly in both horizontal and vertical directions, so the use of a 3D model is necessary. As an example conditions in the lake proper and the floodplain are totally different, floodplain flow and mixing being just a fraction of the corresponding properties in the lake proper. In the floodplain, in the vertical direction the flow, sediment and oxygen conditions are quite different on the surface and near the bottom.

II.2.2 Overview of the EIA 3D hydrodynamic model

14. The EIA 3D hydrodynamic and water quality floodplain/lake/river model utilized in the study is probably the only existing 3D flood model in the world, at least on the level of a practical tool. It has been developed based on a previous 3D lake and sea model. The EIA 3D model was developed by the Environmental Impact Assessment Center of Finland Ltd (EIA Ltd.). The development work started 1974 when EIA Ltd. was still part of the Technical Research Centre of Finland. The model has been applied under the Cambodian National Mekong Committee (CNMC) and Mekong River Commission Secretariat (MRCS) to the Tonle Sap since 2001 (WUP-FIN, 2003).

15. The EIA 3D model system is a fully three-dimensional model based on rectangular grid representation. The system accommodates meteorological, hydrological, topographic, land use and infrastructure characteristics of the area under study. The modelling platform includes data processing, model control, GIS, database control, model data products and visualization. The model is able to describe the three-dimensional characteristics of the flooding, flow, water quality, erosion and sedimentation in the lakes, reservoirs, river channels and floodplains. The EIA 3D model system structure is presented in Figure 8.

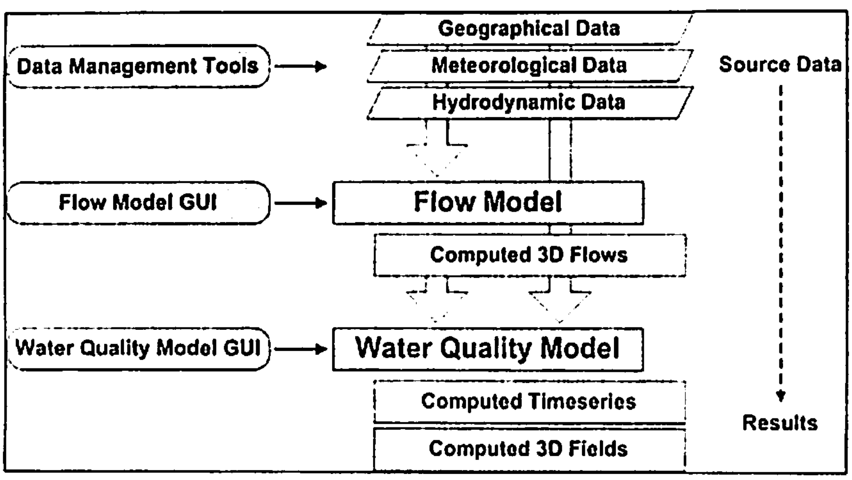


Figure 8. Schematic EIA model structure. GUI = Graphical User Interface.

II.2.3 Hydrodynamic model equations

16. Computed flows are determined by the following factors:
    1. wind force,
    2. atmospheric pressure at the surface,
    3. conservation and incompressibility of water,
    4. internal friction (viscosity),
    5. transport of velocity differences with water currents (advection),
    6. Coriolis force caused by the earth's rotation,
    7. density differences and water level gradients (hydrostatic pressure),
    8. bottom friction,
    9. vegetation impacts on friction and wind stress.

17. The motion of a fluid particle on the surface of the earth is governed by the Navier-Stokes equation of motion (the force balance equation) /1/

$$\frac{\partial u}{\partial t} = fv - \frac{1}{\rho_0}\frac{\partial p}{\partial x} + \frac{\partial}{\partial x}\left(\nu_{hor}\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(\nu_{hor}\frac{\partial u}{\partial y}\right) + \frac{\partial}{\partial z}\left(\nu_{ver}\frac{\partial u}{\partial z}\right) - \mathbf{u}\cdot\nabla u \qquad (1)$$

$$\frac{\partial v}{\partial t} = -fu - \frac{1}{\rho_0}\frac{\partial p}{\partial y} + \frac{\partial}{\partial x}\left(\nu_{hor}\frac{\partial v}{\partial x}\right) + \frac{\partial}{\partial y}\left(\nu_{hor}\frac{\partial v}{\partial y}\right) + \frac{\partial}{\partial z}\left(\nu_{ver}\frac{\partial v}{\partial z}\right) - \mathbf{u}\cdot\nabla v \qquad (2)$$

$$\frac{\partial p}{\partial z} = -g\rho \qquad (3)$$

$$\nabla\cdot\mathbf{u} = 0 \qquad (4)$$

$\mathbf{u}$ = velocity vector, m/s
u, v = horizontal velocity components, m/s
t = time, s
p = pressure, Pa
f = Coriolis coefficient
ρ_0 = average density of water, kg/m^3
ρ = density of water, kg/m^3
g = 9.81 m/s^2
ν_{hor}, ν_{ver} = horizontal and vertical eddy momentum viscosity, m^2/s
∇ = gradient operator, m^{-1}

The forces included are (from left to right) local acceleration, advective (or convective) accelerations, pressure gradient, gravitation, Coriolis force and molecular viscosity.

Equation (4) is the continuity equation (mass conservation equation). /3/ The vertical viscosity can either be calculated by a turbulence model such as k-ε or given. In the Tonle Sap models a constant vertical viscosity of 35 cm^2/s is used.

II.2.4 Hydrodynamic model input and output data

18. Model input data consists of:
    1. bathymetric data for the model grid, either as shorelines, point depth data and depth isolines, or as a digital elevation model,
    2. wind measurements from the modelled area for wind forcing computation, wind speed (m/s) and direction (degrees) with a 3 – 6 h or better time resolution,
    3. boundary flows (m^3/s) including rivers and open boundaries (daily or more frequent values),
    4. flow and/or water level measurements for model calibration, flow is often measured in cm/s for every ten minutes, for surface height the time resolution depends on the modelled area and may vary from 10 minutes to one day,
    5. land use (vegetation types).

19. The land use types affect both the hydrodynamic and water quality parameters. In the hydrodynamic model the effect comes from three sources:
    - wind fetch
    - wind shielding
    - vegetation stress (friction).

    Average vegetation height, cover and friction are given for each land use type. These in turn determine wind and flow friction in different depth zones. Wind friction is diminished proportional to the vegetation cover above the water level. Vegetation flow friction affects flow only in the layers that are lower than the vegetation height.

20. Model outputs include:
    1. water depth (DEPS, DEPZ)
    2. water elevation (SURF)
    3. flow velocity components (U, V)
    4. flood duration (FLDU-files)
    5. flood arrival time (FLAR-files).

II.2.5 Sediment model

21. The governing equation for the *i*th fraction of suspended solids includes advection, dispersion, settling and erosion by re-suspension. It retains the conventional form of the general transport equation as follows:

$$\frac{\partial c_i}{\partial t} + u\frac{\partial c_i}{\partial x} + v\frac{\partial c_i}{\partial y} + w\frac{\partial c_i}{\partial z} = D_h\frac{\partial^2 c_i}{\partial x^2} + D_h\frac{\partial^2 c_i}{\partial y^2} + D_v\frac{\partial^2 c_i}{\partial z^2} - k_{s,i}c_i + S_{e,i}. \qquad (5)$$

c_i concentration of a substance, units/m³
t time, s
u,v,w known water flow velocity components, m/s
D_h horizontal concentration diffusivity, m²/s
D_v vertical concentration diffusivity, m²/s
$k_{s,i}$ settling coefficient cm/d
$S_{e,i}$ net upward suspended sediment flux, depends on critical shear bottom stress or velocity.

A 7 cm/d settling velocity has been used for the Tonle Sap sediment model. It is based on grain size measurements and model calibration. A 12 cm/d settling velocity is used for the Stung Chinit model in order to accommodate large grain size sediments.

The model input values include initial and boundary sediment concentrations. They are obtained from measurements.

II.2.6 Oxygen model

22. Dissolved oxygen concentrations are governed by sediment oxygen demand, BOD (biochemical oxygen demand) and aeration. The equation for oxygen without transport and diffusion (these are the same as in equation 5) is:

$$\frac{\partial c}{\partial t} = -k_1 BOD + k_2(c_s - c) \qquad (6)$$

Here k_1 is the BOD rate, k_2 aeration rate and c_s oxygen saturation value. In the bottom layer the effect of the bottom sediment oxygen demand is added to the equation.

23. In addition, BOD7 (biological oxygen demand) is one of the calculation parameters. It has not been used so far because of the amount of time required for BOD load modelling. Instead bottom sediment oxygen demand (SOD) is used.

24. The aeration and bottom sediment oxygen demand values are given for each land use class. It is obvious that the vegetation cover and land use type have a strong effect on aeration and the decaying biological material on the ground. The degradable biological material in the water phase (BOD) is transported around and consumes oxygen at a rate that is not assumed to be strongly land use dependent. The values for the SOD vary between 0.05 and 1.4 mg/m²/d depending on the land use (vegetation) type. Similarly the aeration coefficient varies between 1 and 10 cm/d.

II.3 TONLE SAP 3D MODEL SET-UP

II.3.1 Model grid

25. The model covers a 261 km x 196 km = 51 000 km^2 area. During the highest flood about 15'000 km^2 of this area is flooded. The model area includes the main tributaries and the Tonle Sap River from Prek Kdam to the lake (Figure 9).

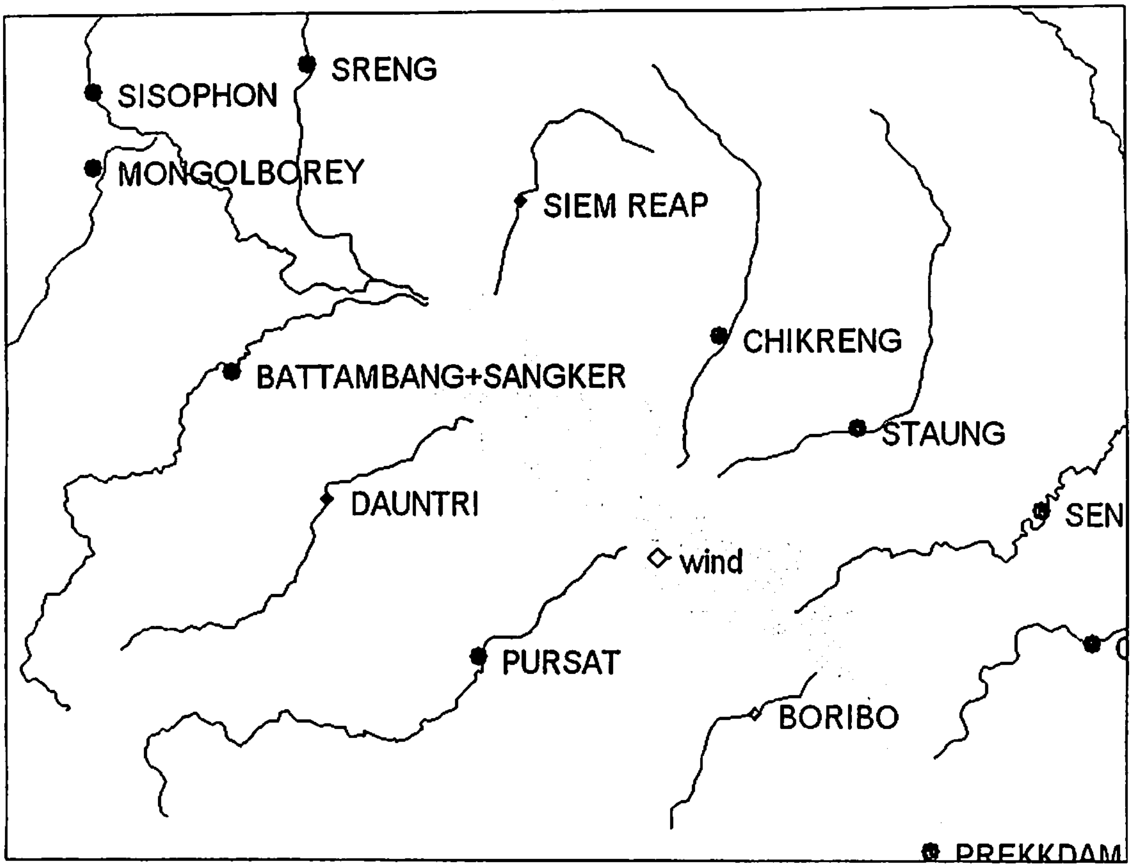


Figure 9. The 3D model application area for Tonle Sap Lake and its floodplain.

26. The basic grid size is 1 km and the number of grid cells on the horizontal plane 261 x 196 = 51 156. On the vertical plane there are 14 layers which are 1 m thick to 12 m depth. Below that grid thickness is 1.5 and 2.5 m. Near the bottom the layer thickness varies depending on the total depth. Altogether there are 716 184 3D grid points. Part of the Tonle Sap model grid is shown in Figure 10.

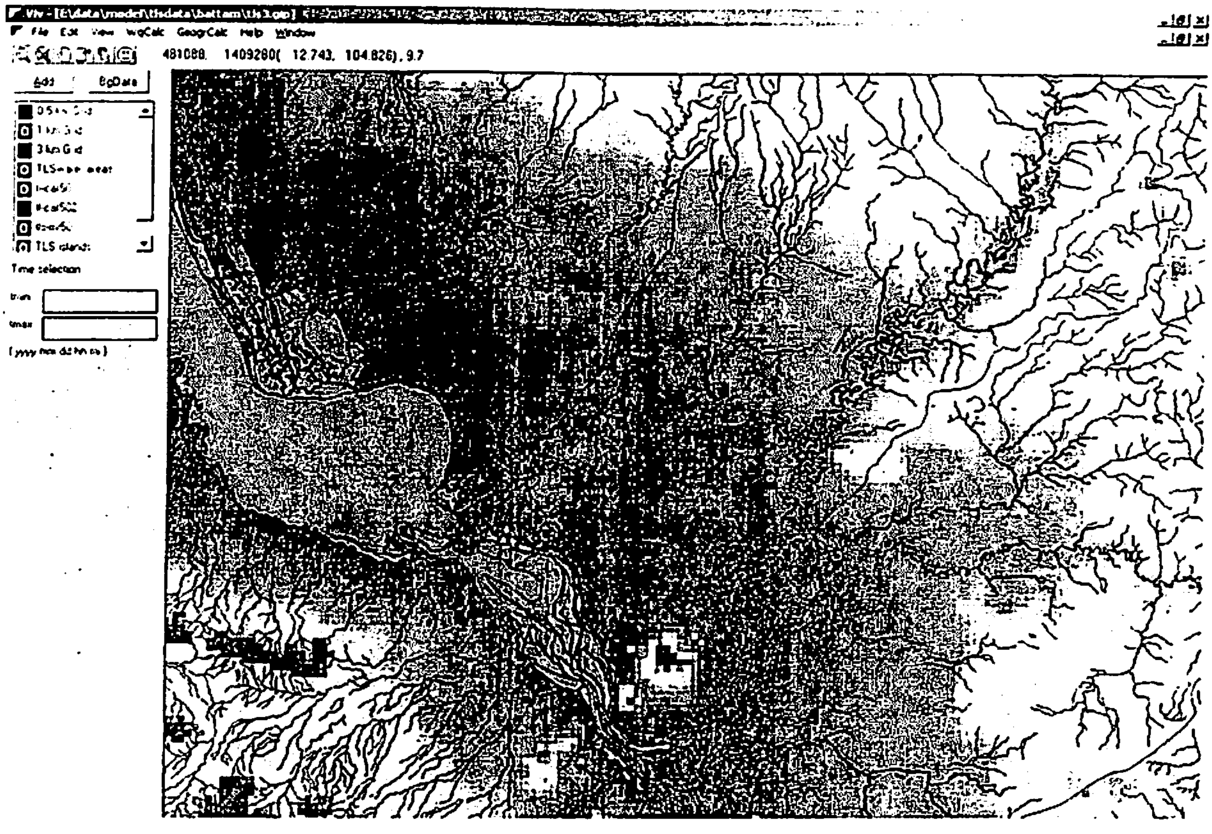


Figure 10. Tonle Sap model grid. Colors show elevations of the grid cells.

II.3.2 Topographic and land use data

27. The floodplain topography is based on the Certeza survey from 1964. It includes first and second order leveling around the lake, 1400 linear km of profile surveys and photogrammetry. The data has been compared to other topographic data, satellite data and recent surveys. The comparisons indicate that the Certeza data is accurate enough for modelling purposes. The data has been further checked and supplemented with MRCS/CNMC topographic survey data consisting of 22 survey lines totaling 470 km.

28. The lake proper and the Tonle Sap River topography are based on the MRCS Hydrographic Atlas survey of 1999. The data has been transformed to the same reference system as the floodplain topography (Ha Tien MSL - Mean Sea Level).

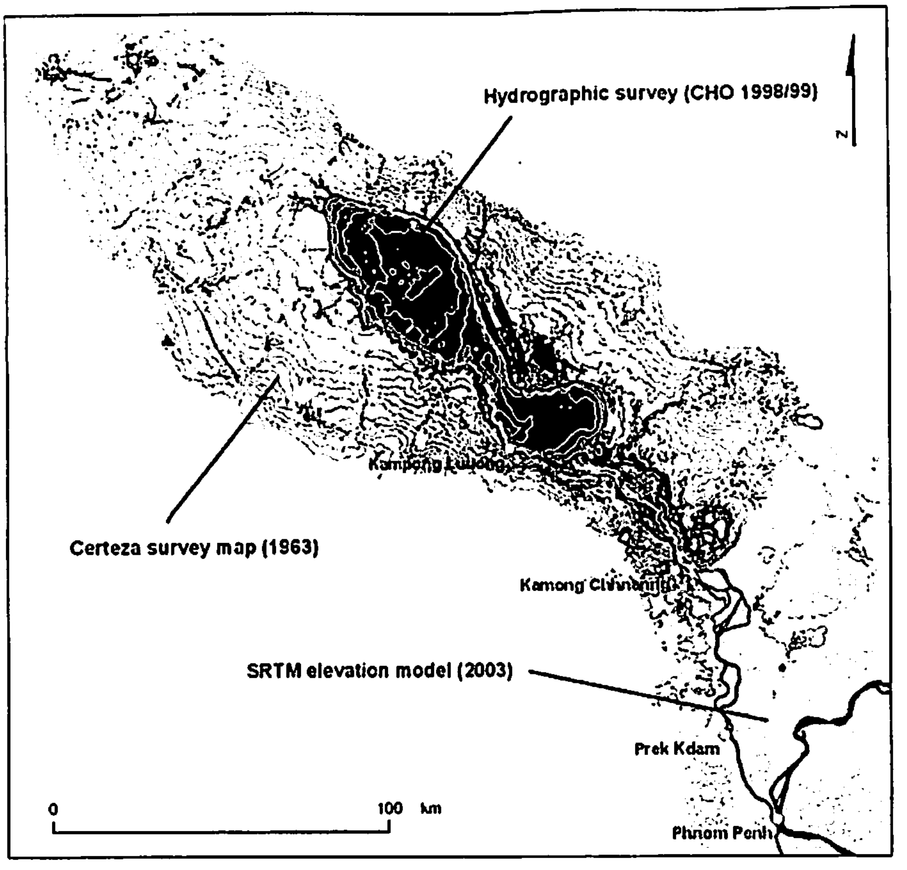


Figure 11. Tonle Sap topographic data.

29. The land use data is based on the JICA Reconnaissance Survey. In the model the 59 original classes have been aggregated to 8 model classes. For instance "shrubland" and "abandoned field covered by shrub" are combined. Only the main classes are used, that is:
    1. agricultural land
    2. grassland
    3. shrubland
    4. forest
    5. water
    6. soil and rock.

II.3.3 Boundary conditions

30. Lake *wind measurements* are used. They have been conducted by the MRCSW WUP-FIN project. Phnom Penh airport winds are quite different, and have not been used.

31. *Discharges* are provided on the model boundaries:
    - 12 tributaries shown in Figure 9
    - Prek Kdam

32. The discharges in tributaries are based on the latest rating curves and hydrological model (MRCS/SWAT) results. The Tonle Sap River and overland flow have been correlated to the available Mekong, Tonle Sap River and Lake water levels and discharges.

33. *Oxygen and sediment* measurements are used for the model boundary values and for model calibration and validation. For each discharge boundary there are also oxygen and sediment boundaries. Oxygen concentrations are based on the monthly averages of the available measurements. Sediment concentrations in tributaries are based on the CNMC and MRC measurements. Sediment concentrations in Prek Kdam are based on the MRC Water Quality Monitor Network data.

II.3.4 Model calibration and validation results

34. The measured and modelled water levels are shown in Figure 12. The simulation was conducted from June 1996 to November 2004. The match is surprisingly good considering that the Prek Kdam and overland flows have been estimated based on one point water level measurements and a second order lake volume model.

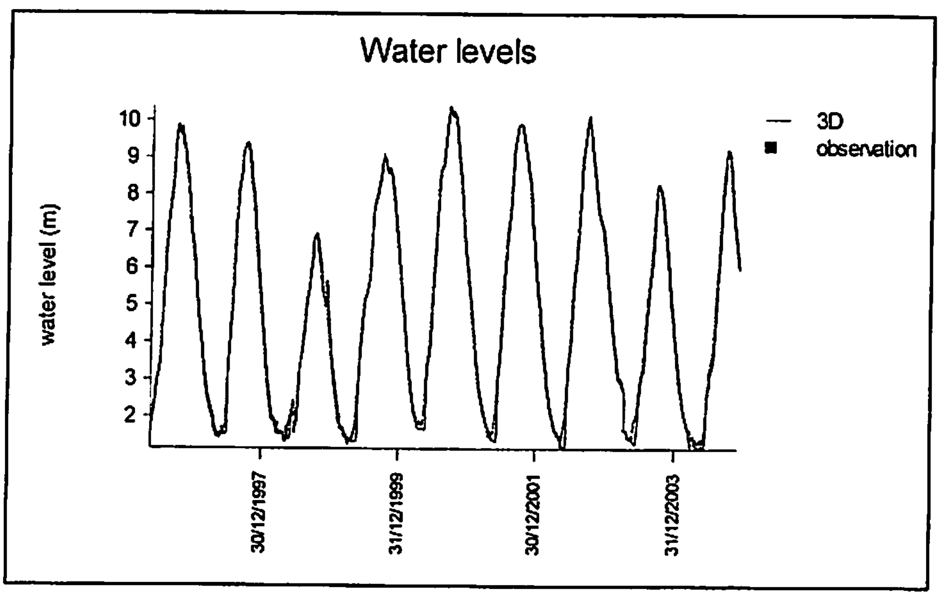


Figure 12. Measured (red dots) and WUP-FIN model calculated water levels at the Tonle Sap (Kampong Luong).

35. The total suspended sediment (TSS) results from Kampong Chhnang (KCH1) station are presented in Figure 13. For the validation, the time period between May 2001 and May 2002 was used. Because of the limited measurement data, only surface suspended sediment (SS) concentrations (0-1 m below the water surface) were used. When comparing the observed SS concentrations with the calculated ones, the correlation is good during the flood period (July-September) except the very high peak when the observed values are higher than the calculated. During the receding flood (October-January) the computed values are higher than the observed ones. This may be due to high sediment resuspension rates in the lake during low water level.

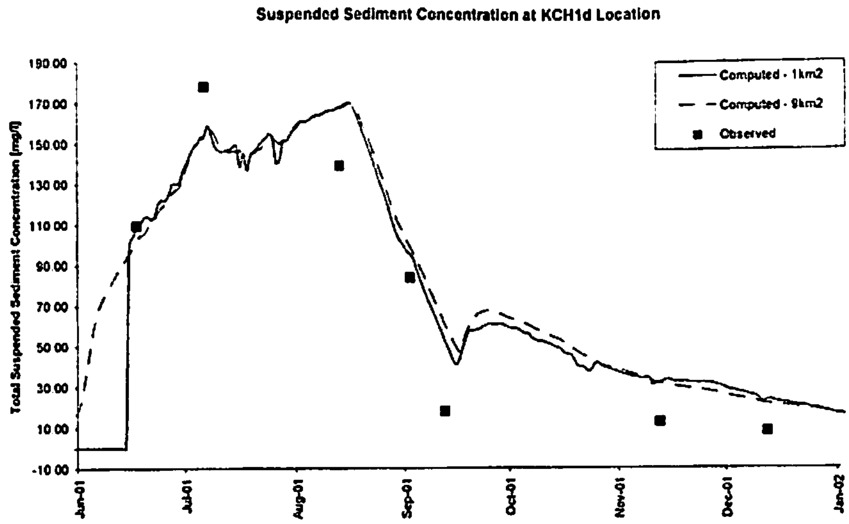


Figure 13: TSS concentration comparison between observed and computed values at KCH1.

Simulated sedimentation (Figure 14) corresponds well with the natural levees that can be seen in the Tonle Sap near the lake proper edge. The simulated net sedimentation is nearly zero in the lake proper, which has been confirmed by field measurements.

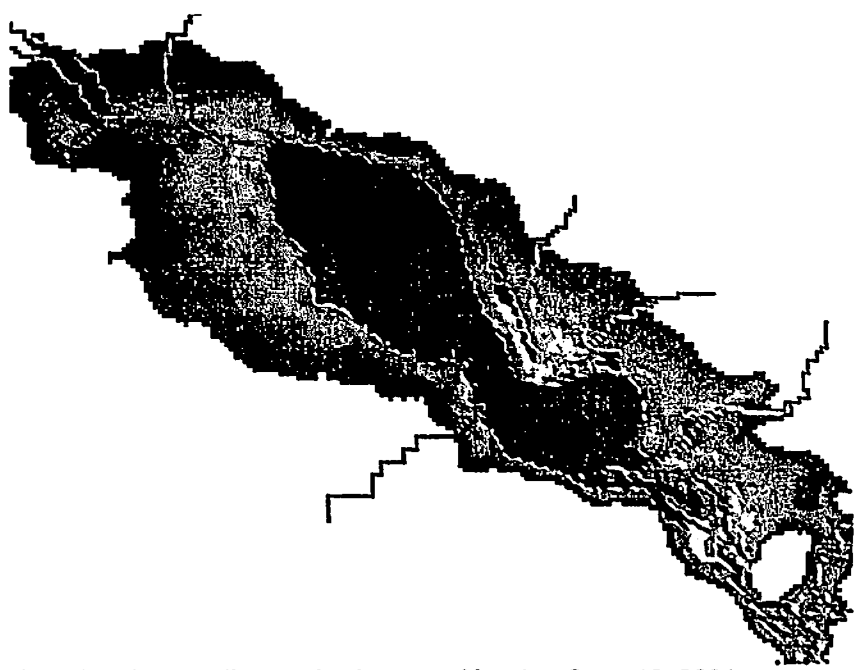


Figure 14. Calculated net sedimentation between May 1. – Sept. 13, 2001.

36. According to measurements the characteristic feature of the floodplains is the large-scale anoxia. The model reproduces this phenomenon well. Figure 15a illustrates typical measured oxygen distributions in two cross-sections from the western floodplains and from the middle of the lake. The measured distribution of surface oxygen can be compared with the simulated values as shown in Figure 15b. In the floodplain the model also produces anoxia near the bottom.

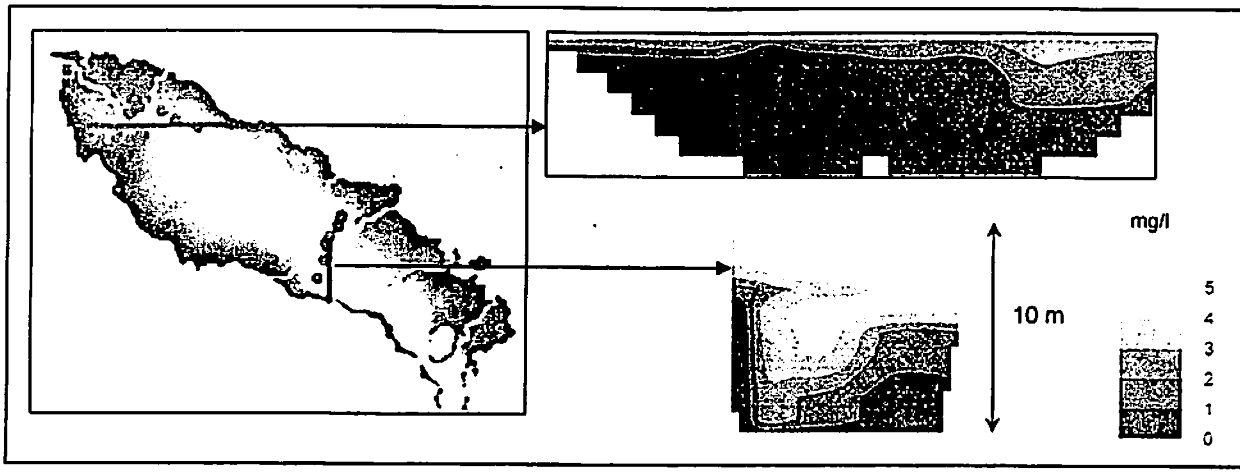


Figure 15a. Two water quality measurement cross-sections and sampling sites. Floodplain water depths are shown on the left hand side (1 m intervals). Measured October 2002 oxygen cross-sections shown on the right hand side from the north and middle of the lake.

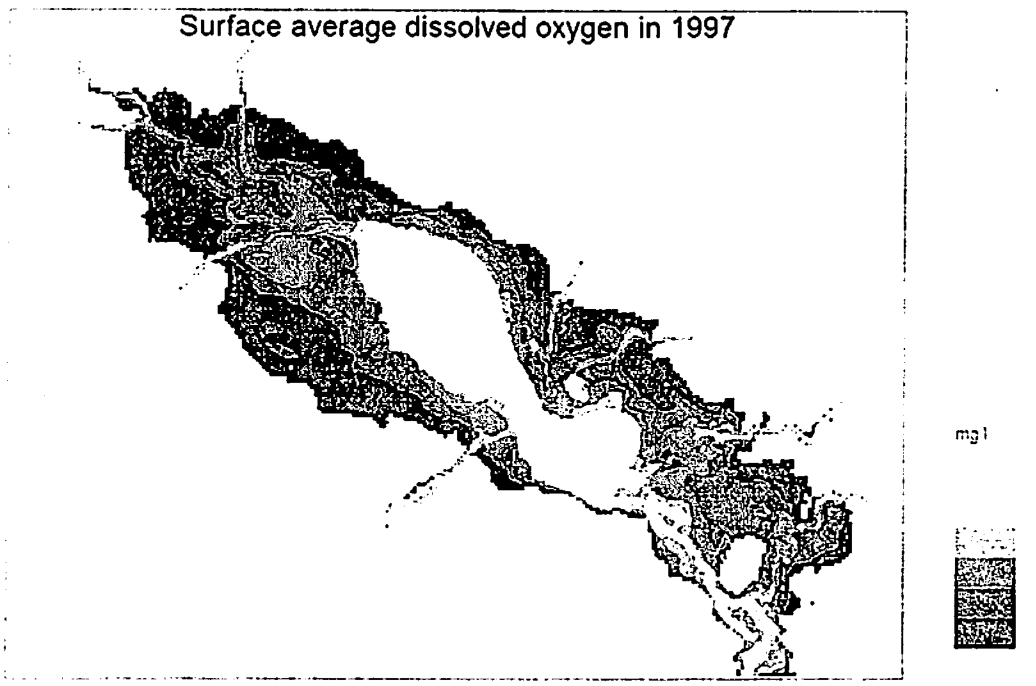


Figure 15b. Modelled time average of the surface oxygen.

II.4 STUNG CHINIT 3D RESERVOIR MODEL

37. Stung Chinit is an irrigation system that was developed by an ADB project. The model application area can be seen in Figure 2. Corresponding model implementation is presented in Figure 16. The model grid size is 50 m. The narrow channels are described with a smaller grid size.

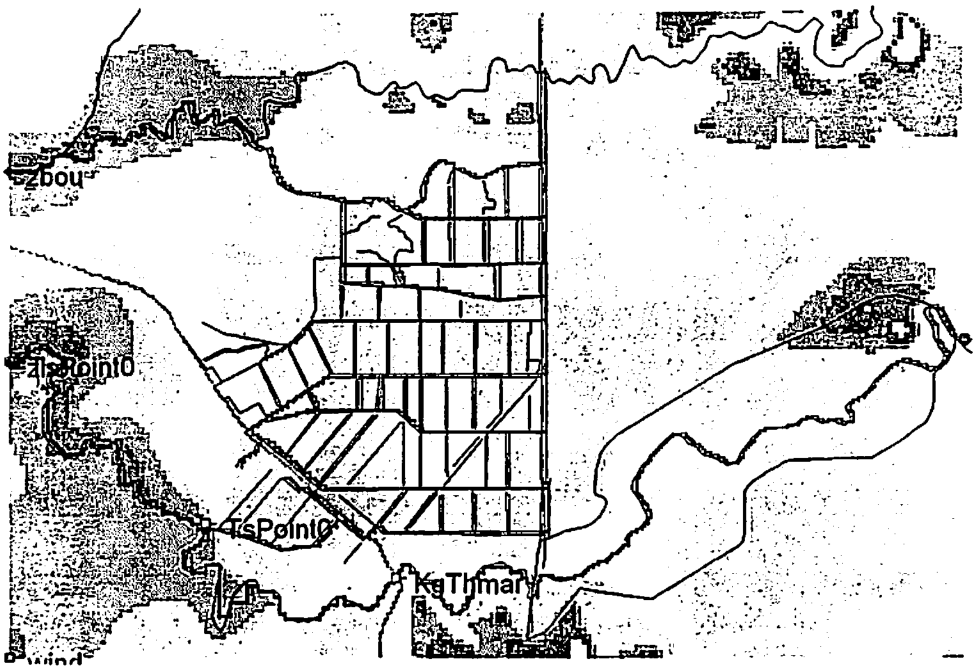


Figure 16. Stung Chinit model implementation area showing the reservoir on the right hand side, river and the irrigation channel system. Colors signify elevations (red lower, blue higher).

38. An alternative *nested* model has been applied to the area (Figure 17). It consists of 1000, 50 and 25 m grids that are combined together. The 25 m grid covers the irrigation channel system. The model has not been used in the final simulations because it requires more computation time. Also, the focus has been on the impacts of the reservoir and not on the functioning of the irrigation channel system.

39. The upstream boundary discharge has been obtained from a rating curve relating measured water levels to discharge. For the downstream a flow rating curve was developed. The reservoir spillway description proved to be a difficult part of the implementation. It was found that utilization of a hydraulic weir description gave stable results. A broad crested weir formula that is solved iteratively has been applied. The sediment and oxygen upstream boundary values have been estimated from available measurements.

40. The model has been used to simulate flow, reservoir fill-up, and sediment and oxygen levels. Similar model parameter values have been used as with the Tonle Sap model.

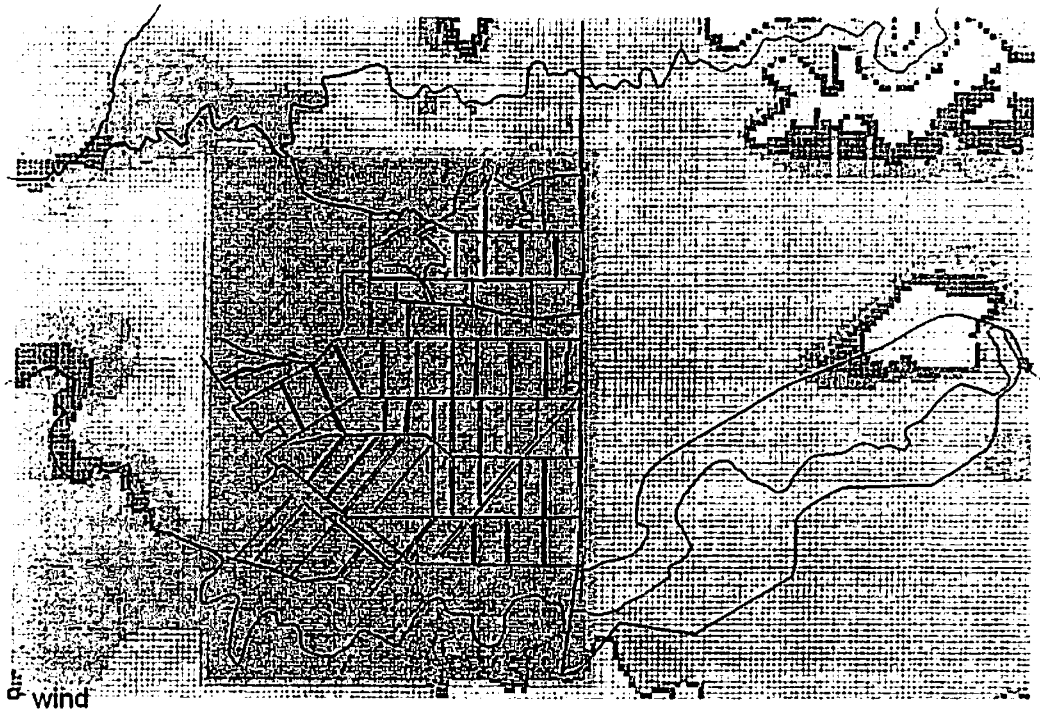


Figure 17. Stung Chinit nested model implementation. Grid sizes are 1000, 50 and 25 m. The finest grid covers the irrigation channel network.

II.5 DEFINITION OF THE MODEL SCENARIOS

41. The model scenarios represent possible future basin-wide and Tonle Sap catchment developments. Intensive scenarios have been selected in order to see more clearly the impacts on the Tonle Sap system. The scenarios assume specific increases in hydropower and irrigation structures. The actual future development depends on economic and political factors and cannot be predicted. The scenarios give an indication of the nature and order of the magnitude of possible impacts on the Tonle Sap but are not intended to predict precisely what will happen in the future.

II.5.1 Basin-wide scenarios

42. Three basin-wide scenarios have been used in the study.

1. **Baseline**: development of the basin is on the current level.
2. **Intensive Development**: 55 km^3 of hydropower and irrigation dams in the Chinese Mekong mainstream and in the upstream Mekong tributaries are constructed.
3. **Mainstream Dams**: dams in the Intensive Development scenario + 85 km^3 of mainstream dams in Lao PDR, Thailand and Cambodia (High Luang Prabang, Sayabouri, Pa Mong, Upper Thakhek, Ban Koum, Stung Treng, Sambor) are constructed.

43. The Baseline scenario is obtained from measured Tonle Sap in- and outflows. The development level changes slightly between years, but in practice the development

changes have been minor compared to the total flow volumes. Because of this the development level can be assumed to stay nearly on the same level between years.

44. The Intensive Development scenario represents possible future intensive development of the Mekong water resources (Table 1 and Norplan and EcoLao, 2004). The projected storage capacity for the year 2025 is 55 km^3. China and Lao PDR will clearly dominate in the hydropower capacity and storage volume and will account for about 83% of the total Mekong capacity.

45. Chinese dam cascade details for 8 dams are presented in Table 2. Plans exist for a total of 14 dams. The existing Lao PDR storage capacity is dominated by the Nam Ngum 1 reservoir with an active storage capacity of 4.7 km^3. At the moment the total Upper Mekong Basin hydropower capacity is 2850 MW and the Lower Basin 1800 MW.

Table 1. Existing and predicted active storage volume (km^3) in the Mekong Basin. (Norplan and EcoLao, 2004).

	China	Lao PDR	Thailand	Cambodia	Vietnam	Total
2004	0.62	5.19	5.53	N/A	0.89	12.24
2010	10.52	12.95	5.53	N/A	0.92	29.92
2025	23.19	22.61	5.53	N/A	3.59	54.92

Table 2. Characteristics of the Chinese Mekong dam cascade (Norplan and EcoLao, 2004).

No.	Project	Year of commissioning	Installed capacity (MW)	Active storage (km^3)
1	Manwan	1993-96	1500	0.26
2	Dachaoshan	2001-2004	1350	0.37
3	Xiaowan	2010-14	4200	9.9
4	Gonguoqiao	2012	750	0.12
5	Jinghong	2013	1500	0.25
6	Nuozhadu	2014	5500	12.3
7	Mengsong	Before 2025	600	-
8	Ganlanba	Before 2025	150	-

46. The Mainstream Dams (MS) scenario is based on the Indicative Basin Plan of the Mekong Committee in 1970. It is not very probable that the MS scenario will be realized because of the environmental and socioeconomic impacts and political complications. However, these plans are still discussed and have even been presented recently in the Thai media. Because of this it is relevant to study the possible impact of these dams.

II.5.2 Tonle Sap watershed scenarios

47. The net storage capacities for hydropower and irrigation development have been obtained from the Lower Mekong Water Resources Inventory (WATCO, 1984). The planned total net storage is 5.5 km^3 in the upper reaches of the Tonle Sap tributaries. The division of the storage between the sub-basins is presented in Table 3 and location of the storages and accompanying irrigation areas in Figure 18.

Table 3. The division of the Tonle Sap hydropower and irrigation storage between the sub-basins (source: Tonle Sap Built Structures database)

Sub-basin	Net storage capacity million m3
Sen	2900
Staung	550
Chikreng	160
Mongkol Borey	115
Sreng	610
Chinit	390
Pursat	860
Total	**5585**

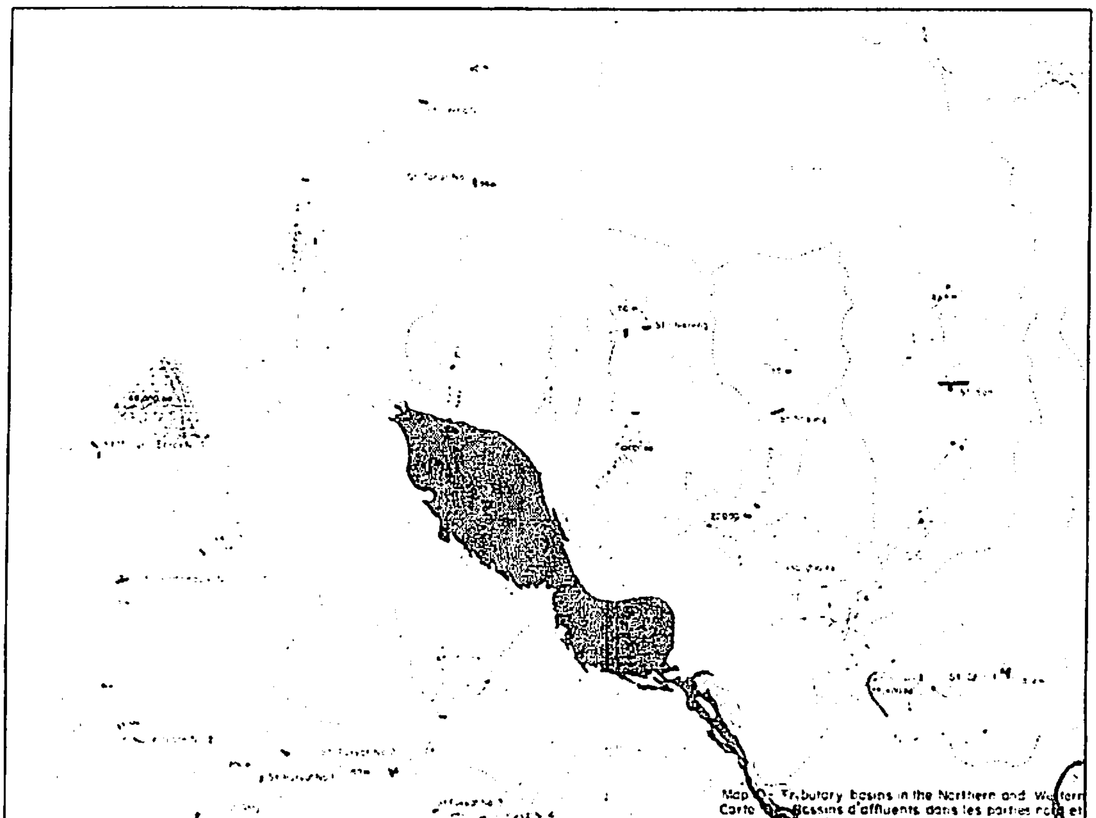


Figure 18. Tonle Sap Hydropower and Irrigation: Baseline + 5.5 km^3 of net storage for hydropower and irrigation in the upper reaches of the Tonle Sap tributaries. Presented in Lower Mekong Water Resources Inventory (WATCO, 1984).

48. Although at the moment there are no major hydropower or irrigation dams in the Tonle Sap, developments are going to be realized in the near future. The China Daily reported on February 17^{th} 2007 that Chinese companies have signed several agreements with Cambodian government officials to build a hydropower plant in Battambang province. The plant will cost USD 190 million. Its power generation capacity will be 53 MW. The plant will be quite small compared to the Chinese dams described in Table 2, but could have a significant impact locally.

III BASIN-WIDE TONLE SAP SCALE RESULTS

III.1 TONLE SAP HYDROLOGICAL CHARACTERISTICS

49. The area of the lake varies between the dry and wet season from around 2,500 km^2 up to about 15,000 km^2, while the water level of the lake increases from less than 1.4 m to 6.8-10.3 m above the mean sea level (amsl) in Ha Tien datum, depending on the year. The bottom of the lake is approximately 0.5 - 0.7 m amsl. During the wet season, the volume of the lake increases from about 1.3 km^3 during the dry season up to 75 km^3, depending on the flood intensity. The summary of the available data is presented in Table 4 and Figure 19. Here the year represents the flood cycle which begins in May of the year in question.

Table 4. Summary of the hydrological data in Tonle Sap Lake during the years 1997-2003.

	Water level [m]		Lake area [km2]		Lake volume [km3]	
	max	min	max	min	max	min
max	10.36	1.48	15278	2402	76.05	1.83
min	6.86	1.19	9637	2061	33.00	1.35
average	9.11	1.34	13218	2237	59.56	1.59

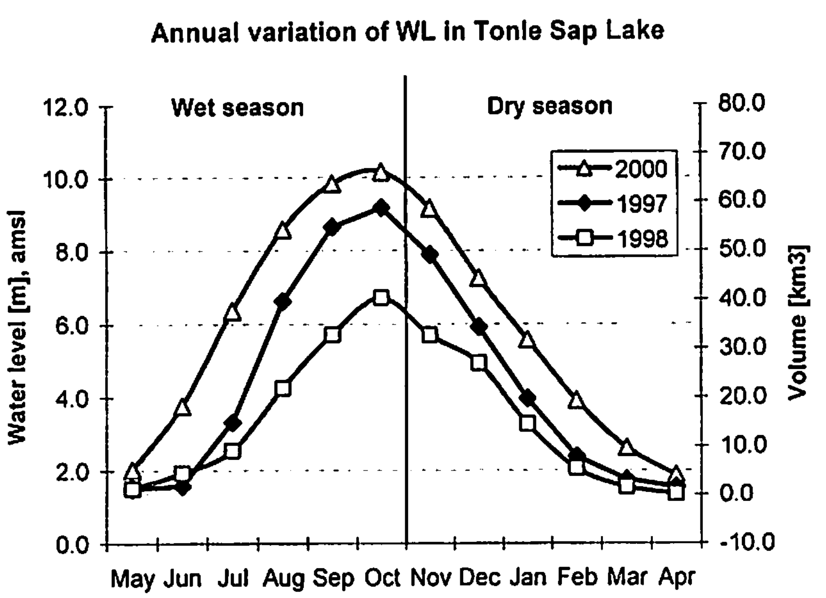


Figure 19. Annual variation of water level in the Tonle Sap Lake. Years 1997, 1998, and 2000 represent average flood, dry year, and high flood, respectively. Water levels are above the mean sea level in Ha Tien, Vietnam. Bottom of the lake lies about 0.7 m above the mean sea level.

50. The Tonle Sap Lake and its sub-catchments with the main tributaries are presented in Figure 20. Also, the locations of the Prek Kdam measurement station, where the discharge into and out of the lake to/from the Mekong is measured, and Kampong Luong, where the lake's water level is measured, are presented.

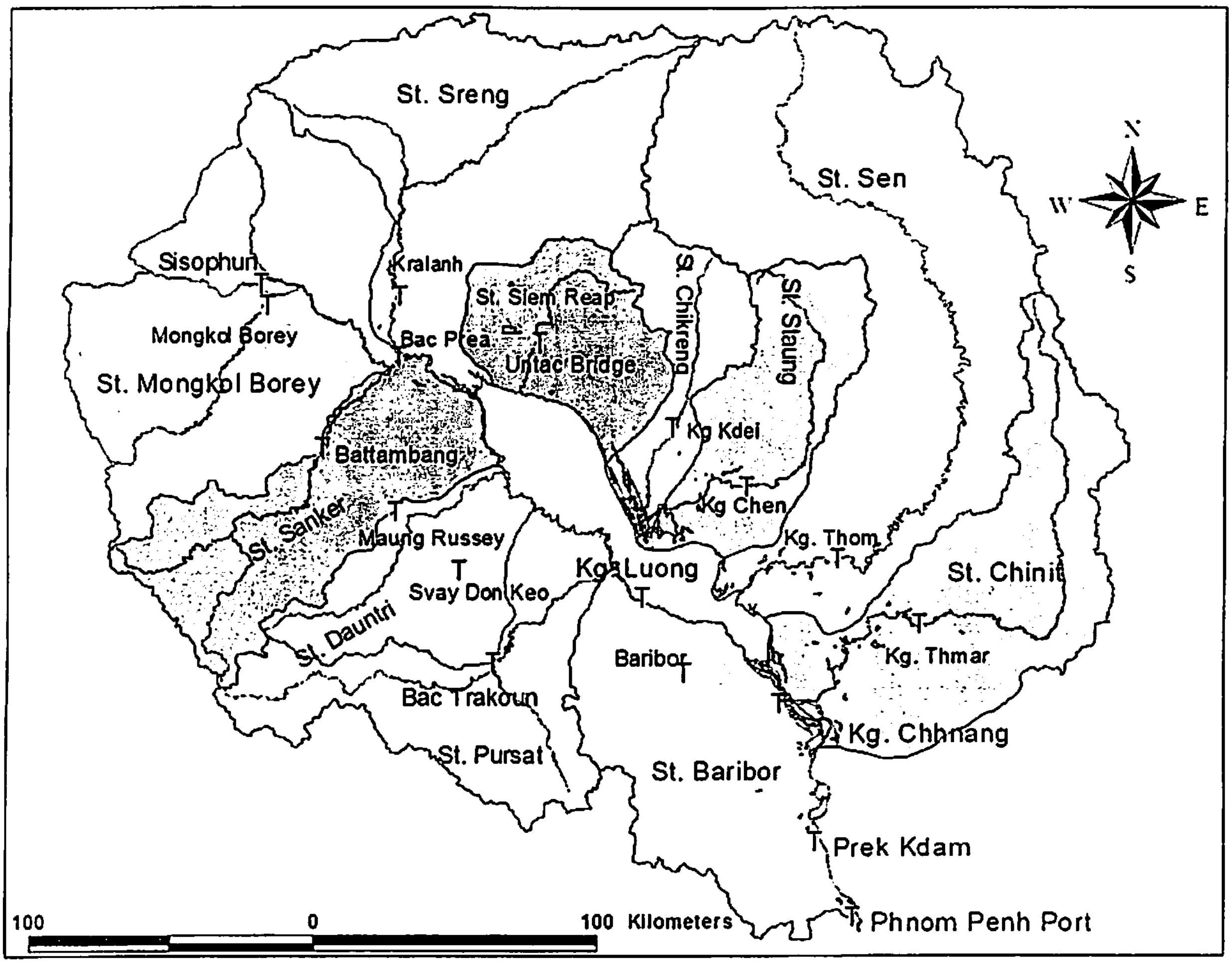


Figure 20. Tonle Sap Basin and its sub-catchments with the main rivers.

51. The following data have been used for the water balance calculations (numbers located in Figure 21):

1. Water level of the lake at Kampong Luong (WL_{KL}) and water level of the Tonle Sap River at Prek Kdam (WL_{PK}) and Phnom Penh Port (WL_{PP})
2. Inflow into and out of the lake through the Tonle Sap River at Prek Kdam - Q_{TSR}
3. Overland flow from the Mekong to the Tonle Sap through floodplains – Q_{OVR}
4. Inflow from the 12 main tributaries - Q_{TRIB}
5. Rainfall data around the lake from two stations - Q_{PREC}
6. Evaporation from two stations – Q_{EVAP}

52. Figure 21 illustrates the location of different components of the water balance study.

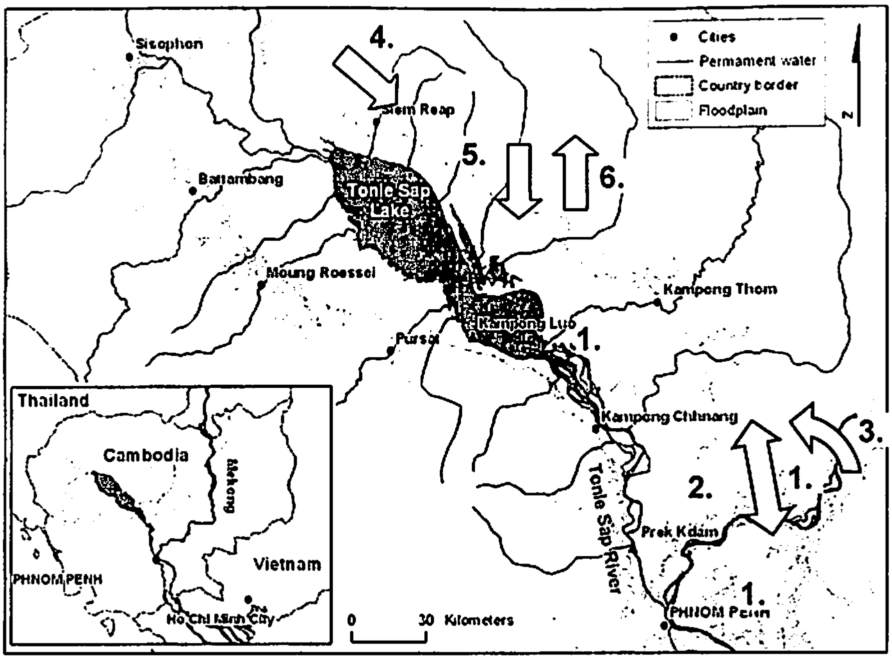


Figure 21. Illustration of the water balance calculation elements' locations.

53. Due to the flooding, the discharge can be measured only from the part upstream from the floodplain. In Table 5 the total area and observed area for each tributary is presented. The total area of the catchment, without the dry season lake area, is 83,011 km^2 from which 54.4% or 48,684 km^2 was observed by the measurements. The total area of the Tonle Sap Basin including the dry season lake, as presented in Figure 20, is 85,786 km^2. This is around 10.8% of the total area of Mekong Basin (Mekong River Commission, 2003).

Table 5. Total catchment and observed area. Observe that Sisophun and Mongkol Borey are separated here whereas in Figure 20 they are combined.

Data available	Area km²	Observed area km²	%	Not observed km²
Chinit	8236	4130	50.1%	4106
Sen	16359	14000	85.6%	2359
Staung	4357	1895	43.5%	2462
Chikreng	2714	1920	70.7%	794
Siem Reap	3619	670	18.5%	2949
Sreng	9986	8175	81.9%	1811
Sisophun	4310	4310	100.0%	0
MKBorey	10565	4170	39.5%	6395
Sangker/Battambang	6052	3230	53.4%	2822
Dauntri	3695	835	22.6%	2860
Pursat	5965	4480	75.1%	1485
Baribor	7153	869	12.1%	6284
Catchment	**83011**	**48684**	**54.4%**	**34327**
Dry season lake	**2774**			
Catch.+lake	**85785**			

54. The monsoon climate has two main seasons in Southeast Asia:
   - Wet season from May to October
   - Dry season from November to April.

55. Around 87% of the precipitation occurs during the 6 month rainy season as can be seen from Table 6 and Figure 22. The annual average precipitation in Siem Reap was 1494 mm during the years 1997-2004 while in Prek Kdam it was 1079 mm. The average, used in this study for rainfall, was 1287 mm (Table 6).

Table 6. Monthly average precipitation at Siem Reap (SR) and Prek Kdam stations.

	SR	Prek Kdam	AVG
Jan	0.7	15.8	8.2
Feb	4.6	1.1	2.8
Mar	20.8	17.2	19.0
Apr	62.9	40.2	51.6
May	164.7	112.8	138.7
Jun	245.7	140.1	192.9
Jul	234.2	139.1	186.7
Aug	205.9	134.2	170.1
Sep	272.1	183.4	227.7
Oct	210.4	192.6	201.5
Nov	65.4	85.2	75.3
Dec	7.0	17.8	12.4
Annual prec	1494.4	1079.4	1286.9

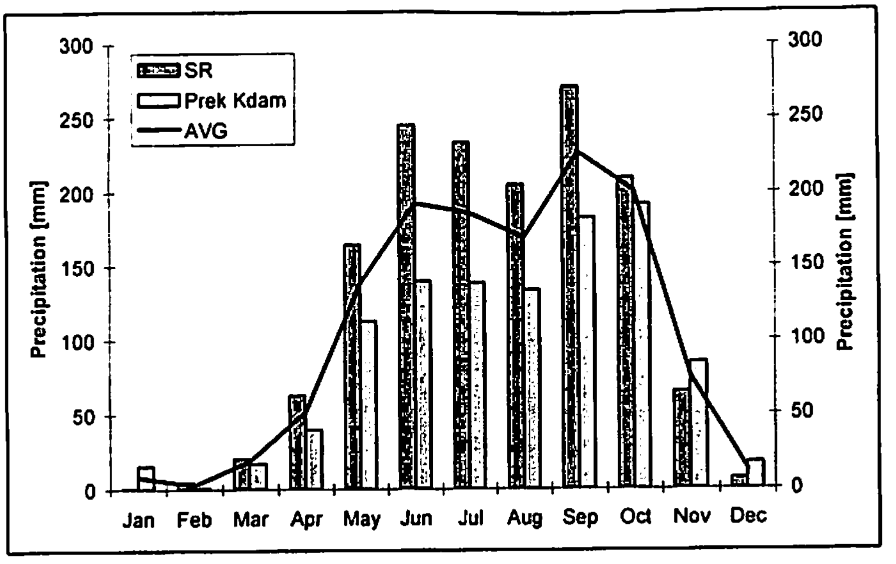


Figure 22. Monthly average precipitation at Siem Reap (SR) and Prek Kdam stations.

56. Overland flow from the Mekong through the floodplains is an important element in the Tonle Sap hydrology (Figure 24). However, based on the modelling done by the MRCS WUP-JICA study (CTI Engineering, 2004), the overland flow was reduced significantly after the national road construction. This happened due to the damming effect of the road and other embankments on the floodplain which link the Mekong River mainstream and Tonle Sap Lake floodplains.

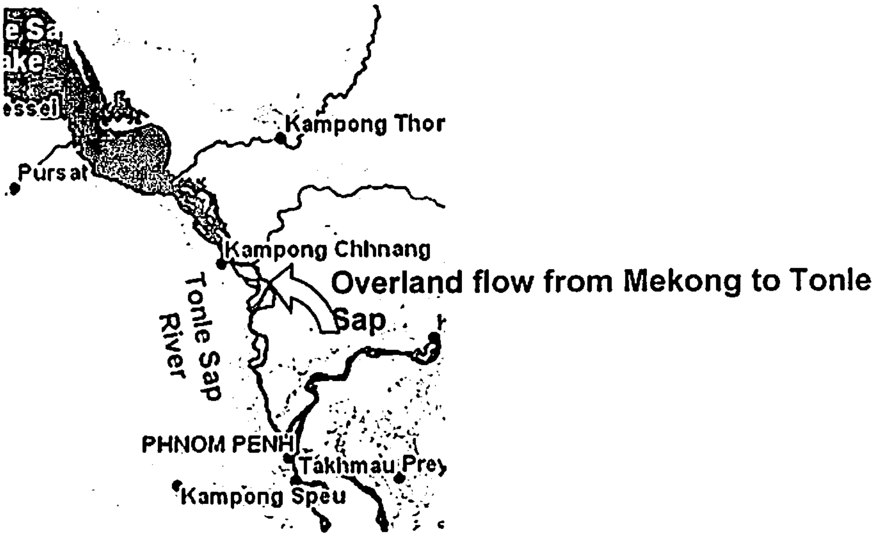


Figure 23. Overland flow from Mekong mainstream to Tonle Sap.

57. Basing the calculations on rating curves or monitoring the overflow continuously is almost impossible . Thus, to be able to include the overland flow in the water balance study the accurate hydrodynamic model should be applied. However, this is not available yet and the overland flow was calculated based on the difference between the calculated flow volume of the tributaries and Tonle Sap River and the measured volume.

58. The average overland flow into the lake was 4.4 km^3 during 1997 – 2003, while the average overland flow from the lake was only 0.7 km^3.

59. The Tonle Sap water balance is summarized in Table 7. The total inflow to the Tonle Sap varies from 44.1 km^3 (1998) to 106.5 km^3 (2000), the average being 79.0 km^3. Of the inflow, around 87% ends up to Mekong through the Tonle Sap River, 1% through overland flow while 12% evaporates directly from the lake.

Table 7. Summary of the inflow and outflow in km^3. Mekong part includes both, flow in Tonle Sap River and overland flow.

	In-Flow				Outflow			Balance
	Tribs km3	Mekong km3	Prec km3	TOTAL km3	Mekong km3	Evap km3	TOTAL km3	km3
1997	23.1	47.3	8.5	78.9	64.2	8.7	72.9	6.0
1998	12.6	24.8	6.7	44.1	36.8	6.7	43.5	0.6
1999	27.4	41.0	11.3	79.8	72.9	10.5	83.3	-3.6
2000	39.7	51.8	15.0	106.5	93.3	11.5	104.8	1.8
2001	27.1	52.9	12.4	92.5	83.0	10.5	93.5	-1.0
2002	21.7	56.8	11.3	89.8	84.3	10.0	94.3	-4.5
2003	15.2	38.5	7.9	61.6	50.4	7.5	57.9	3.7
avg	23.8	44.7	10.4	79.0	69.3	9.3	78.6	3.0 from absolute
% of total	29.7%	57.0%	13.3%		87.8%	12.2%		3.8% values

60. In Figure 24 the annual water balances have been presented. The inflows are precipitation, tributary flows and flow from the Mekong. The outflows are evaporation and flow to the Mekong.

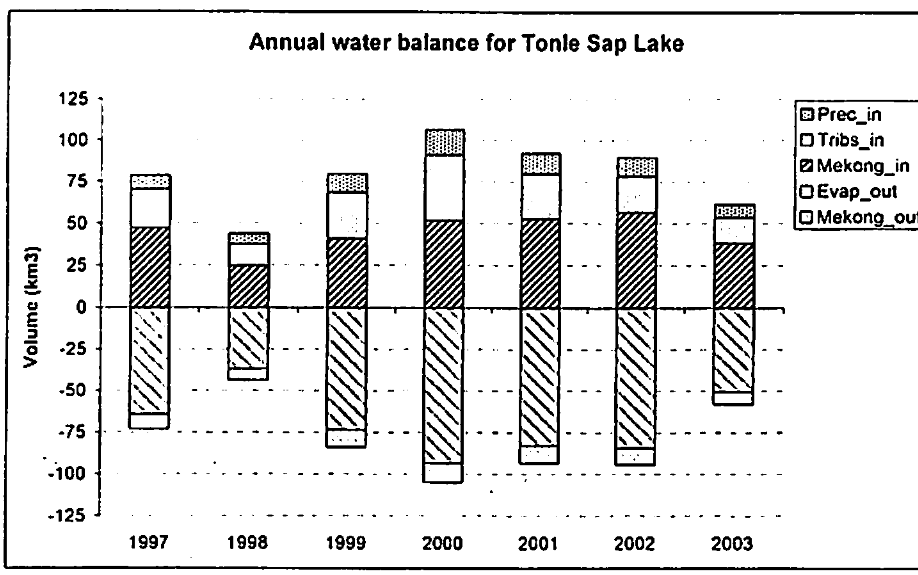


Figure 24. Annual water balances for Tonle Sap Lake (1997-2003). Positive values are flows into the lake and negative ones out of the lake.

61. In Figure 25 and Table 8 the monthly average water balances have been presented. The Tonle Sap fills up in May – September and dries out in October – April.

Table 8. Summary of the inflow and outflow in km³. Mekong part includes both, flow in Tonle Sap River and overland flow.

	Inflow			Outflow	
	Tributaries	Mekong	Precipitation	Mekong2	Evaporation
Jan	0.4	0.0	0.1	-9.4	-0.8
Feb	0.3	0.0	0.0	-4.1	-0.6
Mar	0.3	0.0	0.1	-2.2	-0.5
Apr	0.4	0.0	0.1	-1.2	-0.4
May	0.8	0.9	0.3	-0.7	-0.3
Jun	1.3	5.6	0.7	-0.2	-0.4
Jul	2.2	11.2	1.1	-0.1	-0.7
Aug	3.6	15.5	1.5	-0.3	-0.9
Sep	4.7	10.2	2.8	-1.5	-1.1
Oct	6.0	1.3	2.7	-17.3	-1.2
Nov	2.3	0.0	0.8	-18.9	-1.3
Dec	0.7	0.0	0.1	-14.7	-1.2

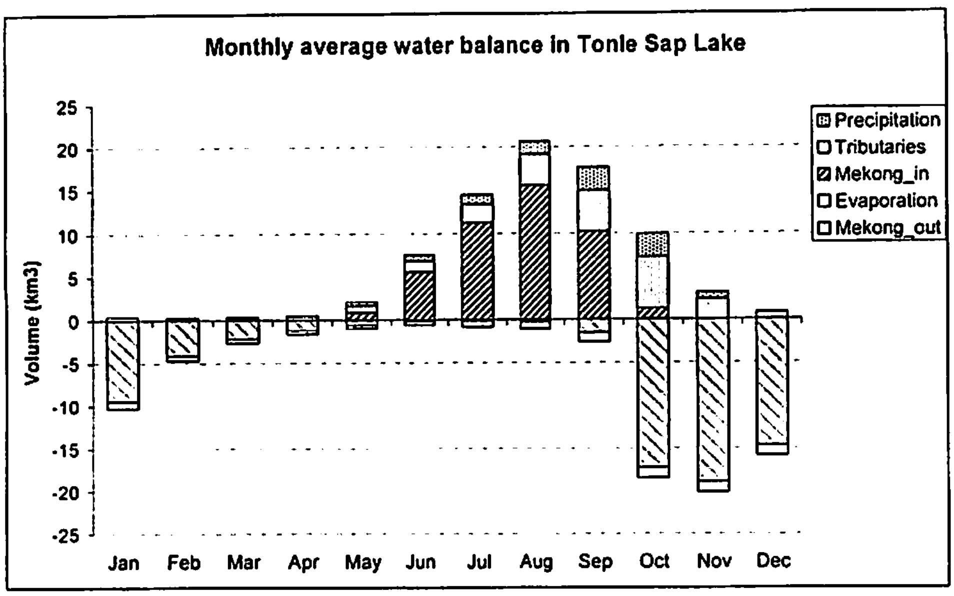


Figure 25. Monthly Tonle Sap water balances.

III.2 MEKONG SCALE BUILT STRUCTURE IMPACTS

III.2.1 Human impact compared with natural variability

62. The conditions in the Tonle Sap are very variable. The total inflow to Tonle Sap varies from 44.1 km^3 (1998) to 106.5 km^3 (2000), average being 79.0 km^3. The maximum lake volume varies between 30 and over 70 km^3 (see Figure 27). The maximum area varies between 10,000 and 15,000 km^2 and maximum lake height between 7 to 10 m.

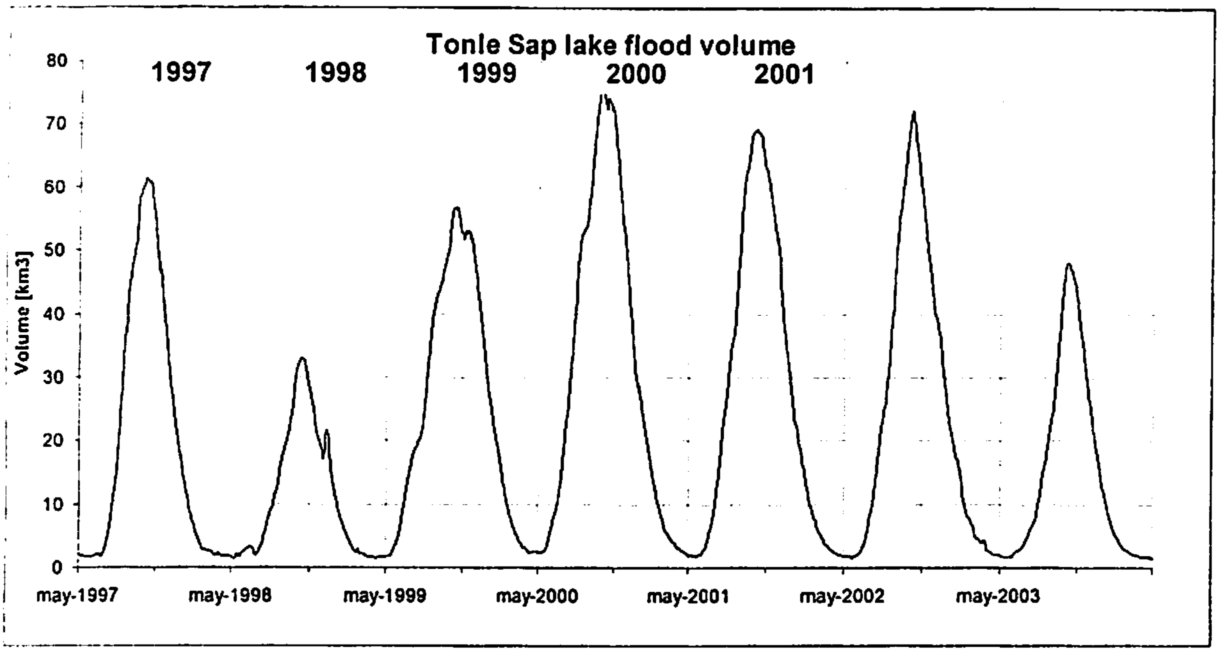


Figure 26. Yearly variation of the Tonle Sap Lake volume

63. The magnitude of the natural variability can be compared with the human impact on the Tonle Sap flow. The change of inflow for the Intensive Development Scenarios is about 4.5 km^3 and for the Mainstream Dams about 11 km^3. These are about 10% and 25% of the dry year (1998) total inflows respectively. In a wet year (2000) the percentages fall to 4% and 10% of the total inflow.

64. The computed impact of the development scenarios is shown in Figure 27 (for a definition of the scenarios see Chapter II.5). The figure presents the current water level (solid line) compared with the Tonle Sap hydropower and irrigation dam (grey line), Basin-wide Intensive (tightly dotted line) and Mainstream Dams Development scenarios. The scenarios change the dry season water level, flood timing and maximum flood height. The changes are most pronounced in the dry year (1998), and because of this in consequent chapters the results are mostly presented from the year 1998.

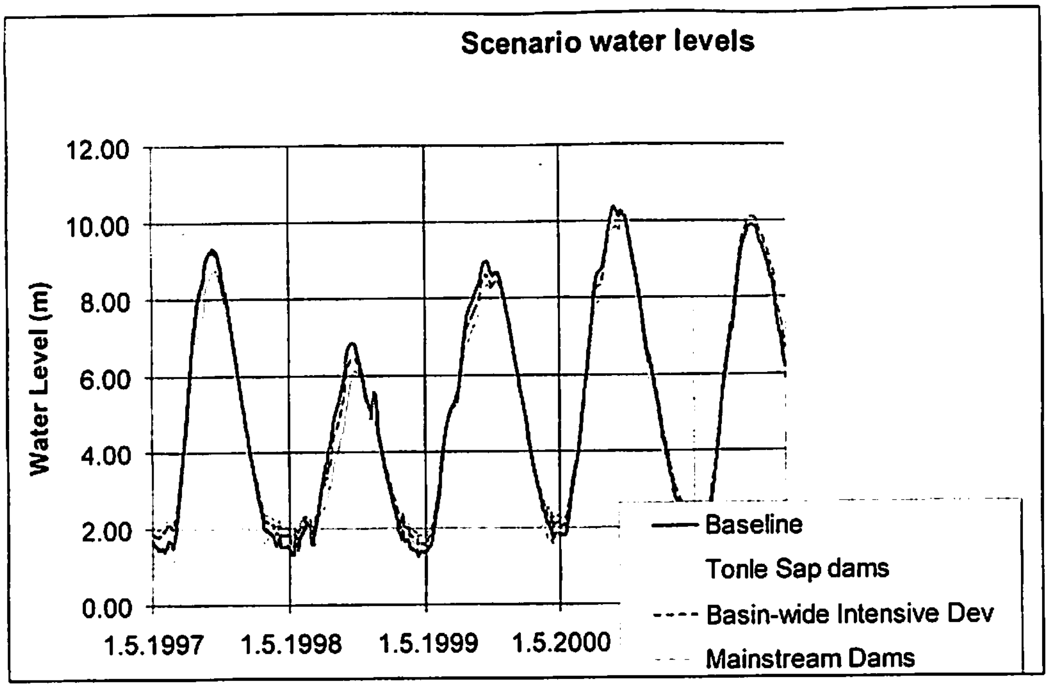


Figure 27. Natural water level variation between years (solid black line) compared with the scenario water levels (gray and dotted lines).

65. Upstream developments cause changes in the Mekong water levels and consequently in the Tonle Sap River flow. The estimated flow changes in the Intensive Development scenarios are based on the basin-wide MRCS model results. The flow changes have been added to the measured in- and outflows. For the Mainstream Dam scenario it is assumed that the flow into the lake changes proportional to the mainstream flow change. The outflows are adjusted to get 20 cm and 40 cm dry season lake water level rises respectively in the Intensive and Mainstream cases. As is discussed below, the actual dry season water level rise is uncertain. Here the lower end of the water level rise is used.

III.2.2 Upstream development impacts

66. In general, development of upstream water resources can have a major impact on the Tonle Sap fisheries. This follows from the fact that the Tonle Sap is strongly influenced by the Mekong. Around 57% of the Tonle Sap water originates from the Mekong either through the Tonle Sap River (52%) or overland flow (5%) while tributaries share is around 30% and precipitation 13%. Not only the Mekong strongly impacts the Tonle Sap, but some of the Tonle Sap fish migrate upstream the Mekong. Obviously, Mekong conditions have a direct impact on these types of fish.

67. As seen in Figure 27, the impact of the upstream dams is most pronounced during dry years. This results from the fact that during dry years the storage capacity of the dams is greatest relative to the flow. The impacts are aggravated by the fact that the fisheries are most stressed during dry years and consequently more vulnerable to adverse flow changes.

68. Figure 28 presents the calculated water levels in 1998 for the Baseline, Intensive Development and Mainstream Dams scenarios. Increasing upstream water storage for hydropower and agriculture lowers the maximal flood height and depth and consequently the flooded area. Although a straightforward relationship between Tonle Sap fisheries productivity and inundated area has been cast into question with recent years' catch data, it is clear that a decreasing flood means less primary production and fish habitat. The decrease of the maximum flood height for the Basin-wide Intensive Development scenario is about 0.5 m and corresponding flooded area about 10% during the dry year (1998). The loss of inundation happens in the very high areas that are flooded in any case for a short period of time. In addition, they are estimated to be nutrient poor and oxygen depleted habitats. A more serious problem is the decreased flood depth and volume over the lower reaches of the floodplain.

69. As seen from Figure 29, increasing upstream water storage delays and shortens the flooding, which impacts fish migration, habitats and fish growth. The delay and shortening depends on the floodplain elevation zone (compare Figure 29a), year (wet/ dry/ average), intensity of the upstream developments and reservoir operation. The largest impacts are encountered during the dry years when the storage capacity is relatively large compared to the natural flows..

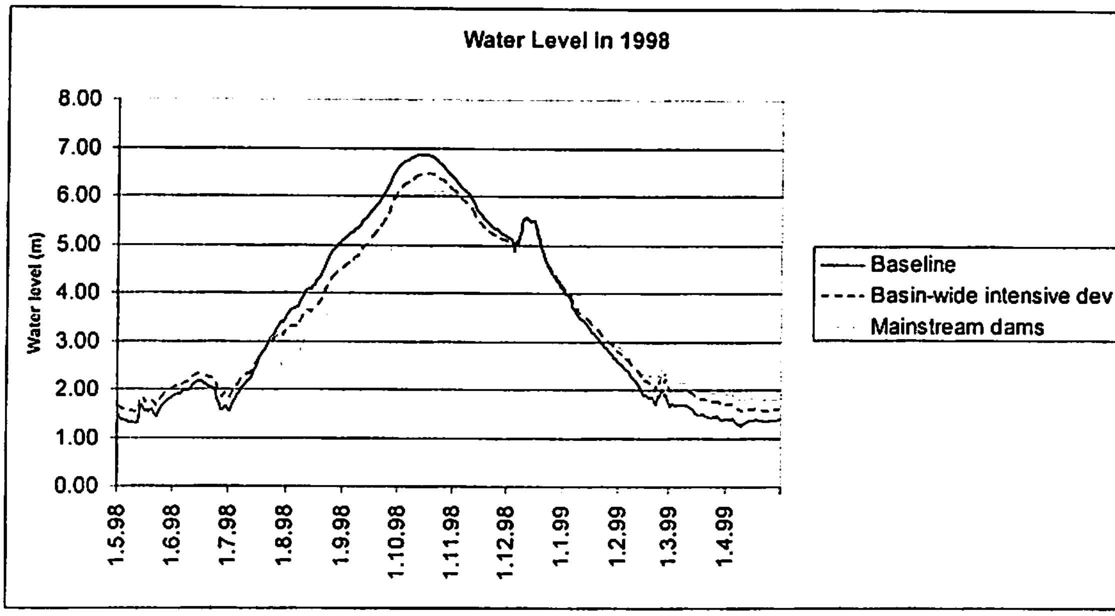


Figure 28. Lake water levels in the Baseline (uppermost line), Intensive Development (middle) and Mainstream Dams (lowest) scenarios.

70. The modelled impact of the Intensive Development scenario on the flood arrival time is presented in Figure 30a. The delay in inundation is typically one week compared to the current situation. In the Extreme Mainstream Dams Development scenario the delay can even be one month in a dry year. The flood duration is related to the flood arrival time. The shortening of the inundation is typically 1 – 2 weeks in the upper areas of the Tonle Sap floodplain (Figure 29b).

71. Because the start of the flood season happens quite regularly every year within a window of a few days, the delay in the flooding can adversely affect fish breeding. Shortening of the inundation affects the habitats on the floodplain and decreases the time fish can feed and grow on the floodplain.

Flood arrival time difference in 1998

Figure 29a. The impact of Intensive Development scenario on flooding. The figure shows the arrival time difference between the Baseline and Intensive Development scenarios. In other words the values show how many days the flood is delayed because of the upstream developments.

Flood duration difference in 1998

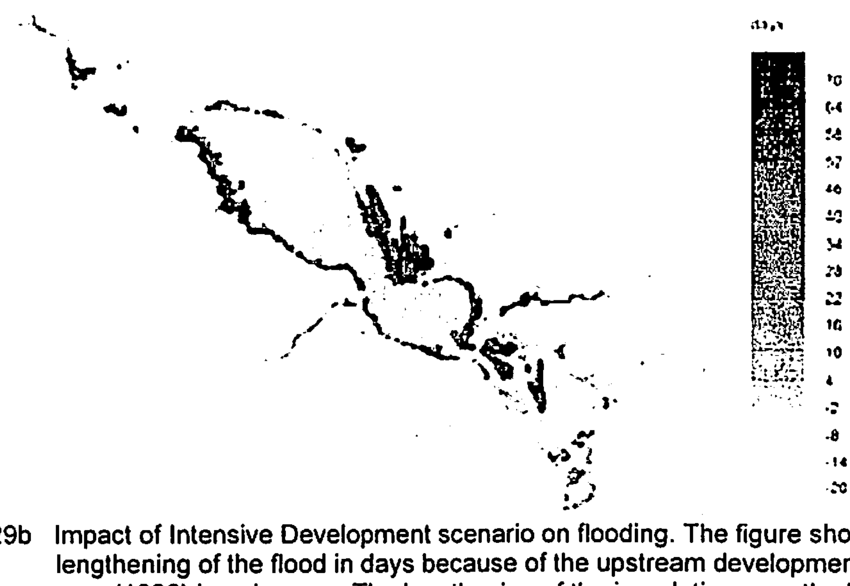


Figure 29b Impact of Intensive Development scenario on flooding. The figure shows shortening and lengthening of the flood in days because of the upstream developments. The simulation year (1998) is a dry year. The lengthening of the inundation near the lake edge is caused by raising water levels during the dry season.

72. During the dry season upstream hydropower dams release water, keeping the Mekong and Tonle Sap River and Lake water levels higher than normal. The estimates for the water level change vary between 0.15 and 0.9 m depending on the study. The studies have been based either on use of rating curves or mathematical models. In the scenario runs it is assumed that the Intensive Development scenario will raise the dry season water levels 20 cm and the Mainstream Dams 40 cm.

73. The permanent water level change impacts the flooded forest near the Lake edge (Figure 30a). The flooded forest in a very narrow fringe on the lake edge acts as a buffer protecting the floodplain against rough conditions in the lake. It is also an important habitat for fish where it can search for shelter for breeding and feeding while benefiting from the oxygen and nutrient rich lake conditions. The dry season lake edge moves to the floodplain permanently inundating the lake edge forest (Figure 31b) and destroys the forest that requires periodical dry conditions. The increase of the dry season lake area is 300 – 900 km^2, or 15 – 45% of the dry season lake area.

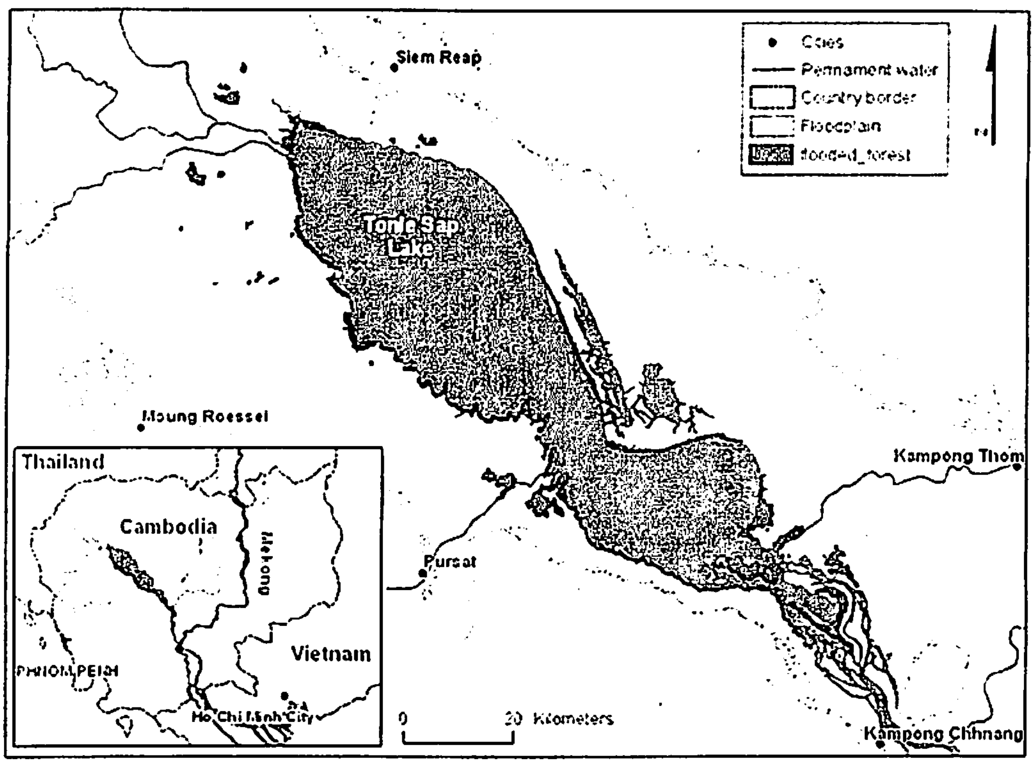


Figure 30a. Flooded forest based on JICA (1999) land use map for the Tonle Sap Lake.

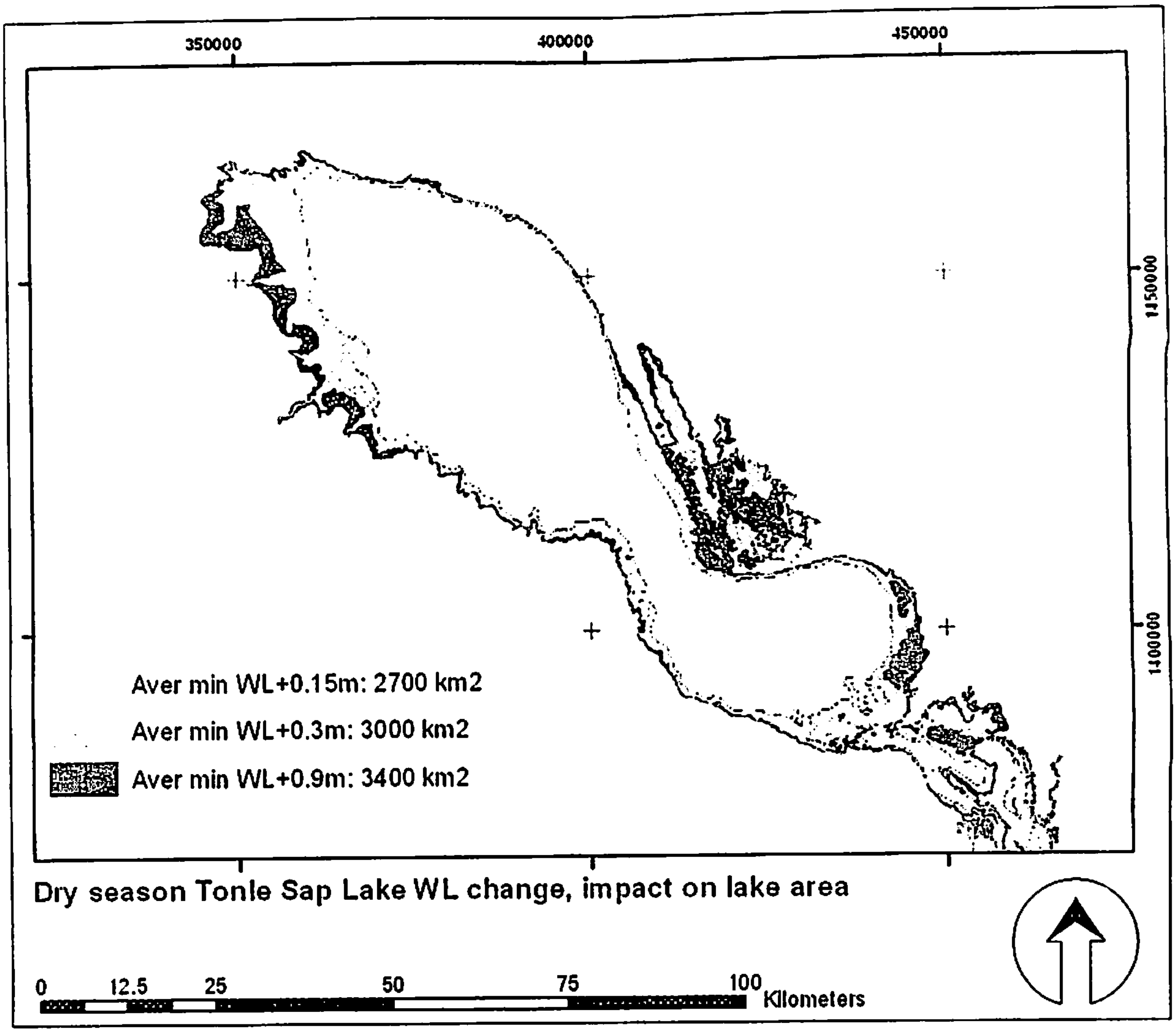


Figure 30b. Increase of the dry season lake area according to different estimates. Yellow corresponds to 15 cm water level rise, orange to 30 cm and red to 0.9 m rise.

74. Although the lake productivity is not well understood, it may be assumed that the sediments may play a key role in providing nutrients to the Tonle Sap system and thus sustaining its high productivity. About 70% of the sediment influx to the Tonle Sap originates from the Mekong (Figure 31). Thus, the changes in the amount and composition of sediment caused for instance by upstream dam development or land use changes can have a major impact on the sediment inflow and Tonle Sap productivity.

75. As an example of the upstream development impact on sedimentation, the impact of the Chinese dam cascade was studied. More than 50% of Mekong downstream suspended sediment originates from China. The planned Chinese dam cascade potentially traps nearly all of this sediment resulting in reduced sediment input and Tonle Sap productivity. Figure 32 represents the corresponding reduction in sedimentation in the Tonle Sap floodplain obtained from modeling results. *The most impacted areas shown in dark are also high fisheries productivity areas.* The hydrological year strongly affects the sediment input and

also the impact of the dams. In the figure the average hydrological year (1997) is presented. During 1998 the impact is less pronounced because the sediment input from the Mekong is smaller.

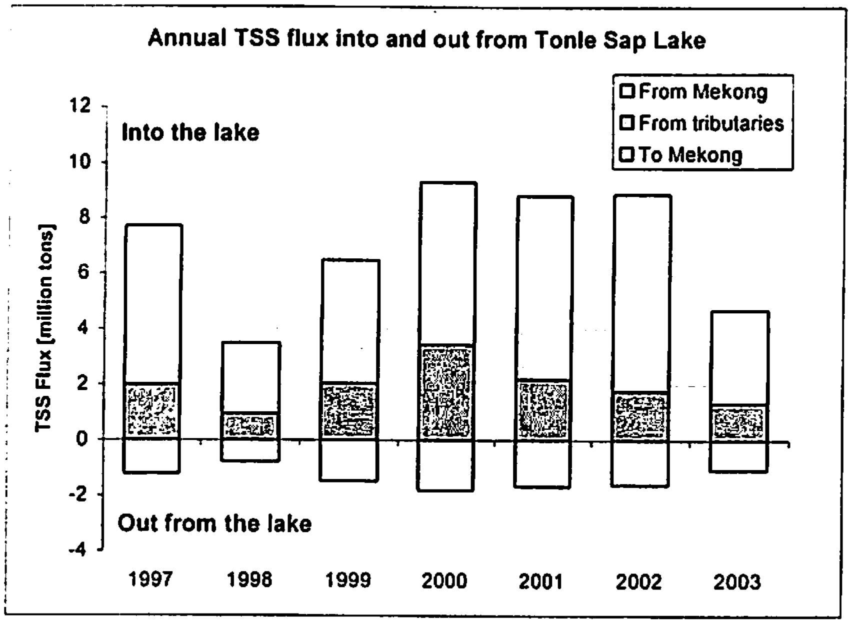


Figure 31. Annual TSS flux into and out from the Tonle Sap Lake (1997-2003). Results based on flow and TSS measurements.

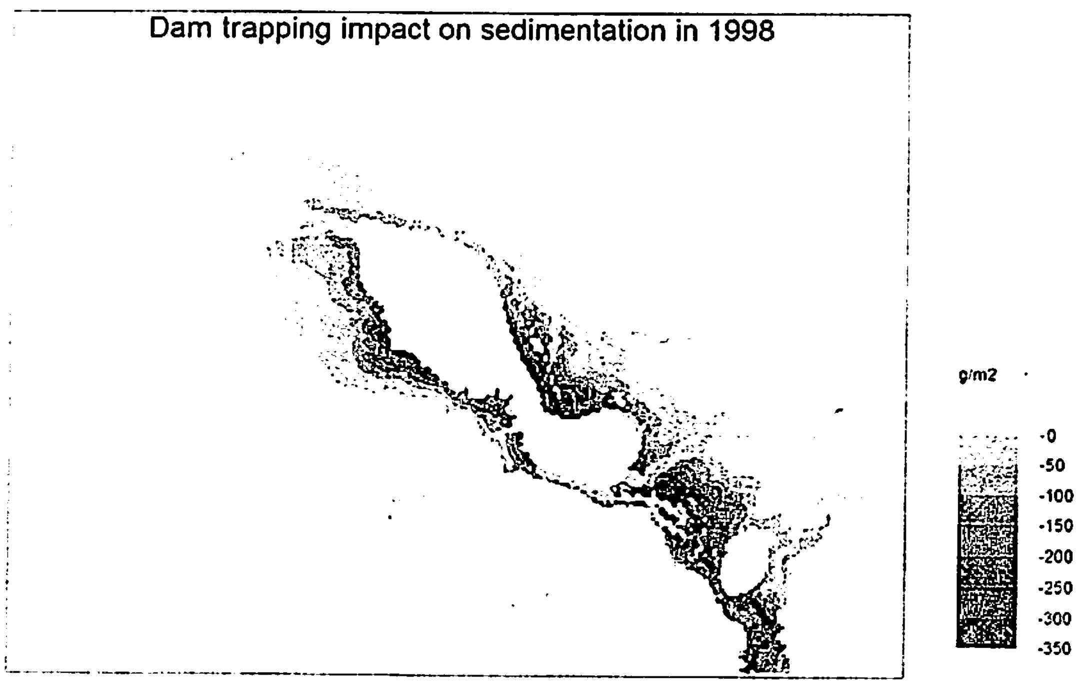
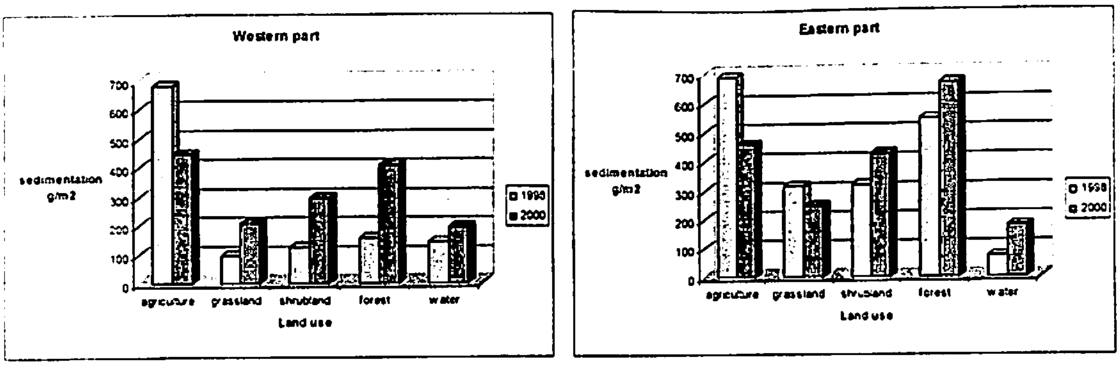


Figure 32. Modelled decrease of sedimentation due to the dam's trapping of sediments. The most impacted areas shown in blue are also high fisheries productivity areas. The average hydrological year (1997) is shown. During 1998 the impact is less pronounced because smaller Mekong sediment input.



a) b)

Figure 33. Modelled sedimentation per square meter in different hydrological years: light grey dry year (1998) and dark grey wet year (2000). On the left hand side western part of the Tonle Sap and right hand side eastern. Results are presented for different land use classes (agriculture, grassland, shrubland, forest and water). The area of the agricultural land is marginal.

76. The impact of the hydrological year on sedimentation is shown in Figure 35. The dry year (1998) is shown in light grey and the wet year (2000) in dark grey. The figure presents the average simulated sedimentation per unit area, and changes in inundated area should be taken into account in estimating the total sedimented material. The impact of the hydrological year can be seen especially on the western part of the lake (left box in the figure). During a high flood year the flood is able to carry significantly more sediment to the western part than during a dry year.

77. The sediment processes in the Mekong Basin are not very well known. The origin of the very fine sediments (average grain size 13 µm) that are most important for the Tonle Sap, has not been specifically studied. Also, the actual dam trapping capacity of the finer sediments has not been estimated. Because of this uncertainty the results presented above must be considered with caution.

78. Oxygen conditions are important for the fish. Fish species have developed strategies to cope with low oxygen conditions, but in general good oxygen conditions favor fish breeding and growth. The upstream developments can negatively impact oxygen conditions in critical breeding areas. The impact is caused by the flood delay especially in dry years and consequent delay of arrival of oxygen rich waters to the floodplain (Figure 36). This delay can have a negative impact on the sensitive juveniles on the floodplain. As the figure shows, the simulated oxygen values diminish by about 0.5 – 2 mg/l during August – September in the highly productive Lake Chhma area. When the oxygen values are low to start with, the reduction can be critical for the fish.

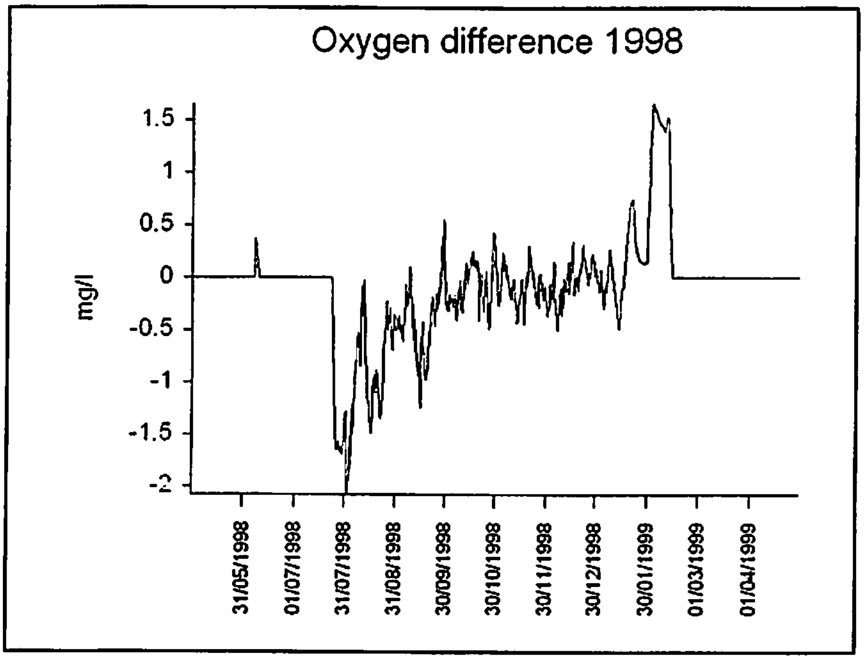


Figure 34. Modelled surface dissolved oxygen concentration difference between Baseline and Intensive Development scenario for 1998. The area is located about 5 km from the lake edge near Lake Chhma. The flat period when the time series is 0 corresponds to time when the area is dry land.

79. The changing flow regime changes water flow in the lake and the floodplain. This in turn impacts fish larvae and juvenile drift. The key process in the larvae drift is the entrance of the migratory fish larvae from the Mekong and drift to the breeding areas. Figure 35 shows the simulated fate of the Mekong larvae and juveniles in the Tonle Sap Lake. Practically all larvae end up on the northern and eastern shores. The intensive development scenario changes the drift more to the western basin. The change of the drift needs to quantified and its importance assessed by fisheries experts.

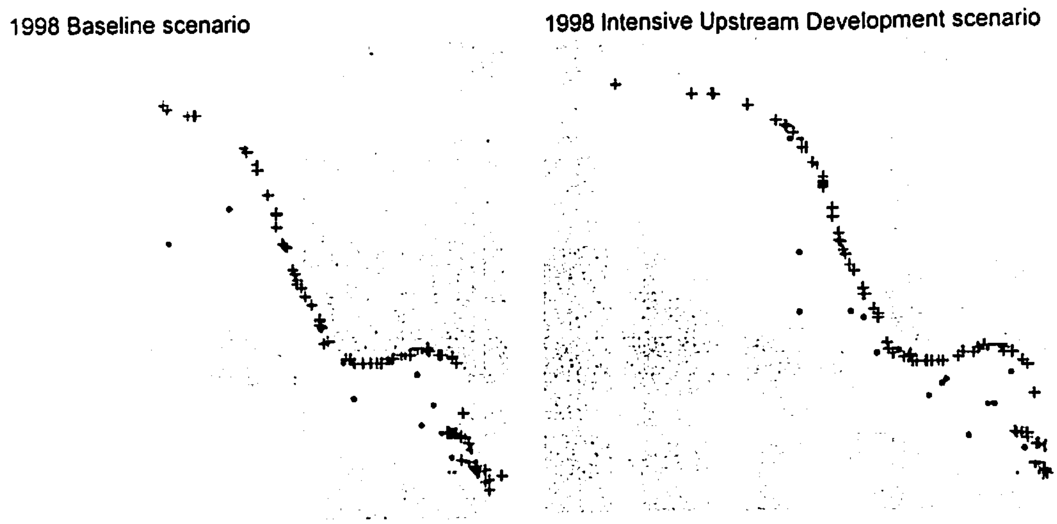


Figure 35. Simulated fish larvae drift from the Tonle Sap River during July – August 1997. Crosses indicate first point where larvae touches the flooded forest. Dots show drifting larvae. Observe lack of drift to the southern/western shore and concentration of the larvae on the eastern and Lake Chhma areas. Increased drift to the western basin in the intensive development scenario, which may result in decreased productivity in the Fishing Lot No 2.

80. Above the impacts of the development scenarios on specific Tonle Sap hydrological, sediment, water quality and fish larvae processes are discussed. Even taken individually, some of the impacts such as destruction of the riparian forest near the lake edge and decrease of sediment input to the lake could potentially have a significant impact on fisheries. When taken together impacts strengthen each other and even the smaller impacts may be important when taken together.

III.3 TONLE SAP SCALE IMPACTS

81. The Tonle Sap development was studied based on the Lower Mekong Water Resources Inventory, WATCO 1984 (see chapter "Tonle Sap watershed scenarios"). The inventory is based on a feasibility study for hydropower and irrigation development. At the moment the watershed water resources remain largely undeveloped. The actual implementation of the plans cannot be predicted, although some hydropower dams are under consideration.

82. For the whole Tonle Sap, the combined hydropower and irrigation storage potential represents relatively a small portion of the total inflow to the Tonle Sap. The total Tonle Sap storage capacity in the WATCO Inventory is 5.5 km^3 (see Table 3). This can be compared to the annual total inflow to the Tonle Sap, which varies between 44 and 107 km^3, the average being 79 km^3.

83. Figure 36 presents calculated current (solid line) and Tonle Sap Dams (grey line) scenario water levels. The levels are compared with the Intensive Development scenario (dotted line). During the rising flood the Basin-wide and Tonle Sap scenarios behave quite similarly. In the Tonle Sap scenario the flood delay starts earlier, but this depends on the actual operation of the dams. Because the Basin-wide Development and Tonle Sap Dams

scenarios are close together, the results presented in the previous chapter are mostly relevant for the Tonle Sap Dams scenario.

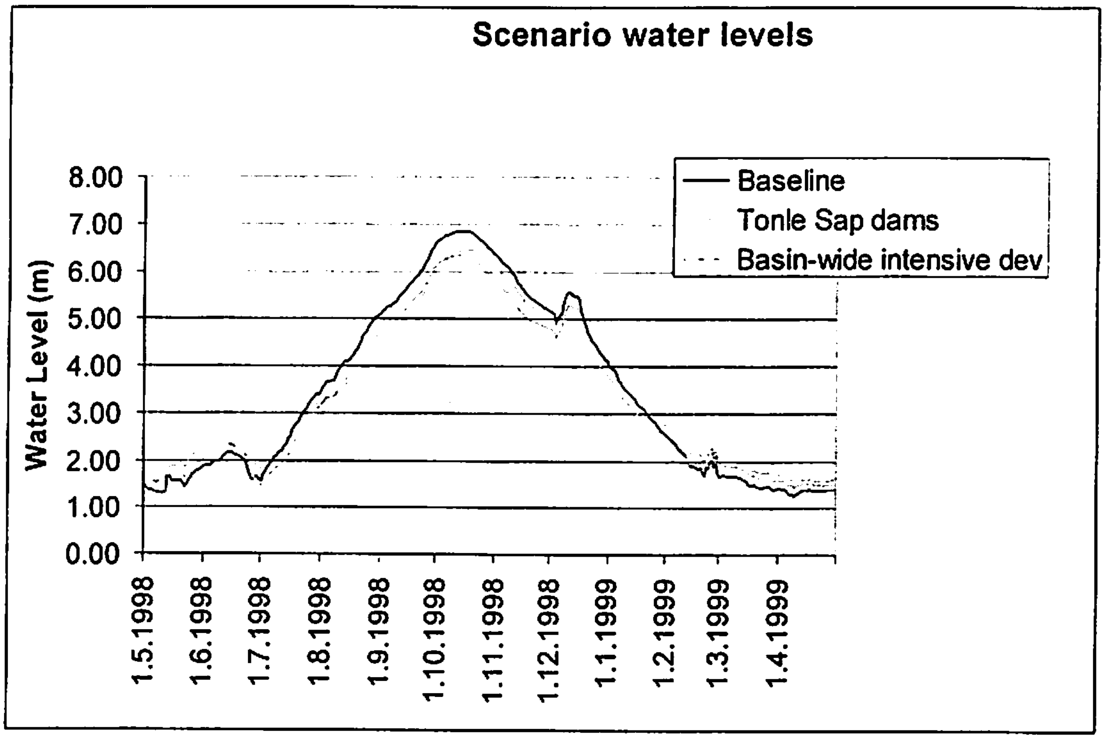


Figure 36. Impact of the potential Tonle Sap dam developments on the Lake water levels. Solid line the Base-line, dotted one Intensive Upstream Development scenario and the grey one Tonle Sap developments defined in Table 3.

84. The Tonle Sap dam storage behaves in similar way to the upstream dams reducing flood flow and increasing dry season flow. The total magnitude of the impact during the rising flood is similar compared to the Basin-wide Intensive Development scenario. Because of this, *the Tonle Sap hydropower and irrigation storage structures can significantly strengthen the upstream development impacts.* The total cumulative impact of the Tonle Sap Dams and Basin-wide Developments scenarios would be about the same as in the Mainstream Dams scenario during the rising flood.

85. The main difference between the upstream Mekong and local Tonle Sap development is that the local developments have less impact on the total inflow. Eventually stored water is released from the local storages minus the amount evaporated from the reservoirs and possible irrigation schemes.

IV LOCAL SCALE RESULTS

IV.1 INFLUENCE OF ROADS

86. Figure 37 presents a figure showing the calculated flow field during rising flood in Pursat province near the Pursat River. The left figure is without road and the right one with a 10 km road from the upper floodplain to the lake edge. The flow velocities are in general very small in the floodplain compared to the lake and flows can easily bypass the road on the lakeside. A road in this type of place does not impact the flooding, although it can block flow from one part of the floodplain to another.

87. A road placed on the upper left hand corner of the area shown in Figure 39 would *block the* flow from the river to the floodplain as long as there was not be a bridge. The flow can be important in bringing oxygen and nutrient rich water to the floodplain as well as spawn from upstream. The importance of taking into account the hydrodynamic conditions of the floodplain is highlighted in Figure 40 showing the fish-rich Lake Chhma area. The complex channel network should not be blocked in order not to cause degradation of conditions by decreased flow, oxygen, nutrient, and spawn inputs.

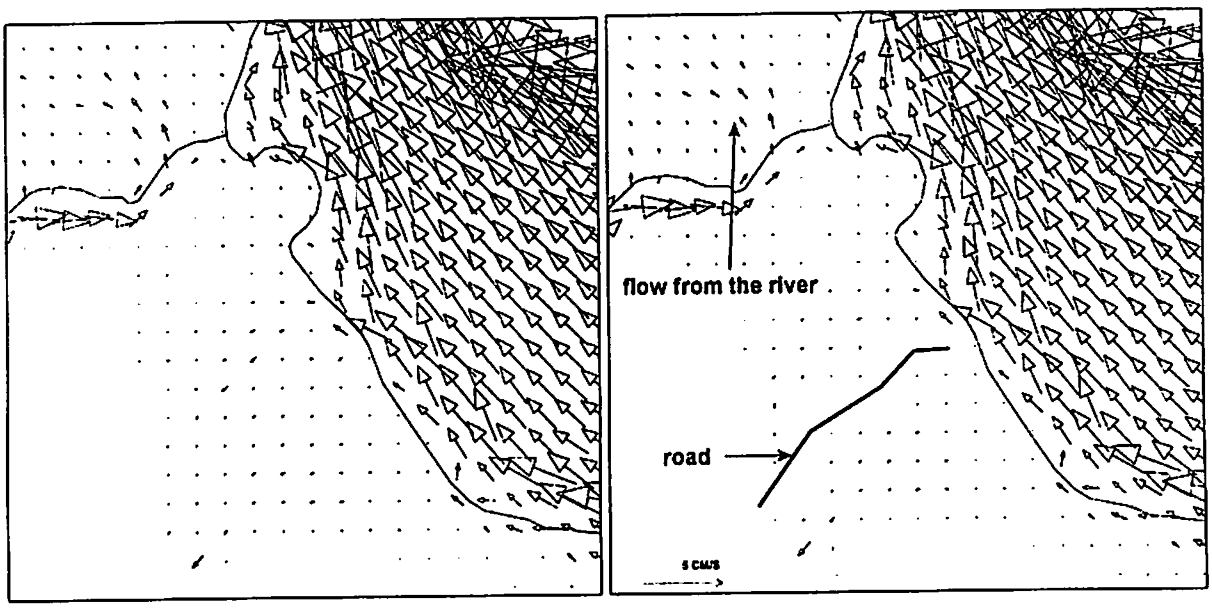


Figure 37. Impact of a road construction on floodplain flow in the Pursat province near the Pursat River. Left without a road and right with about 10 km long road. Lake flow is indicated by large arrows. Flow from the Pursat River to the floodplain indicated on the north-western corner of the figure. Observe very low floodplain flow velocities and small impact on either the floodplain or lake flow.

Figure 38. Lake Chhma area illustrating complex network of channels. Flows essential for the hydrological, hydrodynamic and ecological functioning of the area should not be blocked.

IV.2 INFLUENCE OF IRRIGATION SCHEMES ON HYDROLOGY, SEDIMENTS, WATER QUALITY AND FISH

IV.2.1 Field study based Stung Chinit impact assessment

88. As a representative reservoir, the Stung Chinit irrigation scheme was studied both by modelling and field sampling. The map of the area, set-up of the field study and the measurement points are presented in the chapter "Methods and Tools". The main results indicating reservoir impacts are studied below.

89. Inflow to the Stung Chinit irrigation reservoir and outflow from the reservoir were approximately the same on the measurement days (Figure 39.). Main structure impacts on the flow (inflow versus outflow) are not present. Small differences can be observed, and can be attributed to rainfall pulses, lake water level oscillations caused e.g. by wind, backwater effects and operation of the irrigation system.

90. Figure 39 illustrates the abrupt change in hydrological conditions during the flood and dry seasons. In November the flow is about a fifth of that in October. In January the flow is less than 10% of the peak flood flow. The balance between the in- and outflows did not change during the observation period.

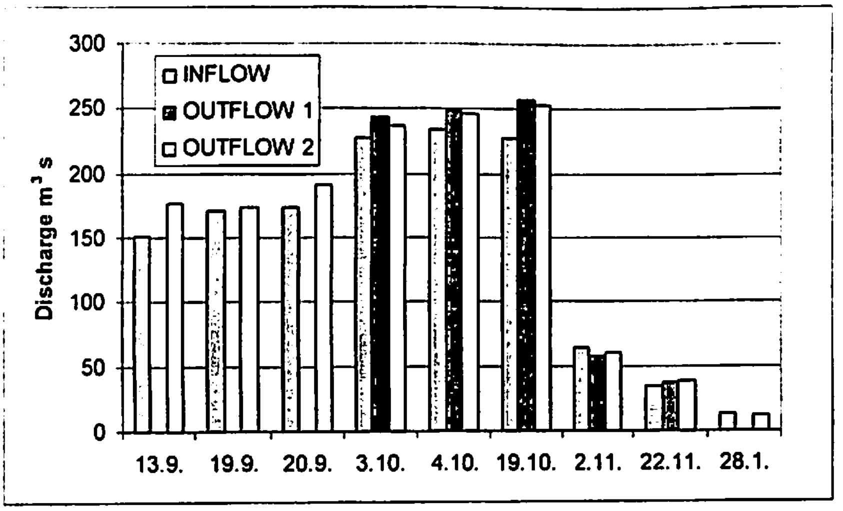


Figure 39. Measured Stung Chinit reservoir impact on flow in September – January 2007. The blue bars show measured inflow (discharge) and red and yellow ones outflow measured in different downstream locations (compare to Figure 2).

91. The Stung Chinit irrigation system positively affects the downstream oxygen conditions. Oxygen concentration in the river increases after flowing over the spillway and through the sluice gate of the dam (Figure 42, outflow oxygen concentrations). The concentration of outflowing water is approximately 20% higher than the concentration of the river water entering the reservoir. This is because of the spillway and sluice gate aerate the through-flowing water effectively.

92. In the reservoir oxygen concentration decreases to some extent because of decay of organic material. Slow flow velocities in the reservoir and the biomass production of the reservoir increase the amount of sedimented organic matter on the bottom. Decay of this material as well as of the inundated terrestrial organic material consumes oxygen. Oxygen concentration decreases in deeper water layers if flow and waves are not able to mix stratified water layers (Figure 42, reservoir profiles). Decreased oxygen concentrations occur especially in the sheltered deep water areas where flow velocities are low, but open areas can also stratify during calm periods. Decreased oxygen concentrations on the bottom layer may have negative impact on some oxygen sensitive fish species and it also increases nutrient concentrations due to anoxic processes. Low oxygen concentrations in the reservoir occur in any case locally. The overall impact of the reservoir is to increase the oxygen concentrations of the outflowing river water. In addition, the surface oxygen concentrations remain good in the reservoir.

93. The oxygen values can be compared with different flow conditions in November and January. In January the flow is less than half of the November flow. The outflowing water is well oxygenated in the whole water column. In January the dissolved oxygen concentration is about 1 mg/l higher because the water temperature is lower and oxygen concentration higher. Surprisingly, the reservoir oxygen conditions are not appreciably affected by the through-flow and the reservoir is rather well oxygenated even near the bottom both in November and January.

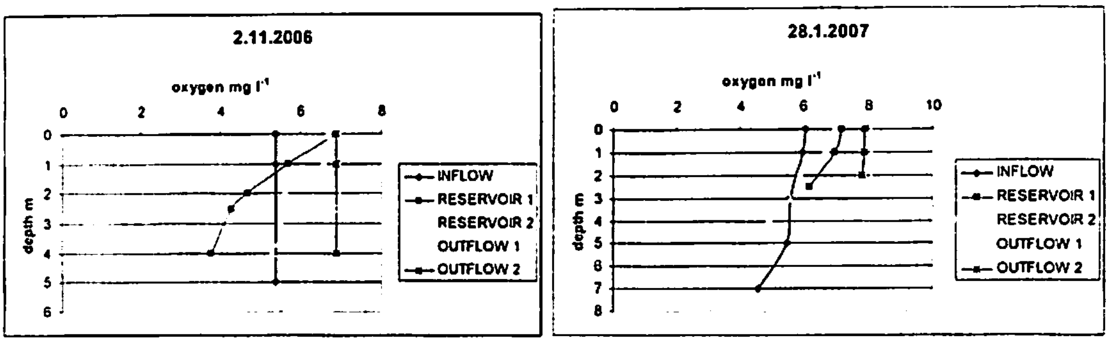


Figure 40. Oxygen profiles in the sampling locations 2.11.2006 and 28.1.2007.

94. The overall tendency of the reservoir is to slightly increase total suspended sediment concentrations (Figure 43.). Values of inflowing water vary between 15 - 37 mg l^{-1} and values of outflowing water between 11 - 45 mg l^{-1}. Visibility, measured as Secchi depth, has a correspondingly decreasing trend in the influence area of the structure. The visibility decreases more or less steadily from upstream to downstream (Figure 44.). The increased value of total suspended sediment concentration and decreased visibility downstream of the structure can be caused by phytoplankton production in the reservoir and resuspension. Erosion of the riverbank downstream of the dam may also explain the changes in the values.

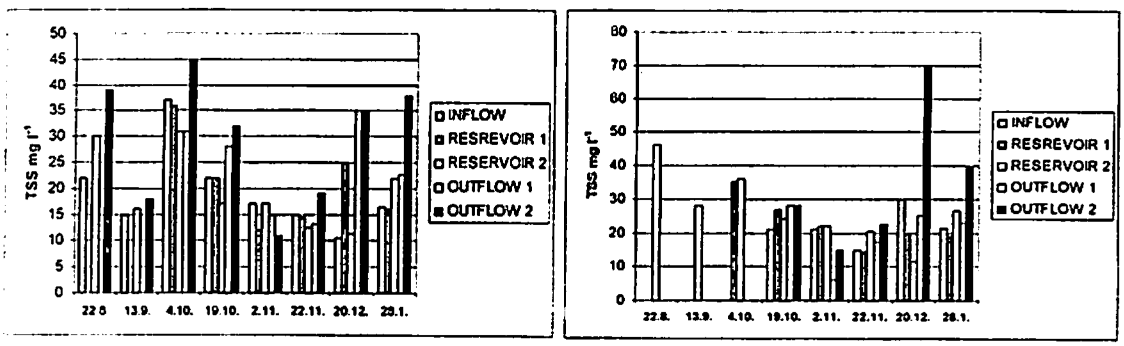


Figure 41. Total suspended sediment concentration one meter under the water surface (on the left) and one meter above the bottom (on the right).

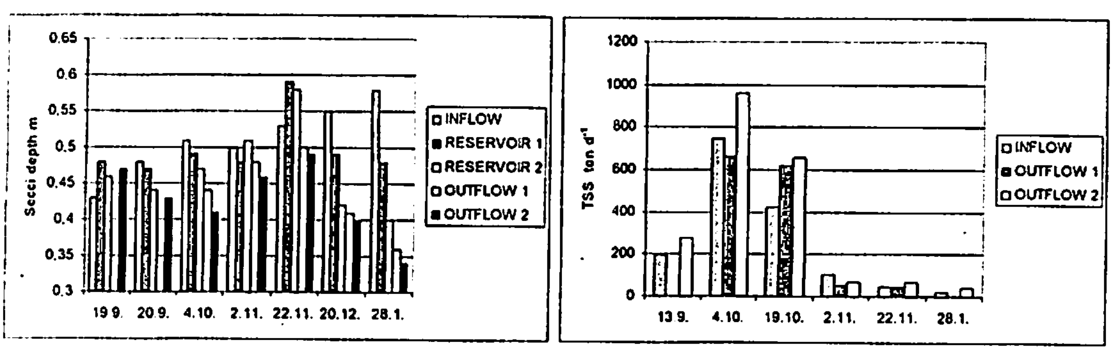


Figure 42. Secchi depths at the sampling locations (on the left) and total suspended sediment mass balance in the river (on the right).

95. A significant reservoir impact on the river nutrient dynamics cannot be observed. Total nitrogen and phosphorus concentrations of inflowing, reservoir and outflowing water vary without a very clear trend (Figure 45.). There is anyway a weak average trend in concentration and nutrient mass balance (Figure 46.) results. During the flood season nutrients are released from the reservoir, during the flood peak trapped in the reservoir, and with smaller discharges the balance is approximately stable.

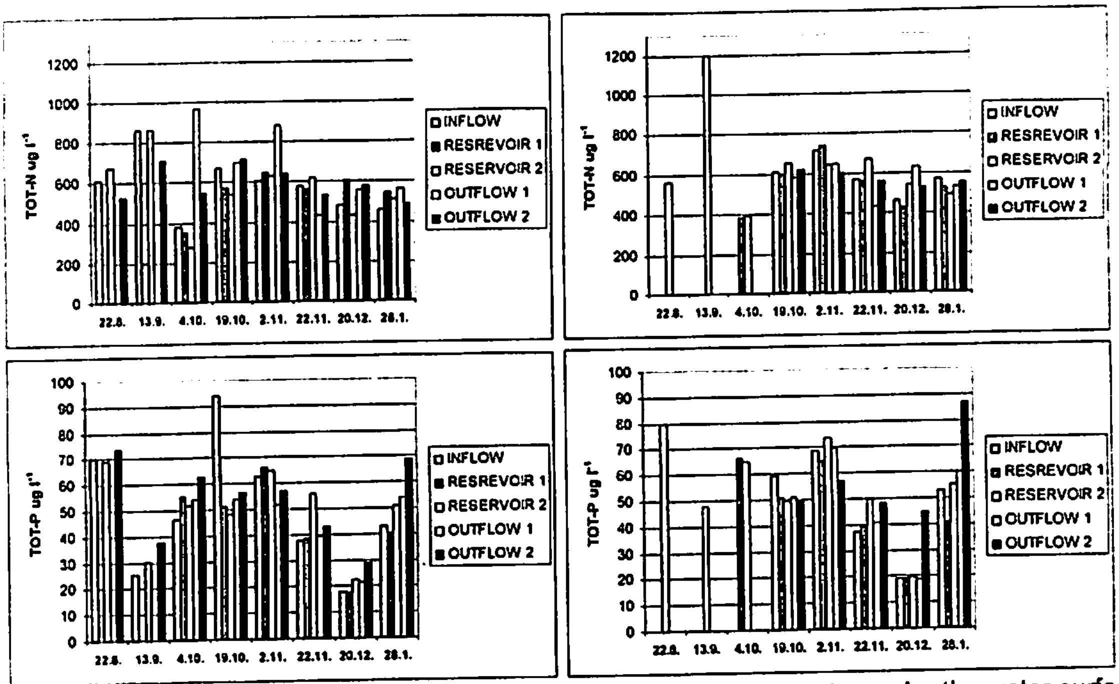


Figure 43. Total nitrogen and phosphorus concentrations one meter under the water surface (on the left) and one meter above the bottom (on the right) at the sampling locations.

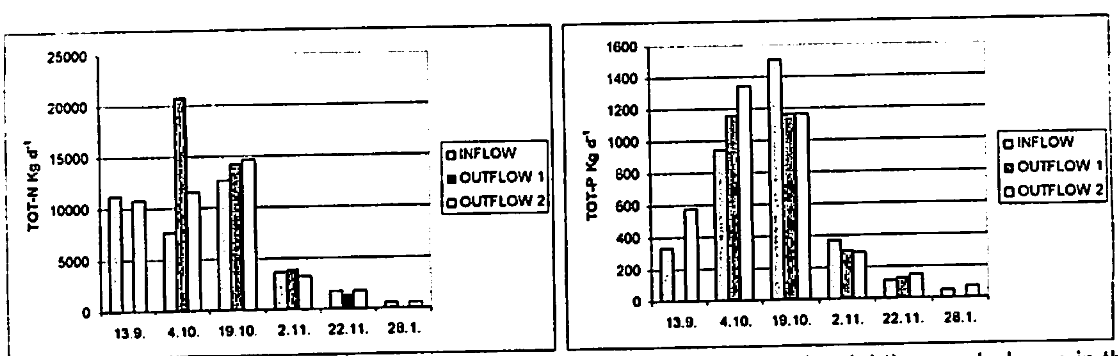


Figure 44. Total nitrogen (on the left) and total phosphorus (on the right) mass balance in the river.

96. Comparing suspended sediment, total nitrogen and total phosphorus concentrations at different times with radically different flows shows that they do not depend on flow in a straightforward way. However, it is important to note that the fluxes are much smaller in the dry season (November and January) than in the flood season because of the much smaller flows (Figure 44).

97. In general, the water quality characteristics of the river water are not significantly impacted by the reservoir. Proportions of phosphorus and nitrogen fractions stay stable or vary inconsistently in the influence area. Also, other measured parameters do not indicate any significant changes in the river water quality. Minimum, maximum and average values of other water quality parameters are listed in Table 9.

Table 9. Chemical oxygen demand, pH, alkalinity and conductivity values.

		CODM mg l^{-1}	pH	ALK+ mgCa	Cond. mS m^{-1}
INFLOW	min	1,4	5,9	7,5	2,4
	aver.	2,7	6,7	11,6	3,0
	max	6,2	8,0	19,2	4,1
RESERVOIR 1	min	1,5	6,1	9,8	2,5
	aver.	2,8	6,7	11,9	2,8
	max	4,5	7,9	15,2	3,2
RESERVOIR 2	min	1,4	5,7	8,1	2,5
	aver.	3,1	6,4	12,0	2,9
	max	8,4	7,9	17,6	3,2
OUTFLOW 1	min	1,1	6,1	8,5	2,6
	aver.	2,5	6,6	12,0	3,0
	max	3,9	7,8	17,2	3,9
OUTFLOW 2	min	1,8	6,0	9,0	2,6
	aver.	3,1	6,5	12,0	3,0
	max	8,5	7,9	17,7	3,5

98. The irrigation canal network maintains water balance in the rice fields and at the same time offers, together with the reservoir, a new habitat for fish. When irrigation is active the discharges of the canals are relatively high. Nutrients and total suspended sediments are released from rice fields and canals during that period. Concentrations of total nitrogen, phosphorus and suspended sediments increase in the irrigation and drainage canals compared to the values in the reservoir (Figure 45). High peaks in the nutrient concentration values indicate the impact of fertilizers. Water flowing back into the river via drainage canals has a loading effect downstream of the river. However, the loading effect of the system is small due to the small through-flow.

99. Connectivity of the canal network depends on the operational status of the irrigation system. When irrigation is active the canal flows are relatively high and the canals are connected with each other. When irrigation is passive the canal flows decrease and many of the canals dry up. During the measurement period irrigation was active until 20.12. At that time the secondary irrigation canal was dry and discharges of tertiary and secondary drainage canals were so small that canals were not connected. All the canals were dry by 28.1. During the passive irrigation phase the connectivity of the canals breaks reducing fish movement and the suitability of the habitat for fish.

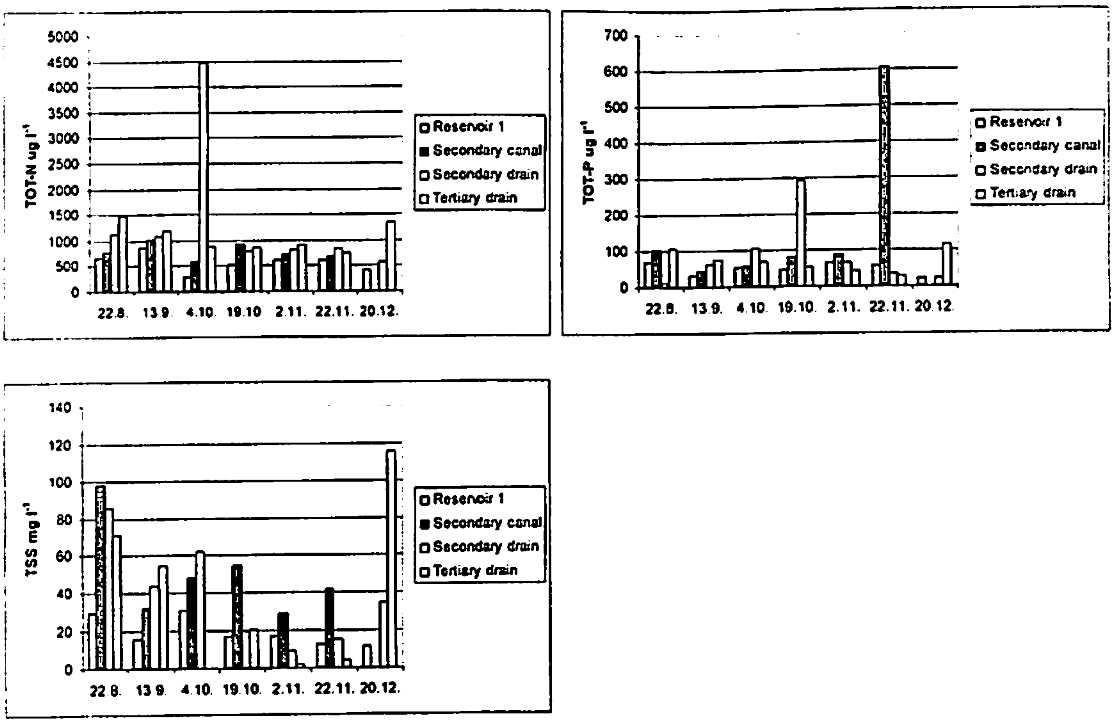


Figure 45. Total nitrogen (above on the left), total phosphorus (above on the right) and total suspended sediment concentrations in the irrigation canals.

100. Oxygen conditions are good in the irrigation canals and chemical oxygen demand is equivalent to the values of the reservoir (Table 10). Significant changes can be seen in the drainage water pH, alkalinity and conductivity. The values are smaller compared to the values in the reservoir.

Table 10. Oxygen, chemical oxygen demand, pH, alkalinity and conductivity values in the reservoir and irrigation canals.

		O_2 mg l^{-1}	CODM mg l^{-1}	pH	ALK+ mgCa	Cond. mS m^{-1}
Reservoir 2	min	1,3	1,4	5,7	8,1	2,5
	aver.	5,6	3,1	6,4	12,0	2,9
	max	8,5	8,4	7,9	17,6	3,2
Secondary canal	min	5,7	1,4	5,8	6,2	1,9
	aver.	6,9	3,8	6,3	12,3	2,8
	max	7,6	8,5	7,4	18,6	3,3
Secondary drain	min	6,5	1,0	5,5	2,6	1,2
	aver.	7,4	3,0	6,4	7,4	2,0
	max	8,3	5,3	7,6	14,2	3,3
Tertiary drain	min	5,3	1,0	5,3	2,0	1,5
	aver.	7,5	3,1	6,5	7,7	2,4
	max	8,4	4,8	7,7	14,2	3,2

IV.2.2 Model based Stung Chinit impact assessment

101. The reservoir has a relatively small hydrological impact. This follows from the small volume of the reservoir compared to the through-flow. Filling up of the reservoir is presented in Figure 46. The figure shows the simulated reservoir water level starting from an empty reservoir. The reservoir fills up in less than a week even in June when flow volumes are not at their peak. When the reservoir is full it has an insignificant impact on flows. This is confirmed by field measurements presented in Figure 41.

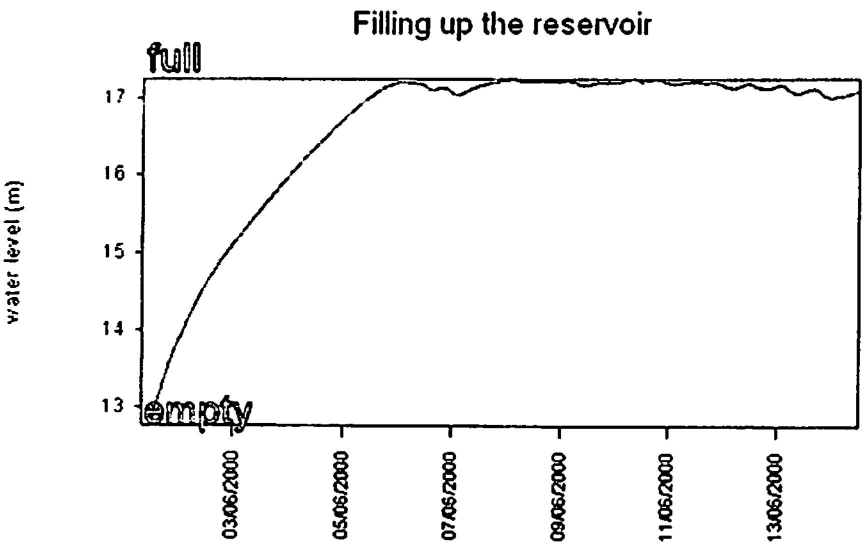


Figure 46. Simulated reservoir fill-up in June 2000 shown by the water level. The simulation starts with an empty reservoir and ends up being full in less than a week.

102. Conditions in the reservoir favor fish growth. Figure 47 presents simulated reservoir oxygen conditions on the surface (line in the middle) and near the bottom (lowest line). The reservoir values are compared to a natural stream (the highest line). Even in the bottom of the reservoir oxygen remains relatively high because of the high through-flow. This finding is supported by field measurements presented in the previous chapter, which gives similar results.

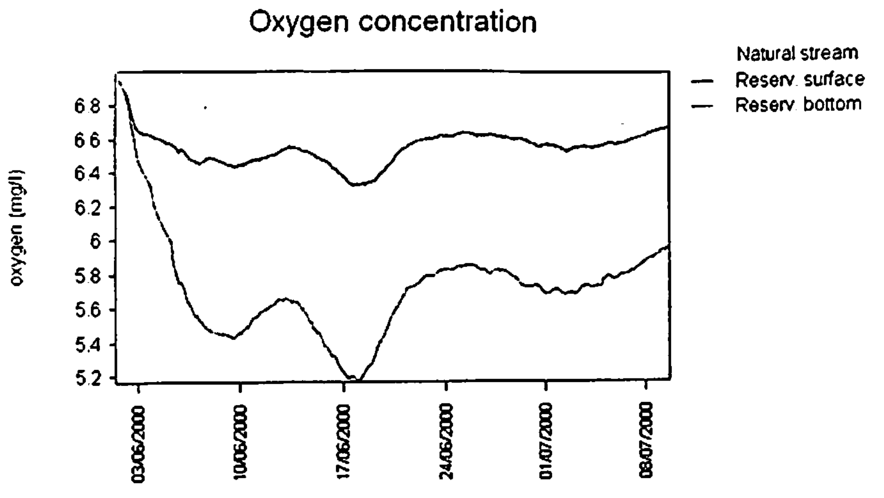


Figure 47. Simulated reservoir oxygen. Uppermost line natural river, middle one reservoir surface and lowest one near the bottom.

103. The simulated reservoir impact on sediment concentration is shown in Figure 48. Based on upstream measurements, the suspended sediment concentration in a free flowing stream is around 25 mg/l. The simulated outflow concentration is slightly below 20 mg/l. In the simulation resuspension from the bottom has not been taken into account. Measurements do not show any clear trapping impact. If there is trapping the downstream productivity could be influenced slightly. On the other hand the reservoir productivity would be enhanced by the trapped sediments.

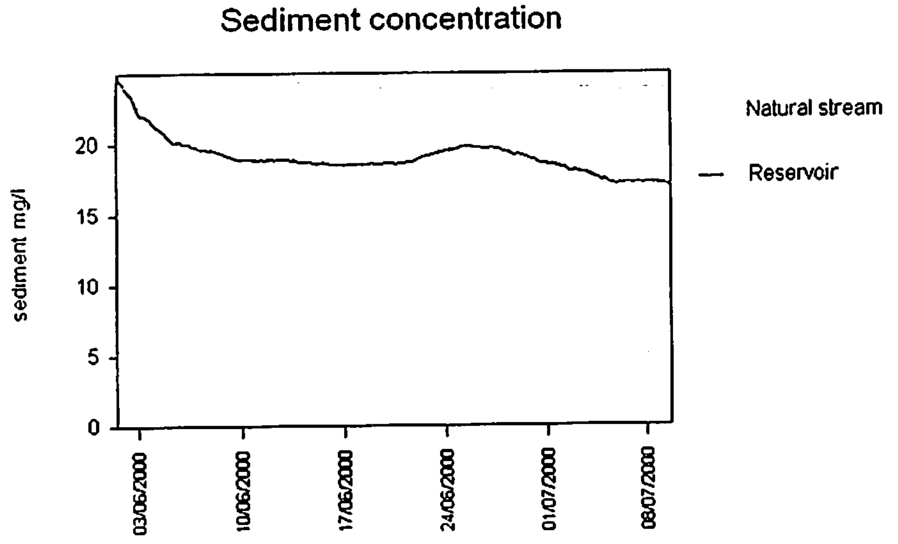


Figure 48. Simulated reservoir outflow suspended sediment concentration. The green line shows concentration in a natural river and black one in the reservoir outflow. Observe dam trapping effect of the reservoir.

104. The sediments provide a source of nutrients for productivity. Figure 49 shows the simulated sedimentation pattern in the reservoir after 1.5 months. Sedimentation varies between 50 and 100 g/m^2, which corresponds to about 0.05 mm sediment thickness.

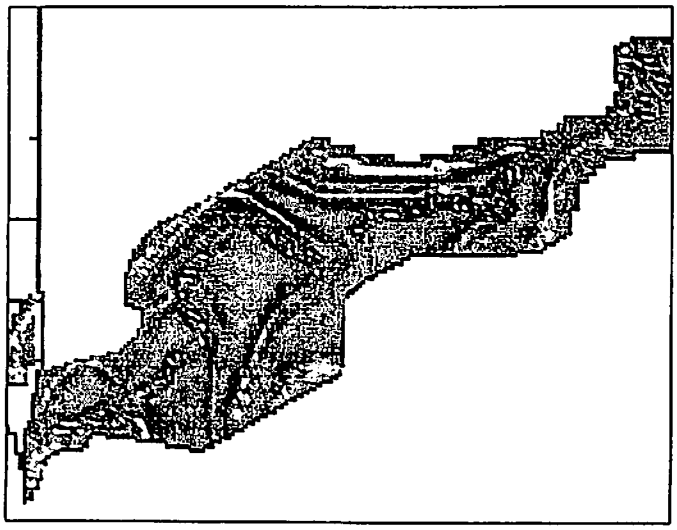


Figure 49. Simulated 1.5 month sedimentation. Sedimentation is about 50 to 100 g/m^2 corresponding to about 0.05 mm in sediment thickness.

105. Although the reservoir favors fish growth, it has substantial impacts on fish migration and the breeding of local species. Also, the reservoir may have some negative impact on downstream productivity. Because of this, the total impact of reservoirs should be assessed by qualified fisheries experts.

106. The generalization of the results to other reservoirs should be done cautiously. The characteristics of the reservoir including storage capacity, area, water depth, through-flow, residency time, soil properties, vegetation, inflowing water quality etc. govern the impacts and are difficult to be generalized. Each planned reservoir should be studied properly.

IV.3 FLOODPLAIN IRRIGATION RESERVOIRS

107. Intensive irrigation structure development is ongoing on the Tonle Sap floodplain. Figure 50 shows the recent developments in Kampong Thom province. The total area of the structures in the figure is about 30 km^2.

108. The cumulative storage capacity of the floodplain irrigation structures is quite limited because the trapped water depth is only 1.5 m. Even assuming further development of 400 1 km^2 reservoirs would amount to only 0.6 km^3 storage volume. This can be compared to the total flood volume between 40 and 107 km^3. However, in the upper reaches of the floodplain the reservoirs trap a significant part of the flood.

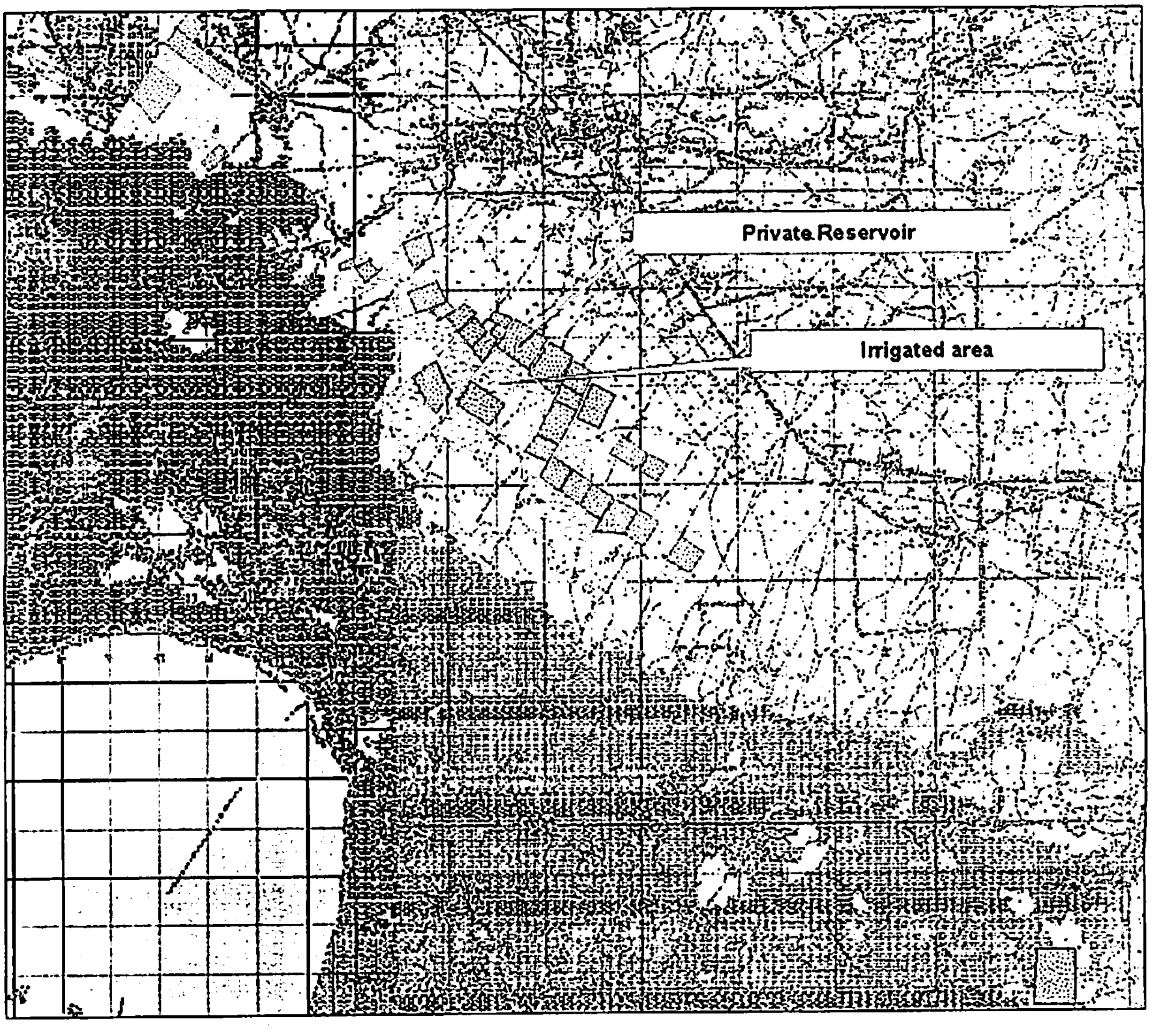


Figure 50. Private irrigation structures in Kampong Thom province. Blue indicates irrigation dams and green the accompanying irrigated rice paddies.

109. A private irrigation structure in Stung Staung District was selected for impact study. Details of the area are presented in the "Methods and Tools" chapter. Results presented below are based on field measurements of the reservoir.

110. Water level reached maximum level on the flood plain next to the reservoir on 24.10 and started to decrease. The gates of the reservoir were closed on 6.11 when the water level was 1.7 meter high and the risk of collapse of the embankment was small. Water level outside and inside the reservoir is presented in Figure 51. The trapping effect of the reservoir is shown by the grey line representing the water level in the reservoir. Initially, the water level goes down as reservoir water evaporates and possibly seeps through the embankment and ground. The water level starts to go down significantly in the middle of December when the flood waters have receded outside the reservoir and the reservoir water starts to be used for irrigation.

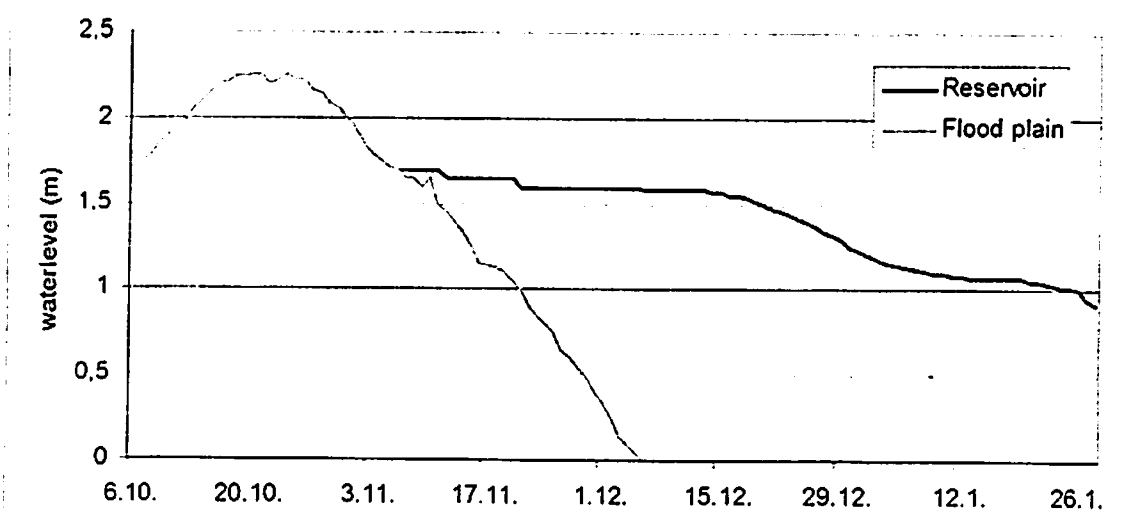


Figure 51. Water level on the floodplain and in the reservoir. Figure illustrates the water trapping function of the reservoir during the receding flood

111. Oxygen concentrations inside and outside of the reservoir were good except near bottom in some locations both inside and outside of the reservoir (Figure 52). Decaying organic material consumes oxygen resources on the bottom and oxygen concentration decreases if flow and wind driven waves are not able to mix the entire water mass. The area of the reservoir on the floodplain is very open, so even a light wind can mix effectively the shallow water. The maximum reservoir water depth is only two meters and the open fetch is several kilometers.

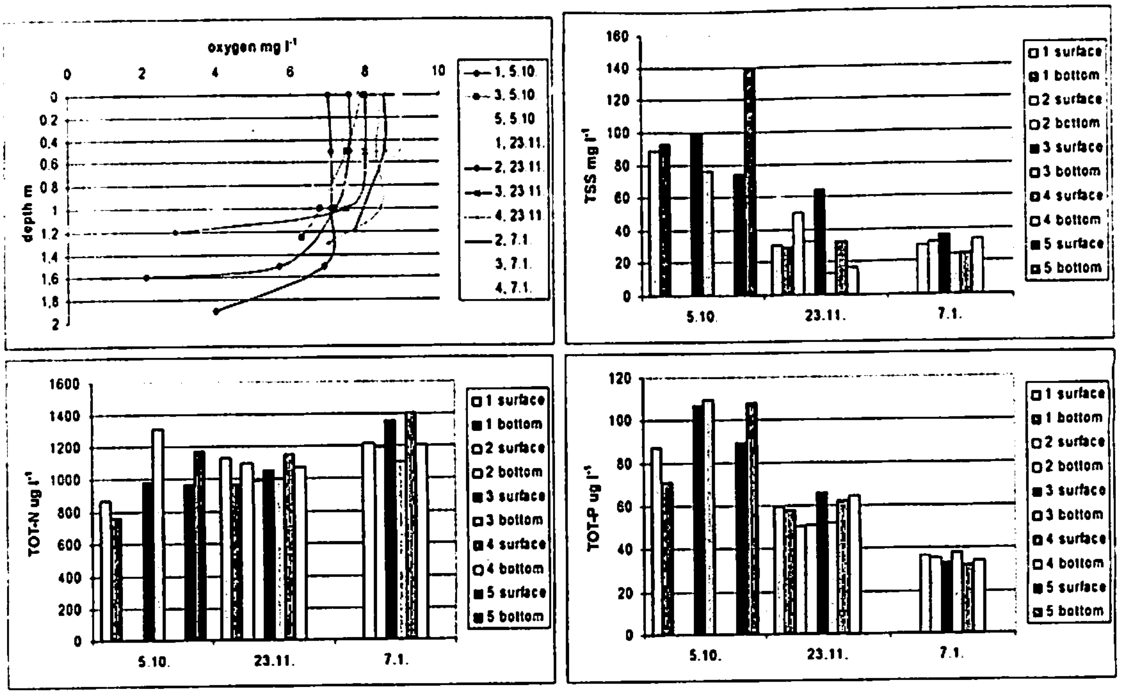


Figure 52. Oxygen, total suspended sediment, total nitrogen and total phosphorus concentrations in the reservoir (points 2,3 and 4) and outside of the reservoir (points 1 and 5).

112. According to the point measurements, the total impact of the structures on floodplain water quality is minor. Total suspended sediment (TSS), total nitrogen and total phosphorus concentration values vary at the same level inside and outside of the reservoir (figure 52.). Similar to the total nutrient concentrations, there is not any significant change in the nutrient fractions.

113. The oxygen values are higher in the reservoir in January than in October. This follows from the fact that temperatures are lower in January and consequently the oxygen saturation values higher. The total suspended sediment and total phosphorus values show a decrease in November and January. This shows the trapping effect of the floodplains in general. When comparing the November and January TSS values the reservoir does not seem to trap sediments, but the conclusion is based on only two measurements. On the other hand total phosphorus concentrations seem to diminish, which would point to net utilization of the phosphorus in the water column by vegetation. Again the conclusion is inconclusive.

114. Values of pH, alkalinity and conductivity of the reservoir water do not differ from the values of flood water outside of the reservoir (Table 11.). Significant change can be seen only in the values of chemical oxygen demand. Values are higher in the reservoir compared to the values outside of the reservoir. Higher values in the reservoir can be caused by organic matter that is trapped and sedimented in the reservoir. The biomass production period is also longer in the reservoir than on the floodplain, which is increasing the amount of sedimented organic matter on the bottom of the reservoir.

Table 11. Chemical oxygen demand, pH, alkalinity and conductivity values in the private irrigation reservoir (points 2, 3 and 4) and outside of the reservoir (points 1 and 5).

		CODM mg l^{-1}	pH	ALK+ mgCa	Cond. mS m^{-1}
1	min	3,4	6,3	8,8	2,0
	aver.	4,2	6,4	9,7	2,3
	max	4,9	6,5	10,9	2,6
2	min	6,6	6,4	9,7	2,3
	aver.	7,7	7,1	10,0	2,4
	max	9,3	7,8	10,4	2,6
3	min	3,2	6,2	5,4	1,8
	aver.	6,5	6,7	8,4	2,3
	max	10,2	7,4	10,7	2,6
4	min	7,0	6,5	9,2	2,3
	aver.	8,6	7,0	9,6	2,4
	max	9,8	7,7	10,0	2,5
5	min	3,0	6,3	7,7	2,2
	aver.	3,0	6,3	8,5	2,2
	max	3,0	6,3	9,4	2,2

115. The floodplain irrigation structures have only a relatively limited impact on the flood and water quality. Even the cumulative impact is relatively low. However, the destruction of habitat and blocking of fish movement may be important for fisheries.

IV.4 INFLUENCE OF LARGE SCALE FISHING GEARS

116. The set-up for the field and laboratory work for finding out fishing gear impacts is presented in the "Tools and Methods" chapter.

117. During the study the flow fields of the Prek Toal area were measured at four locations in entire water profile from the bottom to the surface on 5.8.2006 and 23.8.2006 Velocities of the flow were mostly below 10 cm s^{-1} and directions varied between 62 and 250 degrees (Table 12).

Table 12. Range of flow velocity and direction in the Tonle Sap Lake at Prek Toal area, 5.8 and 23.8.

		cm s^{-1}	degrees
5.8.	min	2,6	62,1
	aver.	5,1	214,1
	max	9,9	265,8
23.8.	min	1,8	98,8
	aver.	9,6	190,7
	max	18,5	250,0

118. Cross section measurements on the lake do not indicate significant hydrological changes caused by the bamboo fences. Measurements were carried out at the end of January 2007 when bamboo fences were installed on the lake and the depth of the lake was about three meters. The direction of the fence was 300 degrees and it was located in the north-west corner of the lake off Prek Toal (48 P 0359713, 1459834). Average flow velocities of 200 m long cross sections were low on both sides of the fence, from three to four cm s^{-1} (Figure 53). Direction of the flow varied between 320 and 355 degrees on both sides of the fence. According to these results bamboo fence does not decrease the velocity and change the direction of the flow with such slow flow velocities. The lowest possible velocity recorded by the survey boat (>1 m s^{-1}) was considerably high compared to the flow velocities of the lake (<0,1 m s^{-1}). Therefore, accuracy of the measured data was not very high and these results should be taken with caution.

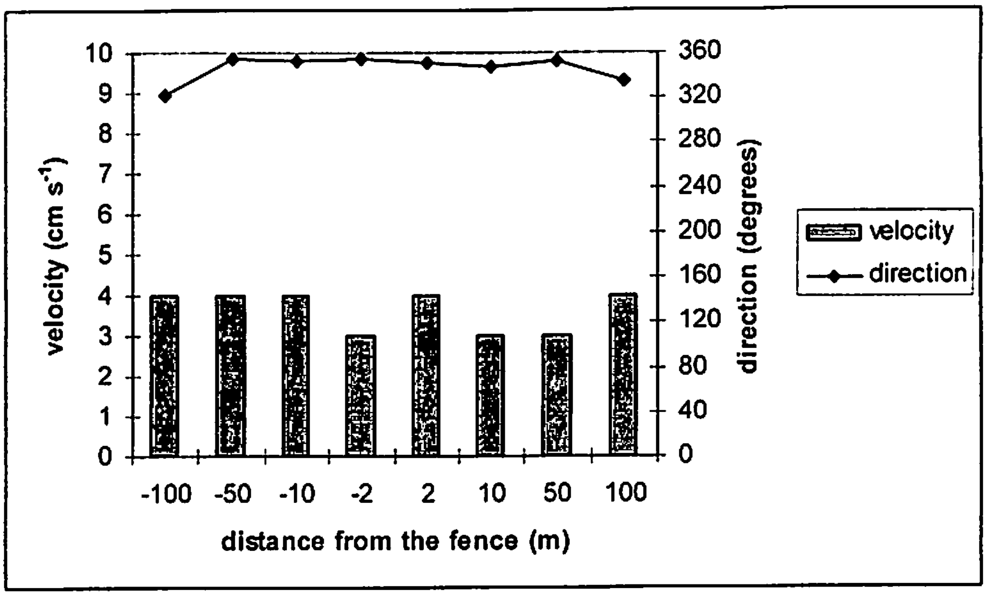


Figure 53. Average velocity and direction of the flow on both sides of the bamboo fence on the lake in Prek Toal area.

119. Laboratory experiments in the fixed bed flume show that the slight opposing influence of the bamboo fences on flow velocities can be observed when the velocity in the flume rises higher than 10 cm s^{-1} (Figure 54). Water level clearly rises upstream of the fence with higher velocities. The opposing influence of the nylon net is minor, the slight influence appearing when flow velocity is higher than 20 cm s^{-1}, but even with the maximum velocity of the flume the influence is still slight.

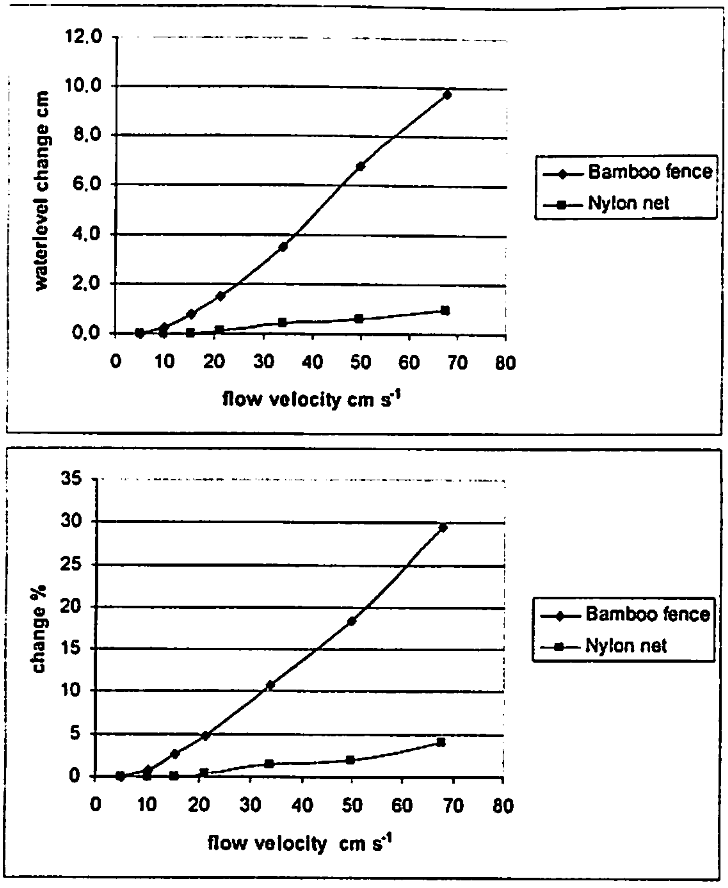


Figure 54. Influence of fishing gears on water level (upper picture) and flow velocity in the fixed bed flume.

120. As a summary typical low floodplain flow velocity causes only small impact on water levels and flooding. The water level changes caused by the fishing gears are in general small, and the low flow velocities encountered in the floodplain cause only slight resistance to the flow. The flood will not be delayed by the gears. The water quality impacts are similarly small because water can flow relatively easily through the structures. The impact of fishing gears on hydrology and water quality is small. However, other impacts to fish such as obstruction of fish movement can be serious.

V CONCLUSIONS AND RECOMMENDATIONS

121. The report describes built structure impacts on Tonle Sap hydrology and water quality. The impacts have been studied by analysis of existing data, new field measurements and mathematical modelling. Currently the Tonle Sap fisheries productivity and its dependence on hydrology and water quality is not understood very well, and consequently quantitative fisheries impact analysis is not possible. However, the study demonstrates the relative importance of different types of structures to the fisheries and presents conclusions related to the main risks and benefits of the developments.

122. The built structures development scenarios that have been studied represent intensive Mekong tributaries, Mekong mainstream and Tonle Sap tributaries/floodplains developments. Also, small-scale Tonle Sap structure impacts including different types of irrigation reservoirs, roads and fishing gears have been studied in detail. The actual development of the Mekong region cannot be exactly predicted, and the scenarios are only indicative.

123. The Tonle Sap system's hydrological characteristics show great natural variability. The lake area is about six times larger during the peak flood season compared to the dry season. The water depth increases about seven and volume about sixty times compared to the dry season. There is also large variability between different years. The flow volumes into the lake can be over two times higher in a wet hydrological year compared to a dry year. The maximum flooded area varies by about 50% between dry and wet years.

124. During wet years, even massive developments have relatively small impacts on the Tonle Sap compared to the natural variability. The study estimates that intensive upstream hydropower and irrigation development will decrease the Tonle Sap inflow by only 4 – 10% during wet years.

125. Upstream developments have the largest impact during dry years. Then storage volumes are relatively larger than during the wet years compared to flow volumes. The Tonle Sap inflow can decrease 10 – 25% during a dry year. A 10% inflow decrease corresponds to about a 0.5 maximal flood height decrease and a 10% decrease in the flooded area. A decrease in the area flooded means less breeding habitat for fish, and a decrease in flood height means less volume for fish food production.

126. The upstream dam developments delay flood arrival from one week to one month. The flood duration is correspondingly shortened. The delay can be critical for breeding fish which may have adapted to the quite regular onset of the flood season. It is also clear that shortened inundation shortens the time fish can feed on the floodplain.

127. The dry season impacts are aggravated by the fact that the fisheries are already stressed during dry years. Whether the additional stress caused by built structures can significantly affect the fisheries cannot be reliably assessed based on the available fisheries data. However, it is clear that realisation of all hydropower and irrigation potential in the Mekong Basin represents a serious threat to fisheries especially during dry years.

128. The water stored in the reservoirs is released during the dry season. Although water release can have a beneficial impact on river water quality and river channel fish habitats, it can also negatively impact floodplain habitats. The river water levels are increased during the dry season and consequently the Tonle Sap water level will stay higher during the dry

season. Because the floodplain vegetation has been adapted to alternation of dry and wet (terrestrial and aquatic) periods, it cannot survive permanent inundation. The flooded forest near the lake edge will be destroyed. The flooded forest is an important fish habitat and it also acts as a protective barrier against strong lake currents and waves. The estimates for the dry season water level rise vary. The estimated increase of the permanently inundated area is 300 – 900 km^2, or 15 – 45% of the dry season lake area.

129. The local Tonle Sap dam development has similar impacts to the upstream Mekong developments. Realisation of the full hydropower and irrigation potential in the Tonle Sap catchment would result in impacts of the same order of magnitude as intensive Mekong upstream tributaries' development. When both local and upstream developments are realised they cause significant impacts together.

130. As described above the dam build-up decreases flows especially in the beginning of the flood season. Decreased flows cause reduced water exchange in the floodplain and can worsen the oxygen conditions. The oxygen conditions are naturally critical in the floodplain because of the large amounts of decaying organic material and because of the sheltering effect of vegetation decreasing aeration and water mixing. The young juveniles feeding in the floodplain are especially sensitive to oxygen conditions and could suffer critically from the oxygen decrease.

131. Although sediment impacts on productivity are not well understood in the Mekong region, there are indications that sediments play a central role in providing nutrients to both aquatic and flooded terrestrial ecosystems. In the worst case scenario the planned Chinese dam cascade will trap nearly all sediments originating from the upper Mekong reaches. This could cause about a 50% sediment concentration decrease in the Lower Mekong Basin. Because most of the sediment in the Tonle Sap originates from the Mekong, this would cause a correspondingly significant sediment input decrease to the Tonle Sap. The exact assessment of the dam impact would require a Mekong scale in-depth sediment study that has currently not been done. Also, the sediment relation to the fisheries productivity needs to be understood better, but potentially the sediment trapping can have serious impact on fisheries productivity.

132. Modelling results show that changing flow regimes alter larvae and juvenile drift especially from the Tonle Sap River. The significance of this drift change cannot at the moment be assessed but needs more in-depth study.

133. Compared to the large-scale upstream and Tonle Sap developments, local small-scale floodplain and near floodplain dams have a rather small impact on hydrology and water quality. The floodplain irrigation reservoirs that are increasingly being built have, even in large numbers, a small storage capacity. Also, their impact on water quality is small. The same applies to the relatively small-scale upstream irrigation schemes such as Stung Chinit. The reservoir provides good conditions for fish breeding. However, structures can significantly disturb fish habitats and block fish migration and movement. Also, the cumulative impact of a large number of small-scale structures may be significant, although it is not well understood.

134. Especially when assessing the impact of any planned reservoir, generalizations drawn from one case should be avoided. The characteristics of the reservoir including storage capacity, area, water depth, through-flow, residency time, soil properties, vegetation, inflowing water quality, etc. govern the impacts and are difficult to be generalized.

135. The floodplain roads in general do not have a significant impact on floodplain hydrology or water quality. However, if built on important flow routes they may decrease oxygen and sediment rich water flows as well as larvae and juvenile drift to important fish breeding grounds. The floodplain's hydrological and hydrodynamic characteristics should be understood before road construction begins, and mitigation structures such as bridges should be built in appropriate places.

136. Fishing gears including bamboo fences and nylon nets have a small impact on hydrology and water quality. However, they can seriously block fish movement and have a significant impact on fisheries.

137. As discussed above, the major uncertainty in the fisheries impact analysis stems from the poor understanding of fisheries dependence on hydrological, hydrodynamic, water quality and habitat conditions. It is necessary first to understand primary productivity and its dependence on these factors. Both terrestrial and aquatic productivity are important for providing food for fisheries and the (quantitative) pathways from primary productivity to fisheries need to be clarified. When the productivity and fisheries are understood, the potential risks to them can be identified and the quantitative impacts of different development scenarios can be estimated.

138. As well as biological uncertainties, physical and chemical ones need to be decreased. The major uncertainties are related to the fate of the sediments, nutrient dynamics, Tonle Sap flow changes, and the magnitude of dry season water level changes. Existing data needs to be utilized more intensively, new field measurements conducted and modelling tools developed and further verified.

139. Especially because the fisheries are understood poorly, upstream and local developments should be planned carefully and cautiously. The operation of reservoirs should take into account downstream conditions and impacts. For instance, the reservoirs could be filled more cautiously in the beginning of the flood season to minimize impacts on early flooding.

140. Although the natural variability of the Tonle Sap system is high and the fish have adapted to it, upstream developments may change conditions in the lake especially during critical periods in a way that the fish can not cope with. The above discussion highlights dry years in this respect.

141. The impacts of the built structures have been discussed mostly individually. The cumulative impact of the individual changes is rather difficult to assess. For instance, changes in flood timing and changes in the floodplain's early flood oxygen conditions both have negative impacts on fisheries, but together they may have a overall impact more important than the sum of individual impacts. However the cumulative impact of many small structures has not been understood very well. This applies especially to the Mekong upstream, but also locally.

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Appendix 3 Fisheries Component Technical Reports

- Relationships Between Bioecology And Hydrology Among Tonle Sap Fish Species

- "BAYFISH-TONLE SAP", A Model Of The Tonle Sap Fish Resource

- Integration Of Databases To The BayFish- Tonle Sap Fish Production Model

- Influence Of Built Structures On Tonle Sap Fish

  Resources

Asian Development Bank
TA 4669-CAM

Technical Assistance to the Kingdom of Cambodia for the Study of the Influence of Built Structures on the Fisheries of the Tonle Sap (financed by the Government of Finland)

Fisheries Component

RELATIONSHIPS BETWEEN BIOECOLOGY AND HYDROLOGY AMONG TONLE SAP FISH SPECIES

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CONTENTS

EXECUTIVE SUMMARY

Creation of a database of all Tonle Sap fish species

- This reports details how several sources of information and databases have been merged together to create a database of all Tonle Sap species and of all bioecological information documented about these species.

- The Tonle Sap species database results from the integration of four main sources of information: i) from scientific publications, summarized in FishBase; ii) from publications and fishers' knowledge as compiled in the MRC Mekong Fish Database; iii) from biological studies undertaken at IFReDI; and iv) from traditional knowledge gathered during the course of the Built Structures project.

- The information available in the Tonle Sap species database covers five fields: i) *species identification* (Species name in Latin, family; author; name in Khmer; name in Khmer (roman); name in English; ii) *biology* (max. total length; max. standard length; length at maturity; food; iii) response to hydrological changes (discharge as migration trigger; water level as migration trigger); iv) *reproduction* (spawning location, date of spawning; reproductive guild; fecundity; nursing location; possible breeding in reservoirs); and v) ecology (Tonle Sap distribution; field notes; migration type; feeding place; status; habitat; resilience; ecological guild.

- Two hundred and ninety-six species are recorded in the Tonle Sap. This is more than double than recorded so far in scientific publications. In terms of fish biodiversity, this makes the Tonle Sap the third richest lake in the world, after lakes Malawi and Tanganyika, and much before Lake Victoria.

- The 296 Tonle Sap species belong to 44 families, the dominant ones being Cyprinids (108 species), Silurids (20 species), Bagrids and Cobitids (17 species) and Pangasids (14 species).

- Thus the Tonle Sap sub-basin, that covers 10.7% of the Mekong Basin, comprises 32% of the Mekong fish species and 48% of the Mekong fish families. This qualifies the Tonle Sap system as an exceptional biodiversity hotspot by global standards, and calls for special attention from national and international institutions.

Response of Tonle Sap species to hydrological changes

- This analysis has been undertaken to better appraise the possible consequences of flow modifications due to built structures on the migration of species targeted by the fishery.

- Among the Tonle Sap species, three species are known to have their migration triggered by a discharge variation and twenty-three species have their migration triggered by a water level variation. In that field there is a large information gap about the other species, i.e. 91% of the Tonle Sap fish community.

- However among the species whose migration is triggered by a variation of water level, three taxa (*Cyclocheilichthys spp.*, *Paralaubuca typus* and *Pangasius spp.*) contribute 13% to overall catches in Cambodia. This means that each year at least 38,000 and 56,000 tons of fish depend on species whose migration is triggered by hydrological cues altered by built structures. If *Henicorhinchus spp.* (Trey riel) is included, then the figure goes up to 38% of the catch, i.e. between 110 and 164,000 tons.

Ecological guilds

- It is usually considered that floodplain fishes belong to two ecological groups of fishes ("guilds"): either black fish, that spend the dry season in floodplain ponds, or white fish, that undertake long distance migrations at the end of the rainy season. Our results show that it is necessary to consider a third group of fish, named "grey fish", whose behavior is neither black nor white. These grey fish spend for instance the dry season in the Tonle Sap tributaries or in the main lake.

- According to current knowledge, 8% of Tonle Sap species belong the "Grey fish" guild. Detailed analyses show that differences between guilds are mainly behavioural, and that there is no significant difference between these guilds in terms of average length of fish. There is also no significant difference between the average trophic level of guilds.

- Last, a resilience analysis focussing on the ability of species to adjust to heavy exploitation has highlighted the species whose resilience is low, and that should be subject to specific monitoring.

I INTRODUCTION

This aim of this study is to clarify the relationship between the bioecology of Tonle Sap fish species and hydrology.
Information is available from:
- scientific publications, summarized in FishBase maintained by the WorldFish Center (Froese and Pauly 2000, and www.fishbase.org).
- published and expert information, summarized in the Mekong Fish Database produced by the Mekong River Commission (MFD 2003);
- expert information available with IFReDI and its biologists;
- traditional knowledge gathered during the course of the Built Structures project.

This approach has already been used in Baran *et al.* (2005) and Baran (in press).

We aim to combine these different sources of information to create a repository of the best available information on Tonle Sap fish species, with a focus on black, grey and white fish species. This repository will then be analysed to provide information relevant to the BayFish model of the Tonle Sap fish resource.

II MATERIAL AND METHODS

II.1 INFORMATION EXTRACTED FROM FISHBASE

The web-based version of FishBase (www.fishbase.org) is used for up-to-date information. In 2005 a specific module has been created by the FishBase team to generate a matrix of all species of a given system, and a number of life-history parameters for these species. A fraction of the quantitative information available in this matrix is summarised in Table I.

Table I: Life history variables detailed for in the species ecology matrix

Variable	Abbreviation; (unit)	Meaning	Measured or calculated
Maximum length	Lmax; (cm)	Maximum length ever reported for the species in question.	Measured
Life span	tmax; (year)	Approximate maximum age that fish of a given population would reach	Calculated (estimated from Linf., K and to.)
Age at first maturity	tm; (year)	Average age at which fish of a given population mature for the first time	Calculated (estimated from Linf., K and to.)
Length at maturity	Lm; (cm)	Average length at which fish of a given population mature for the first time	Calculated (estimated from Linf.)
Length for max. yield	Lopt; (cm)	Length class with the highest biomass in an unfished population	Calculated (estimated from Linf.)
Trophic level		Rank of a species in a food web, calculated from food items, weighted by the contribution of the various food items to the diet.	Calculated

The option used in this study is thus the "Information by ecosystem" (Tonle Sap ecosystem), with the sub-option "Species ecology matrix" (Figure 1).

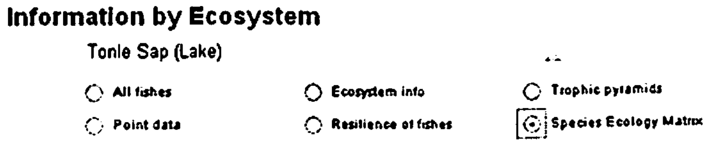

Figure 1: View of the FishBase option producing the matrix of life history parameters for Tonle Sap fish species

This option provides, all the life history parameters of each species recorded in the Tonle Sap, as shown below (Figure 2).

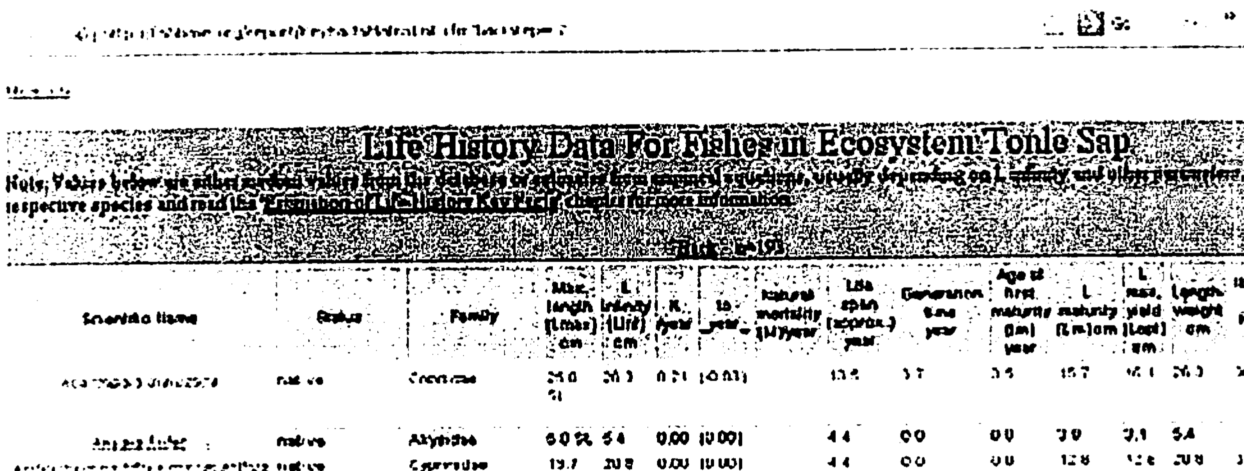

Figure 2: View of the FishBase "species ecology" matrix for the Tonle Sap

Options "All species" and "Resilience of fishes" were also used to supplement data compilation (Figure 3).

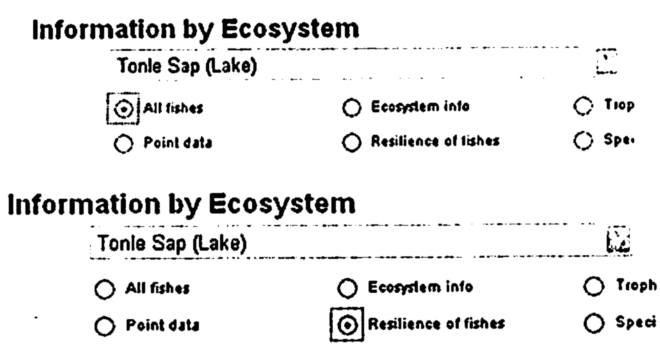

Figure 3: View of the FishBase options for Tonle Sap specific additional information

II.2 INFORMATION EXTRACTED FROM THE MEKONG FISH DATABASE

This information in MFD is of different nature than that of Fish Base, as in includes much more ecological information gathered through field surveys and questionnaires on traditional ecological knowledge. This database includes in particular the knowledge gathered by Chan Sokheng *et al.* (1999), Poulsen (2000, 2003), Poulsen and Valbo-Jorgensen (2000), AMFC (2001), Valbo-Jorgensen and Poulsen (2001) Bao *et al.* (2001), Poulsen *et al.* (2002).

The species found specifically in the Tonle Sap Basin are identified in MFD in an "Occurrence" table, than can be related to the detailed "Location" table and to a "Species Data" table. The tables of the database have been combined to summarize in one table all the information scattered in different tables. For each species of the life history matrix, information on migration was automatically extracted, in MS Access mode, from the Mekong Fish Database. For species listed in FishBase but not present in the MDF, all possible synonyms were searched from a synonyms correspondence table, and the relevant information was then extracted from the synonym species.

II.3 INFORMATION FROM IFREDI

Over the years, the Cambodian Inland Fisheries Research and Development Institute and its biologists previously involved in MRC fisheries monitoring projects have accumulated a significant body of knowledge. This knowledge is partly reflected in the MRC documents on spawning and migrations in the Mekong Basin, but is also still scattered in several local publications such as So *et al.* (1999, 2005), So and Haing (2006) or So (2005). The corresponding list of species is given in Annex A.

II.4 INFORMATION FROM THE BUILT STRUCTURE PROJECT

Last the Built Structures project undertook a sampling of traditional ecological knowledge around the Tonle Sap Lake. This project is based on the interviews of 24 experienced senior fishers in 6 sites round the lake. The methodology is based on the recommendations of IIRR (1996) and Cambpbell and Salagrama (1999) supplemented by Ticheler *et al.* (1998). Experience relative to gathering traditional knowledge of Mekong fishers was integrated thanks to Baird and Overton (2001), Baird (2003) and Dubois (2005). Questionnaires to fishers are detailed in Annex 1.
The questions focussed on 30 species identified by their Khmer name, and for these species, on spawning habitat; spawning location; feeding habitat; nursing habitat and ecology type (black white or grey type).
Equivalences between Khmer fish names and Latin fish names were drawn from Baran (2003) and Baran and Chheng (2003). These two documents tackle the issue of several Latin names for one Khmer name, and provide a list of scientific species for each Khmer fish name. Last, the latest valid Latin names of fish followed the list of Baran and Garilao (2003) based on FishBase.

II.5 MERGER OF DATABASES

II.5.1 FishBase matrix

The FishBase matrix of life history parameters was used as a basis. The original variables of this matrix, including information from "Resilience" and "All Species" supplementary matrices, are as follows:

Table II: Main variables of the FishBase species ecology matrix

Latin name	Author	Family	English name	Max. total length (cm)	Max. standard length (cm)	Life span (years)	Length at maturity (cm)
	Length for max. yield (cm)	Length-weight (cm)	Main food	Trophic level	Status	Habitat	Resilience

One hundred and ninety three species are listed as Tonle Sap species in FishBase. This matrix is converted into an Excel table for further analysis.

II.5.2 MRC database

The ecological information used mostly originates from the MRC Mekong Fish Database. In fact the file used was created for the analyses of migrations and migration triggers in the Mekong Basin (Baran, *in press*). This files combines to the FishBase life history matrix of all Mekong species all the ecological information available in MFD. This information is as follows:

Table III: Main variables extracted from the Mekong Fish Database

Species	Migrating?	Migration Info	Migration type	Spawning info	Breeds in reservoirs?	Note	Mekong distribution	Feeding info
	Yes	text	Longitudinal	text	Yes	text	text	text
	No	#N/A	Lateral	#N/A	No	#N/A	#N/A	#N/A
	#N/A		Both					
			#N/A					

In the resulting table, for readability, it has been concentrated into one single column "Ecological information" compiling all the others listed above.

II.5.3 IFReDI Tonle Sap species list

The list of species met in the Tonle Sap, provided in Annex 1, mainly bears two variables: *Scientific name* and *Khmer name*. Several species were removed from this list, with the following arguments:

Table IV: Species removed from the IFReDI list

Latin name	Family	Tonle Sap distribution
Arius caelatus	Ariidae	Probably not (Vietnam only)
Batrachocephalus mino	Ariidae	Marine and estuarine only (tidal zone)
Butis gymnopomus	Eleotridae	No information at all in MFD, Indonesian species not in Cambodia according to FishBase
Clarias canius	Clariidae	Unknown from MFD and from FishBase
Cynoglossus punticeps	Cynoglossidae	Common in the freshwater tidal zone of the Mekong Delta, but not yet reported from Cambodia (Ref. 12693).
Hemipimelodus bicolor	Ariidae	Only in the delta
Lobocheilos davisi	Cyprinidae	No evidence at all
Lobocheilos quadrilineatus	Cyprinidae	Unlikely (Laos only)
Mystus cavasius	Bagridae	5 occurrences only in Cambodia, none is TS related

This information was added to the previous compilation of matrices.

II.5.4 Built Structures questionnaires

The database integrating the information gathered through the questionnaires of the Built Structures project included questions about the following variables:

Table V: Main variables of the Built Structures – Species ecology database

Species	Spawning location	Feeding habitat	Nursing habitat
In Khmer	Floodplain lake / rice field	Floodplain	Floodplain
	Major river / river	Never caught	Never caught
	Stream / Inlet		
	TS permanent lake		
	Never caught		

The questions asked focussed on 38 taxa selected because they are either i) dominant and important fish species for livelihoods; ii) important fish species for aquaculture development; iii) little known from an ecology viewpoint, or iv) potentially vulnerable.

The corresponding list of taxa, identified by their Khmer name, is as follows:
Ampil tum, Andat chhkae, Angkot prak, Bandol ampov, Chhlang, Chunlungh moan, Chunteas phluk, Dong khteng, Ka-ek, Kamphleav, Kanhchos bai, Kanhchras thom, Kantrorng preng, Kaock, Kasan, Kes, Khlang hay, Kromorm, Krum, Phtoung, Reus Chek,

The problem is that in this case, the specific information is recorded on the field under its Khmer name, and there are often several species corresponding to one Khmer name. So two documents were used to establish the equivalence between Khmer names and Latin names. Baran (2003) in particular, based on FishBase 2004, gives for each Latin names the number of occurrences of a given translation; this allows an assessment of the reliability of the translation.
We propose below a list of equivalences between Khmer names and Latin names (Annex B).

II.5.5 Merging the databases

FishBase and the MFB have in common Latin species names; the IFReDI compilation of species includes Latin species names and Khmer fish names, and the database of ecological knowledge gathered during the Built Structures project is based on Khmer names. Ultimately these databases are merged (Figure 4).

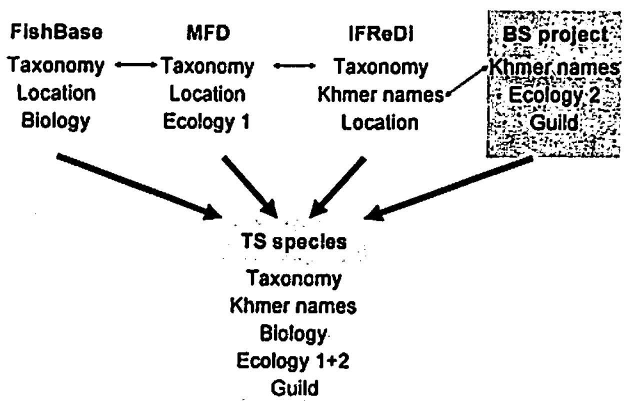

Figure 4: View of the FishBase options for Tonle Sap specific additional information

In view of quantitative analyses, some variables initially expressed qualitatively (e.g.; migration pattern) have been coded. Codes are as follows (Table VI):

Table VI: Coding used in the Tonle Sap species database

MIGRATION	Code
Caught in dry season	1
Caught in dry then rainy season	2
No migration pattern	3
Caught in rainy season	4
Unknown	5

MIGRATION TYPE	Code
Longitudinal and lateral migrations	1
Only longitudinal migrations	2

DISCHARGE VARIATION AS MIGRATION TRIGGER	Code
Yes	1
Unknown	2

WATER LEVEL VARIATION AS MIGRATION TRIGGER	Code
Yes	1
Unknown	2

STATUS	Code
native	1
Introduced	2
Misidentification	3
Questionable	4

RESILIENCE	Code
Very low	1
Low	2
Medium	3
High	4

HABITAT	Code
Benthopelagic	1
Demersal	2
Pelagic	3

RESERVOIR BREEDING	Code
Yes	1
Unknown	2
No	3

III RESULTS

III.1 CONTENTS OF THE TONLE SAP FISH SPECIES DATABASE

The information compiled in the database of Tonle Sap species can be classified as follows:
<u>Identification</u>
Species name in Latin, Family; Author; Name in Khmer; Name in Khmer (roman); Name in English:
<u>Biology</u>
Max. total length; Max. standard length; Length at maturity; Food:
<u>Ecology vs. Hydrology</u>
Discharge as migration trigger; Water level as migration trigger
<u>Reproduction</u>
Spawning location (floodplain lakes / rice fields; rivers; streams; / inlets; TS permanent lake); Date of spawning (based on % of respondents); Reproductive guild; Fecundity; Nursing location; Possible breeding in reservoirs
<u>Ecology</u>
Tonle Sap distribution; All MFD ecological information; Migration type; Feeding place; Status; Habitat; Resilience; Guild (black, grey or white fish)

It is the first time that all the information available about Tonle Sap species is concentrated into a single place.

III.2 PRELIMINARY ANALYSES

The table created is very rich as it covers all the species of the Tonle Sap, and all the information known about these species. It allows all kinds of quantitative analyses. We propose below some exploratory analyses about global trends revealed by this table.

III.2.1 Species and families

The results of this comprehensive review show that two hundred and ninety-six species are recorded in the Tonle Sap. These 296 species represent 2.5 times the number of species identified in 1999 by Puy Lim *et al.* (1999; 120 species) and twice more than twice the 149 species mentioned by Campbell *et al.* (2006). This is also significantly more than the 95 Tonle Sap species whose ecology has been detailed in Chan *et al.* (2001)

When compared to the other major lakes worldwide (figures from FishBase 2004), the Tonle Sap appears to be the third richest lake of the world in terms of fish biodiversity (Table VII and Figure 5). This exceptional feature has never been highlighted before.

Table VII: Comparison of Tonle Sap fish biodiversity with that of other lakes worldwide

Lake	Number of species	Note
Malawi	433	Southeast Africa. Over 2 million years old
Tanganyika	309	East central Africa. About 20 million years old.
Tonle Sap	296	Southeast Asia. About 6000 years old. Combination of freshwater and estuarine fish faunas
Victoria	222	East central Africa. About 4 million years old. World's second largest freshwater lake
Chilka	210	India.Largest tropical lake in Asia
Lake chad/ Chari River	170	Central Africa
Turkana	60	East Africa
Rukwa Basin	54	East Africa
Taal	53	Philippines
Kainji	45	Northern Nigeria. It is part of the Niger river
Liambezi	43	Southwest Africa/ Namibia
Baikal	42	Siberia and north of Mongolia. Largest, deepest and oldest freshwater lake, about 25-30 million years old.
Kariba	41	Southern Africa.

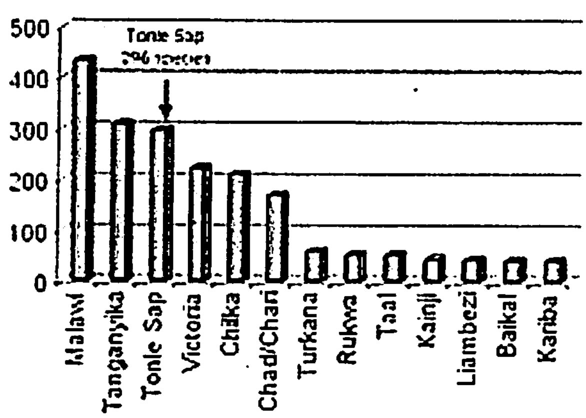

Figure 5: Place of the Tonle Sap fish biodiversity among other lakes worldwide

Forty-four fish families are present in the Tonle Sap. The family represented by most species is that of Cyprinidae (minnows or carps), with 108 species. It is followed by Siluridae (catfishes, 20 species), Bagridae (catfishes, 17 species), Cobitidae (loaches, 17 species) and Pangasidae (catfishes, 14 species).

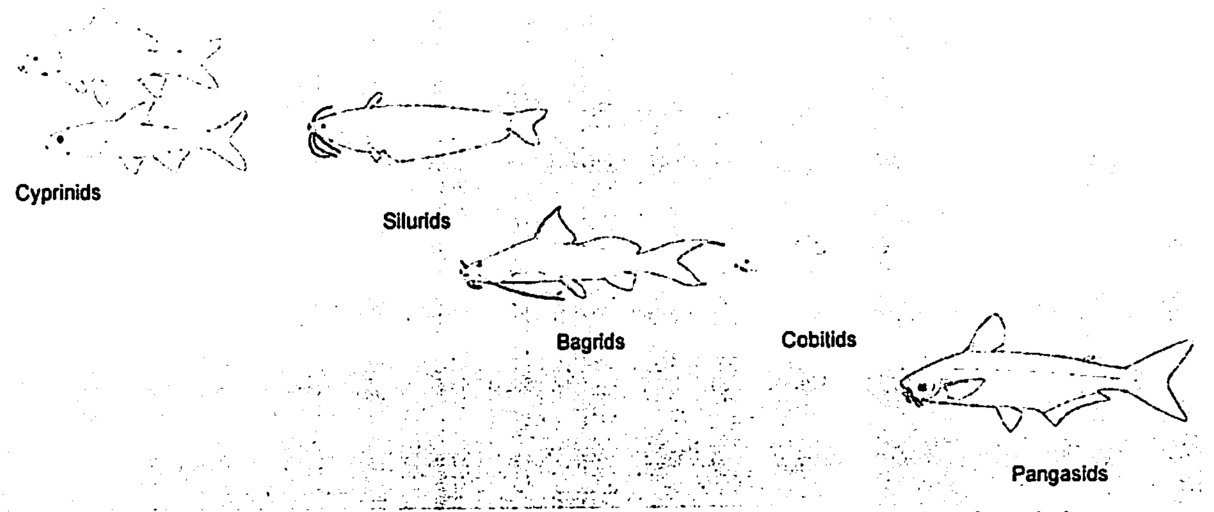

Figure 6: The dominant fish families (in number of species) of the Tonle Sap Great Lake

These 5 dominant families are supplemented by 39 others including from 1 to 10 species: Akysidae, Ambassidae, Anabantidae, Anguillidae, Ariidae, Balitoridae, Belonidae, Callionymidae, Carcharhinidae, Centropomidae, Channidae, Clariidae, Clupeidae, Coiidae, Cynoglossidae, Dasyatidae, Datnioididae, Eleotridae, Engraulidae, Gobiidae, Gyrinocheilidae, Hemiramphidae, Mastacembelidae, Megalopidae, Nandidae, Notopteridae, Ophichthidae, Osphronemidae, Plotosidae, Poecilidae, Polynemidae, Schilbeidae, Sciaenidae, Sisoridae, Soleidae, Synbranchidae, Syngnathidae, Tetraodontidae, and Toxotidae (Figure 7).

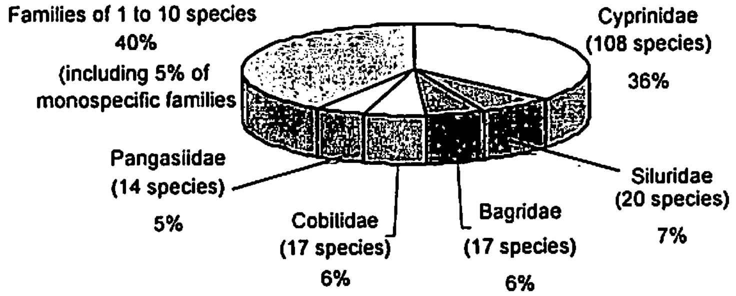

Figure 7: Repartition of Tonle Sap species between 37 families

Thus the Tonle Sap basin that covers, with 85,000 km^2, 10.7% of the Mekong Basin comprises 296 or 32% of the 924 Mekong species recorded in MFD[1]. The families present in the Tonle Sap sub-basin represent 48% of the 91 families present in the Mekong Basin. This confirms the exceptional richness of the Tonle Sap by global standards, and its status of biodiversity hotspot that requires special attention from national and international institutions.

[1] (this is a conservative percentage since FishBase only records 768 Mekong species)

III.2.2 Response to hydrology

III.2.2.1 Number of species whose migration is triggered by hydrological changes

The analysis below aims at identifying species whose migrations are triggered by hydrological changes. The objective is to better appraise the possible consequences of flow modifications (mainly due to damming or built structures in general) on the migrations of the species that contribute to the catch of Cambodian fisheries. This issue has been identified by the Technical Advisory Board of the Mekong River Commission as being an important factor likely to play a major role in the sustainability of the Mekong fishery resources (Baran 2007).

The database records two types of response to hydrological changes: migrations triggered by a variation in discharge, and migrations triggered by a variation in water level.
A preliminary analysis shows that:

- three species are known to have their migration triggered by a discharge variation: *Hemisilurus mekongensis*[2] (Kromorm in Khmer), *Pangasius macronema* (Pra chveat) and *Cyprinus carpio* (Karp samanh)
- twenty-three species have their migration triggered by a water level variation: *Barbonymus gonionotus* (Chhpin prak in Khmer), *Botia modesta* (Kanhchrouk krohorm), *Chitala blanci* (Kray), *Cyclocheilichthys enoplos* (Chhkaok), *Hemibagrus filamentus* (Tanel), *Hemisilurus mekongensis* (Kromorm), *Labeo chrysophekadion* (Ka-ek), *Lycothrissa crocodiles* (Chhmar krapeu), *Macrochirichthys macrochirus* (Dong khteng), *Micronema bleekeri* (Kes krohorm), *Osphronemus exodon* (Trocheak domrei), *Pangasius conchophilus* (Pra kae), *Pangasius hypophthalmus* (Pra thom), *Pangasius krempfi (Bong lao), Pangasius kunyit (Pra kchao), Pangasius larnaudii* (Pra po), *Pangasius polyuranodon* (Pra chveat), *Pangasius sanitwongsei* (Pra po pruy), *Parachela oxygastroides* (Chunteas phluk), *Paralaubuca typus* (Sleuk russey), *Pristolepis fasciata* (Kantrob), *Tenualosa thibaudeaui* (Kbork) and *Wallago leerii* (Stuok).
- there is no information about 270 species (Figure 8)

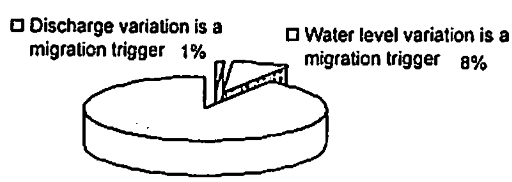

Figure 8: Response of Tonle Sap species to hydrological changes

As detailed by Baran (2007), some other species can be added to this list: *Pangasius bocourti* (Chhuon, 2000), *Puntoplites falcifer* and the southern population of *Pangasius sanitwongsei* (Poulsen *et al.*,2004). "Trey riel" (*Henicorhynchus spp.* and *Cirrhinus spp.)* is apparently receptive to flood recession as well as to lunar stage, but this is an unclear case as: i) the taxonomy of the genus *Henicorhynchus* is confused (in particular with *Cirrhinus*); ii) the number of species in this genus is not fixed; and iii) the identification of most species of the genus is almost impossible in the field.

The main information resulting from the above analysis is that there is a huge knowledge gap and that the response of fish to hydrological changes is not documented for ninety percent of the Tonle

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[2] *Hemisilurus mekongensis* is also recorded among species whose migration is triggered by a water level variation

Sap species. Conversely Baran (2007) highlights that 90% of Mekong fish species *for which migration cues are documented* respond to a variation in water level or in discharge. Data analysed basinwide show (not specifically on the Tonle Sap) show that among documented species, catfishes, with 15 species, are by far the group most sensitive to hydrological migration triggers. This group contributes to dominant species in catches.

III.2.2.2 Biomass of species whose migration is triggered by hydrological changes

In addition to that taxonomic approach, a fishery-centered approach requires an analysis of biomasses at stake. Baran and Chheng reviewed in 2003 the dominant species in Cambodian fisheries. According to their list, three taxa listed above are among whose migration is triggered by a variation of water level. These species are *Cyclocheilichthys spp.* (Sraka kdam in Khmer), *Paralaubuca typus* (Sleuk russey), and *Pangasius spp.* (Trey pra) and they contribute significantly to Cambodian fish catches (by 8.3%, 2.8% and 1.9% respectively).
This means that overall, without mentioning "Trey riel" that makes up to 25.2% of the total catch but whose sensitiveness to discharge is unclear, at least 13% of the fish catch in Cambodia, i.e. between 38,000 and 56,000 tons of fish a year, are made of species sensitive to hydrological variations likely to be altered by built structures. If "Trey riel" is added, this amount goes up to 38% of the catch, i.e. between 110,000 and 164,000 tons. Along the same lines, Baran *et al.* (2005) showed that in Southern Laos, 96% of the total biomass caught is made of species highly sensitive to discharge variations.
These results highlight the potential dramatic effect of built structures that would significantly alter the hydrology and flood dynamics in the lake.

III.2.3 Ecological guilds

Floodplain fish are usually characterised as "black fish" or "grey fish" (Welcomme 1985), and this also applies to the Mekong system. Van Zalinge et al. define these ecological groups (also called "guilds") as follows:
"**Black fish** species undertake relatively short migrations between the flooded areas in the rainy season and permanent water bodies in or close to the floodplain in the dry season. They are adapted to withstand adverse environmental conditions (e.g. low dissolved oxygen) often prevailing on the floodplains. During the wet season the fish go back to the floodplains for feeding and spawning.
"**White fish** species carry out considerably longer migrations. At the beginning of the dry season most species move from the floodplains via the tributaries to the Mekong main stream. Their migrations may extend to several hundred kilometres. In the main stream they use the deeper parts of the river as refuges for the rest of the dry season. At the onset of the rains spawning takes place near these areas before the adult fish move back again for feeding to the floodplains again for feeding. In Cambodia the fish larvae drift downstream with the river current to the floodplains."

In fact floodplain specialists have long acknowledged the need to detail this binary classification in order to better reflect the reality. Thus Régier *et al.* (1989) proposed a third group, of "**grey fish**", made of species that do not clearly belong to white nor to black ecological guilds. This need is confirmed by Welcomme (2001) and So *et al.* (2006) describe grey fish as "species that leave flooded areas and return to rivers or other main water bodies (i.e. dry-season refuge) at the end of wet season. They perform short distance spawning migration (i.e. river/main water-floodplain) and spawn on floodplain in rainy season. They spend a part of their lives on floodplain and another part in rivers/tributaries/streams or other main water bodies. They also have a certain tolerance regarding water quality (e.g. DO = 4 - 5 mg/l?), meaning that water conditions acceptable for grey fish are between those acceptable to white and black fish". In the Mekong Basin, Poulsen *et al.* (2002) have already acknowledged the existence of a group of grey fish, but so far this has never been put into practice, and the Mekong Fish Database for instance does not mention any grey fish. Lévêque and Paugy (1999) detail the specificities of this third group as follows (Table VIII):

Table VIII: Characteristics of Grey fish

	Grey fish
Oxygenation	Gills and adaptations to hypoxia
Tolerance to hypoxia	Low to medium oxygen rates
Type of muscular fibres	Red or white
Migrations	Short range longitudinal migrations, lateral migrations
Body shape	Body compressed laterally, spiny, usually with strong scales
Color	Dark, usually ornamented and colored
Reproduction guild	Nest builders and guarders, lay eggs on the substrate, phytophiles
Dry season habitat	Tributaries or edges of the main stream
Wet season habitat	Floodplain

Following these authors, during project field trips and questionnaires fishers were asked to detail the ecology of a list of fish, and these fish were ultimately classified categorized as belonging to the white, black or grey guild. These results are part of the matrix of Tonle Sap species, and a brief analysis shows that out of 296 species, 55 are classified as white fish, 18 are classified as Black fish, and 24 are characterized as Grey fish[3]. The results of questionnaires are contradictory with the literature for 10 species, whose guild remain undetermined, together with 189 other species (Figure 9).

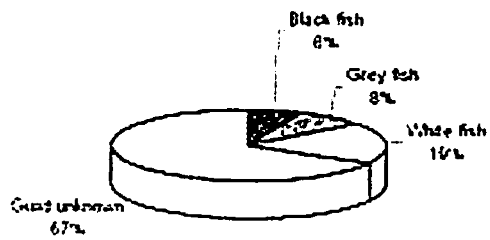

Figure 9: Distribution of Tonle Sap species between 3 ecological guilds

III.2.3.1 Ecological guilds and size of fishes

The database of Tonle Sap species allows detailing the size of fish for each ecological guild. The graph below, that combines total length and ecological guild (Figure 10) shows that there is no significant difference between guilds in terms of average length of fish. However White fishes includes species such as *Pangasionodon gigas* (Reach in Khmer), *Pangasius sanitwongsei* (Pra po pruy), *Catlocarpio siamensis* (Kolreang) or *Wallago attu* (Sanday) that can become giants reaching 366 cm.

[3] The latter grey fish species are:
Arius maculatus (Trey Kaock in Khmer), *Arius sona* (Kaock), *Arius stormii* (Kaock), *Arius thalassinus* (Kaock), *Arius truncatus* (Kaock), *Barbonymus gonionotus* (Chhpin prak), *Belodontichthys dinema* (Khlang hay), *Chitala blanci* (Kray), *Coilia lindmani* (Chunlungh moan), *Hemibagrus wyckii* (Chhlang khmao), *Hemisilurus mekongensis* (Kromorm), *Hyporamphus limbatus* (Phtoung), *Kryptopterus bicirrhis* (Kes prak), *Kryptopterus cheveyi* (Kamphleav stung), *Kryptopterus cryptopterus* (Kamphleav khlanh), *Micronema bleekeri* (Kes krohorm), *Mystus albolineatus* (Kanhchos bai), *Parachela maculicauda* (Chunteas phluk), *Parachela oxygastroides* (Chunteas phluk), *Parachela siamensis* (Chunteas phluk), *Parachela williamminae* (Chunteas phluk), *Parambassis apogonoides* (Kanhchras thom), *Parambassis wolffii* (Kantrorng preng), and *Xenentodon cancila* (Phtoung),

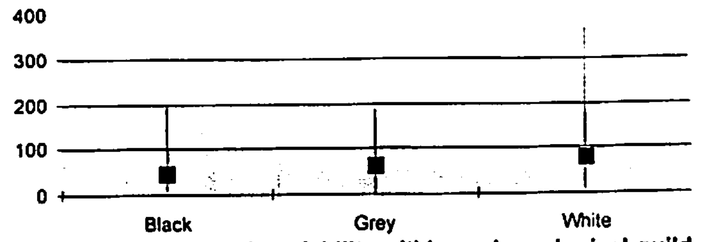

Figure 10: Fish length variability within each ecological guild
(mean, min. and max. total length in centimetres)

III.2.3.2 Ecological guilds and trophic level

The trophic level of a species is its position in the food chain, determined by the number of energy-transfer steps to that level, in other words by the nature of its diet: phytoplankton represents trophic level 1, zooplankton that eats phytoplankton represents trophic level 2, the trophic level of fish that eat zooplankton is 3, that of carnivores eating zooplanktivore fishes is 4, and top predators eating carnivores reach level 5. In practice, since fish diet almost always combines several sources of food from different levels, the trophic level of a given species can be a decimal (Pauly and Christensen 1999).
FishBase gives the trophic level of fishes whose diet has been studied. An analysis also integrating ecological guilds shows that there is no significant difference between the average trophic level of guilds (Figure 11) , although white fish have a slightly lower trophic level corresponding probably to the greater abundance of planktivores in that dominant family.

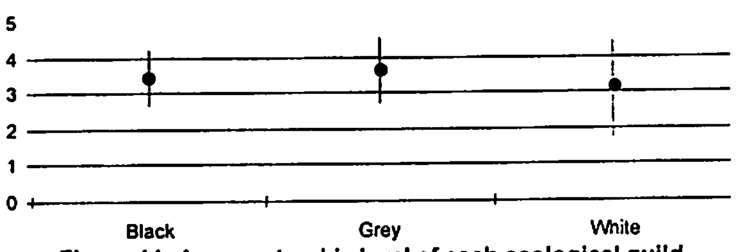

Figure 11: Average trophic level of each ecological guild
(bars indicate the 95% confidence range)

III.2.3.3 Ecological guilds and species resilience

Resilience is the capacity of a system to tolerate impacts without irreversible change in its outputs or structure. In species or populations, this term is often understood as the capacity to withstand exploitation. FishBase calculates the resilience of each species based on several parameters including growth coefficient K, age at first maturity t_m and maximum age t_{max} (Musick 1999, Froese and Pauly 1999). When applied to the three guilds of Tonle Sap species, the analysis shows (Figure 12) that the guild with the highest proportion of resilient species is that of black fish; and that the group of white fish is the only one including species considered of "very low" resilience. The least resilient species (i.e. the most likely to be subject to drastic reduction in catches or collapsing) are *Cyclocheilichthys enoplos* (Chhkaok in Khmer), *Labeo chrysophekadion* (Ka-ek), *L. dyocheilus* (Pava mouk mouy) and *Probarbus jullieni* (Tra sork krohom). It is to be noted that Baird (2006) has already described the extinction threats that this species, classified as "endangered" on the IUCN red list, is subject to. Among black fish, it seems that *Channa micropeltes* (Chhdau) is the species least likely to resist intensive exploitation. These species should be given priority in biological studies so that their level of exposure is better assessed, and specific protection measures can be considered if necessary.

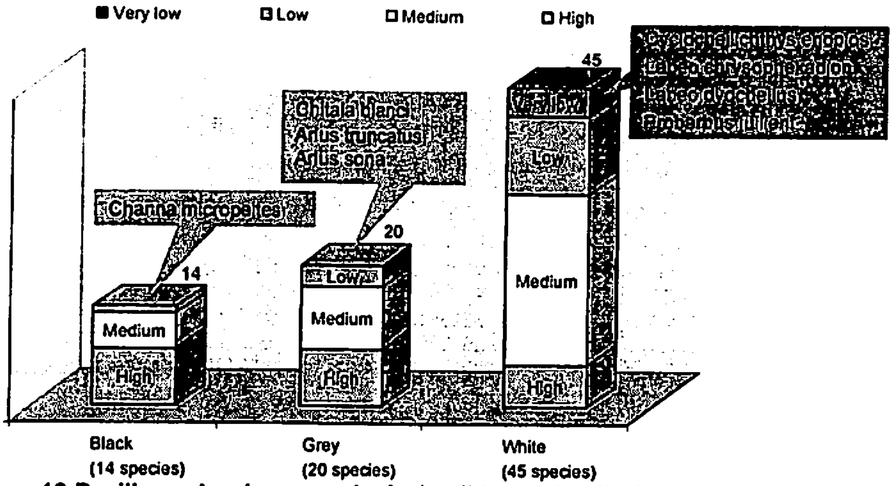

Figure 12:Resilience levels per ecological guild, and detail of species of low resilience

IV CONCLUSIONS

The exploitation of the database of Tonle Sap fish species has just been superficially initiated in that report. A number of additional analyses will follow; they should allow creating a typology of Tonle Sap species and general rules about the response of these various species groups to environmental modifications. Chief among them are the hydrological modifications (changes in water volume and discharge) as well as change in hydrodynamics (flood timing, flood duration, etc) both driven by built structures.

The major conclusion from the preliminary analyses of this report are that three Tonle Sap fish taxa have their migration triggered by changes in water level[4]. This means that the development of built structures, such as dams, that would significantly modify the dynamics of water and the timing of the flood might disrupt the migrations of these taxa. This timing issue can have an impact on the total production, depending on whether migration, spawning, the hydrological regime and the time allowed for growth are matched optimally or not (notion of environmental window for recruitment, Cury and Roy 1989).

Since these three taxa alone contribute between 38,000 and 56,000 tons to fishery yield each year, the issue is significant. Beyond financial value, a comprehensive risk analysis should encompass the livelihood value of these fish, and their role in the diet and food security of rural populations.

Last, it should be noted that not only three taxa are at stake. The extent of our knowledge gap is such (the sensitiveness to hydrodynamics in unknown for 90% of Tonle Sap species) that it is likely that several other species significant to fisheries are sensitive to hydrological modifications induced by infrastructures and likely to collapse in case of excessive perturbations.

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[4] In Khone Falls for instance *Cyclocheilichthys enoplos* is caught between 1,500 and 20,000 $m^3.s^{-1}$, with a sharp peak around 3,000 $m^3.s^{-1}$, and *Paralaubuca typus* displays a sharp and intense peak around 2,000 $m^3.s^{-1}$

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ANNEX A: IFREDI LIST OF TONLE SAP FISH SPECIES

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Khmer name	Latin name	Khmer name
Ampil tum	Puntius orphoides	
Andaeng ngang	*Clarias nieuhofi*	ត្រីអណ្ដែងងាំង
Andaeng reung	Clarias batrachus	ត្រីអណ្ដែងរឹង
Andaeng toun	Clarias macrocephalus	ត្រីអណ្ដែងទន់
Andaeng toun	*Clarias meladerma*	ត្រីអណ្ដែងទន់
Andat chhkae	*Achiroides leucorhynchos*	ត្រីអណ្ដាតឆ្កែ
Andat chhkae	Brachirus harmandi	ត្រីអណ្ដាតឆ្កែ
Andat chhkae	Brachirus orientalis	ត្រីអណ្ដាតឆ្កែ
Andat chhkae	*Cynoglossus feldmanni*	ត្រីអណ្ដាតឆ្កែ
Andat chhkae	Cynoglossus microlepis	ត្រីអណ្ដាតឆ្កែ
Angkot prak	*Puntius brevis*	ត្រីសង្កត់ប្រាក់
Antong	Monopterus albus	ត្រីអន្ទង់
Arch kok	Labiobarbus siamensis	ត្រីអាចម៍កុក
Bandol ampov	Clupeichthys aesarnensis	ត្រីបណ្ដូលអំពៅ
Bandol ampov	*Clupeichthys goniognathus*	ត្រីបណ្ដូលអំពៅ
Bandol ampov	*Clupeoides borneensis*	ត្រីបណ្ដូលអំពៅ
Bandol ampov	*Corica laciniata*	ត្រីបណ្ដូលអំពៅ
Bangkouy/Dorng Darv	Luciosoma bleekeri	ត្រីបង្គួយ រឺ ដងដាវ
Changva	*Rasbora dusonensis*	ត្រីចង្វា
Changva	*Rasbora hobelmani*	ត្រីចង្វា
Changva	*Rasbora myersi*	ត្រីចង្វា
Changva	*Rasbora pauciperforata*	ត្រីចង្វា

Changva chnot	*Rasbora daniconius*	ត្រីចង្វាឆ្នូត
Changva chnot	*Rasbora paviei*	ត្រីចង្វាឆ្នូត
Changva chunchuk	*Crossocheilus reticulatus*	ត្រីចង្វាជញ្ជក់
Changva moul	*Rasbora tornieri*	ត្រីចង្វាមូល
Changva phleang	*Esomus longimanus*	ត្រីចង្វាភ្លៀង
Changva ronoung	*Lobocheilos melanotaenia*	ត្រីចង្វារនោង
Cheik tum	Bagrichthys macracanthus	ត្រីចេកទុំ
Cheik tum	*Bagrichthys obscurus*	ត្រីចេកទុំ
Chhdau	Channa micropeltes	ត្រីឆ្ដោ
Chhkaok	Cyclocheilichthys enoplos	ត្រីឆ្កោក
Chhkaok phleung	Cyclocheilichthys furcatus	ត្រីឆ្កោកភ្លើង
Chhkaok pukmotbai	*Cyclocheilichthys heteronema*	ត្រីឆ្កោកពុកមាត់បី
Chhkok Kda / Kampoul Bai	Cosmochilus harmandi	ត្រីកំពូលបាយ
Chhlang	*Hemibagrus spilopterus*	ត្រីឆ្លាំង
Chhlang khmao	Hemibagrus wyckii	
Chhma	*Setipinna melanochir*	ត្រីឆ្មា
Chhmar krapeu	Lycothrissa crocodilus	ត្រីឆ្មាក្រពើ
Chhpin	Hypsibarbus lagleri	ត្រីឆ្ពិន
Chhpin	Hypsibarbus pierrei	ត្រីឆ្ពិន
Chhpin krohorm	Hypsibarbus wetmorei	ឆ្ពិនក្រហម
Chkaok tytuy	Albulichthys albuloides	ត្រីឆ្កោកទីទុយ
Chlounh	Macrognathus siamensis	ត្រីឆ្លូញ
Chpin prak	Barbonymus gonionotus	ត្រីឆ្ពិនប្រាក់
Chra kaeng	Puntioplites falcifer	ត្រីច្រកែង

Chra kaeng	Puntioplites proctozysron	ត្រីច្រកែង
Chunlungh moan	*Coilia lindmani*	ត្រីជន្លួញមាន់
Chunlungh moan	*Coilia macrognathos*	ត្រីជន្លួញមាន់
Chunteas phluk	*Parachela maculicauda*	ត្រីជន្ទាសភ្លុក
Chunteas phluk	*Parachela oxygastroides*	ត្រីជន្ទាសភ្លុក
Chunteas phluk	*Parachela siamensis*	ត្រីជន្ទាសភ្លុក
Chunteas phluk	*Parachela williamminae*	ត្រីជន្ទាសភ្លុក
Domrei	Oxyeleotris marmorata	ត្រីដំរី
Dong khteng	Macrochirichthys macrochirus	ត្រីដងខ្តែង
Ka-ek	*Labeo chrysophekadion*	ត្រីក្អែក
Kahe krohorm	Barbonymus altus	ត្រីកាហែក្រហម
Kahe lueung	Barbonymus schwanenfeldii	ត្រីកាហែលឿង
Kambot chramos	Amblyrhynchichthys truncatus	ត្រីកំបុតច្រមុះ
Kamphleanh phluk	*Trichogaster microlepis*	ត្រីកំភ្លាញភ្លុក
Kamphleanh srae	Trichogaster trichopterus	ត្រីកំភ្លាញសម្រែ
Kamphleav	*Kryptopterus schilbeides*	ត្រីកំភ្លៀវ
Kamphleav khlanh	Kryptopterus cryptopterus	ត្រីកំភ្លៀវខ្លាញ់
Kamphleav stung	*Kryptopterus cheveyi*	ត្រីកំភ្លៀវស្ទឹង
Kanhchak slar / Khla	Toxotes microlepis	ត្រីកញ្ចាក់ស្លា
Kanhchak slar/Khla	*Toxotes chatareus*	ត្រីកញ្ចាក់ស្លា
Kanhchos	*Mystus wolffi*	ត្រីកញ្ចុះ
Kanhchos bai	*Mystus albolineutus*	ត្រីកញ្ចុះបាយ
Kanhchos chnot	*Mystus multiradiatus*	ត្រីកញ្ចុះឆ្នូត
Kanhchos chnot	Mystus mysticetus	ត្រីកញ្ចុះឆ្នូត

Kanhchoun chey	Channa lucius	ត្រីកញ្ចូនជ័យ
Kanhchras thom	*Parambassis apogonoides*	ត្រីកញ្ច្រាស់ធំ
Kanhchrouk	*Botia beauforti*	ត្រីកញ្ជ្រូក
Kanhchrouk	*Botia morleti*	ត្រីកញ្ជ្រូក
Kanhchrouk chnot	Botia helodes	ត្រីកញ្ជ្រូកឆ្នូត
Kanhchrouk krohorm	Botia modesta	ត្រីកញ្ជ្រូកក្រហម
Kanhchrouk leung	*Botia lecontei*	ត្រីកញ្ជ្រូកលឿង
Kantho	Trichogaster pectoralis	ត្រីកន្ធរ
Kantrob	Pristolepis fasciata	ត្រីកន្ត្រប់
Kantrorng preng	Parambassis wolffii	ត្រីកន្ត្រងប្រេង
Kantuy krohorm	*Discherodontus schroederi*	ត្រីកន្ទុយក្រហម
Kaock	Arius maculatus	ត្រីក្អុក
Kaock	*Arius sona*	ត្រីក្អុក
Kaock	*Arius stormi*	ត្រីក្អុក
Kaock	Arius thalassinus	
Kaock	*Arius truncatus*	ត្រីក្អុក
Kaork	*Hemipimelodus borneensis*	ត្រីក្អុក
Karb sor	Hypophthalmichthys molitrix	ត្រីកាបស
Karp samanh	*Cyprinus carpio*	ត្រីកាបសមញ្ញ
Kasan	Channa gachua	ត្រីក្សាន
Kbork	Tenualosa thibaudeaui	ត្រីក្បក
Keat srang	*Balantiocheilos melanopterus*	ត្រីគៀតស្រង
Kes krohorm	*Micronema bleekeri*	ត្រីកេសក្រហម
Kes prak	*Kryptopterus bicirrhis*	ត្រីកេសប្រាក់

Khchoeung	*Macrognathus maculatus*	ត្រីខ្ជឹង
Khchoeung	Mastacembelus armatus	
Khchoeung	*Mastacembelus favus*	ត្រីខ្ជឹង
Khchoeung pkhar	*Mastacembelus erythrotaenia*	ត្រីខ្ជឹងផ្កា
Khla	*Datnioides pulcher*	ត្រីខ្លា
Khla	Datnioides undecimradiatus	ត្រីខ្លា
Khlang hay	*Belodonthichthys dinema*	ត្រីក្លាំងហាយ
Khman	*Glossogobius aureus*	ត្រីក្បាន
Khman	Hampala dispar	ត្រីខ្មាន់
Khman	Hampala macrolepidota	ត្រីខ្មាន់
Khnorng veng	Labiobarbus lineatus	ត្រីខ្នងវែង
Khya	Hemibagrus wyckioides	
Kranh	Anabas testudineus	ត្រីក្រាញ់
Kray	Chitala blanci	ត្រីក្រាយ
Kray	Chitala lopis	
Kray	Chitala ornata	ត្រីក្រាយ
Kreum	*Trichopsis schaleri*	ត្រីក្រឹម
Kreum	*Trichopsis vittata*	ត្រីក្រឹម
Kromorm	Hemisilurus mekongensis	ត្រីក្រម៉ម
Kros	Osteochilus hasseltii	ត្រីក្រុស
Kros	Osteochilus lini	ត្រីក្រុស
Kros	Osteochilus microcephalus	ត្រីក្រុស
Kros chhnout	Osteochilus waandersii	ត្រីក្រុស
Kros phnom	*Poropuntius deauratus*	ត្រីក្រុសភ្នំ

Krum	Osteochilus melanopleurus	ត្រីក្រុំ
Kuch chreov	*Puntioplites bulu*	ត្រីគុចជ្រៀវ/កញ្ជ្រៀវ
Kul chek	*Epalzeorhynchos frenatum*	ត្រីគល់ចេក
Kulreang	Catlocarpio siamensis	ត្រីគល់រាំង
Linh	Thynnichthys thynnoides	ត្រីលិញ
Lolouk sor	Osteochilus schlegeli	ត្រីលលកស
Pase ee	Mekongina erythrospila	
Pava mouk mouy	Labeo dyocheilus	
Phkar ko	Cirrhinus jullieni	
Phkar ko	*Cirrhinus molitorella*	ត្រីផ្កាគ
Phtoung	Hyporhamphus limbatus	ត្រីផ្ទោង
Phtoung	Xenentodon cancila	ត្រីផ្ទោង
Pra chveat	Pangasius macronema	ត្រីឈ្វៀត
Pra chveat	Pangasius polyuranodon	ត្រីឈ្វៀត
Pra kae	Pangasius conchophilus	ត្រីកែ
Pra kandorl	Helicophagus waandersii	ត្រីប្រាកណ្ដុរ
Pra khchao	Pangasius bocourti	ត្រីប្រាខ្ចៅ
Pra po	Pangasius larnaudii	ត្រីពោ
Pra po pruy	Pangasius sanitwongsei	ត្រីពោព្រុយ
Pra thom	Pangasianodon hypophthalmus	ត្រីប្រាធំ
Prama	Boesemania microlepis	ត្រីប្រម៉ា
Proloung / Chroloeung	Leptobarbus hoevenii	ត្រីព្រលូង/ច្រឡឹង
Pruol / Krolang	Cirrhinus microlepis	ត្រី ព្រួល/ក្រឡង់

Reach	Pangasianodon gigas	ត្រីរាជ
Riel anhkam	*Henicorhynchus cryptopogon*	ត្រីរៀលអង្កាម
Riel thmor	Cirrhinus cirrhosus	
Riel top	Henicorhynchus siamensis	ត្រីរៀលតុប
Ros / Phtuk	Channa striata	ត្រីរស់
Sanday	Wallago attu	ត្រីសណ្តាយ
Slat	Notopterus notopterus	ត្រីស្លាត
Sleuk russey	*Paralaubuca harmandi*	ត្រីស្លឹកឫស្សី
Sleuk russey	*Paralaubuca riveroi*	ត្រីស្លឹកឫស្សី
Sleuk russey	Paralaubuca typus	ត្រីស្លឹកឫស្សី
Sraka kdam	*Cyclocheilichthys apogon*	ត្រីស្រកាក្តាម
Sraka kdam	*Cyclocheilichthys amatus*	ត្រីស្រកាក្តាម
Sraka kdam	*Cyclocheilichthys lagleri*	ត្រីស្រកាក្តាម
Sraka kdam	Cyclocheilichthys repasson	ត្រីស្រកាក្តាម
Stuok	Wallago leerii	ត្រីស្ទក់
Ta aon	Ompok bimaculatus	ត្រីតាអោន
Ta aon	*Ompok hypophthalmus*	ត្រីតាអោន
Tanel	*Hemibagrus filamentus*	ត្រីតានេល
Tra sork krohom	Probarbus jullieni	ត្រីត្រសក់
Tra sork sor	Probarbus labeamajor	ត្រីត្រសក់ស
Trocheak domrei	Osphronemus exodon	ត្រីត្រចៀកដំរី

ANNEX B: QUESTIONNAIRES ON TRADITIONAL ECOLOGICAL KNOWLEDGE

Fisheries Ecology Survey Form

COMPLETE 1 FORM FOR EACH INTERVIEW

Section A. - DETAILS OF THE INTERVIEW

Date	
Location	
Structure type	
Village name	
Commune	
District	
Province	

Respondents	Gender/Age

Who identified them?	

Section B. - MAPPING THE CURRENT SITUATION

Guidelines:

We get the respondents to draw a map of the area as it is now (use large piece of paper).
Important aspects to include are:
1. types of habitat (e.g. canals, paddy fields, ponds, rivers, streams, swamps etc.) that might be important for fish and/or fishing. Highlight which ones are new or have changed. Location name
2. Distances, estimated areas and depths and seasonality of the resource (mark these on map)
3. Any rules that are in place regarding access to and use of resources. Mark these with the letter private or protected areas on the map.
4. Gear and main gear types in each fishing location.
Now go to section C.

Section D - LOCAL MIGRATIONS AND SPAWNING

D1. Use the local map and transparencies to show the location and timing of migrations and where the fisher perceives the source of young fish to be (e.g. local, tributary or Mekong).

Species	Where the young fish come from
Pra Thom	
Prual	
Riel	
Chhpin	
Ta Oan	
Kanh Chos	
Kanthou	
Kray Srae	
Proloong	

D2. Have there been any changes in migrations and movements because of the built structure?
If yes, which species and why do they think this has happened?

Section E. - NEW INFORMATION ON FISH ECOLOGY

H1. Ask fishers for which species they have knowledge of spawning, nursing, feeding and migrations within the basin. For those fish that they have knowledge, complete the following table.
For the ecology type (black/white/grey) you will need to identify this yourself.

Species name	Type of Spawning habitat	Name of Spawning location	Type of Feeding habitat	Type of nursing habitat	Ecology type
Andet Chhkae					
Kanhchos Bay					
Kanchras Thom					
Bandoul Ampov					
Reus Chek					
Kasan					
Phtoung					
Chlaing					
Ka Ek					
Angkot Prak					
Dorng Khteng					
Chunleas Phluk					
Ampil Tum					
Stuk					
Kra Morm					
Ka Uk					
Krum					
Chunluanh Moan					
Kantrang Preing					
Kampleav					
Khlaing Hay					
Kes					

Form completed by:

Asian Development Bank
TA 4669-CAM

Technical Assistance to the Kingdom of Cambodia
for the Study of the Influence of Built Structures
on the Fisheries of the Tonle Sap
(financed by the Government of Finland)

"BAYFISH-TONLE SAP", A MODEL OF THE TONLE SAP FISH RESOURCE

Prepared by

Eric BARAN, Teemu JANTUNEN, CHHENG Phen, Markus HAKALIN

April 2007 update

TABLE OF CONTENTS

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1 INTRODUCTION

As demand for freshwater steadily increases, decision makers at a national as well at basin level require information on the role of river flow in sustaining environmental benefits and tools to assess the necessary trade-offs between different water uses. River and floodplain fisheries are one of these benefits, and in the case of Cambodia are assets of remarkably high importance for the country.

Inland fisheries amounted to 360,000 tons in 2002 according to the Department of Fisheries, contributing up to 16% of the GDP (Van Zalinge *et al.* 2004). Depending upon years, this catch is equal or superior to that of the inland fisheries in the whole Northern America. However, detailed scientific monitoring shows that this annual catch varies a lot from year to year, depending among others on the flood characteristics (Ngor Peng Bun 2000, Baran *et al.* 2001a and b). Recent studies have also shown that the fish production in the Mekong Basin is dependant upon a number of hydrological, environmental and ecological factors (Baran 2001c). A modelling approach is the only possible way to integrate all these states (Baran and Cain 2001; Baran and Baird 2003), as the global trend resulting from intricacy of factors is beyond the reach of individual experts and the number of interacting variables would require decades of data for a standard statistical approach. For example, 60 annual cycles would be required to test all the interactions of four environmental variables on the annual fish production with a non parametric method, the least data-hungry approach (Sokal and Rohlf, 1981).

Reviews of modelling approaches and tools for tropical floodplain rivers management have also demonstrated the interest of Bayesian networks (Baran 2002; Arthington *et al.* 2004) as they allow the integration of quantitative as well of qualitative information (databases or expert knowledge), and they are intuitive, flexible and powerful.

In 2001-2002 a decision support tool based on Bayesian networks was developed to integrate the 25 variables that drive the Mekong fish production (Baran *et al.* 2003a). The paucity of data available at this time at the scale of the whole basin led to a rather crude model, whose parameterization was based on expert knowledge only. Lessons learnt from this undertaking were that:

a) the usefulness of Bayesian networks as a management tool would be better demonstrated if undertaken at a smaller scale, at which sufficient data would be available and variables could be more precisely described;
b) the expert consultation process was a crucial step in building a model that would be recognized as relevant by stakeholders, balancing simplification and accuracy, sophistication and uptake.

Learning from these lessons, in 2003 the WorldFish Center, in collaboration with IFReDI, undertook the development of a model of the Tonle Sap fish production. The objectives of this study were to identify relationships between river hydrology, floodplain habitats and fish production; to raise awareness among stakeholders and decision-makers about the dependency of fish production upon environmental factors; and to predict the relative abundance of the fish groups dominant in the Great Lake fisheries. An additional objective was also to train IFReDI counterparts in modelling approaches.

This report describes the progressive building of this model named BayFish – Tonle Sap (Bay- stands for Bayesian, and Fish- for fisheries). After having introduced the principles of Bayesian networks (section 2) and the process of stakeholders consultation for model building (section 3), we detail the creation of the model framework by selection of relevant variables (section 4), and the characterization of these variables (section 5). Then the parametrization of the variables is described in sections 6 and 7; the integration of data sets in the model, briefly addressed here, is extensively detailed in a companion report by Jantunen (2006). The model obtained is tested and validated, before scenario analyses are run (section 8). The conclusion of this study are presented in the final section.

2 BAYESIAN NETWORKS AS INFORMATION INTEGRATORS

A Bayesian network consists in defining the system studied as a network of variables linked by probabilistic interactions (Jensen 1996). Bayesian networks are also called Bayes nets or Bayesian belief networks (BBN). These methods based on the calculation of dependant probabilities (Bayes theorem) were originally developed in the mid-90s as Decision Support Systems (DSS) for medical diagnostic. Their principles and application to environmental management have been detailed in Charniak (1991), Ellison (1996), Cain (2001) and Reckhow (2002).

Variables representing the modelled environment can be quantitative (e.g. "Number of fishers") or qualitative (e.g. "Fishing strategy"). For each variable a small number of classes are defined. One of the challenges, when building a network, consists in defining enough but not too many variables.

Probabilities are attached to connected variables, based on what is known about the system represented (Figure 1).

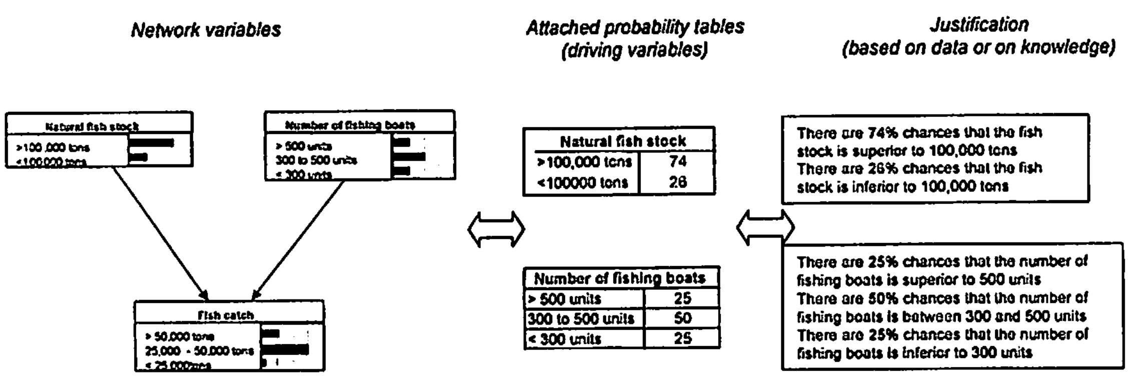

Figure 1: Mini-network of 3 connected variables representing a hypothetical fishery (left). The probabilities of the first two driving variables are detailed in the central section, and the justification is detailed in the right part of the figure.

In a driven variable all the possible combinations of driving variables are integrated (Figure 2).

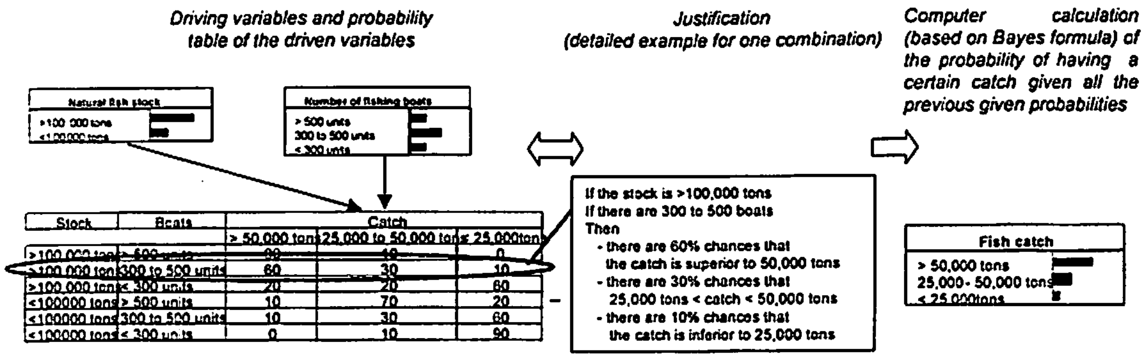

Figure 2: Mini-network of 3 connected variables representing a hypothetical fishery (continued). The probability table of the driven variable is detailed and in the middle of the figure, and the resulting probabilistic computation is given in the right part of the figure.

Thus the major tasks in building the model are:

a) *Network development:*

- ➢ To identify the major variables of the system studied;
- ➢ To arrange them into a meaningful network.

b) *Variables definition:*

- ➢ To define a few relevant states for each variable.

c) *Parameterization:*

- ➢ To define the probability of each state of each driving variable (action named "elicitation of prior probabilities");
- ➢ To define for each driven variable the probabilities of each combination of driving variables.

If data is available, then the quantified relationship between two variables can be automatically converted into probabilities. If data is not available, then expert knowledge can be used to express in terms of probabilities the known relationship between two variables.

Ultimately the computer calculates, based on the Bayes formula of combined probabilities, the probability of having a certain state in a driven variable given all the states defined in all driving variables.

<u>Bayes formula</u>

$$P(a|b) = \frac{P(b|a) \times P(a)}{P(b)} \quad \text{i.e.} \quad \text{Probability of a knowing b} = \frac{\text{(Probability of b knowing a)} \times \text{(Probability of a)}}{\text{Probability of b}}$$

In other words

$$\text{Posterior} = \frac{\text{Conditional likelihood} \times \text{Prior}}{\text{Likelihood}}$$

The possible integration of expert knowledge (an expert being any person having a first hand experience of the system studied) into a modelling framework contributed significantly to the success of the Bayesian approach; such consultations are nowadays being more and more broadly used (e.g. McKendrick *et al.* 2000, Soncini-Sessa *et al.* 2002, Hahn *et al.* 2002, Bertorelle *et al.* 2004). In the field of fisheries, Bayesian networks have been used since the mid-nineties (e.g. Lee and Rieman 1997, Kuikka *et al.*1999, Borsuk *et al.* 2002) and are being increasing used, for instance for stock assessment (Hoggarth *et al.* 2006).

Different software applications are available to build and run Bayesian networks (review in Arthington *et al.* 2004) although some teams prefer to develop their own (Varis 2003). We chose for the development of this model the Netica software developed by Norsys (www.norsys.com) as it is intuitive, user friendly (it does not require to master a computer language) and is easily accessible on Internet, where a freeware version allows the development of small models and the running of any big model such as BayFish – Tonle Sap.

3 THE STAKEHOLDERS CONSULTATION PROCESS

In using Bayesian networks for environmental management, the consultation of experts and stakeholders is acknowledged as being of critical importance (Borsuk *et al.* 2001; Cain *et al.* 2003; Ravnborg and Westermann 2002). The experts or stakeholders consultation has been described with more or less details in almost all studies using Bayesian networks. However for modelling approaches touching up on societal issues such as natural resources management, studies focusing on consultation processes and methodologies are very few (Reckhow 2002). Some authors have addressed specific aspects of consultations, in particular on the formal side (Beierle 2002, Gregory *et al.* 2003, Wilkins *et al.* 2002, Seidel *et al.* 2003), whereas others have highlighted the psychological pitfalls inherent to consultation of individuals or stakeholders (Anderson 1998, De Bruin *et al.* 2002, Fenton 2004). On the practical side, the recommendations provided by Cain (2001) and Ravnborg and Westermann (2002) for stakeholders consultations are among the most detailed; however the lack of concise and pragmatic methodological framework led Baran and Jantunen (2004) to propose guidelines for stakeholders consultation for Bayesian modelling in environmental management.

The Tonle Sap model has been built from scratch following the recommendations of 38 stakeholders overall, met during four one-day workshops, (Hort *et al.* 2004). The meetings were attended by a majority of stakeholders pertaining to the fisheries sector, from national agencies (IFReDI, DoF) but also from local organizations (community fisheries, farmers-fishers organizations). Environmental and socio-economic disciplines were also represented, in particular hydrology, water quality and environmental valuation. Among other disciplines, managers (MRC Basin Development Plan) and policy-makers (Cambodian National Mekong Committee) were also present. In term of origin of the stakeholders, governmental agents were a majority, which is coherent with the target of the tool developed. The presence of independent scientists and representatives from fisher organizations balanced the number of specialists from the governmental agencies.

Several consultations were necessary so that the modellers could progressively convert the information provided by stakeholders into a computer model. This back-and-forth process also permitted to identify missing notions, incoherencies and mistakes. The model presented below is the final accepted one, and the intermediate steps have not been detailed.

The three main steps of the consultation consisted in:

a) building the model framework;
b) defining the model variables, and;
c) parameterizing the variables.

A report following each major step has been produced and served as a basis of the following consultation.

4 BUILDING THE MODEL FRAMEWORK

The model framework is based on contributions from stakeholders, as detailed in Hort *et al.* (2004).
By convention the variables of the network are represented in a box and the states of each variable are in *"Italics"*. In this section, description starts from the driven variables, moving up towards their driving variables.

4.1 Fish production variables

• Tonle Sap fish production is expressed as Total fish catch (Figure 3):

- Fish stock depends on hydrology, habitat available, and amount of fish migrations;
- Fish catch depends on fish stock and on the efficiency of the fishing sector.

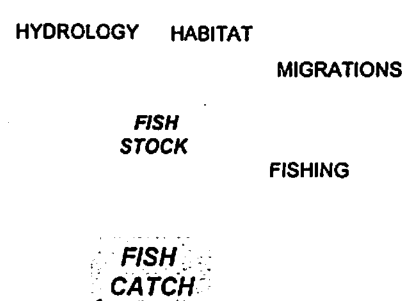

Figure 3: Main variables contributing to Tonle Sap fish production.

4.1.1 <u>Components of the fish catch</u>

• Total fish catch results from Catch of Mekong migrants, Catch of Tonle Sap migrants and Catch of residents.

• "Resident fish" is a term considered here as synonym of "Black fish"; this ecological category is that of species with limited lateral migrations and no longitudinal migrations, able to survive in swamps and ponds all year round. These fish are mostly carnivorous and detritus feeders. The group of "resident fish" includes: *Channidae* (Snakeheads), *Clariidae*, *Bagridae* (*Mystus* sp.) and *Anabantidae* (Van Zalinge *et al. 2004).*

• "Mekong migrants" is synonym here of "White fish"; i.e. the ecological group of species showing long distance migrations, in particular back to the Mekong mainstream. This group includes many cyprinids (e.g. "Trey riel" *Henicorhynchus spp.* and *Cirrhinus sp.*) but also most *Pangasidae*.

• "Tonle Sap migrants" is synonym of Grey fish, as defined by Welcomme (2001). This ecological category corresponds to fishes that do not spend the dry season in floodplain ponds, but do not undertake long distance migrations either. They tend to spend the dry season in Tonle Sap tributaries and their ecological and physiological characteristics are intermediate between those of black and white fish. This guild includes species such as *Belodontichthys dinema* (trey khlang hay in Khmer), *Mystus albolineatus* (trey kanhchos bai) or *Kryptopterus cheveyi* (Trey kamphleav stung).

The terms "resident" and "migrant" have been preferred to the classical terms "black fish", "white fish" or "grey fish" as the latter are not familiar to stakeholders who do not see the point of a classification based on colour, although it is actually based on ecology and behaviour. It is also acknowledged that "resident" fishes also move laterally between different habitats in the floodplain and thus qualify as migrants, but this feature is considered minor by stakeholders when compared to the migrations undertaken over much longer distances by white or grey fishes. Stakeholders also decided not to detail fish groups further, as classifying into more detailed and significant ecological groups the 296 species or so that constitute the Tonle Sap fish community seemed to be impossible at this point of time.

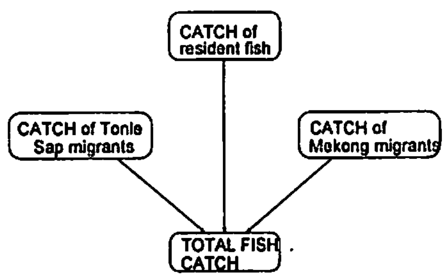

Figure 4: Variables contributing to Tonle Sap fish catch.

• As catch results from a fishing pressure on a fish stock, Catch of Mekong migrants is dependant on Stock of Mekong migrants and of Pressure on Mekong migrants. The same applies to Tonle Sap migrants and resident fish.

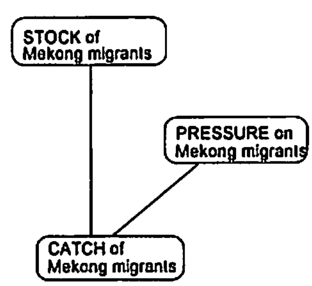

Figure 5: Variables contributing to catch of resident fish .

4.1.2 Components of the fish stock

• Stock of Mekong migrants depends on the annual flooding pattern (Flooding for fish), on the available options for migrations (Migrations of Mekong migrants), and on the quality of the environment used (Habitat for Mekong migrants). The same applies to Tonle Sap migrants and Resident fish (figure 6).

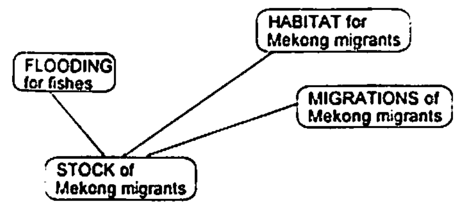

Figure 6: Variables contributing to the fish stock.

Thus these fish stock nodes serve as the combination point for hydrological, environmental and fishing sections of the model.

4.2 Hydrology variables

4.2.1 Quality of flooding

• Flooding for fish is understood as a combination of the Flood beginning (date of beginning of the flood in the floodplain), of the Flood duration and of the Flood level. At the same time Flood duration is affected by Flood beginning and Flood level, i.e. earlier and higher flood causes duration to extend.

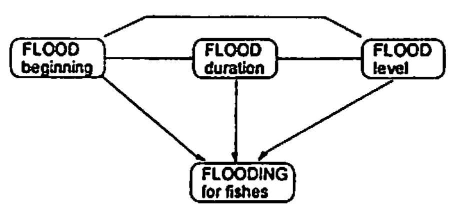

Figure 7: Variables contributing to Flooding for fish.

4.2.2 Details of hydrological variables

• Flood level results from Tonle Sap water level as measured in a reference site. Flood level is also affected by Flood beginning as earlier floods have a higher possibility to cause higher floods.

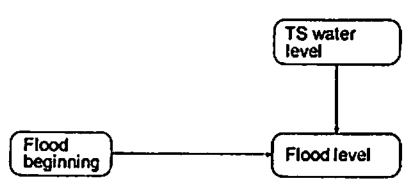

Figure 8: Variables contributing to Floodplain flood level.

• Tonle Sap water level results from Tonle Sap runoff (water originating from rainfall over the Tonle Sap Basin), from the Mekong inflow (water coming from the Mekong River via the Tonle Sap River) and from the Overland flow (Mekong River water spilling over the land, in particular between Kompong Cham and Phnom Penh, hence not contributing to discharge measurements at Prek Kdam). Justifications can be found in Jantunen (2006).

• Tonle Sap runoff results directly from Tonle Sap rainfall over the basin, as seen in figure 9.

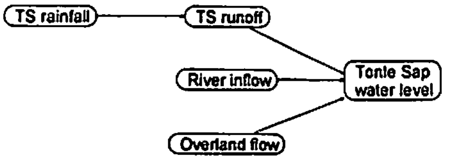

Figure 9: Variables contributing to Tonle Sap water level.

4.3 Habitat variables

• Habitat for Mekong migrants, Habitat for residents and Habitat for Tonle Sap migrants are understood as the quality of the environment used by these fishes. Stakeholders and recent studies show that the states of critical importance to all fish groups are the oxygen level in the floodplain (O2 for resident fish, O2 for Mekong migrants and O2 for Tonle Sap migrants) and the nature of the vegetation in the floodplain (Flooded vegetation). Incidentally dissolved oxygen (DO) is the only indicator of scientifically proven importance to fish production as that of other chemical variables could not be ascertained. In general the lake is well oxygenated due to wind and wave induced aeration, but parts of the floodplain are largely anoxic due to the decaying of vegetation and lack of wind induced mixing (Sarkkula and Koponen 2003).

• O2 for residents is the concentration of Floodplain oxygen biologically acceptable for black fishes used to living in the floodplain. The same applies to O2 for Mekong migrants and O2 for Tonle Sap migrants (a distinction was made as the three groups do not have the same requirements, black fishes being the least demanding, white fish the most demanding in oxygen and grey fish having intermediate requirements).

• Floodplain dissolved oxygen depends upon Tonle Sap water level and upon the nature of Flooded vegetation. Usually the higher the water level the higher the dissolved oxygen levels.
Vegetation type affects DO through the amount of organic matter produced (leaves and branches absorb oxygen when they decompose in the water) as well as vegetation height (high vegetation such as flooded forest reduces wave formation, water stirring and the subsequent mixing of oxygen in the water column).
• Flooded vegetation is a function of the Tonle Sap water level, the amount of vegetation flooded being directly dependant on the surface area covered by the flood.

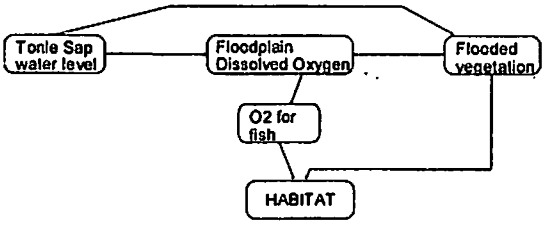

Figure 10: Variables contributing to Habitat for migrant and resident fish.

4.4 Fish migration variables

• Migrations of resident fish is understood as the possibility for fish to migrate within the floodplain and to have access to refuges in the dry season. This variable is thus driven by two factors: the availability of Floodplain refuges and the presence Built structures that reduce access to floodplain habitats and increase fish catchability and mortality. Migrations of Mekong migrants and Migrations of TS migrants depends upon the same factors, although there is more emphasis on longitudinal migrations and larval drift between the Mekong or Tonle Sap tributaries and the Lake.

• Floodplain refuges describe temporary and perennial ponds in the Tonle Sap floodplain that have the potential to offer dry season refuges for fish (mainly for residents and Tonle Sap migrants). Any pond (temporal) that completely dries up at some point of the year is not considered as a refuge. For this reason irrigation channels, most of which dry up, are not considered as refuges (Cambodian irrigated rice fields produce only two crops per year, hence they dry up at some point).

• Built Structures depends upon Tonle Sap water level. The higher the water level the more the built structures affect the flow and especially extent of the flood. Larger area of flood provides wider habitat for fish, therefore built structures have a negative impact on fisheries. The only built structures considered here were National Roads 5 and 6 due to lack and quality of data.

4.5 Fishery variables

4.5.1 Components of the fishing pressure

• Pressure on residents, Pressure on Tonle Sap migrants as well as Pressure on Mekong migrants all depend on the fishing pressure of three major components of the overall fishery: the small scale (SS), middle scale (MS) and large scale (LS) fisheries (DoF 2001; figure 11)

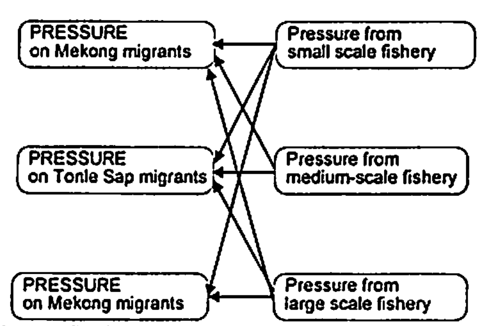

Figure 11: Variables contributing to fishing pressure.

4.5.2 Components of each fishery

• In absence of significant and quantified alternative information, it is considered that the Pressure from large-scale fishery is primarily a reflection of the length of fences constituting the large scale fishing lots.

• The Fishing pressure from small-scale fishery depends on the Gear size of small-scale fishers, on the Activity of small-scale fishers (i.e. their intensity of fishing), and on the Number of small-scale fishers. The Number of small-scale fishers is a combination of the Number of Khmer small-scale fishers and of the Number of Vietnamese/Cham small-scale fishers. As a matter of fact that it is believed by stakeholders that the expertise and impact of Vietnamese and Cham specialised fishers are superior than that of Khmer fishers, who considers themselves mainly as rice farmers (Nettleton and Baran 2004).

The "gear size" variable illustrates the fact that the dominant gear of the small scale fishery is the nylon gill net, whose size has been increasing over years from the 10 meters allowed by law to an average of 300m (Nettleton and Baran 2004).

The Activity of small-scale fishers depends on the Tonle Sap water level since subsistence farmers-fishers spend their time either fishing or farming, depending upon the flooding conditions.

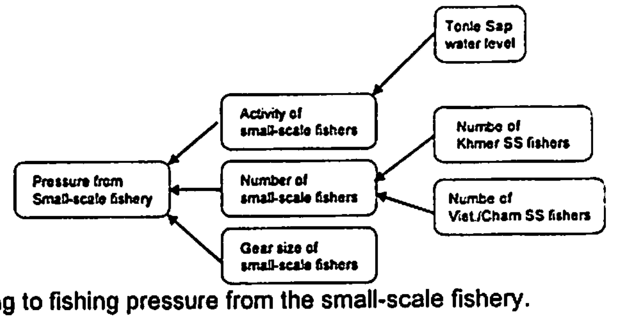

Figure 12: Variables contributing to fishing pressure from the small-scale fishery.

• The Pressure from middle-scale fishery depends on the Number of middle-scale fishers and on the Middle-scale gear efficiency. The number of fishers is the variable easiest to assess (relatively speaking), and can be a proxy of the total fishing effort; however the gear efficiency has also has been evolving, in particular since the fishery reform in 2000, with for instance the spreading of electric fishing, the introduction of the "Boh" gear and the electrification of certain dragnets. These technical evolutions towards more efficiency are well known from fisheries specialists but it remains difficult to quantify them and their impact, and there is currently no monitoring system allowing a quantification of these changes.

• The Number of middle-scale fishers is a combination of the Number of Vietnamese/Cham middle-scale fishers, of the Number of Khmer middle-scale fishers and of the Number of migrant middle-scale fishers, as detailed in Nettleton and Baran (2004). The difference between Vietnamese/Cham or Khmer fishers reflect the fact that the former are considered to operate intensely, whereas the pressure exerted by the latter is believed to be of lesser intensity. Migrant fishers also play a role considered important as they are said to harvest exhaustively and indiscriminately a few months a year.

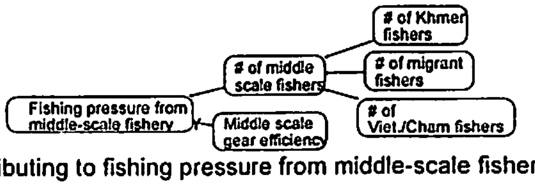

Figure 13: Variables contributing to fishing pressure from middle-scale fishers.

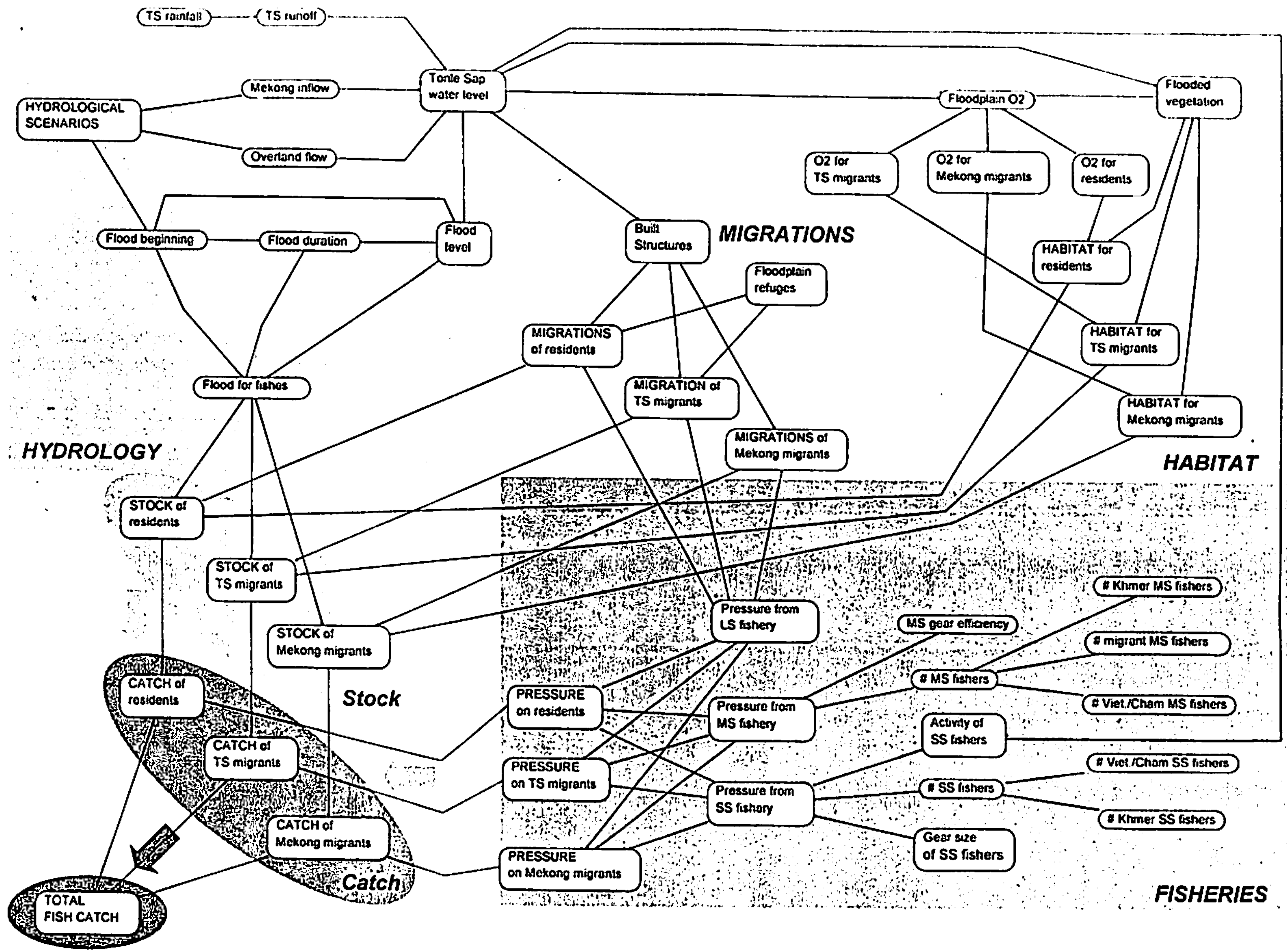

Figure 14: Overview of the model variables

5 DEFINING THE MODEL VARIABLES

Once the model framework built, a second stakeholders consultation led to the definition of the relevant states for each variable (Hort and Baran 2004). Several of these variables had to be qualified in vague terms, such as *"Abundant"* or *"Scarce"*, which illustrates the absence of reliable quantified data for these variables. From this perspective, this modelling study is useful in highlighting the areas that require more research, and shows in particular how little quantitative knowledge exists about the fish resource. The states defined for some other variables can also seem vague (e.g. Flooding for fish, *"Good"* or *"Bad"*) but in that case this is normal and inherent to the integrative nature of these variables, that represent a status indicator (this is reflected in sayings such as "this year the fish production was good").

5.1 Fish production variables

• Total fish catch is defined as *"High"* or *"Low"*. Quantitative estimates would be possible *IF* reliable fishery statistics were available to feed the model, but at the moment such data do not exist (Coates 2002).

• Catch of Mekong migrants, Catch of Tonle Sap migrants as well as Catch of residents are defined as *"High"* or *"Low"* as no detailed catch statistics are available; therefore more precise states were impossible to define.

• Stock of resident fish, Stock of Tonle Sap migrants and Stock of Mekong migrants are simply defined as *"Abundant"* and *"Scarce"*, in absence of any quantitative stock assessment.

5.2 Hydrology variables

• Flooding for fishes is purposely qualified as *"Good"* or *"Bad"*, which synthetically describes the quality of a hydrological year from a fishery perspective. All variables seen as essential by stakeholders for fish are taken into account, i.e. flood maximum level, duration and date of beginning.

• The Flood beginning has been defined as "the date of spill-over from the river to the floodplain"; stakeholders have considered, after extensive debates opposing memorized experience to recorded data and people from different locations, that a flood can be considered as "early" when it starts *"Before mid-July"*, "normal" when it starts from *"Mid-July to mid-August"*, and "late" when it begins *"After mid-August"*. In data analysis this 'spill-over' was defined as occurring when the water level at Kompong Loung exceeded 4 metres (due to highly fluctuating nature of the water level two reference dates were used: 15th July and 15th August).

• Variable Flood duration has been defined as the time span between Flood beginning and date of end of the flooding; the "end of flooding" being defined by the flow reversal towards Mekong in Tonle Sap River at Prek Kdam. In the second stakeholders consultation, flood duration was expressed in terms of dates; this was later converted into a number of weeks. This consultation also identified states as "Long" (over 13 weeks), "Medium" (5-13 weeks) and "Short" (less than 5 weeks) but data analysed showed that no flood was longer than 13 weeks or shorter than 5 weeks in records. Ultimately states were defined as *"Less than 6 weeks"* (short flood), *"Around 8 weeks"* (6 to 11 weeks, normal flood) and *"More than 11 weeks"* (long flood).

• Flood level was characterized as being *"Low"* or *"High"*, and these values are closely associated to the Tonle Sap water level. This simplicity is also required to allow easier elicitation in the probability table of the Flooding for fish child variable that has three parent variables.

• The definition of the Tonle Sap water level in a reference place has been subject to several revisions, due to the complexity of this notion. Kompong Chhnang was initially proposed by stakeholders as a reference site but the analysis of datasets revealed that Kompong Chhnang had 34 gaps (2526 days in total) over 37 years of data whereas Kompong Loung had only 8 gaps (819 days in total) in 20 years of data; subsequently Kompong Loung was chosen as reference site for Tonle Sap Lake water level. Thresholds set for water level in 2nd stakeholders consultation were "Above 11m", "10-11m" and "Below 10m" for Kompong Chhnang; however these thresholds were invalid for Kompong Loung (where water level never reach 11m and rarely 10m). Thus in the 4th stakeholders consultation the thresholds were set at *"Below 8m"*, *"From 8 to 10m"* and *"Above 10m"* (Hort *et al.* 2004). This correlates with the natural system, i.e. *"Below 8m"* being considered bad for fish production (dry year), *"From 8 to 10m"* good and *"Above 10m"* as moderately good for fish production (a high water level favouring the abundance of fish in water but reducing the catchability of these fish by fishers) and bad for agriculture. Jantunen (2006) gives detailed justifications for the final choice, i.e. Kompong Loung as a reference site for gauging and *"Below 8m"*, *"Between 8 and 10m"* and *"Above 10m"* as reference marks of low, normal or high water levels.

• Tonle Sap rainfall, Tonle Sap runoff, Mekong inflow and Overland flow were calculated based on existing databases (Jantunen 2006) and are simply expressed in terms of a state *"Above"* or *"Below"* of their respective average after several rainy seasons. Given existing knowledge it was impossible to define the states more meaningfully, and defining more states would have generated a non-manageable complexity in probability tables, with impossible combinations and unrealistic data requirements (e.g. 3 driving variables with 3 states each = 27 combination of states; when related to 3 states in the driven variables, this would correspond to 27 x 3 = 81 probabilities to be set or calculated into the probability table).

5.3 Habitat variables

• Habitat for residents, Habitat for TS migrants as well as Habitat for Mekong migrants have been described as *"Good"* or *"Bad"*, as this describes the quality of the habitat from a fish perspective. Only two variables define the habitat quality: dissolved oxygen concentration and vegetation type. A lot of other variables were mentioned and discussed during the stakeholder consultations, but these two variables are the only ones whose role vis-à-vis fish production could be substantiated and states defined. Vegetation in particular provides feed and protection from predators for juvenile fishes, but also plays a negative role by reducing dissolved oxygen concentrations through decomposition of organic material at the beginning of the flood.

• O2 for residents has been simply expressed in terms of *"Acceptable"* or *"Impossible"*; this variable is linked to Floodplain Dissolved Oxygen. The same applies to O2 for Mekong migrants. See Floodplain Dissolved Oxygen below for more detailed description.

• The essential states of Floodplain Dissolved Oxygen has been defined, after a review of literature using FishBase (2004), as *"Above 4 mg/l"* (value acceptable to almost all fishes), *"Between 2 and 4 mg/l"* (values acceptable by resident black fishes and most grey fish but too low for migrant white fishes) and *"Below 2 mg/l"* (values too low for any fish species). This rough classification was confirmed by a consultation of local aquaculturists.

• Flooded vegetation is defined in terms of surface of *"Grass"*, *"Shrub"* and of *"Forest"* as these variables has been acknowledged to be the ecologically significant ones by stakeholders, as well as in scientific studies (Baran *et al.* 2001c).

• Floodplain refuges are defined from JICA (1999) data as *"Perennial"* (an actual dry season refuge for fish) or *"Temporal"* (non-refuge because dry in the dry season). Refuges play an important role for resident and Tonle Sap migrant fishes during the dry season providing habitat, shelter and food on the driest months of the year.

• Built Structures are defined for now as structures that prohibit the extent (area) of the flood. Therefore the structures can be either *"Blocking"* or *"Open"*.

5.4 Fish migration variables

• Migrations of resident fish : it is likely that the hydrological and environmental requirements of larvae and juveniles (feeding migrations) are different from those of the adults (breeding migrations), but the paucity of knowledge in that field did not allow the stakeholders to be more specific. In absence of any other information, Migrations of resident fish is qualified as *"Free"* or *"Blocked"* (by unfavourable hydrological conditions or built structures).

• Having to define the Migrations of migrant fish highlighted the knowledge gaps about most of these species (the migration status being known for only one fourth of Mekong fish species; Baran *et al.* 2005), and the difficulty of quantifying migrations on a large scale. As a consequence the status defined were simply *"Free"* or *"Blocked"*, the elicitation of probabilities allowing a full range of situations between these two extremes.

• The (mainly lateral) Migration of resident fish was defined with the same states.

5.5 Fishery variables

In view of developing a model that matches the approach of the Department of Fisheries, the description of the Cambodian fishery sector has been based on the official classification of the Ministry of Agriculture, Forestry and Fisheries (DoF 2001): large scale fishing (fishing lot operations, barrages fishing and bag net fishing), medium-scale fishing (gill nets longer than 10 m, seine net, fishing traps not longer than 500m of bamboo fence, hook lining, etc); and small-scale or subsistence fishing (simple small gears). From the data we gathered on the field, it appeared that small-scale fishers categories harvest around 3,000 kg/fisher/year, as compared to middle scale fishers yielding more than 20,000 kg/year/fisher. It was also felt necessary to disaggregate fishers according to their ethnicity, as the fishing activity (methods, efficiency and pressure on the resource) is quite different depending upon the ethnic group. As put by Luco (1997): "traditionally, important fishermen on the lake are of Cham or Vietnamese descent. The Khmer are farmers first, becoming fishermen in the dry season" The Vietnamese, like the Muslim Chams, are reported to be excellent fishers, and are always consulted by fishing lot operators (Degen & Thuok 1998). As noted by Keskinen (2003), "ethnic minorities are significantly concentrated in the areas close to the lake and particularly in the floating villages where they are involved in fishing and fishing-related activities. One of the main reasons for this is that often ethnic minorities do not own any agricultural land".

• As all stakeholders agreed that the fishing pressure was unlikely to decrease in the coming years because of population growth, Pressure on resident fish, Pressure on Mekong migrant fish and Pressure on Tonle Sap migrant fish were defined as *"Increasing"* or *"Stable"*, even though no quantitative assessment of this fishing pressure is available nor in progress. The on-going reforms of the fisheries sector also justified the need to differentiate between fishing pressure on resident black fish (valuable species targeted in particular by the lot fisheries) and fishing pressure on migrant white fish (mainly small cyprinids, caught in particular with gill nets and by the *dai* fishery).

• The large-scale fishery was the one that could be best quantified; Pressure from large-scale fishery has been described as varying between *"Blockage"* and *"Nil"*. This describes the effect of fences at the end of the flooding period (blockage of the migration routes) or during the rainy season (lots are not in operation, fences have been removed, pressure is nil).

• Considering the Fisheries Reform that opened access to more small-scale fishers than in the past and the recent suppression of licence fees in the middle-scale fishery sector, the Pressure from small-scale fishery has been described as *"Increasing"* or *"Stable"*. The lack of assessments does not allow a quantification of this fishing pressure, but a reduction is not expected in a near future.

• The Activity of small-scale fishers, who are also part-time farmers when they are ethnic Khmers, varies depending on the benefits perceived: they may shift to *"More fishing"* or *"More farming"* depending upon environmental conditions. It is considered that when the water level is high (above 10m), farmer-fishers shift towards more fishing because of relative fish abundance and high value of the catch relatively to rice. When the water level is low (below 8m), fish stock is relative scarce and farmer-fishers tend to shift toward more farming.

• According to Keskinen's study (2003), with 12,000 persons the Vietnamese represent 3% of the population of the Lake's basin, and Chams 2.2%. However the Vietnamese concentrate around the borders of the permanent water body, where they fish and make up to 14% population. The Number of Vietnamese/Cham small-scale fishers is considered to increase moderately. In absence of studies on the demography and migrations of ethnic minorities, field interviews have led to the conclusion that natural population growth in these minorities is largely offset by a push away from the lake and emigration towards booming cities. The state of this variable was thus defined as *"Decreasing"* or *"Stable"*.

• With about 1.2 million persons living around the lake and 94.8% of them being Khmer (Keskinen 2003), the Number of Khmer small-scale fishers was considered significant by stakeholders. At the scale of the country, the population growth rate amounts to 1.8%; however Haapala (2003) has shown that the difficult conditions of living and insufficient natural resources around the lake result in emigration towards cities and borders, and that four out of five of the lake provinces actually lose inhabitants. Subsequently the states of the above variable were defined as *"Decreasing"* or *"Stable"*. It should be noted however that this does not integrate temporary migrants from the upper parts of the Tonle Sap basin that seasonally come to the lake to exploit it, and whose dynamics and impact have never been quantified.

• The Gear size of small-scale fishers was defined as *"Increasing"* or *"Stable"*, because the size of the small scale fishing gears of subsistence family fishers has increased over time, but it is said to have stabilized to a maximum manageable size in recent years. Small-scale gear efficiency is a complementary variable that should be present in the model but that is simply impossible to quantify; therefore it has not been taken into account.

• Considering the Fisheries Reform that opened access to more small-scale fishers than in the past and the recent suppression of licence fees in the middle-scale fishery sector, the Pressure from middle-scale fishery have been described as *"Increasing"* or *"Stable"*. The lack of assessments does not allow a quantification of this fishing pressure, but a reduction is not expected in a near future.

• Depending upon technological improvements, Middle-scale gear efficiency may increase. A common trend is increased motorization and use of smaller mesh sizes that make nets more efficient. Although it is almost impossible to quantify the efficiency of a multi-gear fishery, we consider it is either *"Stable"* or *"Increasing"*.

• The Number of middle-scale fishers is the sum of Number of Vietnamese/Cham, Khmer and migrant fishers. States for this node are defined as *"Stable"* or *"Increasing"*.

• Middle scale fishers consist of Vietnamese, Cham, Khmer commercial fishers, and migrant fishers who come from the surroundings of the basin and exert a temporary but intense pressure on the resources Nettleton& Baran 2004). For the same reasons as those detailed for the number of subsistence fishers, it was considered that the states of the variables Number of Vietnamese/Cham middle-scale fishers, Number of Khmer middle-scale fishers and Number of migrant middle-scale fishers should be "*Stable*" or "*Increasing*".

• Overall the extreme and unrealistic simplicity of the states of the fishery variables sadly reflects the absence of scientific knowledge about the status of the Cambodian inland fishery, and the subsequent weakness of the Fishery module in the overall model. Because of this fact, the BayFish Tonle Sap model can be considered strongly underpinned by best available information down to the Stock level, but not down to the Catch level.

Figure 15 summarizes all the states defined for each variable of the network.

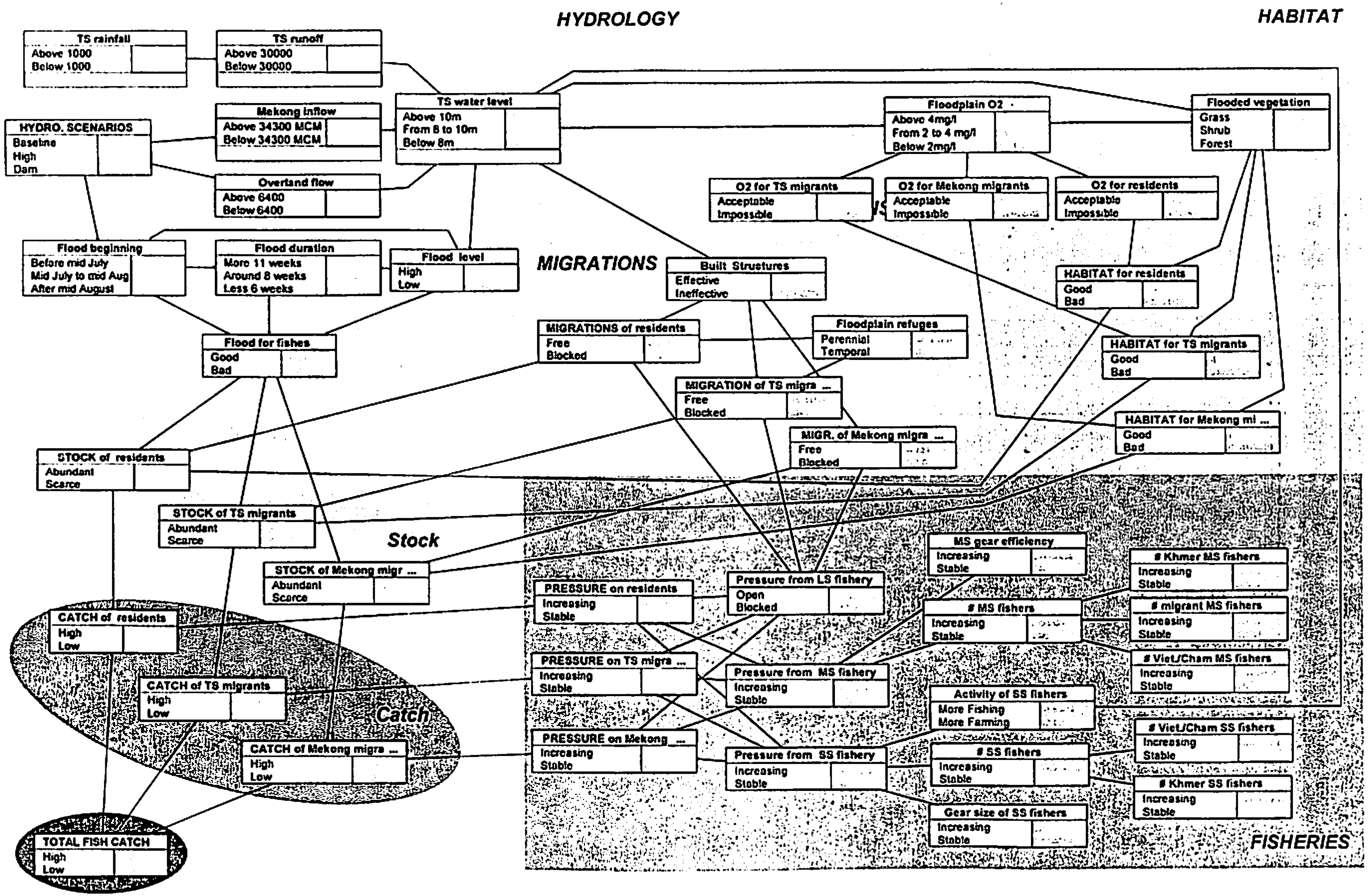

Figure 15: States defined for each variable of the network.

6 INTEGRATING DATABASES

A significant effort was put in the integration of databases to the model. These data consist in hydrological (rainfall, runoff, Mekong inflow, overland flow, flood beginning, and flood duration), water quality (dissolved oxygen), land use for the Tonle Sap Lake and floodplain and built structures (opposing flow, refuges and fishing lots). In addition scenarios of the model are based on output data of MRCS/WUP_FIN hydrological model. Special attention in analysis was given to data accuracy, reliability and suitability for the model. A specific report has been dedicated to this study (Jantunen 2006), and the reader might want to refer to this companion report.

The databases gathered and used in the model are summarized in table 1.

Table 1: Summary of all data sources integrated to the Bayesian model of the Tonle Sap fish resource.

Dataset	Source	Area and period	Description	Format	Obtained from
Water level data	JICA & TSLV Flow Reversal Project	Kratie 1934-2002, Prek Kdam 1960-2002, Kompong Loung 1924-2002, Phnom Penh Port 1960-2002	DSF model input data, corrected for same datum from MRCS Hymos dataset.	Numerical	MRCS/JICA & TSLV Flow Reversal Project
Water level data	MRCS	Kompong Loung 1924-2002, Kompong Chhnang 1924-2002	Datasets with uncorrected datum (measured)	Numerical	MRCS/WUP_FIN
MIKE11 model output data	JICA & TSLV Flow Reversal Project	Discharge Prek Kdam and Kratie, Water level Kompong Loung, Overland flow, 1984-2003	Flow reversal model output data taking into account backwater effect and overland flow. Fills gaps in data.	Numerical	MRCS/JICA & TSLV Flow Reversal Project
Rainfall data	MRCS JICA & TSLV Flow Reversal Project	Tonle Sap catchment 1980-2003	Average rainfall data over each of the sub-cathcments	Numerical	MRCS/JICA & TSLV Flow Reversal Project
Land use, road network, ponds and administrative data	JICA	Tonle Sap catchment	1999 JICA Land use map simplified for Tonle Sap floodplain	GIS layer 1:100 000	MRCS/WUP_FIN
Land use data	WUP_FIN	Tonle Sap floodplain	Calculated percentages of land use types depending on elevation	Numerical	MRCS/WUP_FIN
Dissolved oxygen data	WUP_FIN and MRCS	Tonle Sap Lake and floodplain	Measurements by MOWRAM and MRCS/WUP_FIN	Numerical	MRCS/WUP_FIN
MRCS/WUP_FIN model output data	WUP_FIN	Tonle Sap Lake and floodplain	Average dissolved oxygen levels and anoxic conditions prevalent in the lake and floodplain	Numerical and bitmap	MRCS/WUP_FIN
Certeza survey contour data	MRCS	Tonle Sap floodplain	Digital contour lines based on 1964 levelling survey	GIS layer 1m contour lines	MRCS/WUP_FIN
Water balance data	JICA & TSLV Flow Reversal Project and MRCS/WUP_FIN	Tonle Sap catchment	Calculated water balance to Tonle Sap catchment	Numerical	MRCS/JICA & TSLV Flow Reversal Project and MRCS/WUP_FIN
Fishing lots	MRC	Tonle Sap catchment	Location, extent and state of fishing lots	GIS layer	MRCS/WUP_FIN

7 PARAMETERIZING THE VARIABLES

Parameterizing the variables in the model consists in attributing probabilities to variables; more specifically attributing probabilities to each state of a driving variable and, to each combination of states of a driven variable. This process is the one described in section 2 and illustrated in Figures 1 and 2. Parameterization is detailed in the reports of the third and fourth stakeholders consultations (Hort *et al.* 2004; Baran 2004). In this section, description starts from the driving variables, that combine into driven variables. In the BayFish model all probability tables are open to viewing and to modification by the user if this is felt necessary. For a detailed explanation of the computations in case of variables based on databases it is recommended to refer to the Netica manual (available online at http://www.norsys.com/download.html).

7.1 Fish production variables

• Total fish catch

The Tonle Sap total fish catch results from the yielding of white, grey and black fish. However the creation of a grey fish category is new, and has never been reflected in catch statistics so far. It is therefore impossible to date to quantify the contribution of grey fish to the Tonle Sap total catch. Since grey fish used to be previously considered as white fish (they leave the floodplain when the flood recedes, and do not spend the dry season in ponds), grey fish have been assimilated below by default to white fish. This approximation allows using available statistics regarding white fish and black fish to parametrize the last node of the model.

According to Van Zalinge *et al.* (2000), Black fish harvest represents only 17.5% in biomass while the rest is represented by White fish harvest (See Table 2).

Table 2: Parameterization of Total fish catch variable.

			Total fish catch		
CATCH of residents	ATCH of Mekong migrants	CATCH of TS migrants	High	Low	Justifications
High	High	High	100	0	If the harvest of all guilds is high, the chance that the TS fish harvest is high is 100%
High	High	(Low)	100	0	If the harvest of White and Black fish are both high, the chance that the TS fish harvest is high is 100%. Here Catch of TS migrants is assimilated to that of Mekong migrants (i.e. High)
High	Low	(High)	17.5	82.5	If the harvest of Black fish is high but the harvest of White fish is low, the chance that the TS fish harvest is high is 17.5%. Here Catch of TS migrants is assimilated to that of Mekong migrants (i.e. Low)
High	Low	Low	17.5	82.5	If the harvest of Black fish is high but the harvest of White fish is low, the chance that the TS fish harvest is high is 17.5%. Here Catch of TS migrants is assimilated to that of Mekong migrants (i.e. Low)
Low	High	High	82.5	17.5	If the harvest of Black fish is low but the harvest of White fish is high, the chance that the TS fish harvest is high is 82.5%. Here Catch of TS migrants is assimilated to that of Mekong migrants (i.e. High)
Low	High	(Low)	82.5	17.5	If the harvest of Black fish is low but the harvest of White fish is high, the chance that the TS fish harvest is high is 82.5%. Here Catch of TS migrants is assimilated to that of Mekong migrants (i.e. High)
Low	Low	(High)	0	100	If the harvest of White and Black fish are both low, the chance that the TS fish harvest is high is 0%. Here Catch of TS migrants is assimilated to that of Mekong migrants (i.e. Low)
Low	Low	Low	0	100	If the harvest of all guilds is low, the chance that the TS fish harvest is low is 100%

• Catch of residents

The Catch of residents results from the combination of a stock of resident fish and a fishing pressure on these black fish. In absence of quantitative information we assumed that both variables contributed 50% each to the total Catch of residents.

• Catch of Tonle Sap migrants

The Catch of Tonle Sap migrants results from the combination of a stock of resident fish and a fishing pressure on these grey fish. In absence of quantitative information we assumed that both variables contributed 50% each to the total Catch of residents.

• Catch of Mekong migrants

The Catch of Mekong migrants results from the combination of a Stock of Mekong migrants and a fishing pressure on these white fish. In absence of quantitative information we assumed that both variables contributed 50% each to the total Catch of Mekong migrants.

• In absence of specific information, the Stock of Mekong migrants is considered to result equally from a proper habitat, recruitment from migrations and adequate hydrology; hence 33%-33%-34% chances attributed to each variable.

• In absence of specific information, the Stock of Tonle Sap migrants is also considered to result equally from a proper habitat, possible migrations to local tributaries and adequate hydrology; hence 33%-33%-34% chances attributed to each variable.

• For the Stock of resident fish, less importance is given to migrations (20% only) because of the short homerange of this guild; the size of the stock is considered to also result from a proper habitat (50%, in particular since dry season refuges are required) and adequate hydrology (30%).

7.2 Hydrology variables

• The parameterization of variables Tonle Sap rainfall, Tonle Sap runoff, Mekong inflow and Overland flow is described in detail in Jantunen (2006). Basically the databases provided several years long time series (1985-2003) from which average values for each variable were calculated. Then the modelling software used the data table generated (average per variable per period of time) to fill in the probability table of having an annual value above or below the average. Parameterization was changed for Mekong inflow and Overland flow when hydrological scenarios were made available through ADB Built Structures Project (WUP_FIN) as upstream development only affects inflow originating from Mekong. However, the WUP_FIN model could only process years 1996-2000, thus severely reducing the amount of data available for producing probabilities for the nodes. Changes are described shortly below, and data analysis is detailed in Jantunen (2006).

For Tonle Sap rainfall, data used was the data checked and edited by MRCS/WUP-JICA & TSLV project. For this data no sophisticated spatial weighting were used for rain gauge network due to its non-uniform distribution. In addition, rainfall on the open lake was not accounted for, as it is equal to evaporation. Also, only post-1996 data were used due to inconsistencies before this date. Standard deviation of rainfall data showed that most variation in rainfall amounts takes place between August and November, and thus only half a year of data (from June to December) was used for each hydrological year.

For Tonle Sap runoff, MIKE11 model output data from the MRCS/WUP-JICA & TSLV project was used, whereas Mekong inflow and Overland flow are derived from WUP_FIN model output data. The water balance of the Tonle Sap Lake depends on these three components and deriving them from one and the same dataset ensures compatibility of data in their common child node Tonle Sap water level at Kompong Loung. Even though two parent nodes for Tonle Sap water level were changed with new data, the parameterization of Tonle Sap water level was not changed. The MRCS/WUP-JICA & TSLV project data provides much more comprehensive range of combinations for generating probabilities.

- The reference average value for Tonle Sap rainfall is 1000 mm of rain during the June-December period (45% above average and 55% below average).
- The reference average value for Tonle Sap runoff is 30,000 million cubic meters (MCM) of water during the June-December period (43% above average and 57% below average when TS rainfall is below 1000mm and 67% above average and 33% below average when TS rainfall is above 1000mm).
- The reference average value for Mekong inflow was 37,000 MCM of water during the June-December period (48% above average and 52% below average). This was changed into 34,000 MCM with WUP_FIN data. The resulting probabilities for baseline are 60% above average and 40% below average. This shows a general increase in likelihood of above average floods, but the change is due to lowered threshold level from 37388 to 34363 (average of total time series), shorter time series and generally lower flows of WUP_FIN output data.
- The reference average value for Overland flow is 7,600 MCM of water during the June-December period (43% above average and 57% below average). This was changed into 6,400 MCM with WUP_FIN data. The resulting probabilities for baseline are 60% above average and 40% below average. See scenarios (section 8) for full explanation. Similarly there is a general increase in likelihood of above average floods, but the change is due to lowered threshold level from 7800 to 6400 (average of total time series), shorter time series and generally lower flows of WUP_FIN output data.

• For Tonle Sap water level, the reference is the annual maximum water level at Kompong Loung; Parameterization is derived from the simulation outputs of the MRCS/WUP-JICA & TSLV MIKE11 model for the 1985-2003 period. Measured data were not used because of unexplained daily shifts (+/- 1m per day) and because of approximately 2.5m difference between pre-1965 and post-1996 datasets. Furthermore using the MIKE11 model output data provided a longer dataset (1985-2003). It has an excellent correlation with MRCS/Hymos corrected data (restricted to 1996-2003). In addition MIKE11 model output data was also used for parameterization of some of Tonle Sap water level parent nodes, therefore using the same dataset increases compatibility. Baseline of the node changed a little due to incorporation of hydrological scenarios from WUP_FIN from 25.4/49.8/24.8 to 29.6/47.8/22.6 (*Above 10m/Between 8m and 10m/Below 8m* respectively).

Table 3: Parameterization of Tonle Sap water level variable.

Flow from Mekong	Overland Flow	TS runoff	Water level at Kompong Loung		
			Above 10m	Between 8 and 10m	Below 8m
Above 37000	Above 7600	Above 30000	42.857	42.857	14.286
Above 37000	Above 7600	Below 30000	40	40	20
Above 37000	Below 7600	Above 30000	25	50	25
Above 37000	Below 7600	Below 30000	20	60	20
Below 37000	Above 7600	Above 30000	40	40	20
Below 37000	Above 7600	Below 30000	15	55	30
Below 37000	Below 7600	Above 30000	16.667	66.667	16.667
Below 37000	Below 7600	Below 30000	12.5	37.5	50

• Flood level takes into account flood beginning and Tonle Sap water level. The probability of having a "*High*" Flood level with Tonle Sap water level (at Kompong Loung) being "*Between 8 and 10m*" and Flood beginning from "*Mid Jul to mid Aug*" is based on actual data (4/9 out of example years). In general early floods are correlated with higher floodplain flood levels. Shaded probabilities showing *Low* Flood level even though Tonle Sap Water level is *Above 10m* are dismissed from calculations through declaring them as impossible combinations in Flooding for Fish variable. Baseline of the node changed a little due to incorporation of hydrological scenarios from WUP_FIN from 49/51 to 51.3/48.7 (*High/Low* respectively). This seems to confirm that minor changes to probabilities caused by WUP_FIN data does not significantly alter the hydrological module of the model.

Table 4: Parameterization of Flood level variable.

Tonle Sap water level	Flood beginning	*Flood level*	
		High	Low
Above 10m	Before Mid-July	100	0
Above 10m	Mid July to Mid Aug	100	0
Above 10m	After Mid Aug	0	100
Between 8 and 10m	Before Mid-July	100	0
Between 8 and 10m	Mid July to Mid Aug	44.444	55.556
Between 8 and 10m	After Mid Aug	0	100
Below 8m	Before Mid-July	0	100
Below 8m	Mid July to Mid Aug	0	100
Below 8m	After Mid Aug	0	100

Note: as detailed above, Built structures do not intervene in the calculation of Flood level

• The fourth stakeholders consultation identified the spilling of water to the floodplains (i.e. when water breaches natural levee around the open lake and rivers) as the threshold for Flood beginning. However it is impossible to identify these levees from the 1964 Certeza survey contour lines, as well as from the Hydrographic Atlas (produced in 1998) that only covers the open lake. It should be possible to identify this threshold precisely from the MRCS/WUP-FIN depth measurements, but for a number of reasons these were unavailable during the study. Alternatively we used generic thresholds already agreed by stakeholders (early flood = "*Before mid-July*", normal = "*Between mid-July and mid-August*" and late = "*After mid-August*"). Corresponding water levels for each date from each year were checked, and

4m water level was chosen as the threshold that fits best with floods regarded as early (2000-2002) and late (1998). Probabilities were calculated by the software from the occurrences recorded between 1985 and 2003 ("*Before mid-July*" = 36%, "*Mid-July to mid-August*" = 46% and "*After mid-August*" = 18%). This was then slightly changed due to incorporation of WUP_FIN output data ("*Before mid-July*" = 40%, "*Mid-July to mid-August*" = 40% and "*After mid-August*" = 20%), which shows minor increase in earlier and late floods. This change is due to length of WUP_FIN data available, but even so the simplified version still represents strength of each state well. Detailed justifications and data can be found in Jantunen (2006).

• In order to parametrize Flood duration, the outputs of the MIKE11 hydrological model were used to define the exact moment of flow reversal in the Tonle Sap River at Prek Kdam towards the Mekong. Duration was calculated by combining the date of floodplain flooding, and probabilities were calculated from the recorded occurrences from years 1985 to 2003 ("*More than 11 weeks*" = 15.79%, "*Around 8 weeks*" = 78.95% and "*Less than 6 weeks*" = 5.26%). Flood duration is also influenced by Flood beginning and Flood level, but the 19 years screened did not cover every combination of states theoretically possible. For instance all cases of flood beginning between "*Mid-July* and *Mid-August*" had a duration of "*Around 8 weeks*" whereas in theory longer and shorter durations are possible; therefore these probabilities had to be estimated based on the data available. Furthermore, incompatible hydrological combinations had to be eliminated from the model (they were given 0% probability; see Table 5).

Table 5: Parameterization of Flood duration variable.

		Flood duration			
Flood beginning	Flood level	More than 11 weeks	Around 8 weeks	Less than 6 weeks	Justifications
Before mid-July	High	42.857	57.143	0	3/7 of Before mid-July floods were "*more than 11 weeks*" long and 4/7 lasted "around 8 weeks"
Before mid-July	Low	33.333	66.667	0	Estimated because no examples in data.
Mid-July to mid-August	High	33.333	66.667	0	Estimated because no examples in data.
Mid-July to mid-August	Low	15.79	78.95	5.26	Based on average possibilities calculated from 19 example years
After mid-August	High	0	0	100	Not possible to have more than 6 weeks flood After Mid-July
After mid-August	Low	0	66.667	33.333	2/3 of After Mid-July floods were around 8 weeks, 1/3 Less than 6 weeks

With these changes the baseline of Flood duration ended up being ("*Before mid-July*" = 25.7%, "*Mid-July to mid-August*" = 67% and "*After mid-August*" = 7.3%. This was then slightly changed due to incorporation of WUP_FIN output data which effected Flood duration node through Flood beginning and Flood level nodes ("*Before mid-July*" = 26.2%, "*Mid-July to mid-August*" = 66.1% and "*After mid-August*" = 7.7%). Detailed justifications and setting of thresholds can be found in Jantunen (2006).

• The variable Flooding for fish was parameterized with the values and justifications shown in the table below. Incompatible hydrological combinations such as late *and* long flood are marked with an X and are not taken into account by the model in any of the calculations or respective probabilities.

Table 6: Parameterization of Flooding for fish variable.

Flood Level	Flood Beginning	Flood Duration	Good - Bad	Justifications
High	Before mid-July	More than 11 weeks	80% - 20%	Big and long flood => considered very good for fish (but not 100% positive since longest floods do not correspond to higist catches)
High	Before mid-July	Around 8 weeks	100% - 0%	Big flood and appropriate timing still long enough => considered very good
High	Before mid-July	Less than 6 weeks	X X	Historicaly incompatible
High	Between mid-July and mid-August	More than 11 weeks	90% - 10%	High and timely flood => considered very good for fish
High	Between mid-July and mid-August	Around 8 weeks	100% - 0%	High flood of average duration, coming on time=> considered ideal
High	Between mid-July and mid-August	Less than 6 weeks	60% - 40%	High and timely flood but too short, not so good
High	After mid-August	More than 11 weeks	X X	Incompatible
High	After mid-August	Around 8 weeks	X X	Incompatible
High	After mid-August	Less than 6 weeks	40% - 60%	High, but late and too short flood => not so good for fish
Low	Before mid-July	More than 11 weeks	55% - 45%	Low flood, but timely and long => medium quality
Low	Before mid-July	Around 8 weeks	45% - 55%	Low flood, timely and long => medium quality
Low	Before mid-July	Less than 6 weeks	X X	Incompatible
Low	Between mid-July and mid-August	More than 11 weeks	50% - 50%	Low flood, timely and long duration => medium quality
Low	Between mid-July and mid-August	Around 8 weeks	20% - 80%	Low flood, timely and normal duration=> rather bad for fish[1]
Low	Between mid-July and mid-August	Less than 6 weeks	25% - 75%	Low flood, timely but too short=> rather bad for fish
Low	After mid-August	More than 11 weeks	X X	Incompatible
Low	After mid-August	Around 8 weeks	20% - 80%	Low and late flood of medium duration => bad for fish
Low	After mid-August	Less than 6 weeks	10% - 90%	Short, small and late flood => very bad for fish

Based on experience and model runs, that Flooding for fish variable and associated table seem to have most influence on the outcome of the catch node of the model.

7.3 Habitat variables

- For variable Floodplain dissolved oxygen data was derived from the MRCS/WUP-FIN water quality model due to temporal and spatial limitations in measured point water quality data. As part of collaborative activities with WorldFish, the WUP-FIN team produced directly compatible output data that could be directly inputted into the BayFish model. Data table for this can be seen below and detailed justifications in Jantunen (2006).

[1] This combination was tweaked to better fit the curve of Dai catches

Table 7: Parameterization of Floodplain dissolved oxygen variable.

Water level	Land use	< 2 mg/l	2 – 4 mg/l	> 4 mg/l
Below 8m flood (1998)	grass	54	21	25
	shrub	72	17	12
	forest	37	29	34
From 8 to 10m flood (1997)	grass	51	28	21
	shrub	65	20	15
	forest	27	37	37
Above 10m flood (2000)	grass	60	25	15
	shrub	69	24	7
	forest	32	53	15

• A literature review and discussion with fish biologists and aquaculturists led to the conclusion *that* Dissolved oxygen for residents is not bearable (0% acceptable) if DO level is below 2mg/l; it is considered acceptable for these tolerant black fish between 2 and 4 mg/l, and above 4 mg/l.

• White long-distance migrant fish are less tolerant than black fish; as a consequence in variable Dissolved oxygen for Mekong migrants above 4mg/l only is considered as "*Acceptable*" (100%) for White fish. Therefore the state "*From 2 to 4*" and "*Below 2*" mg/l was elicited as impossible (0% "*Acceptable*").

• Grey short-distance migrant fish are less tolerant to environmental conditions than resident fish, but also more tolerant than Mekong migrants. As a consequence in variable Dissolved oxygen for TS migrants the state "*Above 4mg/l*" is considered as "*Acceptable*" (100%) while state "*From 2 to 4*" was given 50% and "*Below 2*" mg/l was elicited as impossible (0% "*Acceptable*").

• Parameterization of Flooded vegetation was based on the JICA land use GIS map produced in 1999 and edited by the MRCS/WUP-FIN project. When this modelling study started this map was the latest and had the best accuracy available. The original 40 land use classes were reduced to three: Grass (JICA classes 3-17), Shrub (JICA classes 18-21), and Forest (JICA classes 22-32). Other classes such as water or soil and rock left out. The corresponding map is given in Figure 16.

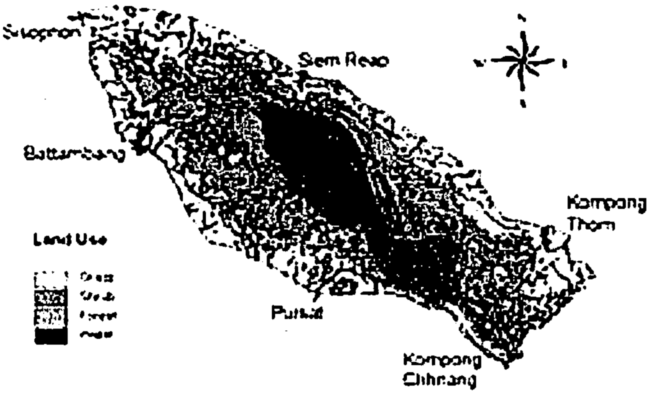

Figure 16: Map of the Tonle Sap vegetation cover (1999, JICA data reclassified; Jantunen 2006).

Percentages for each of the three classes were calculated from surface area to elevation table, and were manually imported into the model probability table (see below).

Table 8: Parameterization of Flooded vegetation variable.

Land use by elevation	Grass	Shrub	Forest
1-8	43.9	53.7	2.4
1-10	55.8	42.3	1.9
1-road	60.8	37.4	1.8

• Habitat for residents, Habitat for TS migrants and Habitat for Mekong migrants were elicited by fishery experts by default. In fact the lack of information about the detailed ecological requirements of each the 3 different guilds did not allow making a difference in the response of each guild to environmental conditions; therefore the parameters are the same for all guild. "*Impossible*" (i.e. unbearable) dissolved oxygen level is 100% bad for fish and acts as a threshold, that defines a given habitat as bad whatever the other environmental conditions. Forest is traditionally seen as the best habitat for fish (100%), but because fish catch has not decreased dramatically even though the forests has been largely cut down shrub is also regarded as a good habitat (90%). Grass does not provide shelter and food in the way that shrub and forest do, therefore it is only 50% "*Good*". The resulting table is detailed below:

Table 9: Parameterization of Habitat for fish nodes.

		Habitat for residents, TS migrants, Mekong migrants	
Flooded vegetation	Dissolved oxygen	Good	Bad
Grass	Acceptable	50	50
Grass	Impossible	0	100
Shrub	Acceptable	90	10
Shrub	Impossible	0	100
Forest	Acceptable	100	0
Forest	impossible	0	100

• Floodplain refuges were parameterized using JICA (1999) data on area of Perennial and Temporal ponds in the floodplain. The total surface area of ponds identified by JICA amounts to 323.7 km^2, and perennial ponds represents 237 km2, or 73.23% of the total (see Jantunen 2006 for details). Hence among floodplain refuges, Perennial refuges = 73.23% and Temporary refuges = 26.77%

• Parametrization of Built structures is based on JICA (1999) road data and Certeza Survey (1964) 1m contour data and the JICA 1999 GIS road layer and 10m contour line data. Probabilities were derived by comparing the total area of the each elevation category (0-8m, 0-10m and 0-12m) to the area limited by the road. Details can be found in Jantunen (2006).

Table 10: Parameterization of the Built Structures node.

	Built structures	
TS water level	Blocking	Open
Above 10 m	8.25	91.75
From 8 to 10	2.51	97.49
Below 8 m	0	100

7.4 Fish migration variables

Overall, information on fish migrations, on the impact of built structures or of fishing practices on fish migrations is very deficient. The parameters below are therefore largely "guesstimates" awaiting for new quantitative studies of fish migrations in the system studied. Overall this module on fish migration is very simplistic and can be largely be improved; at the moment it mainly highlights in a qualitative way the importance of migrations in the sustainability of the overall fishery production system.

• The Migration of Mekong migrants is assumed to be hampered by two main obvious factors: by the fences of the large scale fishing sector and by built structures. In absence of detailed quantitative information, the fishing lots are assumed to contribute 80% of the obstacle to migrations, while built structures contribute 20%. This limited number of factors probably overlooks the role of the two other fishing sectors (middle scale and small scale) whose gears also act against migrations, but the role of these two sectors has been deemed too fuzzy to be quantified.

Table 11: Parameterization of Migration of Mekong migrants node.

		Migration of Mekong migrants	
Built Structures	Pressure from large scale fisheries	Free	Blocked
Blocking	Nil	80	20
Blocking	Blockage	0	100
Open	Nil	100	0
Open	Blockage	20	80

• According to fishery experts consulted, the Migration of residents is hampered by fishing lots but also by the fishing pressure exerted on refuges during the dry season; therefore the 80% previously allocated to fishing lots only (in the case of white fish) were split between fishing lots proper (40%) and refuges (40%), the share of built structures remaining the same (20%).

Table 12: Parameterization of Migration of residents node.

			Migration of Mekong migrants	
Built Structures	Refuges	Pressure from large scale fisheries	Free	Blocked
Blocking	Perennial	Nil	80	20
Blocking	Perennial	Blockage	40	60
Blocking	Temporary	Nil	40	60
Blocking	Temporary	Blockage	0	100
Open	Perennial	Nil	100	0
Open	Perennial	Blockage	60	40
Open	Temporary	Nil	60	40
Open	Temporary	Blockage	20	80

• The migration of Tonle Sap migrants is poorly known. Since these fish have ecological requirements intermediate between white and black fish, it was assumed that the constraint they face is somehow intermediate between those experienced by black and white fish. Hence three parent variables (Pressure from large scale fisheries, refuges and built structures) and a similar weight given to each parent node (33%). The resulting table of probabilities is detailed below:

Table 12: Parameterization of Migration of Tonle Sap migrants node.

			Migration of Mekong migrants	
Built Structures	Refuges	Pressure from large scale fisheries	Free	Blocked
Blocking	Perennial	Nil	66.7	33.3
Blocking	Perennial	Blockage	33.3	66.7
Blocking	Temporary	Nil	33.3	66.7
Blocking	Temporary	Blockage	0	100
Open	Perennial	Nil	100	0
Open	Perennial	Blockage	66.7	33.4
Open	Temporary	Nil	66.7	33.4
Open	Temporary	Blockage	33.3	66.7

7.5 Fishery variables

The fishing component of the model is based on background studies by Nettleton and Baran (2004) and additional field surveys by Kum (2004), supplemented by unpublished stakeholders consultations. The fishing pressure actually results from a combination of four components:

Fishing pressure = fishing intensity = number of fishers + time spent fishing + size of fishing gears + gear efficiency.

In practice, the only factor that could be approached by a degree of monitoring is the number of fishers, hence the focus on this variable in the model. This fact illustrates the fact that significant additional research remains necessary to properly understand the various components of the fisheries and its main driving forces. As a consequence, the fisheries module of the BayFish model, based "only" on the very limited quantitative knowledge available, remains the least strong component of this model.

7.5.1 Small-scale fishery

The fishing Pressure from small-scale fishery results from four driving variables: Activity of subsistence fishers; Gear size of subsistence fishers; Number of Khmer subsistence fishers and Number of Vietnamese/Cham subsistence fishers; the parametrization of these variables is detailed below.

- The Activity of subsistence fishers is directly linked to water level in the Tonle Sap Lake. If there is more water, then there is more fish and thus subsistence fishers' shift to more fishing as fish is more valuable than crops per kilogram. In absence of quantified information the proportions were estimated as follows:

Table 13: Parameterization of the Activity of subsistence fishers variable.

Water_level	More fishing	More farming	
Above_10m	80	20	When water level is above 10m, there is a 80% chances that fishers-farmers switch towards more fishing
From_8_to_10m	50	50	When water level is between 8 and 10m, there is a 50-50% chances that fishers-farmers go fishing or farming
Below_8m	70	30	When water level is below 8m, there is a 70% chances that fishers-farmers switch towards more farming (but fishing still important, as fish catchability is higher)

• According to the World Bank, Cambodia's population growth rate of over 2.5 percent per annum provides almost 200,000 new entrants to the labour force each year, a fraction of these entrants becoming small-scale fishers. This trend is increased by the Fisheries Reform that gives more access to small scale fishers over fishing lots. Despite emigration towards cities mentioned above, we consider that at least in the coming years the Number of Khmer subsistence fishers has 100% chances of *"Increasing"*.

• The Number of Vietnamese/Cham subsistence fishers looks moderately increasing, except in Kompong Chnnang province where they migrate to become workers. According to anecdotal evidence, the growth of Vietnamese/Cham communities is less important than that of Khmer people; subsequently it was decided that this variable would qualify as 75% *"Increasing"* and 25% *"Stable"*.

• According to Keskinen (2003), there are 94.8% of Khmer, 3% of Vietnamese and 2.2% of Cham in the Lake's basin (see section 5.5.1). The combinations of these variables are detailed in Table 14.

Table 14: Parameterization of the Number of subsistence fishers variable.

Number of Khmer subsistence fishers	Number of Vietnamese/Cham subsistence fishers	# of subsistence fishers	
		Increasing	Stable
Increasing	Increasing	100	0
Increasing	Stable	5.2	94.8
Stable	Increasing	94.8	5.2
Stable	Stable	0	100

• The Gear size of subsistence fishers is changing over time. During field interviews all villagers admitted that the length of their gillnets had increased two to four times in the past years, up to 200m to 400m per gill net (Kum, 2004). However, the gear size cannot increase forever: the longer the gillnets, the more time required to process the catch. Moreover, longer gillnets require more capital investment, which is not always possible for the subsistence fishers whose investment power is limited. Given this context the chances of fishing gear size increasing were estimated to 25% and those of staying stable to 75%.

• The overall fishing Pressure from small-scale fishery is determined by 3 variables, whose combination is detailed in Table 15 (after Kum, 2004):

Table 15: Parameterization of Pressure from small-scale fishery variable.

Subsistence fisher activities	Size of gear	Number of subsistence fishers	Pressure from small-scale fishery		Justification
			Increasing	Stable	
More fishing	Increasing	Increasing	100	0	If the number of subsistence fishers increases, their activity involves more fishing and the size of gear increases, there is a 100% chance that this will result in an increase of the small scale fishing pressure
More fishing	Increasing	Stable	50	50	If the number of subsistence fishers is table, but their activity involves more fishing and the gear size increases, there is a 50% chance that this will result in an increased fishing pressure
More fishing	Stable	Increasing	80	20	If the number of subsistence fishers increases, their activity involves more fishing, but the size of gear is stable, there is a 80% chance that this will result in an increased fishing pressure
More fishing	Stable	Stable	30	70	If the number of subsistence fishers is stable, their activity involves more fishing, and the gear size is stable, there is a 30% chance only that this will result in an increased fishing pressure
More farming	Increasing	Increasing	70	30	If the number of subsistence fishers increases, the size of their gears increases but their activity involves more farming, there is a 70% chance that this will result in an increased fishing pressure
More farming	Increasing	Stable	20	80	If the number of subsistence fishers is stable, the size of their gears increases but their activity involves more farming, there is a 20% chance only that this will result in an increased fishing pressure
More farming	Stable	Increasing	50	50	If the number of subsistence fishers increases and their activity involves more farming, but the size of gears is stable, there is a 50% chance that this will result in an increased fishing pressure
More farming	Stable	Stable	0	100	If the number of subsistence fishers is stable, their activity involves more farming and the size of their gears is stable, there is a 100% chance that this will result in a stable small scale fishing pressure.

7.5.2 Middle-scale fisheries

• Number of Khmer middle-scale fishers

Nettleton *et al.* (2004) reported that for Khmer fishers who can own land, fishing is becoming less and less profitable, in particular considering the significant capital investment needed in this fishery. In the other hand the recent abolishment of the licence fees on middle-scale fisheries created an incentive to invest in this sector. In absence of additional information, we define the Number of Khmer commercial fishers as 50% "*Increasing*" and 50% "*Stable*".

• Number of Viet./Cham middle-scale fishers

The Vietnamese families around the Lake do not usually own any land and depend on fishing for their livelihood, and the fishing seems more attractive to them because of their well-known expertise in the job (e.g. only 15 out of the total 1,072 Vietnamese families in Psar Chnnang commune are running sale business). Therefore, although the growth trend of the Vietnamese population is not clearly known (Kum, 2004), it is expected that the chance that the number of Vietnamese fishers in the floodplain increases is more likely at least by the natural growth. Based on this, we define the Number of Viet./Cham middle-scale fishers as 75% "*Increasing*" and 25% "*Stable*".

• Number of migrant middle-scale fishers

There is no recorded data about the migrant families who come seasonally to fish in some areas in the Tonle Sap Great Lake. Interviews of local fishers (Kum 2004) led to the conclusions that despite a significant social problem with migrant fishers who tend to over-harvest fish, there is no significant increase in the number of families of migrant fishers. Because of the lack of data, we define the state of Number of migrant middle-scale fishers as 50% "*Increasing*" and 50% "*Stable*".

• Total Number of middle-scale fishers

After discussion and vote among the stakeholders, the share of each community in the fishing pressure has been amounted to 40% to Vietnamese and Cham fishers, 40% to Khmer fishers and 20% to migrant fishers respectively (Kum, 2004).

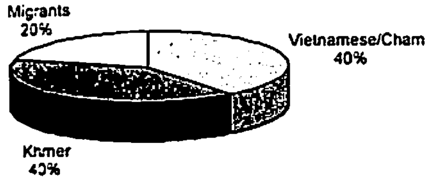

Figure 17: Share of each ethnic group in middle scale fisheries

Table 16: Parameterization of the variable Number of middle-scale fishers.

Number of migrant fishers	Number of Vietnamese/ Cham fishers	Number of Khmer fishers	Pressure from middle-scale fishers		Justification
			Increasing	Stable	
Increasing	Increasing	Increasing	100	0	If the number of migrant, Vietnamese/Cham and Khmer middle-scale fishers increases, the chance that the fishing pressure from middle scale fishers increases is 100 %.
Increasing	Increasing	Stable	60	40	If the number of migrant and Vietnamese/Cham fishers increases but the number of Khmer fishers is stable, the chance that the pressure from middle scale fishers increases is 60%
Increasing	Stable	Increasing	60	40	If the number of migrant and Khmer fishers increases but the number of Vietnamese/Cham fishers is stable, the chance that the pressure from middle scale fishers increases is 60%.
Increasing	Stable	Stable	20	80	If the number of migrant fishers increases but the number of Vietnamese/Cham and Khmer fishers is stable, the chance that the pressure from middle scale fishers increases is 20%
Stable	Increasing	Increasing	80	20	If the number of migrant fishers is stable but the number of Vietnamese/Cham and Khmer fishers increases, the chance that the pressure from middle scale fishers increases is 80%
Stable	Increasing	Stable	40	60	If the number of migrant and Khmer fishers is stable but the number of Vietnamese/Cham fishers increases, the chance that the pressure from middle scale fishers increases is 40%
Stable	Stable	Increasing	40	60	If the number of Khmer fishers increases while the number of Vietnamese/Cham and migrant fishers remains stable, the chance that the pressure from middle scale fishers increases is 40%
Stable	Stable	Stable	0	100	If the number of migrant, Vietnamese/Cham as well as Khmer fishers remain stable, the chance that the fishing pressure from middle scale fishers increases is nil.

• Middle-scale gear efficiency

In the past few years new ways of operating middle-scale fishing gears have spread, such as electrification of drag-nets, and overall the mesh size has been reduced. In the other hand the cost of operation (engine, petrol) has also increased, which slows down the tendency to increase the overall size and reduce the mesh size of the gears actively dragged.. Based on this anecdotal evidence and in absence of additional information, we define the state of Middle-scale gear efficiency as 75% "*Increasing*" and 25% "*Stable*".

• Pressure from middle-scale fishery was roughly estimated to be 30% determined by the efficiency of middle-scale gears, and 70% by the number of fishers. The subsequent table of probabilities is:

Table 17: Parameterization of Pressure from middle-scale fishery variable.

Number of middle-scale fishers	Fishing efficiency	Pressure from middle-scale fishery		Justification
		Increasing	Stable	
Increasing	Increasing	100	0	If the number of fishers and the gear efficiency both increase, the chance that the fishing pressure from middle scale fishery increases is 100 %.
Increasing	Stable	70	30	If only the number of fishers increases, the chance that the pressure from middle scale fishery increases is 70%.
Stable	Increasing	30	70	If only the gear efficiency increases, the chance that the pressure from middle scale fishery increases is 30%
Stable	Stable	0	100	If both the number of commercial fishers and the gear efficiency remain stable, there is a 100% chance that the pressure from the middle-scale fishery remains stable.

7.5.3 Large-scale fisheries

• Pressure from large-scale fishery

Basically, the fishing pressure from large scale fishery results from the number of lots and from the extent of fishing fences associated to lots. In order to reflect the actual fishing conditions, we encompassed as part of lots the fishing pressure from community fisheries in former lots decommissioned in 2000. The extent of fences was calculated from a digitization of GIS maps, and operating fishing lots currently total 409 km of fences (see Jantunen 2006 for details). The extent of fishing lots decommissioned amounts to 596 km, and it was considered that in these former lots the fencing is less systematic, and only blocks 50% of the waterways[2], hence an assumed length of fences of 298 km in decommissioned fishing lots. The total length of fences thus amounts to 409+298 = 707 km, which represents 59% of the periphery of the lake. Hence the elicitation of the Pressure from large scale fishery node: 59% *blockage*, 41% *nil*.

[2] The team attempted to calculate the actual ratio [length of fences / area considered] in the Prek Toal study site (current fishing lot n°2 and former lot n°3 not under community fishery regime). However this calculation was impossible because:
- the resolution of orthophotomaps does not allow formally identifying lines as fences without extensive field verification;
- a lot of gears and fences are located among the vegetation and under trees, and are not visible from the sky;
- extensive nets are set underwater over hundreds of meters, but cannot be seen by remote sensing.

7.5.4 Fishing pressure on each fish guild

The fishing pressure on the TS fish harvest results from small-scale fishery, medium scale fishery and large-scale fishery as officially defined (Gum, 2000). An assessment of the pressure of each type of fishery on each guild of fish requires 1) a quantification of the share of each fishery to the total catch, and 2) an assessment of the proportion of each guild of fish in each type of fishery.

Share of each fishery to the total catch

According to Van Zalinge *et al.* (2000):

- Large scale fishing ranks between 39,000 and 91,000 tons (average 65,000 tons);
- Middle scale fishing operation ranks between 85,000 and 100,000 tons (average 92,500 tons);
- Small scale fishing operation rank between 165,000 and 240,000 tons (average 202,500 tons).

The above data reflects the situation before the 56% reduction in surface of the lots in 2000. To better reflect the present situation, we assume that the reduction in the fishing lots surface results in a 56% decrease in total catch of the large scale fishing operation (although it is said that the decommissioned lots were much less productive than the remaining ones). We also assume that the catch lost by fishing lots, i.e. around 36,400 tonnes, is shared between the two other fisheries according to their respective importance (31% for the middle scale fishery, and 69% for the large scale fisheries). Based on this, the average catch from the Lake fisheries is:

- Large scale fishing operation: 65,000 - 56% = 28,600 tonnes = 7.9%
- Middle scale operation is 92,500 + 11,300 = 103,800 tonnes = 28.8%
- Small scale operation is 202,500 + 25,100 = 227,600 tonnes = 63.2%
- Average total catch: 360,000 tons.

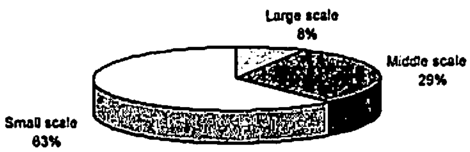

Figure 18: Estimated proportion of the total catch by type of fishery.

Share of each guild to each fishery

Table 18, based on bibliographic references applying to the whole of Cambodia, shows the proportion of resident black and migrant white fish in the catch of small scale, middle scale and large scale fisheries.

Table 18: Proportion of resident and migrant fish in the catch of Cambodian fisheries.

	Black fish (%)	White fish (%)
Small scale fishing*	25.5	74.5
Middle scale fishing**	17	83
Large scale fishing**	39	61
* Source: Ahmed *et al.* (1998) **Source: Baran *et al.* (2003)		

This gives the estimated proportion of resident black fish and migrant white fish in the total catch of the Tonle Sap system:

Table 19: Proportion of resident and migrant fish in the catch of Tonle Sap fisheries.

	Black fish (%)	White fish (%)
Small scale fishing	25.5*63 =16%	74.5*63 =47%
Middle scale fishing	17*29 =5%	83*29 =24%
Large scale fishing	39*8 =3%	61*8 =5%
Total	24%	76%

Pressure of each fishery on each guild

Pressure on residents

- small-scale fishing contributes 16/24 of the Catch of residents (cf. Table 19); i.e. 66.7%
- middle-scale fishing contributes 5/24 of the Catch of residents; i.e. 20.8%
- large-scale fishing contributes 16/24 of the Catch of residents; i.e. 12.5%

Thus when these fisheries are integrated, the probability table of their combinations is next:

Table 20: Parameterization of Pressure on resident fish variable.

Small scale fishing	Middle scale fishing	Large scale fishing	Fishing pressure on resident fish	
			Increasing	Stable
Increasing	Increasing	Nil	100	0
Increasing	Increasing	Blockage	87.5	12.5
Increasing	Stable	Nil	79.2	20.8
Increasing	Stable	Blockage	66.7	33.3
Stable	Increasing	Nil	33.3	66.7
Stable	Increasing	Blockage	20.8	79.2
Stable	Stable	Nil	12.5	87.5
Stable	Stable	Blockage	0	100

Pressure on Mekong migrants

- small-scale fishing contributes 47/76 of the Catch of residents (cf. Table 21); i.e. 61.8%
- middle-scale fishing contributes 24/76 of the Catch of residents (cf. Table 21); i.e. 31.6%
- large-scale fishing contributes 5/76 of the Catch of residents (cf. Table 21); i.e. 6.6%

Thus when these fisheries are integrated, the probability table of their combinations is next:

Table 21: Parameterization of Pressure on Mekong migrants variable.

Small scale fishing	Middle scale fishing	Large scale fishing	Fishing pressure on White fish	
			Increasing	Stable
Increasing	Increasing	Nil	93.4	6.6
Increasing	Increasing	Blockage	100	0
Increasing	Stable	Nil	61.8	38.2
Increasing	Stable	Blockage	68.4	31.6
Stable	Increasing	Nil	31.6	68.4
Stable	Increasing	Blockage	38.2	61.8
Stable	Stable	Nil	0	100
Stable	Stable	Blockage	6.6	93.4

Pressure on Tonle Sap migrants

The absence of catch statistics for grey fish forced us to assimilate again grey fish to white fish (see section 7.1), and to parametrize the table of Pressure on Tonle Sap migrants just like in Table 21.

The overall BayFish – Tonle Sap model is depicted in Figure 19.

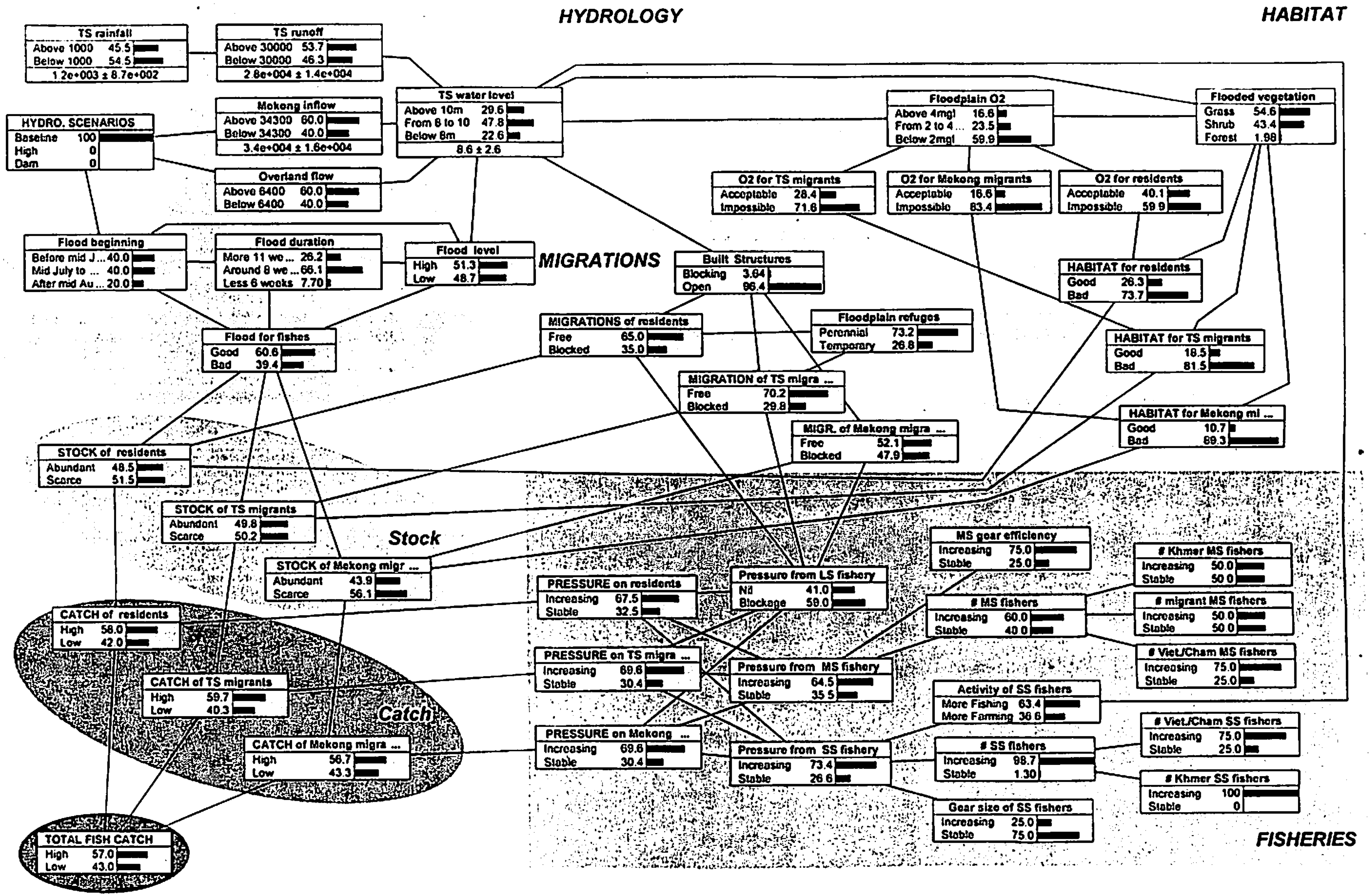

Figure 19: Overview of the Bay-Fish – Tonle Sap model

8 RESULTS

Model testing was carried out in order to verify the models logical workability. Testing consisted in choosing 100% probability for a given state of each variable and analysing the changes in the probabilities of other variables, especially the most relevant ones. A number of scenarios, based on MRC/WorldBank scenarios (2004) and computed at MRCS/WUP_FIN were tested with the model, concentrating on hydrological changes. In addition to development scenarios a baseline scenario production figures for several years was compared with the Dai fisheries fish catch data in order to obtain estimates of the model accuracy.

8.1 Model testing and verification

The model testing concentrated more on hydrology and habitat sections of the model as these are largely supported by data, with all nodes checked and approved by extensive stakeholders consultations (less consultations contributed to the building and elicitation of the fisheries module). In addition, in the hydrological section of the model there are several nodes with state combinations that are incompatible in the natural system, and therefore careful testing, modification and validation was required to address this issue. These testing results were achieved with MRCS/TSLV_JICA data.

8.1.1 Bugs identification

One problem in the model workability was found during testing with Overland flow probabilities. In the natural system when Overland flow state "*Above 7600*" has 100% probability it should increase the Water level at Kompong Loung probabilities linearly from "*Below 8m*" to "*Above 10m*". However, as can be seen in Table 21 the probabilities actually decrease from "*Below 8m*" to "*From 8 to 10m*" before increasing again.

Table 22: Initial results for Water level at Kompong Loung node testing of problematic probabilities.

	TS Runoff		Flow from Mekong		Overland flow	
Water level K. Loung	Above 30000	Below 30000	Above 37000	Below 37000	Above 7600	Below 7600
Baseline	53.7	46.3	47.6	52.4	42.9	57.1
Below 8m	41	59	38.3	61.7	37.2	62.8
From 8 to 10m	57.9	42.1	49.1	50.9	35.3	64.7
Above 10m	57.9	42.1	53.6	46.4	61.3	38.7

The problem was located in Water level at Kompong Loung node, where one set of probabilities was just averaged between the three states due to lack of examples in the data. The problem was solved by giving weights to the averaged probabilities based on probabilities derived from the data.

The combinations of states causing the lower water levels were chosen for comparison. From Table 23 it can be seen from the probabilities (selected node state = "*Above*") that the most effect on water level in the Lake is inflicted by TS Runoff (row 2) and Flow from Mekong (row 1) respectively. Therefore, Overland flow probabilities for high water levels (and vice verse for low water levels) should be below that of rows 1 and 2, but above the lowest possible probabilities (row 3). So Water level at Kompong Loung state "*Above 10m*" probability was set at 15% which is between otherwise lowest probabilities in rows 2 and 3 (Table 22). "*From 8 to 10m*" was set at 55% (lower than both rows 1 and 2, but higher than 3) and "*Below 8m*" at 30% (higher than rows 1 and 2, but lower than 3). By changing the probabilities in above manner based on existing weights between the probabilities derived from the data the workability problem was solved (Table 24).

Table 23: Changes made to Water level at Kompong Loung probability table. Row 4a (bolded) represents averaged probabilities and 4b (italics) weighted probabilities.

				Water level at K. Loung			
Row	Flow from Mekong	Overland flow	TS Runoff	Above 10m	From 8 to 10m	Below 8m	Notes
1	Above 37000	Below 7600	Below 30000	20	60	20	Flow from Mekong has second highest influence on water level
2	Below 37000	Below 7600	Above 30000	16.667	66.667	16.667	TS Runoff has highest influence on water level
3	Below 37000	Below 7600	Below 30000	12.5	37.5	50	All "*below*" average
4a	Below 37000	Above 7600	Below 30000	**33.333**	**33.333**	**33.333**	Original probabilities averaged between all states
4b	Below 37000	Above 7600	Below 30000	*15*	*55*	*30*	New weighted probabilities

Table 24: Final results for Water level at Kompong Loung node testing of problematic probabilities.

	TS Runoff		Flow from Mekong		Overland flow	
Water level K. Loung	Above 30000	Below 30000	Above 37000	Below 37000	Above 7600	Below 7600
Baseline	53.7	46.3	47.6	52.4	42.9	57.1
Below 8m	41.6	58.4	38.9	61.1	*36.3*	*63.7*
From 8 to 10m	55.3	44.7	46.9	53.1	*38.2*	*61.8*
Above 10m	62.3	37.7	57.6	42.4	58.4	41.6

8.1.2 Hydrology section analysis

Hydrological analysis of the model workability included testing sensitivity of hydrological variables to changes in selected nodes (Table 24). Sensitivity of Tonle Sap water flow input variables to water level changes in the Lake revealed that Overland flow **has the highest impact on the "*Above 10m*" water level. This is because the variable is closely linked to inflow from the Mekong River as overland flow only takes place when water levels are high enough in the Mekong, especially characteristic of extreme floods such as years 2000 and 2001. The water level in the Lake is extremely low in years not experiencing any overland flow, such as 1998. Therefore "*Below 6400*" overland flow also causes "*Above 10m*" water level** to decrease to 19.5% compared to the baseline value of 29.6% while increasing "*From 8 to 10m*" water level from 47.8% to 54%.

On the other hand overland flow has slightly less impact on probabilities of Water level at Kompong Loung state "*Below 8m*" compared to Tonle Sap Runoff and Mekong Inflow. In conclusion flood cycles with average or high overland flow are likely to have high water levels in the Tonle Sap Lake. Also, approximately 50% of all floods are between 8 and 10m, with roughly 30% extremely high (>10m) and 20% very low (<8m) as shown by the baseline values. Both extremes are considered bad for fish production.

Table 25: Results for testing Water level at Kompong Loung node.

		Water level at Kompong Loung		
		Above 10m	From 8 to 10m	Below 8m
Baseline		29.6	47.8	22.6
Mekong Inflow	Above 34400	34.0	46.8	19.2
	Below 34400	22.9	49.4	27.6
Overland flow	Above 6400	36.3	43.7	20.0
	Below 6400	19.5	54.0	26.5
Tonle Sap runoff	Above 30000	33.7	47.7	18.6
	Below 30000	24.8	48.0	27.2

Analysis of flood beginning, duration and flood level revealed that **high, long and early floods provide the best flooding conditions for fish stocks whereas low, short, and late floods are detrimental to them** (see Table 26). This has also been shown in literature, e.g. van Zalinge *et al.* (2000). It seems that late flood has more negative gross effect than early flood has positive. Similarly short flood is more detrimental than a long flood is beneficial. Perhaps this is a sign that the **natural system is more effective and productive with earlier and longer floods; manmade changes to this pattern might severely affects its balance.** Therefore serious consideration should be given to dam building upstream which could cause the floods to become shorter and to arrive later. **The single most influential variable for flooding conditions in terms of fisheries is Flood level, followed by Flood beginning and Flood duration.** However, flood beginning has an effect on flood level and duration, whereas flood level only affects flood duration (section 4.2). Mekong migrant fish seem to be most susceptible to hydrological changes, whereas residents are less susceptible. All probabilities reflect the natural system and its fluctuations as they are understood by experts at the moment.

Table 26: Tests on the effect of hydrological variables on flooding conditions in the floodplain.

	Node	Flood for fishes		STOCK TS resident		STOCK TS migrants		STOCK Mek migrants	
	State	Good	Bad	Abundant	Scarce	Abundant	Scarce	Abundant	Scarce
	Baseline	60.6	39.4	48.5	51.5	49.8	50.2	43.9	56.1
Flood beginning	Before mid July	81.7	18.3	56.5	43.5	56.8	43.2	49.1	50.9
	Mid July to mid Aug	61.4	38.6	48.8	51.2	50	50	44.1	55.9
	After mid Aug	16.7	83.3	31.7	68.3	35.1	64.9	32.9	67.1
Flood duration	More than 11 weeks	76.2	23.8	54.4	45.6	54.9	45.1	47.7	52.3
	Around 8 weeks	60.1	39.9	48.3	51.7	49.6	50.4	43.8	56.2
	Less than 6 weeks	12	88	30	70	33.7	66.3	31.8	68.2
Flood level	High	93.5	6.5	61	39	60.4	39.6	51.7	48.3
	Low	25.9	74.1	35.3	64.7	38.5	61.5	35.6	64.4

8.1.3 Habitat section analysis

Habitat analysis concentrated on flooded vegetation, floodplain dissolved oxygen levels and water level changes (Table 26). Flooded vegetation "*Forest*" state is by far the best vegetation type for both dissolved oxygen and habitats. "*Grass*" is better than "*Shrub*" for dissolved oxygen, but worse as overall habitat, because "*Shrub*" provides more food and shelter for fish than "*Grass*". Water level directly affects the surface area of vegetation flooded as well as dissolved oxygen levels. With a high flood (>10m) dissolved oxygen levels are lower than normal (8-10m) because more floodplain periphery with more or less anoxic condition water are included in the calculation. Also, resident fish depend more on water level than migrant fish due to accessibility of their dry season refuges to open water.

Table 27: Tests on habitat variables

		O2 for Mekong migrants		O2 for residents		Habitat for Mekong migrants		Habitat for residents	
		Acceptable	Impossible	Acceptable	Impossible	Good	Bad	Good	Bad
Baseline		16.1	83.9	39.5	60.5	10.3	89.7	25.9	74.1
Flooded vegetation	Grass	19.3	80.7	44.7	55.3	9.66	90.3	22.3	77.7
	Shrub	11.5	88.5	31.5	68.5	10.3	89.7	28.4	71.6
	Forest	28.3	71.7	68.3	31.7	28.3	71.7	683	31.7
Floodplain oxygen	Above 4mg/l	100	0	100	0	64.1	35.9	64.1	35.9
	From 2 to 4mg/l	0	100	100	0	0	100	66.6	33.4
	Below 2mg/l	0	100	0	100	0	100	0	100
Water level	Above 10m	12	88	37.1	62.9	7.2	92.8	23.8	76.2
	From 8 to 10m	18.7	81.3	43.5	56.5	12.3	87.7	28.4	71.6
	Below 8m	18.2	81.8	36.7	63.3	12.1	87.9	25.1	74.9

8.1.4 Fishery section analysis

Both subsistence fisher activity and small scale gear size have more impact on fishing pressures than nodes affecting middle scale fisheries because small scale fishing contributes most to the annual fish catch. From the number of middle scale fisherman the Khmer fishers have the most impact, while Vietnamese and migrant fishers have equal importance.

Table 28: Results for testing fisheries variables.

			Pressure from small scale fishery		Pressure from middle scale fishery		PRESSURE on residents		PRESSURE on Mekong migrants	
			Increasing	Stable	Increasing	Stable	Increasing	Stable	Increasing	Stable
Baseline			73.4	26.6	64.5	35.5	67.5	32.5	69.6	30.4
Small scale fishery	Activity of SS fishers	More fishing	84.3	15.7			74.8	25.2	76.4	23.6
		More farming	54.4	45.6			54.8	45.2	57.9	42.1
	Gear size of SS fishers	Increasing	88.4	11.6			77.5	22.5	78.9	21.1
		Stable	68.4	31.6			64.1	35.9	66.5	33.5
	No. of Khmer SS fishers	Increasing	73.4	26.6			67.5	32.5	69.6	30.4
		Stable	-	-			-	-	-	-
	No. of Viet./Cham SS fishers	Increasing	74	26			67.9	32.1	70	30
		Stable	71.4	28.6			66.2	33.8	68.4	31.6
Middle scale fishery	No. of Khmer MS fishers	Increasing			78.5	21.5	70.4	29.6	74	26
		Stable			50.5	49.5	64.6	35.4	65.2	34.8
	No. of migrant MS fishers	Increasing			71.5	28.5	68.9	31.1	71.8	28.2
		Stable			57.5	42.5	66	34	67.4	32.6
	No. of Viet./Cham MS fishers	Increasing			71.5	28.5	68.9	31.1	71.8	28.2
		Stable			43.5	56.5	63.1	36.9	63	37
	MS gear efficiency	Increasing			72	28	69	31	72	28
		Stable			42	58	62.8	37.2	62.5	37.5

In terms of actual fish production, migrant fish contribute more than resident fish (see section 7.5). However it was decided not to analyze in detail the catch of each guild nor the total Tonle Sap catch. This is justified by two main reasons:

1) **there are excessive knowledge gaps regarding grey fish and the nature and functioning of the overall fishery sector** (absence of disaggregated catch statistics for Tonle Sap migrants, lack of quantitative factors describing precisely each type of fishery, and overly simplistic descriptors of the each type of fishery);

2) the nature of the fishery module of the model is different from that of the other modules: while the Hydrology, Habitat and Migration variables are based on the current or past situation as documented by data and expert experience, the fishery module uses variables that refer to the future (e.g. number of fishers increasing). This fact is due to the quasi-total absence of information and data about the fishery sector and its history (how many fishermen, what fishing effort, etc). This situation introduces a twist in the model and an excessive reliance, for that module, on assumptions and guesses; it also highlights the **urgent need for researchers and managers to start documenting and monitoring the fishery sector for its role in the sustainability of the fish production can be better appraised.**

For these reasons, we focused on the relationship between environmental factors (hydrology, habitat, migrations) and the fish stocks. Fish stock variables were also used for scenario analysis and for comparison with Dai fishery fish catch data. The model shows that **the main influence on resident fish stocks is due to Flood for fishes and Habitat for residents, whereas Mekong migrants are mainly influenced by Migrations of Mekong migrants**. For Tonle Sap migrants no single driving variable is more influential than another.

8.2 Model validation

This model validation is based on the Baseline scenario fish production. The baseline scenario based on probabilities elicited by the stakeholders was compared with the Dai fisheries annual fish catch data. This dataset is regarded as the best fish catch data available in Cambodia, and reflects the Tonle Sap Lake fish production quite well.

Years 1995 to 2003 were used for the comparison, even though WUP-FIN model has output data for years 1996-2000 only. During the testing it was assumed that same consistency shown in Tables 32-34 in WUP_FIN and WUP_JICA baselines would apply for 1995 and 2001-2003. Model input states for Mekong flow, Overland flow and Flood beginning were used for each year at a time to set up the model (Table 29). Years 1996-1997 and 2000-2001 have the same flooding states, and therefore flood for fish probabilities as well.

Table 29: Input states for Baseline scenarios 1996-2000 based on hydrological data.

Year	Date of floodplain flooding	Flow from Mekong	Overland flow
1996	Mid July to mid Aug	Above 34300	Above 6400
1997	Mid July to mid Aug	Above 34300	Above 6400
1998	After Mid Aug	Below 34300	Below 6400
1999	Before mid Jul	Below 34300	Below 6400
2000	Before mid Jul	Above 34300	Above 6400

Comparison of actual data vs. predicted outputs

We ran BayFish for each year between 1995 and 2004, and calculated for each year the probability of a high fish stock, knowing all actual environmental parameters for these years. The model outputs were then compared to the data of the Dai fishery, that is the only fishery for which catches have been scientifically monitored over a long period of time. The modelled curves of Mekong migrant and Tonle Sap resident fish stocks fits well with published catch data for the Dai fishery (Figure 20).

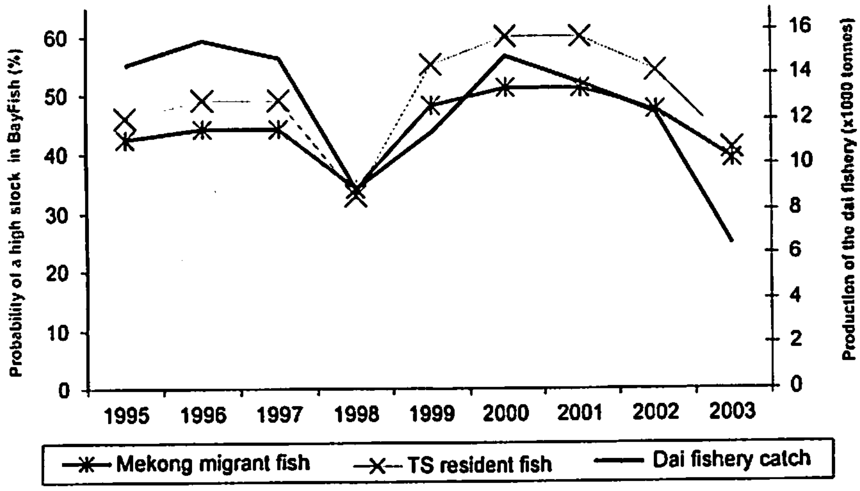

Figure 20: Comparison of actual Dai fishery catches (data from Starr, 2004) with model predictions (residents and Mekong migrants disaggregated)

These results have been produced by the BayFish model on the sole basis of variables and parameters proposed *a priori* by stakeholders and extracted from databases; no adjustment nor recalibration has been done at this stage.

Table 30: Results for Baseline scenario analysis for fish harvest and fish stocks.

Node	Flood for fishes		STOCK of resident		STOCK of TS fishers		STOCK of Mekong	
State	Good	Bad	Abundant	Scarce	Abundant	Scarce	Abundant	Scarce
Baseline	60.6	39.4	48.5	51.5	49.8	50.2	43.9	56.1
1995	54.4	45.6	46.2	53.8	47.9	52.1	42.5	57.5
%	-10.2	15.7	-4.7	4.5	-3.8	3.8	-3.2	2.5
1996	62.9	37.1	49.2	50.8	50.4	49.6	44.3	55.7
%	3.8	-5.8	1.4	-1.4	1.2	-1.2	0.9	-0.7
1997	62.9	37.1	49.2	50.8	50.4	49.6	44.3	55.7
%	3.8	-5.8	1.4	-1.4	1.2	-1.2	0.9	-0.7
1998	20	80	33	67	36.5	63.5	34.1	65.9
%	-67.0	103.0	-32.0	30.1	-26.7	26.5	-22.3	17.5
1999	76.6	23.4	55	45	55.4	44.6	48.1	51.9
%	26.4	-40.6	13.4	-12.6	11.2	-11.2	9.6	-7.5
2000	91	9	59.9	40.1	59.7	40.3	51.2	48.8
%	50.2	-77.2	23.5	-22.1	19.9	-19.7	16.6	-13.0
2001	91	9	59.9	40.1	59.7	40.3	51.2	48.8
%	50.2	-77.2	23.5	-22.1	19.9	-19.7	16.6	-13.0
2002	75.9	24.1	54.1	45.9	54.6	45.4	47.5	52.5
%	25.2	-38.8	11.5	-10.9	9.6	-9.6	8.2	-6.4
2003	40.6	59.4	40.9	59.1	43.4	56.6	39.3	60.7
%	-33.0	50.8	-15.7	14.8	-12.9	12.7	-10.5	8.2

8.3 Scenario analysis

8.3.1 Development scenarios

Development scenarios for Lower Mekong Basin and Tonle Sap Lake have been designed by Mekong River Commission Basin Development Programme, WorldBank (2004) and Cambodian National Mekong Commission (2004). However, very little has been published in actual numeric data on the scenarios required as an input for this model. Therefore, WUP-FIN hydrological model was used to obtain the data for the scenario input states (nodes: Mekong Inflow, Overland flow and Flood beginning). Due to differences between the MRCS/TSLV_JICA and WUP_FIN models the output data is somewhat different. Two hydrological development scenarios were created for testing purposes, both based on MRC scenarios:

1) High development (HD) scenario. The High Development Scenario has been defined by the MRCS according to the table below (Koponen *et al.* 2007):

Table 31: High Development scenario assumptions (Koponen, 2007)

Scenario Summary	Baseline	High Development
Upper Mekong Basin Dams	None	Xiowan and Nuozhadu
Diversions	None	• Inter-basin diversion from Chiang Rai tributary • Intra-basin diversion from Mun Chi tributary • Intra-basin diversion from Mun Chi mainstream
Domestic Water Consumption (litres per capita per day)	• Based on MRC (2004) data on per capita water demands: Laos – 64, Thailand – 115, Cambodia – 32, Viet Nam – 66	• Laos – 150 , Thailand – 200, Cambodia – 100, Viet Nam – 150
Irrigated Areas	• Total irrigated area of 74,655 km^2 allocated among sub-areas on the basis of the data contained in the DSF	• Total irrigated area of 104,287 km^2 allocated among sub-areas on the basis of the projections used in the DSF
Hydropower	• 4 dams modelled: Nam Ngum, Theun Hinboun, Houay Ho, Yali •	• 8 dams modelled: Nam Ngum, Theun Hinboun, Nam Theun 2, Nam Theun 3, Yali, Xe Kaman 1, • Se Kong 5, Lower Se San & Lower Sre Pok

2) Main stream dam (MSD) development scenario. The Mainstream Dams scenario includes mainstream dam development to the High Development Scenario. The net storage of the reservoirs is assumed to be 85 billion m3 (Mekong Committee, 1970) based on the most feasible hydropower and irrigation development plan.

Results from the scenario testing can be seen in tables 32-35. The results are also compared to the baseline of TSLV/WUP_JICA results that were used previously in the model to ensure data integrity. It is clear from the tables that the baselines from two different models fit well (bold figures representing years with *Above* average flows, or beginning of the flood). For the development scenarios average of WUP_FIN baseline was used. This produced clear differences especially with Mainstream dams development scenario. For Mekong inflow above average flow probabilities drop from 60% to 40% (HD) and 20% (MSD), similar trend being seen in Overland flow. MSD scenario for overland flow was not received from WUP_FIN, but by analysing the data it can be seen that the trend follows closely Mekong inflow trends, hence only year 2000 is going to be above average flow (giving 20% above average probability). For overland flow baseline year 1997 flow of 6400 was counted as above average (average being 6408) in order to follow old baseline based on WUP_JICA model data.

Table 32: Mekong inflow results from WUP_FIN model

Year	1996	1997	1998	1999	2000	Average
Baseline	37523	35910	20624	29865	47895	34363
High Development	34775	33083	15704	26012	46568	31228
Mainstream Dam dev	25256	24206	8461	20301	38494	23344
Baseline from WUP_JICA	43910	40897	22110	35718	49772	38481

Table 33: Overland flow results from WUP_FIN model

Year	1996	1997	1998	1999	2000	Average
Baseline	8400	6400	240	4500	12500	6408
High Devevelopment	6500	4800	20	3100	10700	5024
Mainstream Dam dev						
Baseline from WUP_JICA	9118	11621	1309	7036	16366	9090

Flood beginning remained the same for both of the baselines and HD scenario, but MSD scenario showed a change towards later floods. Also the analysis showed that another stakeholders consultation would be required to be able to determine flood beginning in a more precise way to increase the sensitivity of the model.

Table 34: Flood beginning results from WUP_FIN model

Year	Date	1996	1997	1998	1999	2000
Baseline	15.7	2.48	2.58	2.55	4.05	5.03
	1.8	3.69	4.56	3.56	4.82	6.72
	15.8	5.18	6.31	3.95	6.25	7.22
High Development	15.7	2.51	2.64	2.54	3.85	4.85
	1.8	3.55	4.44	3.27	4.46	6.44
	15.8	4.86	6.05	3.51	5.80	6.79
Mainstream Dam dev	15-Jul	2.48	2.57	2.43	4.05	4.74
	01-Aug	3.43	4.00	2.94	4.67	6.07
	15-Aug	4.48	5.16	3.23	5.65	6.42
WUP_JICA baseline	15.7	2.9	2.9	2.9	5	5.7
	1.8	4.2	4.9	3.8	5.8	7.1
	15.8	5.6	6.7	4.3	7.1	8.3

After analyzing results from WUP_FIN output data it was noted that Flood duration did not change at all with HD scenario and very little even with MSD scenario, except for one year in the time series (1996). In addition, the data showed that with MSD scenario all but one year actually had an increase in flood duration, whereas one had 2 weeks shorter duration, hence no clear trend was seen. It also appears that development scenarios mainly cause flood beginning to change, but not flood duration. This is partly due to the definition of flood duration in the model in weeks, which blends in the minor changes in duration occurring often in days. The phenomenon is well illustrated by figure 10 below.

Table 35: Flood duration results from WUP_FIN model

Year	Date	1996	1997	1998	1999	2000
WUP_FIN Baseline	Length (d)	67	48	45	80	67
	Weeks	9.6	6.9	6.4	11.4	9.6
	Flow reversal	07-Oct	18-Sep	29-Sep	03-Oct	23-Sep
High Development	Length (d)	68	48	45	81	68
	Weeks	9.7	6.9	6.4	11.6	9.7
	Flow reversal	08-Oct	18-Sep	29-Sep	04-Oct	24-Sep
Main stream Dams Development	Length (d)	52	50	48	83	73
	Weeks	7.4	7.1	6.9	11.9	10.4
	Flow reversal	05-Oct	19-Sep	01-Oct	05-Oct	25-Sep
WUP_JICA baseline	Length (d)	69	51	49	81	69
	Weeks	9.9	7.3	7.0	11.6	9.9
	Flow reversal	09-Oct	21-Sep	03-Oct	04-Oct	22-Sep

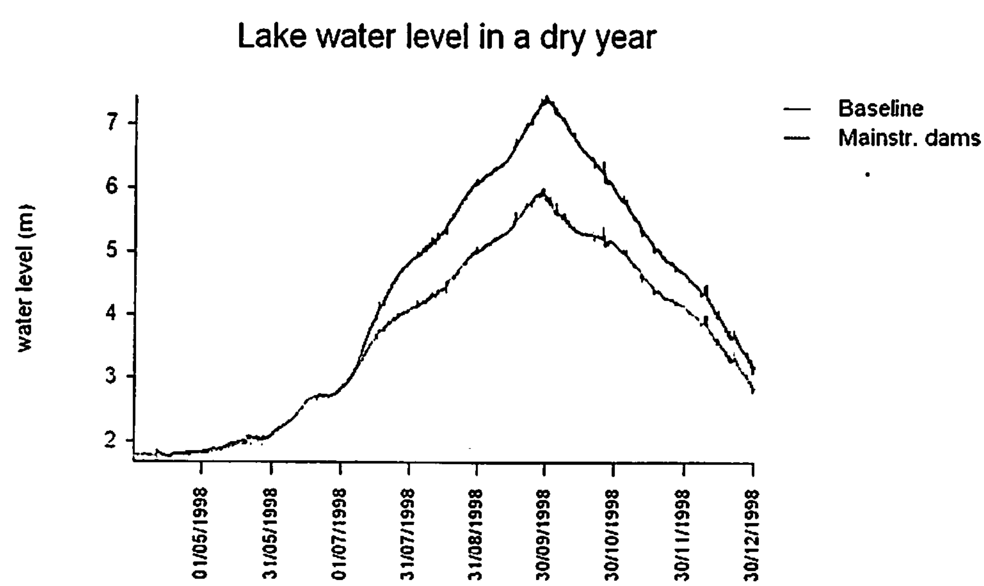

Figure 10: Simulated Tonle Sap Lake water levels for the WUP_FIN baseline and Mainstream Dams scenario (Koponen *et al.* 2007).

8.3.2 Results of scenarios

When comparing WUP_FIN (baseline) and High Development scenario it can be seen that there is tendency for lower flood levels at the Lake, as well as some shortening of the floods. However, the difference in stock is minute. On the other hand, MSD scenario shows alarming rate of lowering of flood levels and increasing of shorter floods, also reflected in fish stocks. Resident fish stocks seem to be more sensitive to mainstream dam development with 8.6% reduction in stock probability units in model (4.3 units), while similar reduction is 6% for Mekong migrants. Tonle Sap migrants stock are reduced by 7.1% in the model. Scenario comparison can be seen in table below:

Table 36: Scenario comparison

	Flood for fishes		Tonle Sap water level			Flood duration			Abundant STOCK for fishes		
	Good	Bad	Above 10	8-10	Below 8	>11	7-10	<7	TS residents	TS migrants	Mekong migrants
WUP_JICA	63.2	36.8	25.4	49.8	24.8	25.7	67	7.3	38.2	-	51.7
WUP_FIN	60.6	39.4	29.6	47.8	22.6	26.2	66.1	7.7	48.5	49.8	43.9
difference	-2.6		4.2	-2	-2.2	0.5	-0.9	0.4	10.3	-	-7.8
%	-4.1		16.5	-4.0	-8.9	1.9	-1.3	5.5	27.0	-	-15.1
High dev	58.8	41.2	24.2	50.2	25.6	25.7	66.5	7.8	47.9	49.3	43.5
difference	1.8		5.4	-2.4	-3	0.5	-0.4	-0.1	0.6	0.5	0.4
%	-3.0		-18.2	5.0	13.3	-1.9	0.6	1.3	-1.2	-1.0	-0.9
Dam dev	49.3	50.7	19.3	51.9	28.8	20.7	65.4	13.9	44.3	46.2	41.3
difference	11.3		10.3	-4.1	-6.2	5.5	0.7	-6.2	4.2	3.6	2.6
%	-18.6		-34.8	8.6	27.4	-21.0	-1.1	80.5	-8.7	-7.2	-5.9

9 CONCLUSIONS

The Bayesian approach is a good modelling option for situations where the structure of the system is not well known or data are nonexistent. Including years of expert knowledge, often untapped in scientific studies and model building, can substantially improve and develop a model to represent the modelled system more accurately and reliably. Moreover, a Bayesian model can be used as a teaching and training tool for decision makers, civil servants and other stakeholders to improve their understanding of the linkages and trade-offs of a given system. However, the model output is in probabilities which can only be used indicatively for management decisions and scientific predictions.

BayFish – Tonle Sap model has proven in scenario analysis the accuracy obtainable with the combination of data integration and extensive stakeholders consultations into a Bayesian Belief Network. Even though the model is simplified it can be used as an efficient management and planning tool for the Tonle Sap fisheries and environment.

The next steps of the model development are:

1) training of decision makers in using and modifying the model;
2) fine tuning the model according to feedback from decision makers and stakeholders;
3) studying the importance and linkages of overland flow to fish and larvae migration (replenishment of fish stocks);
4) dissemination of model results as well as the model itself to wider audience.

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ANNEX: Abbreviations used in the Netica model framework and corresponding model section for each of the variables

Abbreviation	Corresponding variable	Model section
BFMigrations	MIGRATIONS of residents	Fish migrations
BS	Built Structures	Fish migrations
GFMigrations	MIGRATION of TS migrants	Fish migrations
Refuges	Floodplain refuges	Fish migrations
WFMigrations	MIGRATION of Mekong migrants	Fish migrations
BFCatch	CATCH of residents	Fish production
BFStock	STOCK of residents	Fish production
GFCatch	CATCH of TS migrants	Fish production
GFStock	STOCK of TS migrants	Fish production
TotalCatch	TOTAL FISH CATCH	Fish production
WFCatch	CATCH of Mekong migrants	Fish production
WFStock	STOCK of Mekong migrants	Fish production
BFPressure	PRESSURE on residents	Fishing
GFPressure	PRESSURE on TS migrants	Fishing
LSPressure	Pressure from LS fishery	Fishing
MSFishers	# MS fishers	Fishing
MSGear	MS gear efficiency	Fishing
MSKhmer	# Khmer MS fishers	Fishing
MSMigrant	# migrant MS fishers	Fishing
MSPressure	Pressure from MS fishery	Fishing
MSVietCham	# Viet./Cham MS fishers	Fishing
SSActivity	Activity of SS fishers	Fishing
SSFishers	# SS fishers	Fishing
SSGear	Gear size of SS fishers	Fishing
SSKhmer	# Khmer SS fishers	Fishing
SSPressure	Pressure from SS fishery	Fishing
SSVietCham	# Viet./Cham SS fishers	Fishing
WFPressure	PRESSURE on Mekong migrants	Fishing
BF_DO	O2 for residents	Habitat
BFHabitat	HABITAT for residents	Habitat
DO_Floodplain	Floodplain O2	Habitat
FVegetation	Flooded vegetation	Habitat
GF_DO	O2 for TS migrants	Habitat
GFHabitat	HABITAT for TS migrants	Habitat
WF_DO	O2 for Mekong migrants	Habitat
WFHabitat	HABITAT for Mekong migrants	Habitat
FBeginning	Flood beginning	Hydrology
FDuration	Flood duration	Hydrology
FFish	Flood for fishes	Hydrology
FLevel	Flood level	Hydrology
MInflow	Mekong inflow	Hydrology
OverlandFlow	Overland flow	Hydrology
Scenarios	Hydrological scenarios	Hydrology
TSRainfall	TS rainfall	Hydrology
TSRunoff	TS runoff	Hydrology
TSWLevel	TS water level	Hydrology

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Technical Assistance to the Kingdom of Cambodia
for the Study of the Influence of Built Structures
on the Fisheries of the Tonle Sap
(financed by the Government of Finland)

INTEGRATION OF DATABASES TO THE BAYFISH – TONLE SAP FISH PRODUCTION MODEL.

Prepared by

Teemu JANTUNEN

April 2007 update

Table of contents:

Abbreviations:

ADB	Asian Development Bank
BBN	Bayesian Belief Network
BOD	Biological Oxygen Demand
CNMC	Cambodian National Mekong Committee
DHI	Danish Hydrologic Institute
DO	Dissolved Oxygen
DSF	Decision Support Framework
GIS	Geographical Information Systems
IFReDI	Inland Fisheries Research and Development Institute
IWMI	International Water Management Institute
JICA	Japan International Cooperation Agency
MCM	Million Cubic Meters
MOWRAM	Ministry of Water Resources and Meteorology
MPWT	Ministry of Public Works and Transport
MRCS	Mekong River Commission Secretariat
MSL	Mean Sea Level
PPT	Precipitation
TA	Technical Assistance
TIN	Triangulated Irregular Network
TSD	Technical Support Division
TSLV	Tonle Sap Lake and its Vicinities
WUP	Water Utilisation Project

Executive Summary:

A series of datasets have been gathered, analysed, summarised and integrated into the Bayesian Belief Network (BBN) fisheries model. Bayesian networks are based in probabilistic interactions between variables. They have been mainly used for medical diagnosis but recently more for environmental management as well. The data consists of hydrological characteristics (rainfall, runoff, Mekong flow, overland flow, flood beginning, and flood duration), water quality characteristics (dissolved oxygen) and land use characteristics for the Tonle Sap Lake and floodplain. Data accuracy, reliability and suitability for the model were given special attention in the analysis. All datasets have been handed over to IFReDI.

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1 Introduction

The Asian Development Bank approved a grant for the capacity building of IFReDI (Inland Fisheries Research and Development Institute), with WorldFish Center as an implementing agency. The aim of the technical assistance is to build IFReDI as a relevant and efficient research and development institute.

The project has four components. One of these components focuses on research and development. This component includes a Bioecology-Modelling sub-component. In the field of modelling, this sub-component aims to identify relationships between river hydrology, floodplain habitats and fish production, to integrate this information into a Bayesian model, and to prepare a base for a decision support system aimed for assisting in the management of the river and its floodplain.

The current study consisted in gathering and compiling numerical databases on land use, hydrology and water quality. These sources of information were then analysed, manipulated and validated for integration into the Bayesian model of the Tonle Sap fish resource being developed by the Bioecology-Modelling sub-component of the project (Baran *et al.*, 2004).

The objective of this consultation is to strengthen the model of the Tonle Sap fish resource by including quantitative information extracted from various recent databases of different formats spread across a number of organisations. The use of quantitative data on land use, hydrology and water quality will strengthen the model developed on the basis of stakeholders consultations and will improve its predictive power and accuracy.

This report is divided into four sections and corresponding annexes. The first section introduces the databases that were utilised and the method of data analysis with results. Validation for the use of the selected datasets is given in this section. The second section briefly describes the methodology, options for data input to the Netica model, and how nodes might be parameterised and thresholds set. A detailed description of each node with input data parameterisation and thresholding follows with justifications. The third section deals with aspects of the model outside the scope of this consultancy. Due to the inter-connectivity of the model framework they are dealt with briefly. The final section concludes the findings. In all sections, text in boxes refers directly to nodes of the Bayesian Belief Network fisheries model whereas the node states are referred in *italics*.

2 Tasks and methods

2.1 About the literature review

A review of relevant documents on the availability and quality of hydrological data with emphasis on fish production was undertaken at the beginning of the consultancy. Geographical Information Systems databases and contact persons were identified from several reports (Campbell, 2003; Eloheimo *et al.*, 2002a and 2002b; MekongInfo MRC online database, 2004). Previous models and water balance calculations on the Tonle Sap Lake were also studied (Sopharith, 1997; Kite, 2000; Koponen *et al.*, 2002a). Stakeholders consultation reports for the fisheries model were reviewed (Baran, *et al.*, 2003; Hort and Baran, 2004; Hort, *et al.*, 2004). The review also assisted in the discovery of some possible linkages between variables in the model and in their parameterisation. A full reference list is included in chapter 6.

2.2 Data collection

Data collected from a number of databases, their format and short descriptions are listed in Table 1. The data collection effort aimed to use existing edited numerical databases and data summaries as much as possible in order to avoid overlapping and duplicating work already done by other technical assistance projects. Some projects were visited to find out, not only the nature of their studies, but also information about ongoing work and future developments. This information was provided to IFReDI and Department of Fisheries employees in seminars.

Table 1 Summary of all data requested through IFReDI and handed over to the institute as a collection of CDs with a short description of the data and their sources.

Dataset	Source	Area and period	Description	Format	Obtained from
Water level data	JICA & TSLV Flow Reversal Project	Kratie 1934-2002, Prek Kdam 1960-2002, Kompong Loung 1924-2002, Phnom Penh Port 1960-2002	DSF model input data, corrected for same datum from MRCS Hymos dataset.	Numerical	MRCS/JICA & TSLV Flow Reversal Project
Water level data	MRCS	Kompong Loung 1924-2002, Kompong Chhnang 1924-2002	Datasets with uncorrected datum (measured)	Numerical	MRCS/WUP_FIN
MIKE11 model output data	JICA & TSLV Flow Reversal Project	Discharge Prek Kdam and Kratie, Water level Kompong Loung, Overland flow. 1984-2003	Flow reversal model output data taking into account backwater effect and overland flow. Fills gaps in data.	Numerical	MRCS/JICA & TSLV Flow Reversal Project
Rainfall data	MRCS JICA & TSLV Flow Reversal Project	Tonle Sap catchment 1980-2003	Average rainfall data over each of the sub-cathcments	Numerical	MRCS/JICA & TSLV Flow Reversal Project
Land use, road network, ponds and administrative data	JICA	Tonle Sap catchment	1999 JICA Land use map simplified for Tonle Sap floodplain	GIS layer 1:100 000	MRCS/WUP_FIN
Land use data	WUP_FIN	Tonle Sap floodplain	Calculated percentages of land use types depending on elevation	Numerical	MRCS/WUP_FIN
Dissolved oxygen data	WUP_FIN and MRCS	Tonle Sap Lake and floodplain	Measurements by MOWRAM and MRCS/WUP_FIN	Numerical	MRCS/WUP_FIN
MRCS/WUP_FIN model output data	WUP_FIN	Tonle Sap Lake and floodplain	Average dissolved oxygen levels and anoxic conditions prevalent in the lake and floodplain	Numerical and bitmap	MRCS/WUP_FIN
Certeza survey contour data	MRCS	Tonle Sap floodplain	Digital contour lines based on 1964 levelling survey	GIS layer 1m contour lines	MRCS/WUP_FIN
Water balance data	JICA & TSLV Flow Reversal Project and MRCS/WUP_FIN	Tonle Sap catchment	Calculated water balance to Tonle Sap catchment	Numerical	MRCS/JICA & TSLV Flow Reversal Project and MRCS/WUP_FIN
Fishing lots	MRC	Tonle Sap catchment	Location, extent and state of fishing lots	GIS layer	MRCS/WUP_FIN

2.2.1 Mekong River Commission Secretariat Technical Support Division (MRCS/TSD)

A request was made to the MRCS/TSD for water level, discharge, precipitation, land use, topography, administrative border, road network and dissolved oxygen data (full list of requested data in annex 1.1). During the discussions with Geographical Information Systems and database experts it was discovered that the MRCS Hydrographic Atlas (1998) was soon to be released as a Geographical Information Systems layer, but that would not be available before May 2004. All of the data used for the modelling were obtained from sub-projects because the majority of the data has not been added into the MRCS/TSD database to date.

Overall, the MRCS holds the best and most comprehensive Geographical Information Systems, hydrological, environmental and remote sensing datasets about Cambodia, the Mekong and the

Tonle Sap. According to experts there will be no new data collection or measurement programmes by the MRCS for the Tonle Sap Lake and floodplain in the near future. After the MRCS moves into Laos the MRCS database will be available in Cambodia through the Cambodian National Mekong Committee (CNMC). Also, the MRCS is currently developing an online database with functions for data searching and possibly downloading. The plan is to have the database for internal use only at first, but it may be made available for public use at a later date. According to estimates, the online database should be ready sometime in the year 2005.

2.2.2 Mekong River Commission Secretariat Water Utilization Project - Finland (MRCS/WUP-FIN)

The MRCS/WUP-FIN has collected a very good database of hydrological and water quality data for the Tonle Sap Lake to meet their model requirements. In addition, the MRCS/WUP-FIN has undertaken extensive data gathering and field sampling programmes in and around the lake. The model developed by the MRCS/WUP-FIN can be used to produce various outputs for this Bayesian model, particularly on the water quality side. The MRCS/WUP-FIN model expert was asked to run this model in order to produce outputs for dissolved oxygen levels in different floodplain land use classes. Also, there is Geographical Information Systems data available at the MRCS/WUP-FIN on the relationship between elevation and land use on the Tonle Sap floodplain.

The MRCS/WUP-FIN project has gathered a wealth of information and expertise about the lake. The model structure, particularly regarding oxygen levels, was discussed with project experts for a broader understanding of possible linkages between dissolved oxygen and other variables in the Bayesian model and their relative importance.

2.2.3 Mekong River Commission Secretariat Water Utilization Project - Japan International Cooperation Agency (MRCS/WUP-JICA)

A MRCS/WUP-JICA hydrology and modelling expert was interviewed to learn more about water level and rainfall data, the water balance in the Tonle Sap Lake, and bank structures affecting the lake's flow. A MRCS/WUP-JICA project has worked extensively on flow measurements and hydrological data analysis, and this data was utilised for the purposes of the Bayesian model. In addition, the MRCS/WUP-JICA & TSLV Flow Reversal Project produced extremely useful model output data on discharges from the Mekong to the Tonle Sap and on water levels the Tonle Sap Lake as part of their project. For modelling they used MIKE11 hydrological model originally developed by DHI in Denmark.

Overall, the discussions were very useful in establishing the strength of relationships between hydrological variables and in assessing the usefulness of the data for the purposes of the Bayesian fisheries model. Valuable information regarding data quality was also drawn from the discussions. The MRCS/WUP-JICA data is estimated to be available through the MRCS and the Cambodian National Mekong Committee upon request by July 2004.

2.2.4 Ministry of Public Works and Transport (MPWT)

The Ministry of Public Works and Transport (MPWT) mainly holds databases on road networks, topography, build structures (urban areas, bridges, etc.), land use and water courses. Practically all data is available upon request through the MRCS and the Cambodian National Mekong Committee for national line agencies.

A Geographical Information Systems expert from the Ministry of Public Works and Transport was interviewed about JICA land use maps, water level datum and bank structures. Land use maps for all of Cambodia are reportedly going to be ready at the end of April 2004 (in case they are required for modelling the whole Tonle Sap catchment or other activities in the IFReDI). Also, according to the Geographical Information Systems expert there has been no work done on the extent and length of bank structures around the Tonle Sap Lake. Thus, no data are available on bank structures for the purposes of the Bayesian model.

The results of a recent levelling work done around the lake have only been used for comparison with the contour lines of the Certeza Survey (1964). There is very little difference in average elevation data between the Certeza Survey and the recent levelling work. Therefore, the use of Certeza Survey elevation data in the floodplain is justified. Kampong Loung is regarded as one of the main water level measurement stations on the Tonle Sap Lake. However, the datum level and accuracy of the water level measurement station have not been checked by a levelling survey. Therefore, other means have to be used to check the accuracy of the data from the Kampong Loung station.

2.2.5 Geography Department

The Geography Department has databases on land ownership and titling, road networks, build structures, remote sensing and topography. Most of the data is available upon request through the MRCS and the Cambodian National Mekong Committee to national line agencies.

The Director of the Geography Department was visited mainly to learn more about new developments on the Tonle Sap Lake, but also about the Geographical Information Systems databases held at the department. The discussion yielded no new information about data, but there were suggestions for aerial photography and laser surveying of the Tonle Sap floodplain.

2.3 Data analysis and validation

The Bayesian Belief Network model is designed to handle hydrological, biological and socio-economic parameters in order to predict fisheries and agricultural production in a given flooding season. Therefore, it was decided to handle most of the data in the form of hydrological years (i.e. from the beginning of May to the end of April). If data is analysed in calendar years rather than hydrological years there can be inaccuracies especially in averaged data. This can be caused by the different hydrological properties of the previous rainy season (i.e. a high or low flood the previous year can cause annual statistics to distort for the following year).

2.3.1 Tonle Sap rainfall

According to all experts and reports, precipitation data is the most problematic of all data necessary for the Bayesian fisheries model of the Tonle Sap catchment. This is due to the fact that station records are often short and full of gaps, and that the station network changes from year to year (Garsdal, 6.4.2004, personal communication). The MRCS/WUP-FIN project also found that the mutual correlations between different stations are quite weak (Eloheimo *et al.*, 2002a). Therefore, the existing records are quite inconsistent and unreliable. Thus, it was decided to use the DSF (Decision Support Framework) model (MRCS/WUP-JICA & TSLV Reverse Flow Project) precipitation input data generated by calculating simple mean area rainfall for all Tonle Sap sub-catchments with each station having equal weight (MRCS/WUP-JICA, 2004). With the relatively large uncertainty in some of the rainfall data as well as the non-uniform distribution of the rainfall station network, the MRCS/WUP-JICA did not attempt to apply any sophisticated weighting of the individual stations (MRCS/WUP-JICA, 2004).

The precipitation data was provided as daily totals from 1980 to 2003 for each Tonle Sap sub-catchment (Boribo, Pursat, Dauntri, Sangker, Mongkol Borey, Sisophon, Sreng, Siem Reap, Chikreng, Staung, Sen and Chinit). Rainfall for the whole Tonle Sap catchment was calculated simply by adding the average rainfall for all the Tonle Sap sub-catchments. Monthly averages, maximum, minimum and standard deviation values were calculated from the Tonle Sap catchment totals (annex 1.2). Because of its crucial importance for rainfed agriculture, the rainfall data was also analysed in rainy season (from June to December) amounts. Rainfall for the open lake is not accounted, as evaporation and precipitation over the lake are almost equal (Sarkkula *et al.*, 2004) and therefore cancel each other out.

In the third stakeholders consultation (Hort, *et al.*, 2004) the years 1996, 2000, 2001 and 2002 where named as especially wet years. However, when looking at the data (Figure 1) these years do not appear especially wet, rendering either the longer term data series or the opinions of stakeholders incorrect. In this case, long term data series unreliability was seen as the cause of the incompatibility of the two sources. Due to major uncertainties in the 1980 to1995 period it was decided to use only the most recent years, namely 1996 to 2003, as rainfall data for the model.

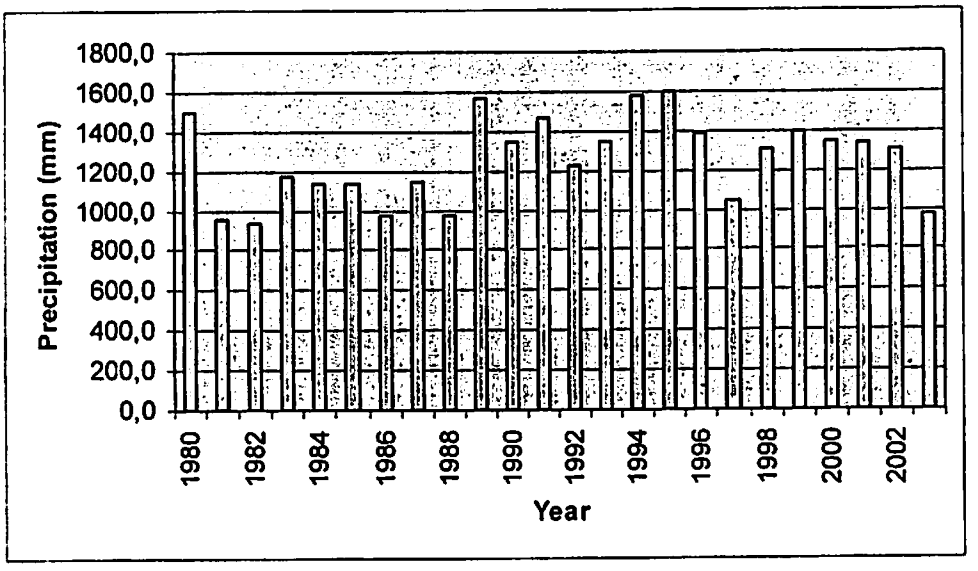

Figure 1 Average rainfall for the Tonle Sap catchment from 1980 to 2003 (millimetres).

2.3.2 Mekong flow

Prek Kdam (station number 20102), about 50 km North of Phnom Penh on the Tonle Sap River was used to determine the discharge of water flowing into the lake from the Mekong. The dataset used consists of simulated discharge values from the MIKE11 model used by the MRCS/WUP-JICA & TSLV project. Reverse flow towards the Tonle Sap Lake .dominates from June to September with maximum flows between July and August (annex 1.3.1). The discharge data corresponds well with Tonle Sap water level and Overland flow as well as Tonle Sap runoff discharge, which is essential to keep the proportions of all Kampong Loung water level parent nodes correct in the Bayesian model. The MIKE11 model was calibrated with the years which had direct measurements from the MRCS/WUP-JICA & TSLV project. For the years without direct measurements, the discharge level at Kratie was used as a reference for the model, because Kratie is the only measurement station with records extending back to 1985. The discharge records used are from 1985 to 2003 (Table 2) even though the water level records for Prek Kdam start much earlier. There are doubts about data accuracy at Prek Kdam the further back the records originate. This is mainly because the data has not been corrected for backwater effect and overland flow impact.

Table 2 Rainy season date (from June to December): Precipitation (mm), River inflow (flow from the Mekong), Overland flow and Runoff totals in Million Cubic Meters; Tonle Sap water level at Kampong Loung (in meters). Years are named as wet or high flood in third stakeholder consultation are marked in bold and 1998 dry year marked in italics.

Flood year	*Precipitation*	*River inflow*	*Overland flow*	*Runoff*	*Water level at K. Loung*
1985	878,6	43376	6751	25680	9.0
1986	792,1	43266	5935	15636	8.4
1987	900,4	35522	4451	18322	7.8
1988	753,6	26105	1416	18123	7.2
1989	1196,0	28119	2295	39246	8.4
1990	1113,8	37999	7668	33970	9.4
1991	1292,8	35561	10639	48354	9.9
1992	1068,0	26758	3807	31652	8.3
1993	1115,9	33704	3299	27185	8.2
1994	1240,8	36535	13076	45501	10.4
1995	1353,3	39309	7606	40583	9.6
1996	**1071,4**	**43910**	**9118**	**29717**	**9.5**
1997	851,7	40897	11621	22923	9.1
1998	*1029,8*	*22110*	*1309*	*23635*	*7.1*
1999	1031,5	35718	7036	31855	9.0
2000	**1057,4**	**49772**	**16366**	**30886**	**10.3**
2001	**1035,9**	**48488**	**13627**	**30803**	**10.0**
2002	**1066,6**	**49466**	**14222**	**28121**	**10.2**
2003	837,8	33753	4555	21632	8.4
Average	1036	37388	7621	29675	8.9
Max	1353	49772	16366	48354	10.4
Min	754	22110	1309	15636	7.1
St Dev	168	7988	4574	9039	1.0

2.3.3 Overland flow

For Mekong overland flow to the Tonle Sap, simulated output data from the MRCS/WUP-JICA & TSLV project model was used (MIKE11). The MRC/WUP-JICA project measured the flow under the main bridges on National road number 6 where overland flow took place in the year's 2001 to 2003. There are no other existing overland flow data based on actual measurements, but a few estimates from secondary data have been done on the role of overland flow (Sarkkula *et al.*, 2004). Therefore, simulated model output data for 1985 to 2003 (Table 2) is the best available. The simulated data was used to extend the records and to ensure that discharge data is compatible with Prek Kdam and Tonle Sap runoff data and simulated Kampong Loung water level data. There is some overland flow over the year (in channels), but the main flow takes place between July and September (annex 1.3.2). Interestingly, there is usually some overland flow from the Tonle Sap Lake towards the Mekong between October and November. The role of this overland flow in fish migration has not been studied and therefore has not been included in the model at this stage.

2.3.4 Tonle Sap Runoff

At first it was believed that Tonle Sap rainfall includes all precipitation in the Tonle Sap catchment Therefore, noting separate water flow contributions from Tonle Sap tributaries was deemed unnecessary. However, the correlation between water levels and monthly precipitation is quite weak with R^2 only 10 to 25% (Eloheimo *et al.*, 2002). Therefore, a new node was established between Tonle Sap rainfall and Tonle Sap water level in order to maintain proportions between different variables contributing to Tonle Sap water level and to distinguish between rainfall and runoff. This also enables the best possible probabilities to be calculated for Tonle Sap water level from the MIKE11 model output (MRCS/WUP-JICA & TSLV project). Tonle Sap runoff describes the discharge of water into the lake from the Tonle Sap tributaries. This provides a better combination of variables than using Tonle Sap rainfall directly, and also enables more detailed use of Tonle Sap rainfall for the use of Agricultural production, where it is much more important than in fisheries production. The correlation between the simulated runoff in the MIKE11 model and the Tonle Sap rainfall is high (R^2 = 0.914) and can be seen in Table 2 and Figure 2.

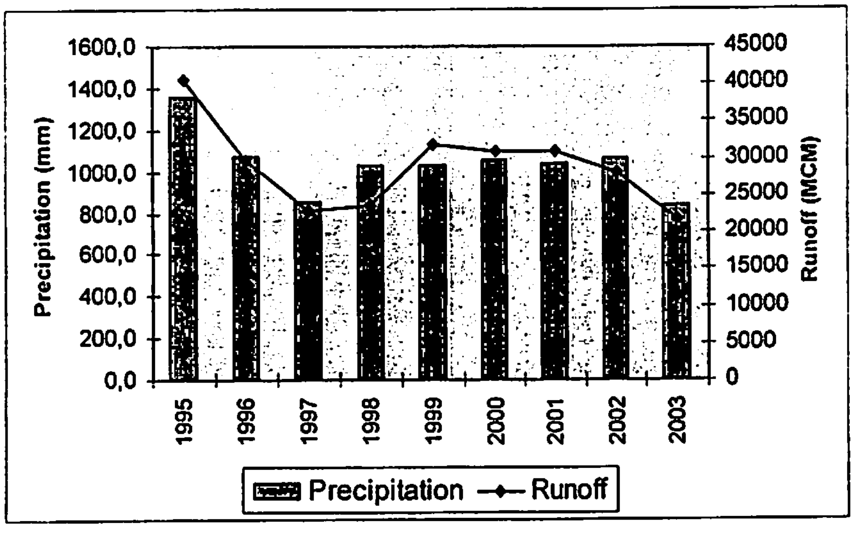

Figure 2 Comparison of Tonle Sap rainfall and runoff during rainy months (June to December).

2.3.5 Tonle Sap water level data

It is very difficult to represent the whole lake with only one water level value. The water level varies spatially around the lake depending on the topography, distance from build structures, local flooding conditions and duration of water flow from the Mekong and Tonle Sap tributaries. For example, between Snoc Trou and Prek Dam the extreme differences in water levels are -2.5 meters when the flood is rising to +1.5 meters when the flood is receding. (Eloheimo *et al.*, 2002). However, the model can only accept one set of values, and so Kampong Loung (station number 20106), situated on the shore of the southern part of the lake, was seen as a good reference point out of the few possibilities.

At the second stakeholders consultation, the station along the Tonle Sap River in Kampong Chhnang (station number 20103) was named as the reference water level for the lake (Hort and Baran, 2004). According to the original measured datasets, however, there are 34 gaps with 2526 missing days in 37 years of data from Kampong Chhnang but only 8 gaps with 850 missing days in 20 years of data from Kampong Loung (Eloheimo *et al.*, 2002a). For details, see annex 1.4.1.

In addition, parts of the Kampong Chhnang daily water level dataset are uncertain and some of the daily readings inconsistent (Figure 3). Also, for Flood beginning node requirements, a comparison in daily water level differences was done. The statistics between Kampong Chhnang and MIKE11 output for Kampong Loung clearly show that the model output data from Kampong Loung is much more consistent (Table 3). Daily differences in a given flooding season (May to

December) of ±1 meter and over are unrealistic and cannot be considered accurate or reliable. Due to this discrepancy, only the years with a standard deviation of less than 0.1 were included in further analysis (for Flood beginning and Flood duration node purposes). Also, weekly averages of the daily values were calculated to see if greater consistency could be achieved (once again from May to December). These calculations proved to be correct and more gradual changes in the daily water level difference could be seen from the data (annex 1.5.2). For more information see chapters 2.3.6 and 3.2.4.

From literature and data analysis it is clear that Kampong Loung provides the most representative lake level measurements (Koponen *et al.*, 2003a; Hellsten *et al.*, 2003). Therefore, Kampong Loung was chosen in order to most accurately and reliably represents the lake's water level.

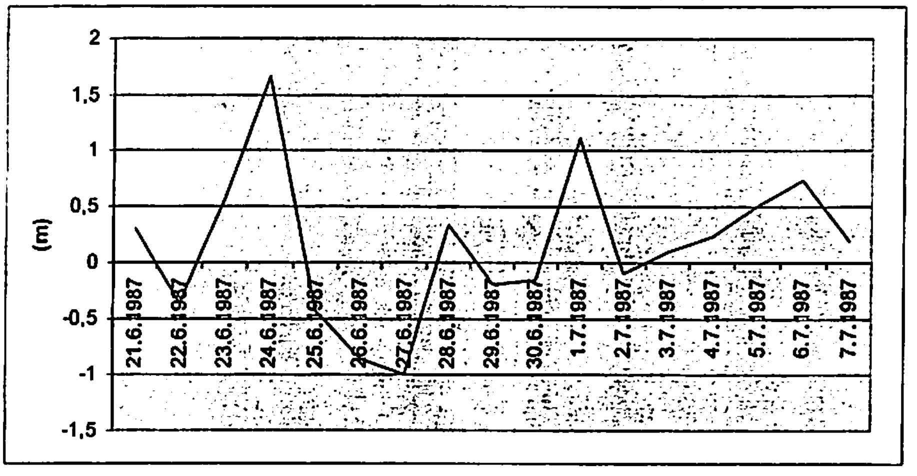

Figure 3 Kampong Chhnang daily water level difference from the 21st of June to the 7th of July, 1987.

Table 3 Comparison of Daily water level differences from the May to December period for the years 1985 to 2002 at K. Chhnang and K. Loung (for K. Loung MIKE11 output water levels were used).

	Kompong Chhnang (measured)			*Kompong Luong (MIKE11)*		
Year	Max	Min	St Dev	Max	Min	St Dev
1985	1.500	-0.710	0.161	0.199	-0.049	0.051
1986	1.200	-1.300	0.198	0.092	-0.049	0.047
1987	2.340	-0.990	0.239	0.149	-0.049	0.047
1988	0.520	-0.840	0.109	0.096	-0.049	0.042
1989	0.940	-0.750	0.129	0.113	-0.051	0.048
1990	0.800	-0.670	0.117	0.130	-0.052	0.052
1991	1.020	-0.500	0.126	0.125	-0.054	0.057
1992	0.770	-1.350	0.139	0.119	-0.050	0.052
1993	0.810	-0.160	0.097	0.121	-0.049	0.048
1994	0.670	-0.470	0.088	0.131	-0.057	0.059
1995	0.240	-0.140	0.073	0.107	-0.052	0.054
1996	0.360	-0.340	0.086	0.131	-0.052	0.052
1997	0.350	-0.140	0.074	0.142	-0.053	0.057
1998	0.990	-1.040	0.127	0.120	-0.047	0.041
1999	0.330	-0.150	0.068	0.095	-0.050	0.046
2000	0.400	-0.160	0.077	0.112	-0.053	0.056
2001	0.250	-0.160	0.069	0.107	-0.052	0.054
2002	0.680	-0.160	0.079	0.104	-0.050	0.054

Equations between different water level measurement stations could be used to fill in the gaps in the data for Kampong Loung. For example, equations between Prek Kdam and Kampong Loung (see below) have been established by Sopharith (1997) and Kite (2000). Sopharith's equation overestimates the level at Kampong Loung (Kite, 2000). The problem with the equations is that they do not take into account overland flow directly from the Mekong to the Tonle Sap Lake from bridge openings on National Road 6 and the backwater effect in the Tonle Sap River. Therefore, the relationship equations are not accurate on all water levels.

1. Equations on the relationship between Kampong Loung and Prek Kdam (H_{KL} = Water level at Kampong Loung, H_{PK} = water level at Prek Kdam):

$H_{KL} = (0.905533 \times H_{PK}) + 1.235901$ ($R^2 = 0.84$)
International Water Management Institute model (Kite, 2000)

2. Equations on the relationship between Kampong Loung and Kampong Chhnang (H_{KL} = Water level at Kampong Loung, H_{KC} = water level at Kampong Chhnang):

$H_{KL} = (1.0068 \times H_{KC}) + 0.50$ ($R^2 = 0.838$)
Sopharith (1997) based on data from Carbonnel and Guiscafre (1964).

$H_{KL} = (0.950519 \times H_{KC}) + 0.806588$ ($R^2 = 0.94$)
For the period from 1924 to1960 - International Water Management Institute model (Kite, 2000).

$H_{KL} = (0.926343 \times H_{KC}) + 0.522631$ ($R^2 = 0.92$)
For the period from 1960 to1998 - International Water Management Institute model (Kite, 2000).

The decision was made to use simulated Kampong Loung water level data from the MRCS/WUP-JICA & TSLV project flow model. This was seen as a way to deal with the unreliable equations and unexplainable gaps and shifts in the data. For example, there is an average 2.5 meter shift when the 1924 to 1965 and 1996 to 2003 Kampong Loung water level datasets are compared (Garsdal, 6.4.2004, personal communication). Because reference data and datum information is missing from the earlier period it is impossible to estimate whether the shift was caused by changes in gauge level or by the hydrological regime of the Mekong River. However, Nam (2000) found that the peak flood levels during the wet season are lower in the period from 1979 to1998 than from 1924 to 1963. Nam suggested that upstream dam building since the 1960s was responsible for the difference. This conclusion partly explains the differences in Kampong Loung data between 1924 and 1965 and between 1996 and 2002.

There are also other unexplained shifts in the original measured daily water level data (e.g. Figure 4). The MRCS has prepared a dataset (available in Hymos) with the datum level corrected to the mean sea level (MSL) at Ha Tien (Vietnam). For the later period (from 1997 to 2003) the correction for Kampong Loung is approximately +0.6 meters compared to measured water levels from 1996 to 2003. The MRCS/WUP-JICA & TSLV project model uses this corrected data as input data for their model.

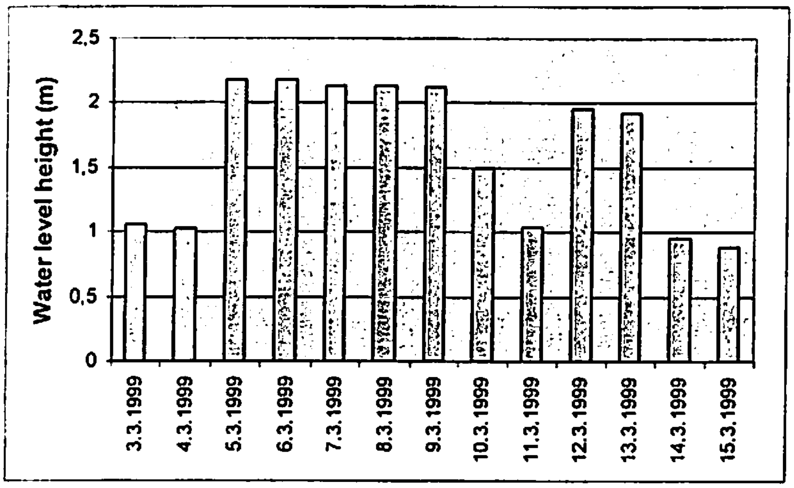

Figure 4 Daily water level shifts in Kampong Loung original measured data from the 3rd to the 15th of March, 1999.

The model data corresponds well to the use of the same dataset for discharge data from Mekong via Prek Kdam, overland flow and Tonle Sap tributaries runoff. The monthly maximum water levels for the period from 1985 to 2003 with related statistics are in annex 1.4.2. The differences in the monthly average water level between the original measured, the original data corrected with Ha Tien Mean Sea Level datum, and the simulated model output datasets can be seen in annex 1.4.3.

The water balance calculated by the MRCS/WUP-JICA & TSLV project (MRCS/WUP-JICA, 2004) is about 40% from Tonle Sap runoff, 50% from River inflow (flow coming from the Mekong River) and 10% from Overland flow. Detailed water balance calculations for the 1985 to 2003 period can be seen in Table 4. The water balance varies every year depending on the input from the Mekong (River inflow and Overland flow) on the one hand and Tonle Sap rainfall (Tonle Sap runoff) on the other. Generally, runoff from the tributaries has a much more significant contribution to the overall volume during dry years.

Table 4 Water balance for the Tonle Sap Lake from 1985 to 2003. Based on MRCS/WUP-JICA & TSLV Flow Reversal Project output data. Years identified by stakeholders as high flooding are marked in blue and low flooding years are marked in red.

Year	*Mekong*	*Overland*	*Tonle Sap runoff*
1985	57	9	34
1986	67	9	24
1987	61	8	31
1988	57	3	40
1989	40	3	56
1990	48	10	43
1991	38	11	51
1992	43	6	51
1993	53	5	42
1994	38	14	48
1995	45	9	46
1996	53	11	36
1997	54	15	30
1998	*47*	*3*	*50*
1999	48	9	43
2000	51	17	32
2001	52	15	33
2002	54	15	31
2003	56	8	36
Mean	51	9	40

2.3.6 Flood beginning and duration

The analysis of the flooding season from May to December was used to determine flood beginning and duration as this is the timeframe when flooding begins. The difference in daily water level was calculated and the results were visually analysed to find the exact date when the given threshold was breached (annex 1.5.1). The validation of the thresholding used to obtain this data is explained in chapter 3.2.4 with the corresponding results.

The third stakeholders consultation (Hort *et al.*, 2004) identified timing of flow reversal as one component that is important for flood beginning. Therefore, Flood beginning dates derived from data on daily and weekly water level differences were also compared with the dates of flow reversal at Prek Kdam. The other component identified was spillover (local flooding of floodplains), but this could not be defined in the available time and data as it is a function of the local topography and varies extensively over the whole area of the lake. The thresholds and parameters for Flood beginning are dealt with in detail in chapter 3.2.4. Due to copyright restrictions, data on daily Mekong discharge at Prek Kdam could not be presented in numerical format in this report.

Flood duration is determined by time span between Flood beginning and a set threshold for the end of the flooding. The same datasets were used to determine Flood duration as Flood beginning because they are so closely related. However, Flood duration can be defined in a number of ways depending on when and where one looks at in the floodplain. As discussed in the above section about water level, the differences in water level on the lake and floodplain can vary significantly. This of course affects the time span when a given area is flooded.

2.3.7 Flooded vegetation

The surface area for different vegetation types in the floodplain was used to determine Flooded vegetation node probabilities. Surface areas were calculated depending on the thresholds of the Tonle Sap water level node. The Certeza Survey (1964) 1 meter contour lines for the floodplain correspond to water level at Kampong Loung directly and therefore these contour lines were used to define the surface area flooded at determined water levels.

Major simplifications were required in order to combine the 39 classes of the JICA (1999) classification into the three identified as the main vegetation types during the second stakeholders consultation (Hort and Baran, 2004). The MRCS/WUP-FIN provided numerical data in which the original data had already been analysed and its accuracy tested (Keskinen and Huon, 2002). The original JICA land use classification is in annex 1.6.1. The percentages of *Grass* (JICA classifications 3-17), *Shrub* (JICA classifications 18-21) and *Forest* (JICA classifications 22-32) at 1 meter elevation intervals can be seen in Figure 5. The JICA land use classes 1-2 (*Urban*), 33-37 (*Water features*) and 38-39 (*Soil and rock*) were left out of this new classification used for the Bayesian fisheries model (annex 1.6.2).

The JICA (1999) land use map for the Tonle Sap floodplain is the latest available, and it has proven relatively accurate by recent field work (Hellsten *et al.*, 2003). The findings of recent Ministry of Public Works and Transport levelling work at the floodplain justify the use of elevation contour lines from the Certeza Survey (1964) to obtain vegetation cover areas from the JICA land use map. According to the Ministry of Public Works and Transport there are only small differences between the latest survey and the original Certeza survey (Huon, 5.4.2004, personal communication; Sarkkula, *et al.*, 2003). The spatial distribution of the three major land use classes used for the Bayesian Belief Network can be seen in Figure 6, and detailed maps of each of the land use classes can be seen separately in annex 1.6.3.

With regard to water quality, the flooded forest has the best dissolved oxygen levels of the three classes (MRCS/WUP-FIN). This fact is due to the location of the forest in the immediate vicinity of the lake as a narrow strip. Therefore, oxygen rich water from the open lake continuously flushes the flooded forest, which brings nutrients from the Mekong for biological primary production. On the other hand, shrub vegetation has low dissolved oxygen levels because water flow is restricted which reduces the flushing effect. Additionally, shrub vegetation produces the most organic material causing more decay, which in turn increases the Biological Oxygen Demand. However, the relationships between Biological Oxygen Demand and land use types have not been quantified and are still being studied. Only approximate best available values can be used to explain the relationships.

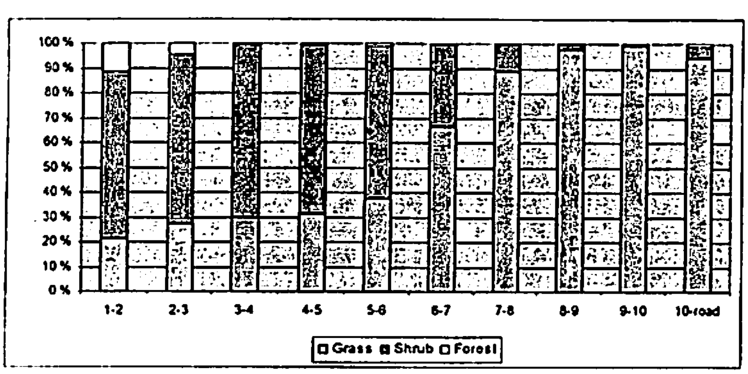

Figure 5 Percentages of Tonle Sap floodplain land use classes depending on elevation (in meters).

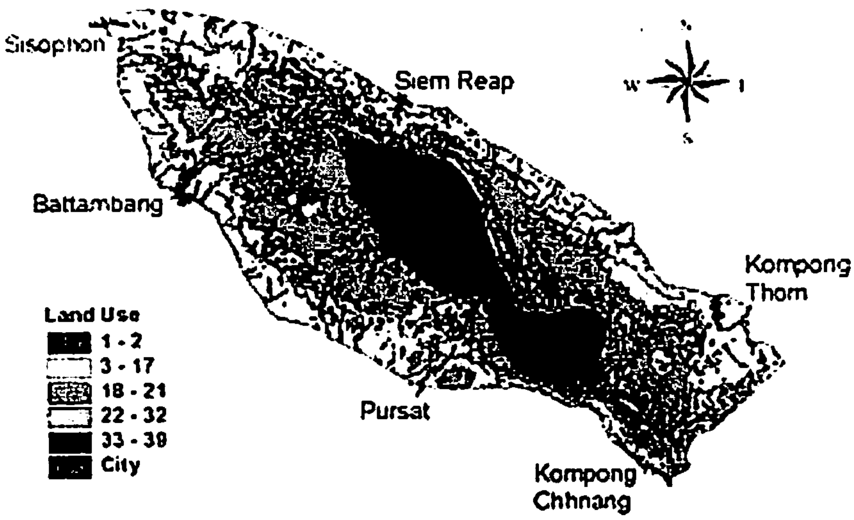

Figure 6 Distribution of selected land use classes in the Tonle Sap floodplain. JICA Land use classes 1-2 refer to *Urban*, 3-17 *Grass*, 18-21 *Shrub*, 22-32 *Forest* and 33-39 *Water feature, soil and rock.*

2.3.8 Dissolved Oxygen data

Only dissolved oxygen was chosen as an indicator of the quality of lake water because of its proven importance in fish production and because other chemical parameters could not be related to fish production (water quality for agricultural production is not considered in this Bayesian fisheries model). The relationship between sediment concentrations and fish production has been studied by the MRCS/WUP-FIN (Koponen *et al.*, 2003b), but definable links between the variables have not been established.

According to the MRCS/WUP-FIN, the lake water is well oxygenated because of wind and wave induced mixing. Also, during flooding, inundated areas are to a large extent anoxic (Koponen, 23.4.2004, personal communication; Koponen, *et al.*, 2003b). Naturally low oxygen concentrations are observed in the floodplain, where the decomposition of organic matter is responsible for high oxygen consumption (Koponen, *et al.*, 2003b). Overall, the organic material has largely decayed after the first 4 to 6 weeks a given area is flooded. However, strong flow caused by a rise in the water level of the lake can force the anoxic "bad" water further into the floodplain in the form of waves. Therefore, the dissolved oxygen levels decrease as the flood begins and then increase again around September or October (Figure 7), when the high water level effectively dilutes the anoxic waters and increases oxygen mixing on the water surface (at higher water levels more vegetation is completely covered by water, thereby exposing more open water surfaces for wind). When the flood recedes around November the anoxic waters from higher elevations flush through the floodplain causing severe anoxic conditions. This possibly causes the fish to begin their annual migration away from the Tonle Sap Lake (Sarkkula, 7.4.2004, personal communication).

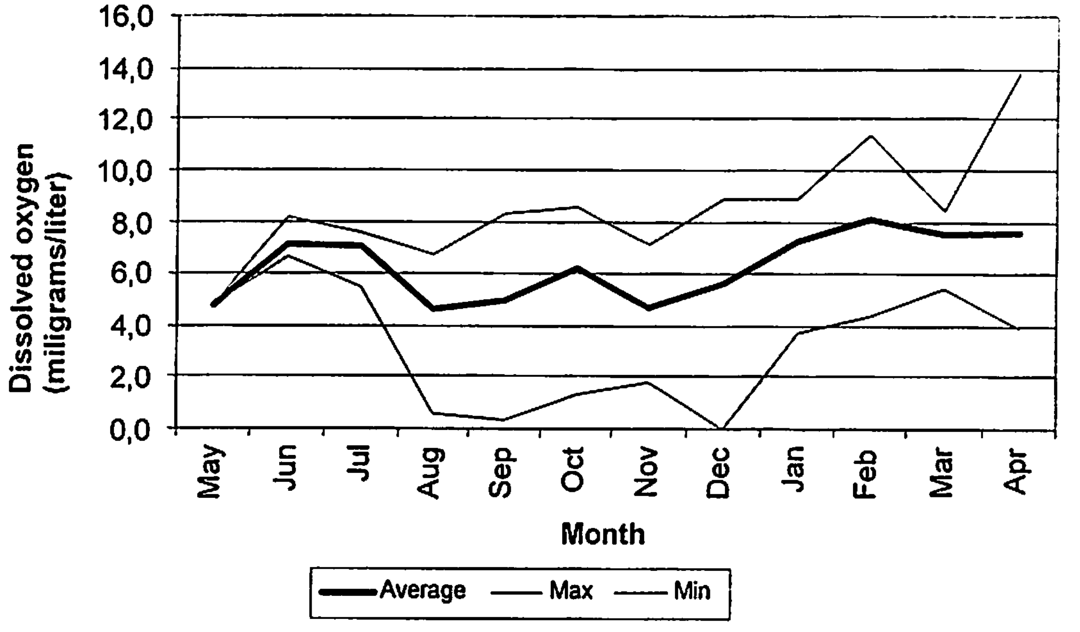

Figure 7 Dissolved oxygen levels for the 2000 and 2001 hydrological years (in milligrams per liter).

Analysis of the water quality data according to station, year and flood cycle was undertaken. The analysis showed that out of all the stations Phnom Krom 4 (PNK4) and 6, (PNK6) and Kampong Loung 3 (KGL3) had less than 10 samples each (annex 1.7). In addition, all these samples had been taken between August and January. Thus, they do not represent the dissolved oxygen levels at other times of the year. Subsequently, these stations were deleted from the dataset. After removing these three unsuitable stations the standard deviation for maximum and minimum values improved from 3.32mg/l and 1.71mg/l to 2.7mg/l and 0.95mg/l respectively. The other stations have between 45 and 136 samples each, which represent the sites adequately.

When analysing the data on the annual flood cycle (Table 5), it can be seen that there are only four samples for the 1998 to 1999 period (May and June). This is clearly not representative of the annual flood cycle, as can be seen from the much lower average and maximum dissolved oxygen levels. Therefore, this particular flood cycle was removed from the dataset. The flood cycles from 1995 to 2001 have 16 to 24 samples each, and the distribution of these groups of samples cover almost all parts of the flood cycle. Only the early flood samples for 1999 (May to August) are missing. There are 299 samples, on the other hand, for the 2001 to 2002 period due to the sampling programme by the MRCS/WUP-FIN project that commenced in July 2001. A particularly large number of samples are taken from various locations each month during a rising flood. Even though the sampling programme was scaled down in late 2002 the hydrological year from 2002 to 2003 still has a relatively large number of samples (114). The average dissolved oxygen level does not seem to vary radically between flood cycles even though the sample sizes are very different. On the other hand, the two extensively sampled flood cycles show a larger variance in the results (0 –to 15 milligrams per litre) compared to the earlier years with 16 to 24 samples per year (3 to 8 milligrams per litre). Nevertheless, such a small number of measurements taken at a limited number of locations are far from ideal or representative given that the Tonle Sap system is highly dynamic.

Even after removing all the years with insufficient data the data was not deemed representative enough to upscale to cover the situation within the entire floodplain. However, the MRCS/WUP-FIN water quality model deals with the upscaling issue efficiently by linking hydrological, chemical and biological processes. Therefore, the output data for the MRCS/WUP-FIN water quality model was used to investigate dissolved oxygen relationships according to water level and floodplain land use.

Table 5 Dissolved oxygen statistics according to hydrological year, 1995 to 2003 (milligrams per litre).

Water quality statistics	*Average*	*Max*	*Min*	*No of samples*
All	*6.0*	*16.5*	*0*	*500*
95-96	5.7	7.7	1.7	20
96-97	5.4	7.2	2.7	24
97-98	5.3	8.5	2.5	24
98-99	4.9	6.2	3.9	4
99-00	5.8	7.8	4.1	16
00-01	6.2	8.1	4.2	20
01-02	6.1	13.8	0	278
02-03	6.3	16.5	0.1	114

MRCS/WUP-FIN model takes into account a number of variables when computing the water columns dissolved oxygen levels. Decaying mainly takes place at the bottom, and this is taken into account, whereas the total biological oxygen demand of the water column is not taken into account. Wind induced mixing of oxygen is modelled and also the effect of vegetation (above water level) is considered.

In the model run for the output data for the Bayesian fisheries model a model grid cell was considered flooded when water level in the grid reaches 0.3m. For each of the different land use classes MRCS/WUP-FIN calculated the average surface area with a given Dissolved Oxygen level (3 different ones - < 2, 2-4 and > 4 mg/l) out of the total surface area of that land use class at a given time unit. The final percentage was the average over all time units. I.e. floodplain is divided into three land use types with the aim to find out how large percentage of each of these land use types in one hydrological year (average) has Dissolved Oxygen of less than 2, between 2-4 and more than 4 (data request format can be seen in table 6). The land use classes used for the modelling exercise were Grass (JICA land use classes 3-17), Shrub (JICA land use classes 18-21) and Forest (JICA land use classes 22-32). The use of the model capable of presenting the whole lake at the same time rather than point measurements improves this part of the Bayesian model significantly.

Table 6 Format of requested DO data from MRCS/WUP-FIN.

DO Mg/l	*Grass (%)*	*Shrub (%)*	*Forest (%)*
Less than 2			
2-4			
More than 4			

Summary data of modelled years used by the MRCS/WUP-FIN water quality model to produce Dissolved Oxygen output data for the Bayesian model can be seen in table 7. Year 1997 represented a normal flood (in the model "From 8 to 10" meter flood), whereas 1998 represented a low (in the model "Below 8" meter flood) and 2000 a high flood (in the model "Above 10" meter flood).

Table 7 Summary of flooded year 1997, 19998 and 2000 used for MRCS/WUP-FIN model runs.

Year	*1997*	*1998*	*2000*
Flood type	Normal	Low	High
Average total flooded area	5726	3712	7491
Average grass land area	1945	1185	2893
Average shrub land area	3621	2382	4429
Average forest land area	160	145	169

The results from the MRCS/WUP-FIN modelling exercise are presented in a summary (used for the model input) in table 8, and completely in annex table 25. The output data included three depths, surface, middle and bottom, as well as an average over all of them. Because the fish can migrate from one layer to another, it was decided to use the average to describe the situation in the whole lake (table 8).

Table 8 Format of requested DO data from MRCS/WUP-FIN.

		Percentage of Dissolved Oxygen levels			
Year	*Vegetation*	*< 2 (mg/l)*	*2-4 (mg/l)*	*> 4 (mg/l)*	*Sum*
	Grass	60	25	15	100
2000	Shrub	69	24	7	100
	Forest	32	53	15	100
	Grass	51	28	21	100
1997	Shrub	65	20	15	100
	Forest	27	37	36	100
	Grass	54	21	25	100
1998	Shrub	72	16	12	100
	Forest	37	29	34	100

2.3.9 Built structures

Built structures consist in a diversity of constructions or items set up by man, which contribute to changing the hydrology of a natural system. Built structures can consist of constructions that (i) oppose water outflow (e.g., dams, weirs, irrigation schemes, dykes, levees); (ii) prevent water inflow (e.g. embankments, polders, flood control works); or (iii) alter water inflow or outflow (e.g., roads, railways, drainage canals, diversion structures, agricultural works[1], banks and flows modifications[2])

The Built structures effect on Flood level was not defined in detail in the second stakeholders consultation (Hort and Baran, 2004). Through the data collection effort it was learnt that the only available sources for possibly determining the aerial extent and hence importance of Built structures are the Hydrographic Atlas (by MRCS, 1998), road network (by JICA, 1999) and Certeza Survey contour lines of the floodplain (1964). The Hydrographic Atlas is only in numerical form and there are no Hydrographic Atlas Geographical Information Systems layers available at this time. In addition, the Atlas only covers the dry season lake and the Tonle Sap River. The National Roads 5 and 6 are the upper limit of the floodplain and are very rarely overflow by floodwaters (overflow requires more than 11 meters water level height at Kampong Loung). There are a number of roads from the National Roads towards the lake, but there is no data regarding their elevation. Often they get flooded at the same time as the surrounding floodplain, so the flood movement is virtually unrestricted. The Certeza Survey (1964) contour lines are at 1 meter elevation intervals making it impossible to identify any levees or built structures from the contour maps.

There are no data directly available on levees, barriers or other structures situated in the Tonle Sap floodplain because they have never been measured or

[1] such as rice field dikes

[2] such as the Chaktomuk peninsula development works and, in the case of the Tonle Sap Great Lake, fishing gears that are set on a massive scale, altering hydrological flows and obstructing fish movements

surveyed (Huon, 5.4.2004, personal communication; Ith, 7.4.2004, personal communication). In addition, the floodplain is very flat and does not seem to affect the relationship between water level and flood surface area (Figure 8). However, the built structures have a significant effect on overland flow from the Mekong to the Tonle Sap (Garsdal, 6.4.2004, personal communication). The overland flow commences when the Mekong discharge at Kampong Cham exceed 30,000 m^3/s. The effect of overland flow on the transport of larvae and migration of fish is not known.

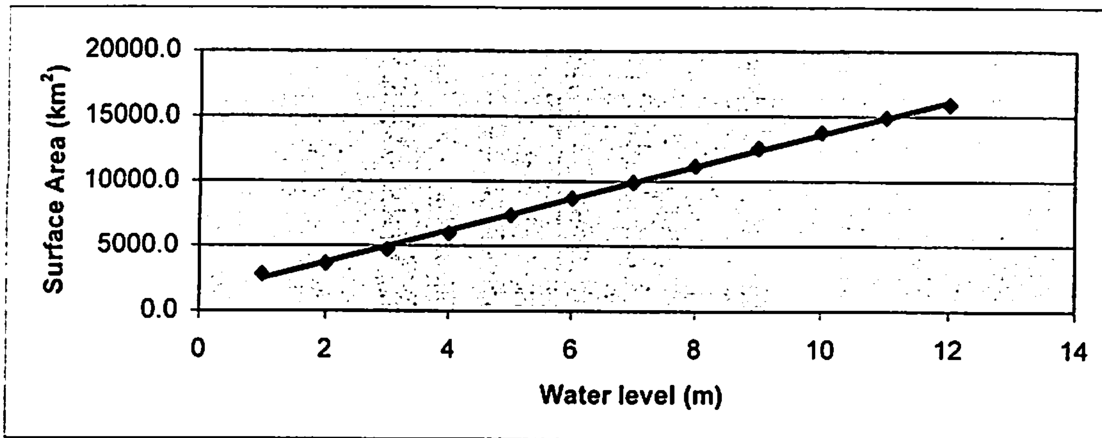

Figure 8 Certeza Survey based Triangulated Irregular Network (TIN) water levels plotted against lake surface areas with an added trendline (S_{lake}) y = 1880.4x + 1859.8 with R^2 = 0.9856 (Jantunen, 2001).

For the ADB Built Structures project definition in the model was crucial. However, available data only consisted of JICA (1999) road network. The data does not contain information of the height of these roads compared to the elevation of the floodplain. Smaller roads could not be taken into the analysis as this information was missing. In addition, roads perpendicular to the contour lines of the floodplain are flooded from both sides at the same time; hence the roads are not opposing flow. Also these roads have many bridges and culverts. Therefore it was decided to use the differences between the surface areas of each elevation category and surface area limited by the national roads 5 and 6 to determine the probabilities of the Built Structures node. Elevations used were 8 m contour, 10 m contour and 12 m contour. 12 m contour represents the total catchment area. Certeza Survey (1964) contours were used to create the polygons for each elevation category and JICA 1999 road layer was used to generate the polygon covering the area between the national roads 5 and 6. Each elevation polygon was clipped using the road polygon as a clipping layer to obtain the areas of elevation categories limited by the roads (Figure 9). The analysis assumes the national roads 5 and 6 being definite barriers to water flow and particularly to fish movements, which is based on stakeholders consultation that revealed all culverts and bridges are used by locals for fishing, hence practically catching all fish trying to pass through.

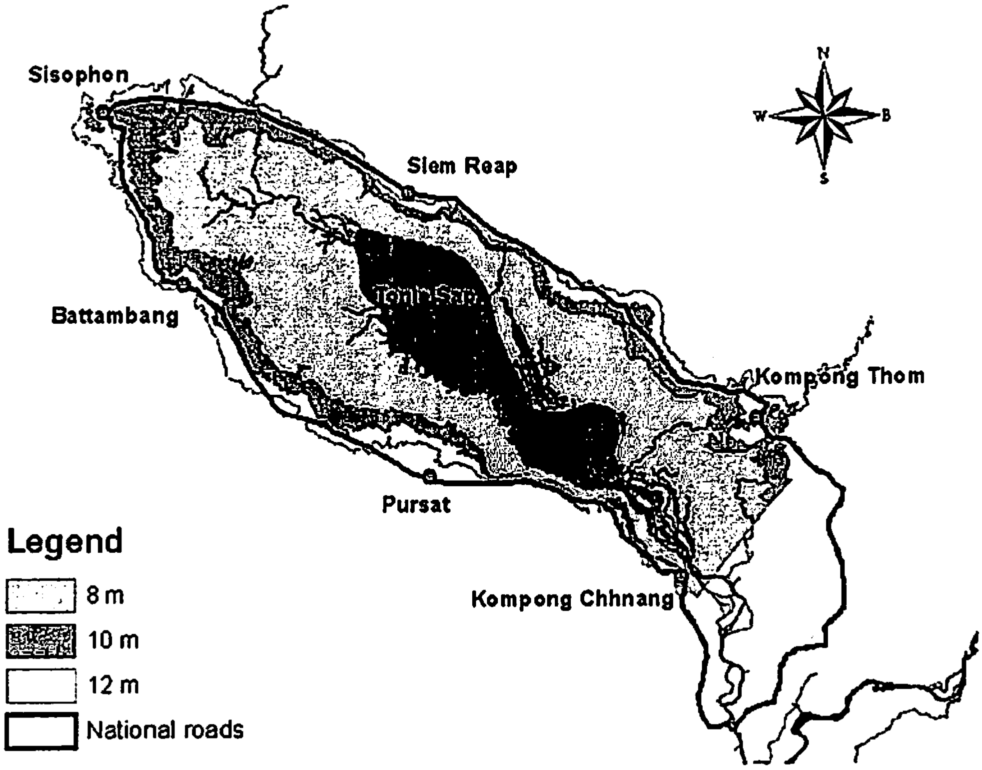

Figure 9: Elevation categories and the national roads 5 and 6

2.3.10 Floodplain refuges

JICA (1999) lake and river layer contains data about the temporal and perennial ponds. Temporal ponds dry up at some point, hence not providing refuge for the fishes, whereas perennial ones have water all year round. This data was used to determine the probabilities of the Floodplain refuges node. Total area of the ponds was obtained and probabilities of each type of pond from the total area was calculated. Areas and probabilities can be seen in table 9. In Cambodia only insignificant area is irrigated to provide three crops per year, hence having water in the canals and partly on the fields all year round. Floodplain refuges node defines that any pond or refuge that is drained or dries up during the year is not a refuge. Therefore canals that dry up are not refuges either. Therefore irrigation canals were not accounted as a floodplain refuge and idea of having them represented as a separate node was dropped.

Table 9: Areas and percentages of perennial and temporal ponds.

Ponds	Perennial	Temporal	Total
Area (km2)	237.04	86.65	323.68

% of total	73.23	26.77	

2.3.11 Pressure from large scale fishery

Probabilities for the Pressure from LS fishery node are derived from the MRC fishing lot data. The border fences of the Lots that are facing either a river or the lake were digitized from each Lot and the existing and dismantled Lots were identified. Probabilities for the states were then calculated by comparing the length of the digitized Lot boundaries to the periphery of the lake. In case where the Lot fences also border a river the length of the river up to the Lot boundary was also added to the periphery of the lake. The existing lots are assumed to be 100% effective and dismantled lots are assumed to be 50% effective. Lots and digitized boundaries can be seen in figure 10.

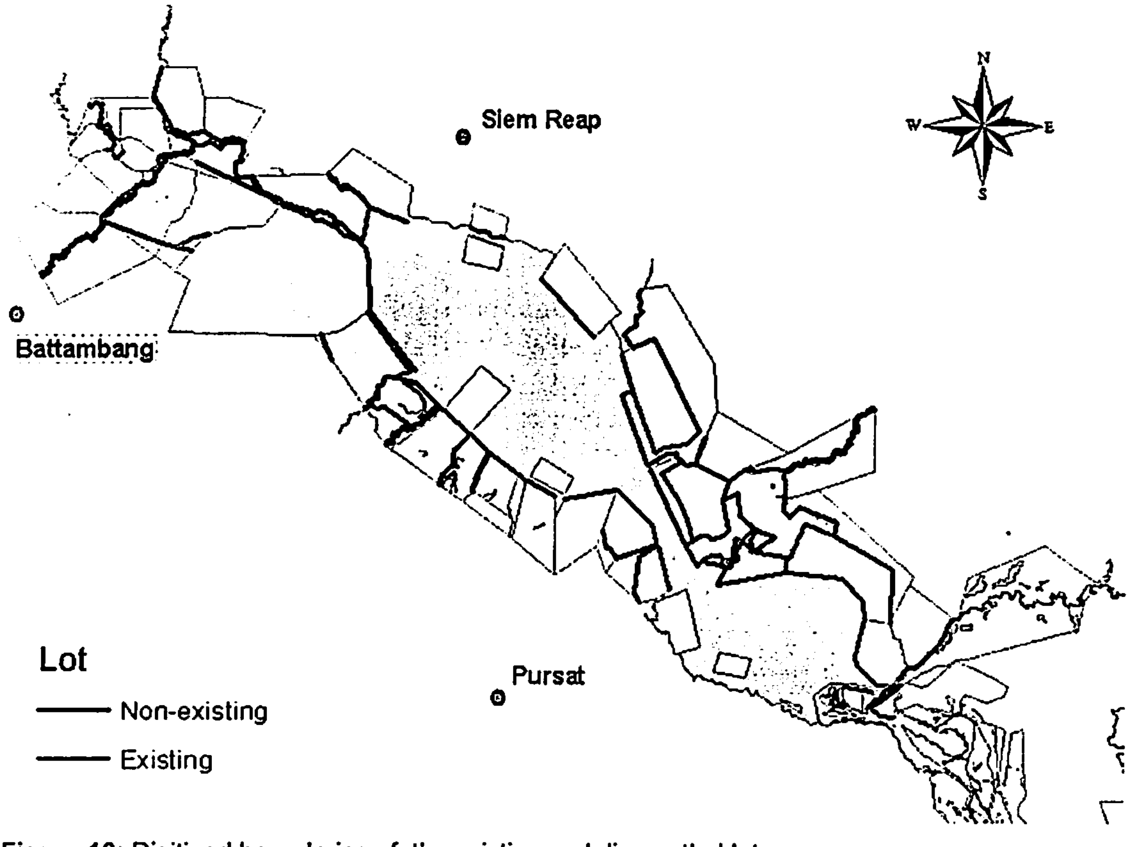

Figure 10: Digitized boundaries of the existing and dismantled lots

Existing lots	Km	409
Dismantled lots (total length divided by 2)	Km	298
Periphery of the lake	Km	1189
Percentage	%	59

Table 10: Lengths of the lot boundaries facing the lake and the percentage of lot boundaries from periphery of the lake.

3 Data input, parameters and thresholds

3.1 Netica model parameter and threshold options

The Tonle Sap fish model developed during the stakeholders consultations (Hort *et al.*, 2004) is easy to use and both parameters and thresholds are easily changed after the data has been analysed, edited and formatted for the model requirements. Example of a Netica Bayesian model can be seen in Figure 9. Parent nodes (PN1 and PN2) are connected via links to child node (CN). The probabilities of the states for each node have been derived from their respective probability table. The number of states can be as many as required, but the more states are present the more complicated the child node probability tables will become. Three states per node could be seen as the upper limit, but it could be higher or lower depending on the structure of the network. Therefore, it depends on how many parent nodes are linked into a child node (the combined size of the probability table of a child node).

A threshold for a state (or parameter) can be defined either as "discrete" or "continuous". When the variable is "discrete" or discontinuous, the state of the node is simply selected (e.g. *Yes* or *No*, *Good* or *Bad*), whereas when the variable is "continuous" a precise numerical values are used. The probability table defines the likelihood of each state if findings are not entered in terms of data. There is no need to fill in the probability tables if a case file with data is incorporated. Data will only fill in all combinations of parent node states if the data also contains all of these combinations. Therefore, the number of states should be as few as possible and probability tables simple. In this Bayesian fisheries model, the nodes Flood beginning, Flood duration and Flooded vegetation are discrete and all others are continuous. For more information about the options and about using Netica, see the Netica User Manual (Norsys), which is also available online at www.norsys.com.

Setting up the exact thresholds and states is absolutely essential in the Bayesian model. The parent node states will directly affect the child nodes. Incompatible or impossible combinations (in nature) can be left out of the probability calculations by marking them with "x" in the corresponding probability table.

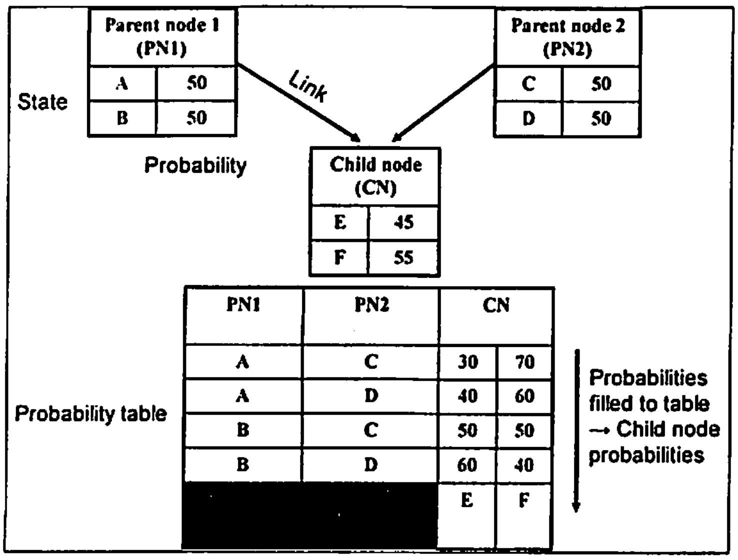

Figure 11 Example Diagram of a Netica Bayesian Belief Network model, terms used and structure of the probability table.

3.2 Input of data to model

After the initial model was reviewed, a number of precise questions were raised at the stakeholders consultation on the 9th of April, 2004. . The purpose of these questions was to find thresholds for the nodes and to gather information about and justifications for the relationships between the nodes. The results from the stakeholders consultation were incorporated into the model wherever possible. However, some of the thresholds defined by the stakeholders could not be used due to differences in the data ranges and datasets.

Data was entered into the Bayesian model by importing data as a text file with values in textual and numerical form (the command in Netica: *Relation/Incorp Case File*). This ensures optimal data accuracy because the model will directly calculate the probabilities from the data. Also, changing the parameterisation and thresholds then becomes much easier. For an example of an input file see Table 10. A series of input files was created in order to assess the suitability of slightly different datasets for modelling purpose. The comparisons can be seen in annex 1.9. The differences within nodes are small, but a better picture of the differences can be obtained after the next stakeholders consultation because parameters and thresholds for the nodes are still largely to be set by the stakeholders.

The same input file must be used for all data on connected nodes. Otherwise, Netica will not automatically calculate the probabilities for the probability table. For example, Tonle Sap rainfall, Tonle Sap runoff, Rived inflow, Overland flow and Tonle Sap water level have to be in the same input file (as well as

Floodplain dissolved oxygen). The Flooded vegetation node probability table is filled in manually.

Table 10 Example of the input file format. Code (// ~->[CASE-1]->~) is required by the software in order to identify the file as an input file for probabilities.

```
// ~->[CASE-1]->~
// Hydrology input file 2.3 (27.4.2004 - operator Teemu Jantunen)
IDnum     PK_Flow    TSRainfall    Water_level    Flood_duration
1991      35561      *             9.9            Shorter
1992      26758      *             8.3            Shorter
1993      33704      *             8.2            Shorter
1994      36535      *             10.4           Shorter
1995      39309      1597          9.6            Shorter
1996      43910      1389          9.5            Longer
1997      40897      1047          9.1            Shorter
1998      22110      1304          7.1            Shorter
1999      35718      1400          9.0            Longer
2000      49772      1345          10.3           Longer
2001      48488      1342          10.0           Longer
2002      49466      1311          10.2           Longer
2003      33753      979           8.4            Longer
```

3.1.1 Tonle Sap Rainfall

As can be seen from the data the driest months are December to February with average total rainfall only 56 to 113 millimetres per month (annex 1.2). March and April are relatively dry, but also can have quite high levels of precipitation due to convective rainstorms (also called mango rains). However, these rains have a very limited impact on the water level of the Tonle Sap. Standard deviation is the highest for the period of August to November showing that the main variability in total precipitation per hydrological year comes from the rainiest months (August to October). Because of the importance of rainy season precipitation to flood level as well as to the total variation in hydrological year precipitation levels it was decided to use data from rainy months only (June to December).

The third stakeholders consultation recognised 1996, 2000, 2001 and 2002 as years with high rainfall and flooding (Hort, *et al.*, 2004). This is largely true (Figure 1), but precipitation in year 2002 was almost the same as in 1998, which is also the lowest flooding year in the records. Therefore, it was decided to use two states for the Tonle Sap rainfall node in the Bayesian model, *Above 1000 mm* and *Below 1000 mm* (average rainfall over records). In addition, an input file for the whole rainfall data was prepared even though the reliability of pre-1996 rainfall data is questionable. These thresholds were agreed upon in the fourth stakeholders consultation (Baran, 2004).

3.1.2 Tonle Sap Runoff, Mekong flow and Overland flow

The relationship between Tonle Sap runoff, River inflow and Overland flow discharges (Figure 10) was analysed and tested statistically. As can be seen from the figure Mekong flow and overland flow correlate with each other quite closely. The statistical Pearson correlation R^2 = 0.826 between the variables is reasonably high. There are exceptions, though. For example, overland flow is much higher than average and Mekong flow lower than average in 1994 (Table 2). Similarly, 1995 Mekong flow is above average when overland flow is below average. Runoff does not correlate with overland flow (R^2 = 0.365), and neither do runoff and Mekong flow (R^2 = 0.018). The relationship between water level at Kampong Loung and the combined discharge of Mekong flow, overland flow and runoff (Figure 11) correlate very strongly (R^2 = 0.987).

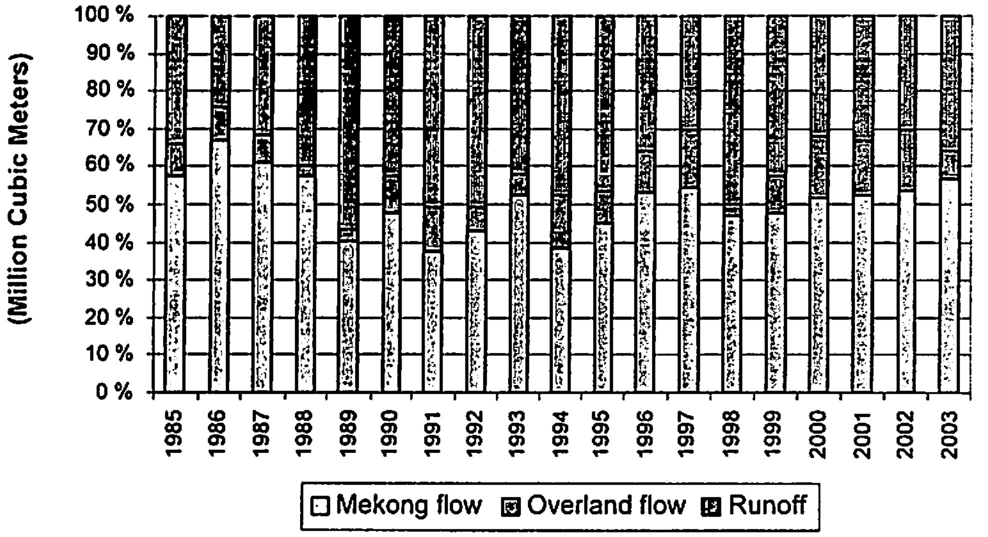

Figure 12 Comparison between total rainy season discharge shares of Mekong flow, Overland flow and Runoff (Tonle Sap).

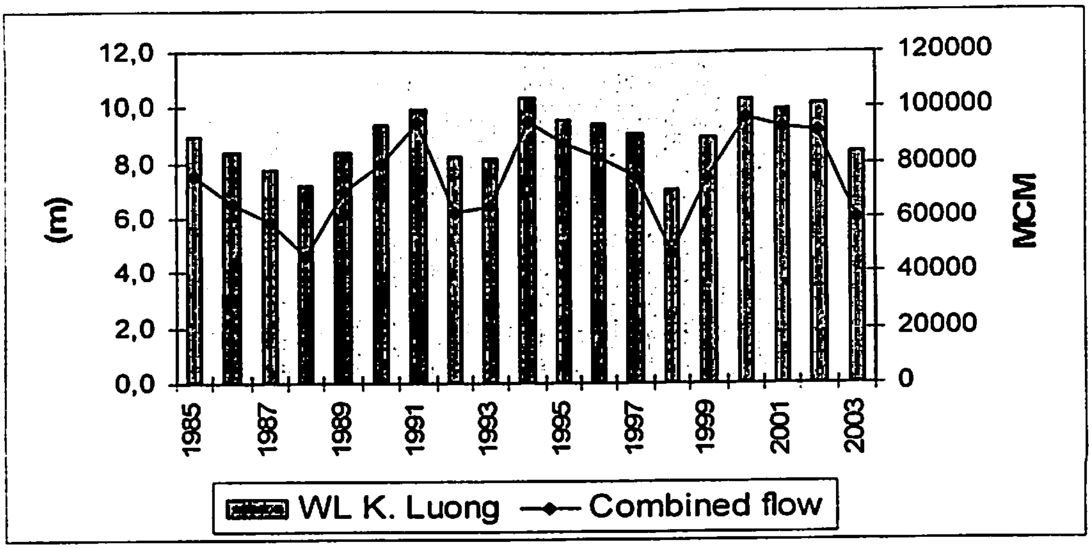

Figure 13 Comparison between combined discharge into the Tonle Sap Lake from River inflow, Overland flow and Runoff, and Tonle Sap water level at K. Loung.

At first a threshold for discharges and runoff with a 1/5 return period (see annex 1.8) was used to determine the extreme parameters of the node (*High* and *Low*) because these parameters correspond with the high flood years (1996, 2000, 2001 and 2002) identified in the third stakeholders consultation (Hort, *et al.*, 2004). Also, the 1998 dry hydrological year supports the *Low* parameter (see Table 2). However, because the *Medium* parameter is required (otherwise, it is not present at all in the Tonle Sap water level node) the probability table expands close to an unmanageable size and also introduces an impossibility factor: it is physically impossible (in the Tonle Sap system) for the River inflow discharge to be *High* and Overland flow discharge to be *Low*, because these two nodes are interlinked (i.e. high discharge at Prek Kdam is caused by high water levels on the Mekong, which also causes high overland flow). When these combinations are included in the probability table they distort the ultimate probabilities of the child node (Tonle Sap water level) therefore reducing the accuracy and reliability of the model.

In order to test the model framework and overcome these problems it was decided to simplify the parameters. A method used was to select only two parameters for each node, *Above mean* (average) and *Below mean*. As discussed above it is possible to have River inflow as *Above mean* and Overland flow as *Below mean*. In addition, this reduces the size of the probability table in Tonle Sap water level and therefore strengthens the probabilities. These thresholds were agreed upon in the fourth stakeholders consultation (Baran, 2004).

3.1.3 Tonle Sap water level

In the second stakeholders consultation, the thresholds for Water level at K. Chhnang were set as *Above 11m*, *Between 10 to 11m* and *Below 10m* (Hort and Baran, 2004). However, it was decided to use Kampong Loung as a reference water level for the lake, and therefore these thresholds are no longer valid. The average difference between Kampong Chhnang and Kampong Loung is +25 centimeters (Garsdal, personal communication). However, changing *Above 11m* to *Above 10.75m* is futile, because in the records used the water level has never reached 10.75 meters at Kampong Loung. Therefore, it was decided to change the thresholds into *Above 9m* and *Below 9m* (average maximum water level at Kampong Loung on record). The frequency distribution of the water level at Kampong Loung can be seen in annex 1.8. The parameters and thresholds were finally defined more precisely in the fourth stakeholders consultation (Baran, 2004). The states agreed upon are *Above 10m*, *From 8 to 10m* and *Below 8m*. These correspond well with stakeholders's expert views about the functioning of the Tonle Sap system and the response in fish and agricultural production.

3.1.4 Flood beginning and duration

The third stakeholders consultation set the threshold for Flood beginning to a 10 centimetre daily increase in the water level at Kampong Chhnang (Hort, *et al.*, 2004). In the interpretation of the daily water level difference values, it was also checked that the water level continued rising after this threshold was reached (annex 1.5.1). On many occasions the water level actually dropped significantly after the threshold was reached. In these cases, the threshold was set after a steady rise in the following months could be seen. For the end of the flooding, it was decided to use the first negative value (receding flood), because the threshold set in the third stakeholders consultation (receding less than 2 to 5 centimetres per day) in most cases took place around February (Hort, *et al.*, 2004). This extended the duration of the flood too long (approximately 6 months) compared to the duration set in the second stakeholders consultation (Hort and Baran, 2004) of *Long* (over 13 weeks), *Medium* (5 to 13 weeks) and *Short* (less than 5 weeks).

At Prek Kdam the flow towards the Tonle Sap Lake can reverse several times in a short period of time due to the delicate balance between Mekong flow, overland flow and water level at the lake. In order to define only one moment in time at which the flow reverses at Prek Kdam a threshold of 1000m^3/s was used. The threshold eliminated most of the numerous minor reversals back and forth in the May to June period. The end of the reversal is very sharp and therefore the first negative value could be used.

By analysing the results (Table 11) of a comparison between the three different methods of determining Flood beginning and Flood duration nodes, it was decided to use flow reversal at Prek Kdam as the data for the Bayesian model. The original data for flow reversal (MIKE11 output) seems to be the most reliable, the time series the longest, and the results (for Flood duration) closest when taking into account what stakeholders decided in the second consultation (Hort and Baran, 2004). However, input files for the Bayesian model with daily values and averaged weekly values has also been prepared for comparison purposes. For Flood beginning and Flood duration the parameters were changed into *Below* and *Above* average. The average value depends on the dataset used (Table 11).

Table 11 Flood beginning and duration derived from weekly averages of daily water level difference data, directly from daily difference data and flow reversal dates from Prek Kdam discharge data.

	Kampong Chhnang						Prek Kdam		
Data	Weekly averages			Daily differences			Flow reversal		
Year	*Beginning*	*End*	*Duration*	*Beginning*	*End*	*Duration*	*Beginning*	*End*	*Duration*
1985							19-Jun	27-Sep	14
1986							23-May	21-Sep	13
1987							22-Jun	5-Oct	15
1988							7-Jun	22-Sep	15
1989							17-Jun	22-Sep	14
1990							8-Jun	16-Sep	14
1991							30-Jun	17-Sep	11
1992							24-Jun	17-Sep	12
1993							2-Jul	26-Sep	12
1994	6-Jun	10-Oct	18	23-May	9-Oct	22	11-Jun	15-Sep	14
1995	1-Aug	24-Oct	12	10-Jun	18-Oct	19	21-Jun	25-Sep	14
1996	11-Jul	17-Oct	14	3-Jun	16-Oct	19	26-Jun	9-Oct	15
1997	27-Jun	10-Oct	15	24-Jun	10-Oct	15	1-Jul	21-Sep	12
1998							6-Jul	3-Oct	13
1999	30-May	10-Oct	19	15-May	9-Oct	21	31-May	4-Oct	18
2000	16-May	26-Sep	19	17-May	27-Sep	19	23-May	22-Sep	17
2001	30-May	10-Oct	19	17-May	1-Oct	20	5-Jun	21-Sep	15
2002	13-Jun	3-Oct	16	24-May	4-Oct	19	10-Jun	27-Sep	15
2003							5-Jun	4-Oct	17
	Beginning	*End*	*Duration*	*Beginning*	*End*	*Duration*	*Beginning*	*End*	*Duration*
Mean	17-Jun	10-Oct	16.5	28-May	8-Oct	19.25	15-Jun	25-Sep	14.20
Max	1-Aug	24-Oct	19	24-Jun	18-Oct	22	6-Jul	9-Oct	18
Min	16-May	26-Sep	12	15-May	27-Sep	15	23-May	15-Sep	11
St Dev	25.4	8.4	2.7	14.1	7.1	2.1	12.9	7.1	1.8

In the fourth stakeholders consultation Flood beginning and Flood duration parameters and states were defined more clearly (Baran, 2004). The thresholds suggested in the third stakeholders consultation did not fit with the data used. Therefore, it was decided to use water spilling onto the floodplain as a threshold for Flood beginning. However, the natural levee around the lake (Koponen *et al.*, 2003b) is not visible in the Certeza Survey (1964) contour lines, and this part of the floodplain was not included in the Hydrographic Atlas (1998) bathymetric survey of the lake. On the other hand, the MRCS/WUP-FIN undertook some depth measurements between the open lake and the floodplains. Unfortunately, this data was not available in time for this report, but it should be included in the future. Thus, another method had to be used to extract thresholds for the Flood beginning node. In the fourth stakeholders consultation it was agreed that an early flood is *Before 15 July*, a medium flood *Around 1 August*, and a late flood *After 15 August*. The water level at Kampong Loung for these dates and for each hydrological year was checked (Table 12). A threshold of four meters for flood beginning was chosen. When water level at Kampong Loung is 4 meters, the level at Snoc Trou (Northwest end of the lake) approximately 3 meters, and at Kampong Chhnang approximately 5 meters (Eloheimo *et al.*, 2002a). Thus, years regarded as late flood (1998) and early flood (2000 to 2002) coincide with the states derived from data.

Table 12 Flood beginning and Flood duration states used for Bayesian model input based on stakeholders consultation and water level data from Kampong Loung and discharge at Prek Kdam. 4 meter threshold used to mark the beginning of flooding. Flood duration calculated from timespan between Flood beginning and flow reversal in the Tonle Sap River at Prek Kdam towards the Mekong.

	Flood beginning			
Year	*15 July*	*1 August*	*15 August*	*Bayesian Belief Network state*
1985	4.7	5.3	6.3	Before_mid_July
1986	3.9	4.9	5.9	Mid_July_to_mid_Aug
1987	2.9	3.9	4.2	After_mid_August
1988	2.8	3.7	4.7	After_mid_August
1989	3.2	4.4	5.7	Mid_July_to_mid_Aug
1990	5.1	6.0	6.9	Before_mid_July
1991	3.7	5.2	6.3	Mid_July_to_mid_Aug
1992	2.8	4.0	5.3	Mid_July_to_mid_Aug
1993	3.4	4.9	5.7	Mid_July_to_mid_Aug
1994	5.2	6.7	8.0	Before_mid_July
1995	3.3	4.7	6.0	Mid_July_to_mid_Aug
1996	2.9	4.2	5.6	Mid_July_to_mid_Aug
1997	2.9	4.9	6.7	Mid_July_to_mid_Aug
1998	2.9	3.8	4.3	After_mid_August
1999	5.0	5.8	7.1	Before_mid_July
2000	5.7	7.4	8.3	Before_mid_July
2001	5.1	6.2	7.1	Before_mid_July
2002	4.8	6.0	7.0	Before_mid_July
2003	3.5	4.3	5.2	Mid_July_to_mid_Aug
	Flood duration			
Year	*Flow reversal*	*Days*	*Weeks*	*Bayesian Belief Network state*
1985	27-Sep	74	11	More_11_weeks
1986	21-Sep	51	7	Around_8_weeks
1987	5-Oct	51	7	Around_8_weeks
1988	22-Sep	38	5	Less_6_weeks
1989	22-Sep	52	7	Around_8_weeks
1990	16-Sep	63	9	Around_8_weeks
1991	17-Sep	47	7	Around_8_weeks
1992	17-Sep	47	7	Around_8_weeks
1993	26-Sep	56	8	Around_8_weeks
1994	15-Sep	62	9	Around_8_weeks
1995	25-Sep	55	8	Around_8_weeks
1996	9-Oct	69	10	Around_8_weeks
1997	21-Sep	51	7	Around_8_weeks
1998	3-Oct	49	7	Around_8_weeks
1999	4-Oct	81	12	More_11_weeks
2000	22-Sep	69	10	Around_8_weeks

2001	21-Sep	68	10	Around_8_weeks
2002	27-Sep	74	11	More_11_weeks
2003	4-Oct	64	9	Around_8_weeks

The fourth stakeholders consultation decided that flooding ends when flow reverses in the Tonle Sap River at Prek Kdam (Baran, 2004). This data was used with the three different flood beginning dates to calculate flood duration (Table 12). The states had to be changed slightly in order to accommodate both the data and stakeholders views. None of the floods were longer than 13 weeks or less than 5 weeks as noted in the third stakeholders consultation (Hort and Baran, 2004). Therefore, states *Less 6 weeks*, *Around 8 weeks* and *More 11 weeks* were used for Flood duration node.

The values are somewhat vague and should be defined more precisely in the future. However, there was much uncertainty and disagreement about how to define both Flood beginning and Flood duration, because these terms mean very different things to people depending on occupation, spatial and temporal distribution, etc.

3.1.5 Floodplain vegetation

Percentages of the land use classes (*Forest*, *Shrub* and *Grass*) were first calculated from the data for 1 meter to 9 meter elevation and 1 meter to National Road. The 9 meter contour line of the Certeza Survey (1964) quite accurately corresponds with the 9 meter water level at Kampong Loung. In the fourth stakeholders consultation states for Tonle Sap water level were changed and therefore new percentages were calculated for Flooded vegetation. These can be seen in Table 13. The percentages were manually filled into the probability table.

Table 13 Percentages of land use classes used for the BBN model.

Land use	*Grass*	*Shrub*	*Forest*
1-8	43.9	53.7	2.4
1-10	55.8	42.3	1.9
1-road	60.8	37.4	1.8

3.1.6 Floodplain dissolved oxygen

Hellsten *et al.* (2003) conducted a study on habitats in the floodplain. According to them flooded forest, flooded shrubs, grassland and aquatic vegetation grow largely on organic deposits of up to 6 meters elevation (Certeza Survey contour lines, 1964). This would suggest that there is more decay in these areas than in others. However, the parameters and thresholds have to be set from the combination of Tonle Sap water level and Flooded vegetation. As mentioned earlier, the higher the flood the more dilution of anoxic water and mixing of oxygen into the water take place. Flooded vegetation on the other hand has direct relation to the quantity of anoxic water produced by decaying vegetation. The MRCS/WUP-FIN water quality model produced output data on the relationship between dissolved oxygen and floodplain vegetation type.

The results give percentages of the average time over the flooding season for dissolved oxygen levels in three categories; *Above 4mg/l*, *From 2 to 4mg/l* and *Below 2mg/l*. These categories were determined from literature and by interviewing aquaculture experts. They relate to conditions which are tolerable or intolerable for general black and white fish categories. The model was run with 1997, 1998 and 2000, of which 1998 was a low flood, 1997 average flood and 2000 high flood. Therefore probabilities could be connected with Tonle Sap water level node directly as the sample years relate with the states of the water level node. Results and input data for the Bayesian model can be seen in table 14 below.

Table 14 MRCS/WUP-FIN output percentages for dissolved oxygen levels in the floodplain detailed per year (different flood height), land use and dissolved oxygen concentration.

Water level	Land use	< 2	2 - 4	> 4
Below 8m flood (1998)	grass	54	21	25
	shrub	72	17	12
	forest	37	29	34
From 8 to 10m flood (1997)	grass	51	28	21
	shrub	65	20	15
	forest	27	37	37
Above 10m flood (2000)	grass	60	25	15
	shrub	69	24	7
	forest	32	53	15

The MRCS/WUP-FIN model produced percentages for near bottom, middle and surface depths of the water column as well as an average. Because the fish tend to move and migrate away from anoxic areas, and therefore no single depth is more important than the others, it was decided to use the average of the water column for Floodplain dissolved oxygen node probabilities. An example of the depth distribution can be seen in figures 12-14 below.

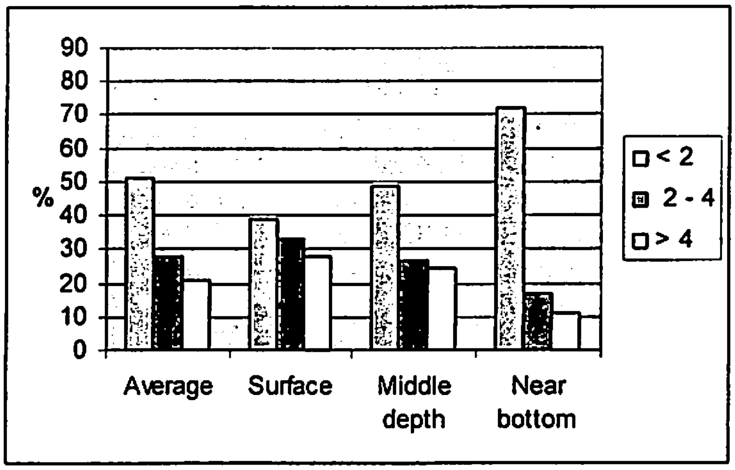

Figure 12 Comparison between 1997 *Grass* area dissolved oxygen levels at different depths for Below 2mg/l, From 2 to 4 mg/l and Above 4mg/l dissolved oxygen level categories.

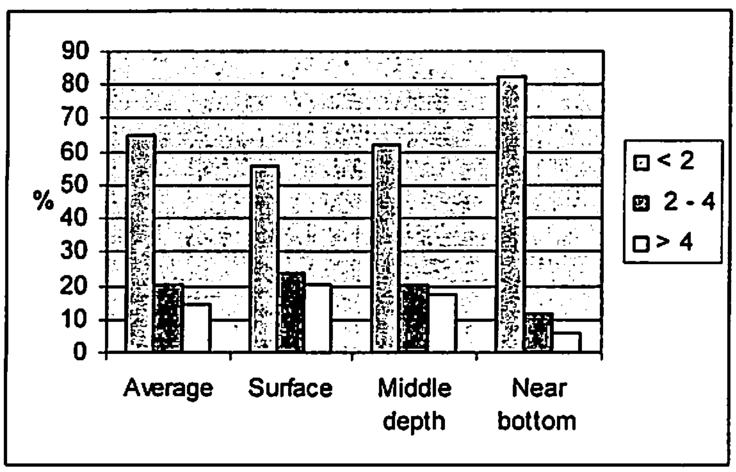

Figure 13 Comparison between 1997 *Shrub* area dissolved oxygen levels at different depths for Below 2mg/l, From 2 to 4 mg/l and Above 4mg/l dissolved oxygen level categories.

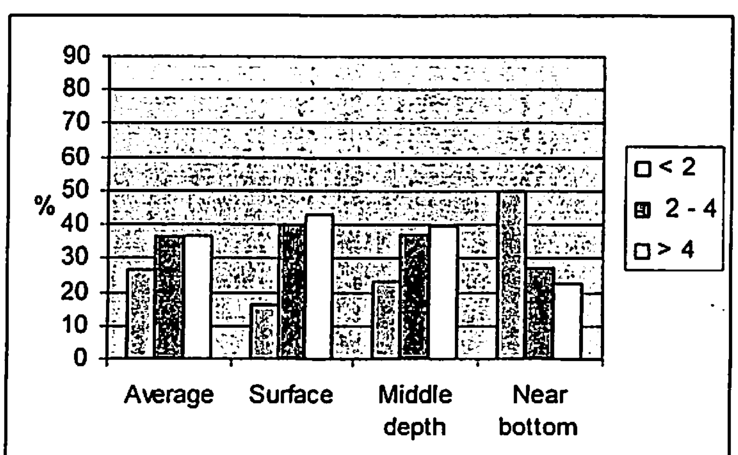

Figure 14 Comparison between 1997 *Forest* area dissolved oxygen levels at different depths for Below 2mg/l, From 2 to 4 mg/l and Above 4mg/l dissolved oxygen level categories.

From the figures it can be seen that forest has the best dissolved oxygen ranges, with only near bottom depth having over 50% *Below 2mg/l* levels. Shrub has the worst levels, clearly affected by the large amount of decaying material produced by shrubs. For grass land use type surface and middle depths are pretty good in terms of dissolved oxygen levels, probably due to wind induced mixing, but near bottom depth levels are not good for fish.

4 Notes about linkages

4.1 Flooding for agriculture

Floating rice cultivation largely takes place between floodplain elevations of 6 to 8 meters (corresponding to the same water level on the lake) whereas wet season rice cultivation takes place around 5 meters elevation and is located on lake bed and deltaic deposits (Hellsten *et al.*, 2003). According to Hellsten *et al.* (2003) there has been a slight increase in rice production around the lake in recent years. Importantly, wet season rice totals up to 90% of the production and floating as well as recession rice cultivation have a minor role. Therefore, a level of flooding that affects wet season rice production at water levels around 5 meters should be considered critical here, because of the minor importance of floating rice below 5 meter elevation. Moreover, the duration and timing of floods affect agricultural activities as transplanting takes place from July to August and harvesting from November to December (Hellsten *et al.*, 2003). For example, an early flood can cause crop damage but is good for fish productivity (Hort, 2004).

4.2 Tonle Sap Agricultural production

Rain fed lowland rice is almost completely dependent on rainfall and runoff water (Hellsten *et al*, 2003). Therefore, stakeholders (agriculturalists) should be asked to define more precise rainfall thresholds for agriculture. Because there is a new node (Tonle Sap runoff) between Tonle Sap rainfall and Tonle Sap water level, using more parameters would not render the Tonle Sap water level probability table too complicated.

4.3 Number of farmer fishers

In the third stakeholders consultation the link between high floods and farmer fishers was discussed (Hort, *et al.*, 2004). High floods can destroy crops and thereby drive people towards more fishing. This can have a significant effect on the fisheries. Both agriculture and fisheries experts should be interviewed to define this link more precisely.

5 Conclusions

5.1 Data

Overall, the accuracy and availability of data was identified as an important issue. Hydrological data from the Tonle Sap Lake and floodplain has a number of shortcomings. Pre-1975 data is unreliable and impossible to verify, and because of this and possible changes in the Mekong hydrological regime (e.g. effects of upstream dam building) it is not very representative of the present situation. For almost all of the stations, there is a gap in measurements between 1975 and the mid-1990s. Only datasets measured and produced after 1996 can be seen as reliable and representative of the present situation. Therefore, most effort was directed to analysis and utilisation of post-1996 data. In addition, the best existing fisheries data are from the Dai fisheries for the period of 1995 to 2000. When combining the fisheries data with the hydrological, land use and water quality data it is possible to check how well the model runs on a smaller scale (without detailed fisheries activities and the agricultural sector). Due to the complex relationships between flow directions, volumes and water levels between the Tonle Sap Lake and the Mekong, the use of the MIKE11 flow reversal model output data was appropriate. This provides the latest data available on the hydrological interactions between the Mekong and the Tonle Sap and the best way to estimate probabilities of nodes representing different water inflows to the lake.

The utilisation of land use data was straightforward because only one dataset exists and it is regarded as both reliable and accurate. On the other hand, water quality measurements from the lake and floodplain were analysed and it was clear that point measurements cannot represent the different floodplain vegetation classes over the whole lake. Therefore, it was seen that using output data from the MRCS/WUP-FIN water quality model to evaluate proportions of dissolved oxygen in different land use areas would be beneficial. Unfortunately, the model output data was not ready in time for the report, but the data will be incorporated as soon as it becomes available.

5.2 Results

The reliability of the nodes on hydrology, water quality and land use were strengthened by entering probabilities based on data into the model. The reliability of the interactions between these nodes was also strengthened in this way. After the results from this data analysis study have been presented, the data in the model will aid stakeholders to decide upon parameters and thresholds in a more quantitative way. All hydrological nodes as well as Flooded vegetation have data to define probabilities. The thresholds were set by the stakeholders thereby incorporating expert knowledge. Compromises had to be made to accommodate data limitations and stakeholders expertise into a dataset with proper thresholds. In addition, the structure of the model had to be kept as simple as possible due to data limitations and to ensure the model is manageable.

Overall, the probabilities interact in the way expected and correspond to the physical nature of the lake (e.g. choosing *Below 7600* state for Overland flow node reduces probabilities of *More than 10m* in Tonle Sap water level node. Another example is how *Above 1000* state for Tonle Sap rainfall node increases the probability of *Above 7600* state for Tonle Sap runoff node and *More than 10m* state for Tonle Sap water level node. A more thorough study of the accuracy should be performed once the stakeholders expertise and fisheries data has been incorporated into the model system as parameters and thresholds.

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1 Annex

1.1 Data collection

<u>List of data requested from the MRCS for the Bayesian Belief Network fisheries modelling activities:</u>

1. Water level data (daily) corrected to same datum level and used as the DSF model input data. The recordings requested are for the entire period of record from the following stations:

H 14901	Mekong River at Kratie
H 20106	Tonle Sap Lake at Kampong Loung
H 20101	Tonle Sap River at Phnom Penh Port
H 20102	Tonle Sap River at Prek Kdam

2. Water level data (daily) recordings requested are for the entire period of record from the following station hold at the MRCS/WUP-FIN database:

H 20103	Tonle Sap River at Kampong Chhnang
H 20106	Tonle Sap Lake at Kampong Loung

3. MIKE11 model output data 1984-2003 produced in the MRCS/WUP-JICA & TSLV Flow Reversal study for the following: Water level at 20106 (Kampong Loung), discharge at 14901 (Kratie) and 20102 (Prek Kdam) and overland flow.
4. Average rainfall data for sub-catchments of the Tonle Sap catchment edited and checked in the MRCS/WUP-JICA & TSLV project. We would like daily precipitation data for the period of 1980 to 2003.
5. JICA (1999) land cover data and calculations from the Tonle Sap floodplain edited by MRCS/WUP-FIN for floodplain vegetation/habitat and water level analysis purposes. In addition, JICA (1999) Geographical Information Systems layers on topography (1:100 000), road networks, administrative borders and population centres are requested from MRCS/WUP-FIN.
6. MRCS/WUP-FIN water quality model output data on dissolved oxygen levels in the Tonle Sap Lake and Floodplain.
7. Certeza Survey (1964) contour lines Geographical Information Systems layers by MRCS (2001) in the MRCS/WUP-FIN database.
8. MRCS/WUP-FIN database on dissolved oxygen measurements in and around the Tonle Sap Lake from 1995 to 2003.
9. Tonle Sap Lake water balance calculations by the MRCS/WUP-FIN and MRCS/JICA & TSLV.

1.2 Tonle Sap rainfall

Table 15 Hydrological year precipitation monthly averages, annual averages and data statistics (mm).

Year	May	June	July	August	September	October	November	December	January	February	March	April	Total
1980	115,4	67,3	198,8	304,1	234,7	276,2	95,8	19,4	1,7	20,8	26,5	136,0	1496,8
1981	122,2	78,8	114,5	96,0	140,0	130,1	131,0	0,4	3,5	18,6	40,4	77,4	952,8
1982	86,8	130,3	116,9	149,8	212,2	136,6	55,2	0,0	4,1	0,0	24,3	19,0	935,2
1983	106,9	114,8	145,3	159,4	173,6	253,8	120,1	1,8	1,4	4,6	37,5	59,9	1179,1
1984	147,2	111,2	151,4	133,7	162,6	188,1	13,6	5,9	9,6	45,5	46,0	121,3	1136,3
1985	184,7	90,5	169,0	98,7	250,9	163,7	101,4	4,3	4,8	12,6	23,3	33,3	1137,3
1986	98,5	127,7	92,7	201,0	165,4	164,4	31,1	9,8	2,1	4,4	29,0	52,6	978,7
1987	71,0	109,8	81,5	129,2	224,9	111,5	243,1	0,4	0,2	2,8	31,0	141,6	1147,1
1988	92,0	91,6	138,4	189,2	116,7	198,9	18,2	0,5	1,6	4,7	58,1	69,4	979,4
1989	200,9	123,0	163,8	311,2	314,2	206,4	77,4	0,0	9,8	26,8	30,0	102,1	1565,6
1990	128,7	208,1	163,2	143,3	269,8	245,0	79,9	4,5	0,0	0,4	41,5	58,8	1343,2
1991	121,3	166,6	247,7	257,7	333,4	267,3	19,0	0,9	23,9	0,4	0,0	25,1	1463,5
1992	52,2	164,4	192,9	366,5	172,0	149,0	14,1	9,3	16,3	9,3	37,5	42,2	1225,5
1993	92,3	252,6	167,3	144,5	249,2	262,6	31,0	8,5	0,0	14,4	105,8	17,0	1345,3
1994	214,1	251,1	188,1	335,0	308,0	141,0	10,2	7,4	0,0	4,1	49,3	72,6	1580,8
1995	127,6	170,9	211,9	194,9	419,7	307,8	37,0	11,0	0,4	5,1	0,7	109,7	1596,6
1996	175,1	180,9	129,0	120,9	221,8	284,6	116,1	18,1	1,3	15,7	24,0	101,6	1389,1
1997	111,9	112,1	220,6	160,8	217,1	128,0	12,7	0,3	0,0	8,5	4,8	70,2	1047,0
1998	79,0	153,7	125,3	198,8	259,8	131,9	152,1	8,1	5,7	1,1	32,4	156,3	1304,4
1999	194,4	179,0	151,6	118,6	158,0	170,5	218,2	35,6	1,9	10,6	23,9	137,3	1399,5
2000	84,4	92,5	245,2	173,1	200,1	297,7	40,6	8,1	19,4	6,8	129,5	47,4	1344,8
2001	165,9	155,8	107,4	248,3	199,0	278,3	38,8	8,2	0,1	0,0	34,6	105,7	1342,2
2002	112,1	178,8	88,6	184,0	303,2	119,7	158,5	33,8	0,0	0,3	67,3	64,2	1310,5
2003	141,1	141,1	197,7	137,7	171,4	173,2	16,2	0,5	-	-	-	-	979,0
Mean	126,1	143,9	158,7	189,9	228,2	199,4	76,3	8,2	4,7	9,4	39,0	79,2	1257,5
Max	214,1	252,6	247,7	366,5	419,7	307,8	243,1	35,6	23,9	45,5	129,5	156,3	1596,6
Min	52,2	67,3	81,5	96,0	116,7	111,5	10,2	0,0	0,0	0,0	0,0	17,0	935,2
StDev	43,78	49,55	47,41	75,96	70,93	64,97	66,99	9,8	6,74	10,8	29,79	41,41	209,42

1.3 Discharge data

1.3.1 Mekong flow

Table 16 Mekong flow (Million Cubic Meters) monthly average discharge at Prek Kdam from 1985 to 2003. Negative values indicate flow towards the Mekong and positive values flow towards the Tonle Sap Lake.

Year	May	June	July	August	September	October	November	December	January	February	March	April
1985	-488.6	2111.9	3933.7	6303.9	3580.8	-5894.8	-7109.5	-5909.7	-4706.6	-3149.8	-1605.2	-469.3
1986	292.5	1952.8	3644.5	6751.7	2735.2	-4833.7	-6101.8	-5431.8	-4002.6	-2472.7	-956.9	-252.5
1987	-82.9	289.3	3222.8	3798.9	5953.2	-3165.4	-5932.9	-5483.0	-4287.7	-2676.9	-1098.5	-360.4
1988	-369.5	1107.0	945.6	5141.2	853.2	170.7	-5308.7	-4905.6	-3422.7	-1841.6	-577.1	-150.8
1989	-5.8	861.3	1767.7	5749.3	1221.8	-4508.9	-7051.3	-6449.9	-4730.1	-3083.9	-1403.8	-421.1
1990	-213.3	3131.6	4135.9	4833.2	1830.9	-4809.3	-7599.1	-7100.0	-5410.0	-3723.8	-2062.3	-668.7
1991	-292.8	43.4	3470.0	6158.2	1766.3	-6928.7	-9334.9	-7664.6	-5650.0	-3903.5	-2205.1	-703.7
1992	-195.9	405.5	2225.2	5555.4	764.3	-5560.5	-6238.3	-5624.9	-3950.5	-2400.5	-883.9	-243.9
1993	-59.5	23.4	3738.4	5251.6	3334.9	-5205.0	-6871.0	-5595.4	-4094.7	-2505.2	-983.6	-294.6
1994	-231.8	2126.4	5830.0	4773.7	-986.3	-8653.5	-9231.9	-6964.9	-5124.3	-3454.9	-1746.5	-541.9
1995	-185.6	401.2	3119.4	6293.0	4429.9	-6404.1	-8614.9	-7340.1	-5537.0	-3810.9	-2096.8	-726.0
1996	-288.8	9.7	2175.5	6950.4	5473.4	-2641.0	-7174.8	-7498.6	-6082.2	-4383.5	-2783.9	-1202.2
1997	-547.4	-350.7	4709.7	8265.2	1728.3	-5402.7	-7731.3	-6272.3	-4498.5	-2849.0	-1182.0	-457.1
1998	-309.1	-286.3	2405.9	2639.5	3227.0	-4335.7	-5163.8	-4599.7	-3601.9	-2042.6	-648.5	-383.4
1999	50.4	2915.8	2428.2	5528.2	2228.7	-4702.3	-6182.9	-7053.8	-5714.2	-4047.1	-2366.1	-980.8
2000	521.7	3562.6	7529.1	3750.3	2071.4	-7648.7	-9142.2	-7523.4	-5725.1	-4052.7	-2494.1	-1152.7
2001	-564.3	2541.1	6080.2	7130.2	1576.8	-7231.1	-8023.3	-7357.8	-5669.7	-4028.9	-2452.9	-964.5
2002	-237.6	2147.1	6197.1	7574.3	2460.8	-7535.9	-8346.4	-7165.1	-5522.8	-3966.7	-2416.0	-1037.1
2003	-572.0	484.4	1595.7	4724.	5763.	-	-	-	N/A	N/A	N/A	N/A

				2	2	4652.0	6865.5	5562.0				
Mean	-198.4	1235.9	3678.6	5760.3	2624.8	-5257.8	-7250.9	-6392.3	-4865.6	-3236.5	-1657.4	-606.2
Max	521.7	3562.6	7529.1	8265.2	5953.2	170.7	-5163.8	-4599.7	-3422.7	-1841.6	-577.1	-150.8
Min	-572.0	-350.7	945.6	2639.5	-986.3	-8653.5	-9334.9	-7664.6	-6082.2	-4383.5	-2783.9	-1202.2
St. Dev	274.6	1228.4	1732.5	1469.4	1769.4	1975.1	1248.8	950.2	810.9	766.0	695.0	324.6

1.3.2 Overland flow

Table 17 Overland flow monthly average discharge from 1985 to 2003 (Million Cubic Meters). Bold indicates monthly average overland flow towards the Mekong from the Tonle Sap Lake.

Year	*May*	*June*	*July*	*August*	*Septemb er*	*October*	*Novembe r*	*Decembe r*	*January*	*February*	*March*	*April*
1985	4.7	13.8	47.7	782.6	1508.9	**-141.1**	**-66.5**	47.5	12.8	6.5	4.7	3.5
1986	3.9	5.6	16.5	770.1	1210.0	45.0	83.7	70.6	30.6	11.9	7.1	5.7
1987	4.9	5.7	6.0	270.5	1033.1	155.8	90.0	78.5	35.8	14.5	7.3	6.0
1988	7.8	9.9	17.0	78.5	88.4	129.0	99.4	42.4	16.5	7.9	6.0	5.0
1989	5.3	6.8	10.3	220.3	431.3	**-5.6**	**-21.7**	61.8	20.4	8.1	6.3	5.0
1990	4.5	5.1	7.9	483.4	1575.8	615.4	**-305.9**	58.5	29.0	8.6	5.9	4.6
1991	4.5	4.8	8.8	832.0	2354.1	242.4	**-546.6**	39.3	33.2	9.0	5.8	4.3
1992	3.2	4.2	16.8	454.8	654.6	84.6	97.0	61.1	27.2	11.1	6.9	5.6
1993	5.7	11.6	47.7	191.6	752.1	59.0	63.7	55.3	20.8	8.3	6.2	5.2
1994	5.2	16.2	378.0	1604.8	2668.1	**-842.1**	**-339.9**	70.7	25.3	8.5	5.7	4.5
1995	3.8	4.9	15.1	410.2	1997.2	24.1	**-403.0**	73.2	42.3	14.6	7.5	5.6
1996	4.3	5.1	17.0	636.9	1532.6	905.8	**-405.0**	**-28.8**	49.6	20.5	8.7	6.9
1997	8.6	38.5	163.9	2026.5	1530.8	292.6	**-61.7**	59.7	19.2	7.8	5.6	4.3
1998	4.1	4.9	8.4	35.8	106.9	148.1	90.6	60.7	30.5	13.6	7.6	6.0
1999	7.3	15.7	47.0	1097.5	946.0	259.5	**-119.2**	61.9	41.0	12.4	7.1	6.3
2000	6.9	11.7	1142.1	1426.8	3271.3	**-438.4**	**-639.6**	31.7	39.4	10.4	7.1	6.3
2001	5.6	7.1	134.0	1813.3	2771.0	**-249.4**	**-521.4**	22.8	40.0	10.8	6.3	5.0
2002	4.8	6.6	267.7	1883.3	2742.9	**-314.5**	**-357.6**	64.9	41.1	12.2	7.3	6.5
2003	7.8	25.4	57.4	120.9	1164.8	127.5	68.6	40.5	N/A	N/A	N/A	N/A
Mean	5.4	10.6	121.1	838.8	1518.8	58.3	-165.6	51.6	30.1	10.7	6.6	5.3
Max	8.6	38.5	1142.1	2026.5	3271.3	905.8	99.4	78.5	49.6	20.5	8.7	6.9
Min	3.2	4.2	6.0	35.8	88.4	-842.1	-639.6	-28.8	12.8	6.5	4.7	3.5
St. Dev	1.5	8.5	259.8	667.1	917.6	364.4	249.5	23.8	10.5	3.4	1.0	0.9

1.4 Water level at Kampong Loung

1.4.1 Water level data gaps in Kampong Loung and Kampong Chhnang

Based on Eloheimo *et al.* (2002a).

<u>Kampong Loung Gaps:</u>

Sep. - Dec., 1960	122 days
Jan. - Jul.22, 1962	203
Jan. – May, 1996	151
Dec. 3, 4, 31, 1996	3

Aug. 30, 1997 - June,1998		305
Dec.,1998	31	
Feb.28, Mar.5, 1999		2
May 3 - 4, 1999	2	
Dec, 2000	31	
Altogether	**850 days**	

<u>Kampong Chhnang Gaps:</u>

Aug. - Dec., 1956	153 Days	
Nov. 2, 1957	1	
Sep. 1 - Oct. 9, 1961		39
Oct. 23, 62 - Feb. 15, 1963		116
Mar. 15 - 21, 1963	63	
Sep. 2 - 5, 1963	63	
Oct. 20 - Nov. 8, 1963		20
Dec. 26 - 31, 1963	6	
Jan.1 - 22, 1964	22	
Sep. 28 - Oct. 14, 1964	17	
Aug. 16 - Dec. 31, 1967	138	
Aug. - Dec., 1970	153	
Aug., 1971	31	
Nov. 16, 1971 - Jan.11, 1972		57
Feb. 1 - Apr. 1, 1972		61
May 29 - Jun. 15, 1972	18	
Oct., 1972	31	
Jan. – Jun.19, 1982		170
Dec.1982 - Aug.,1983	274	
Feb. - May 6, 1984	95	
Apr. 26 - 30, 1985	5	
Oct. – Nov. 1985	61	
Mar. - Sep., 1986	214	
Dec. 1986 – 1987	396	
Feb. - May 6, 1988	95	
May 11 – Jun. 11, 1996	32	
Nov. 12 – Dec. 12, 1996	31	
Jun. 23 - 30, 1998	8	
Aug. 1998	31	
Oct. - Dec., 1998	92	
Jan. 16, 21, 26, 1999		3
Feb. 28, 1999		1
Mar. 4 – 15, 17 – 20, 22 - 25, 27 - 31, 1999	25	
Apr. 20, 21, 26, 1999		3
Dec. 31, 1999		
Altogether	**2526 Days**	

1..4.2 Water level at Kampong Loung

Table 18 Monthly maximum water levels (meters) for Kampong Loung from 1985 to 2003.

Year	*May*	*June*	*July*	*August*	*September*	*October*	*November*	*December*	*January*	*February*	*March*	*April*	*Max*
1985	2.1	3.5	5.3	7.4	8.9	9.0	8.4	7.3	5.9	4.4	3.1	2.1	9.0
1986	2.1	3.3	4.9	7.2	8.4	8.4	7.8	6.7	5.2	3.8	2.6	1.9	8.4
1987	1.6	2.1	3.9	5.4	7.6	7.8	7.3	6.6	5.4	3.9	2.7	1.9	7.8
1988	1.9	2.8	3.6	5.9	6.4	7.2	7.2	6.1	4.6	3.2	2.2	1.7	7.2
1989	1.9	2.9	4.3	7.0	8.3	8.4	8.3	7.3	5.7	4.2	2.9	2.0	8.4
1990	1.7	4.0	5.9	7.7	9.1	9.4	9.1	7.9	6.4	4.8	3.5	2.3	9.4
1991	1.8	2.3	5.1	7.8	9.7	9.9	9.6	8.2	6.5	5.0	3.6	2.3	9.9
1992	1.8	2.2	3.9	7.0	8.2	8.3	7.8	6.6	5.1	3.6	2.5	1.9	8.3
1993	1.6	2.2	4.8	6.7	8.2	8.2	7.9	6.7	5.2	3.7	2.5	1.9	8.2
1994	1.9	3.8	6.7	8.9	10.3	10.4	9.4	7.7	6.1	4.5	3.2	2.2	10.4
1995	1.7	2.3	4.6	7.0	9.3	9.6	9.3	8.0	6.5	4.9	3.5	2.3	9.6
1996	2.0	2.5	4.1	6.8	8.7	9.5	9.3	8.5	7.0	5.4	4.0	2.7	9.5
1997	2.0	1.9	4.8	8.0	9.1	9.1	8.6	7.2	5.6	4.1	2.8	1.9	9.1
1998	1.7	1.7	3.7	5.3	6.9	7.1	6.7	5.9	4.8	3.4	2.3	1.8	7.1
1999	2.5	4.5	5.7	7.7	8.8	9.0	8.5	8.0	6.6	5.1	3.7	2.5	9.0
2000	2.6	4.5	7.4	8.9	10.3	10.3	9.8	8.3	6.7	5.1	3.8	2.7	10.3
2001	2.0	3.8	6.1	8.6	10.0	10.0	9.4	8.3	6.7	5.2	3.8	2.5	10.0
2002	1.9	3.5	5.9	8.4	10.1	10.2	9.3	8.1	6.6	5.1	3.8	2.6	10.2
2003	1.9	2.6	4.3	6.2	8.2	8.4	7.9	6.5	N/A	N/A	N/A	N/A	8.4
Average	1.9	3.0	5.0	7.3	8.8	8.9	8.5	7.4	5.9	4.4	3.1	2.2	8.9
Max	2.6	4.5	7.4	8.9	10.3	10.4	9.8	8.5	7.0	5.4	4.0	2.7	10.4
Min	1.6	1.7	3.6	5.3	6.4	7.1	6.7	5.9	4.6	3.2	2.2	1.7	7.1
St Dev	0.25	0.86	1.05	1.08	1.08	1	0.9	0.81	0.74	0.7	0.59	0.31	1

1.4.3 Comparison of different Kampong Loung datasets

Table 19 Comparison of Kampong Loung average monthly water level (meters) between simulated MIKE11 model output, Ha Tien datum corrected and original measured data.

Year	1999			2000		
Dataset	*MIKE11*	*Ha Tien*	*Measured*	*MIKE11*	*Ha Tien*	*Measured*
January	4.1	3.3	2.6	5.9	5.6	4.9
February	2.8	2.1	1.4	4.4	3.9	3.2
March	2.0	1.8	1.2	3.1	2.5	1.9
April	1.7	1.4	0.7	2.2	1.9	1.2
May	2.0	1.9	1.2	2.0	2.0	1.4
June	3.6	3.9	3.2	3.4	3.8	3.1
July	5.1	5.3	4.7	5.9	6.4	5.7
August	7.0	7.1	6.5	8.2	8.6	7.9
September	8.2	8.2	7.6	9.8	9.8	9.2
October	8.8	8.8	8.2	10.1	10.2	9.5
November	8.3	8.5	7.9	9.1	9.2	8.5
December	7.4	7.3	6.6	7.5	N/A	N/A
Year	2001			2002		
Dataset	*MIKE11*	*Ha Tien*	*Measured*	*MIKE11*	*Ha Tien*	*Measured*
January	5.9	5.6	4.9	6.0	5.3	4.7
February	4.5	3.9	3.3	4.5	3.7	3.1
March	3.2	2.6	2.0	3.2	2.4	1.8
April	2.3	1.9	1.2	2.2	1.7	1.1
May	1.9	1.5	0.9	1.8	1.4	0.8
June	2.7	2.6	2.0	2.5	2.3	1.7
July	5.1	5.2	4.6	4.8	4.7	4.0
August	7.3	7.5	6.9	7.1	7.0	6.4
September	9.5	9.5	8.8	9.4	9.3	8.6
October	9.8	9.7	9.1	9.8	9.7	9.0
November	8.9	8.9	8.2	8.6	8.3	7.6
December	7.5	7.2	6.5	7.4	7.2	6.6

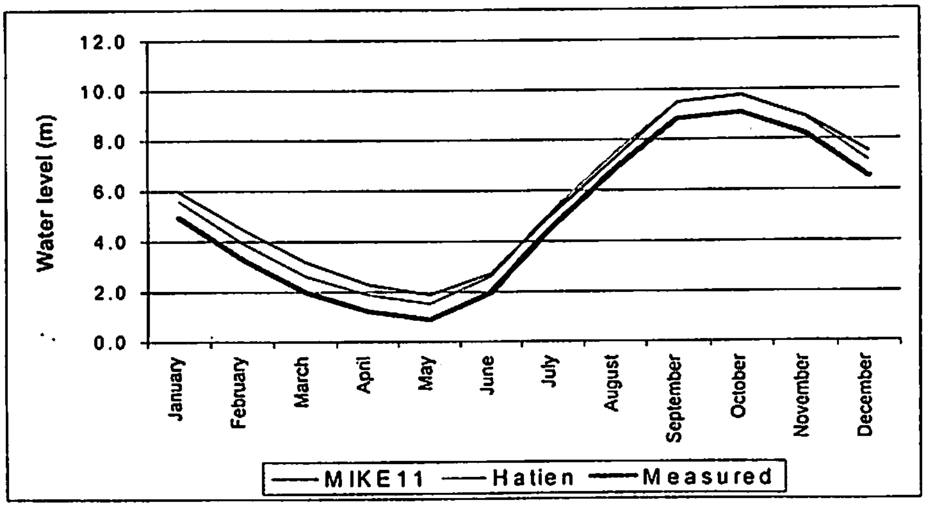

Figure 14 Comparison of average monthly water levels between MIKE11 model output, Ha Tien datum corrected and original measured data for the year 2001.

1.5 Flood beginning and duration

1.5.1 Kampong Chhnang daily water level difference

Table 20 Daily Kampong Chhnang water level difference (meters). Beginning and end of flood is marked in bold, possible inaccuracies in the data are highlighted.

Day	*1994*	*1995*	*1996*	*1997*	*1999*	*2000*	*2001*	*2002*
2-May	-0.09	-0.07	0	0	0.08	0.05	-0.03	0.02
3-May	-0.15	0	-0.07	-0.01	0.1	0.04	-0.01	-0.04
4-May	0.1	0	0.06	-0.02	0.02	0.05	0	0.02
5-May	-0.47	0	0.01	0.02	0.07	-0.01	0.02	-0.03
6-May	0	-0.02	0.02	-0.01	0.05	0.02	0	-0.06
7-May	0.06	-0.01	-0.04	0	0.06	0.02	0.07	-0.06
8-May	0.1	0.07	-0.04	-0.03	-0.02	0.02	0.11	-0.08
9-May	0.67	0.03	-0.02	0.01	-0.1	0	-0.01	-0.01
10-May	0.04	-0.08	0.05	-0.01	-0.15	-0.02	-0.06	0
11-May	0	-0.01	-0.18	0.01	-0.03	-0.06	-0.02	-0.04
12-May	0	0.06	0.12	-0.06	0	0	-0.1	0.05
13-May	-0.02	0.05	0.11	-0.06	0.07	0.04	0.05	0.02
14-May	-0.02	0.01	0.13	-0.05	0.05	0.02	-0.1	0
15-May	0	-0.04	0.12	-0.14	**0.32**	0.08	0.04	-0.01
16-May	-0.11	-0.03	0.24	0.09	0.33	0.08	-0.05	0.02
17-May	-0.09	-0.05	0.33	-0.07	0.21	**0.17**	**0.24**	0.01
18-May	-0.04	0.06	0.24	0.04	0.09	0.03	0.12	-0.04
19-May	-0.02	0.02	0.36	0.02	-0.01	0.14	0.17	-0.02
20-May	0.06	0.03	0.16	0.04	-0.02	0.18	0.09	0.06
21-May	0.07	0.05	-0.04	0.07	0	0.05	0.05	0
22-May	0.1	0.05	-0.12	0.04	0.02	0.05	0.01	0
23-May	0.13	0.01	-0.1	0.05	0.05	0.1	0.02	0
24-May	0.12	0.04	-0.26	0.05	0.03	0.24	-0.02	**0.11**
25-May	0.06	0.08	-0.16	0.1	0.08	0.4	-0.03	0.2
26-May	0.08	0	-0.13	-0.02	0.08	0.28	0	0
27-May	0.04	-0.04	-0.14	0.06	0.06	0.13	0.02	0.03
28-May	0.03	0	-0.06	0.04	0.04	-0.01	0.06	0.15
29-May	0.05	-0.02	-0.01	0.05	0.05	0	0.04	0.08
30-May	0.04	-0.01	0.08	0.08	0.03	-0.05	0.06	0.18
31-May	-0.02	0.19	0.09	-0.01	0.06	0	0.17	0.08
1-Jun	-0.03	-0.08	0.08	0.04	0.08	-0.01	0.11	0.07
2-Jun	-0.01	-0.09	0.09	0.05	0.2	0	0.11	0.02
3-Jun	0.03	0.05	**0.11**	0.07	0.16	0.04	0.08	0.05
4-Jun	0.05	-0.04	0.1	0.1	0.18	0.11	0.11	-0.01
5-Jun	0.06	-0.02	0.06	0.06	0.14	0.14	0.14	-0.01
6-Jun	0.06	-0.02	-0.02	0.04	0.14	0.01	0.11	-0.01
7-Jun	0.12	-0.04	0.04	0.04	0.16	-0.04	0.1	0.03
8-Jun	0.07	0.04	0.01	-0.02	0.18	-0.1	0.04	0.02
9-Jun	0.26	0.05	-0.03	0	0.13	-0.04	0.06	0.05
10-Jun	0.19	**0.11**	-0.07	-0.06	0.02	-0.01	0.09	0.09
11-Jun	0.19	0.1	-0.16	-0.14	-0.01	0	0.1	0.13

12-Jun	0.17	0.1	0.26	-0.06	-0.03	0.01	0.11	0.16
13-Jun	0.16	0.1	0.04	-0.02	-0.05	0	0.16	0.09
14-Jun	0.16	0.08	0.04	-0.04	-0.06	-0.02	0.09	0.07
15-Jun	0.2	0	0.03	-0.03	-0.02	0.02	0.07	0.11
16-Jun	0.16	-0.02	0.05	-0.02	0.04	0.03	0.06	0.18
17-Jun	0.12	0.12	0.04	-0.02	0.07	0.13	0.05	0.19
18-Jun	0.05	0.14	0.04	0.01	0.07	0.24	0.06	0.04
19-Jun	0.03	0.14	0.04	-0.04	0.06	0.38	0.11	0.11
20-Jun	0.06	0.11	0.04	-0.01	0.08	0.27	0.05	0.01
21-Jun	0.09	0.13	0.06	-0.09	0.08	0.23	0.02	-0.01
22-Jun	0.11	0.09	0.02	0.04	0.1	0.02	-0.06	0
23-Jun	0.14	0.05	0.04	-0.01	0.07	0	-0.04	0.03
24-Jun	0.14	0.1	0.04	0.11	0.05	0.08	0.03	0.12
25-Jun	0.24	0.06	0.04	0.09	0.04	0.02	0.21	0.09
26-Jun	0.04	0.02	0.04	0.04	0.02	0.11	0.17	0.17
27-Jun	-0.02	0.02	-0.01	0.11	0.04	0.14	0.25	0.06
28-Jun	-0.06	-0.1	0.1	0.07	0	0.1	0.11	-0.01
29-Jun	0.06	-0.1	0.05	0.11	0.02	0.11	0.1	0.02
30-Jun	0.08	0.02	0.04	0.2	0.03	0.04	0.03	0.01
1-Jul	0.06	0	0.03	0.28	0.03	0.03	0.05	0.03
2-Jul	-0.02	0.14	0.05	0.24	0.02	0.08	0.1	0.04
3-Jul	0.15	0.04	0.05	0.21	-0.01	0.04	0.1	0.01
4-Jul	0.04	0.1	0.07	0.13	0.01	0.03	0.07	-0.03
5-Jul	0	0.05	-0.02	0.13	0.01	0.02	0.11	0
6-Jul	-0.01	0.05	0.1	0.12	0.04	0.05	0	0.12
7-Jul	0.01	0.08	0.12	0.08	0.05	0.08	0.03	0.03
8-Jul	0.01	0.08	0	0.03	0.04	0.07	0.11	0.68
9-Jul	0.02	0.09	0.09	0.01	0	0.04	0.16	0.18
10-Jul	0.06	0.09	0.05	0.03	-0.02	0.1	0.16	0.15
11-Jul	0.06	0.06	0.12	0.04	-0.02	0.05	0.1	0.09
12-Jul	0.27	0.16	0.12	0.07	-0.02	0.13	0.1	0.15
13-Jul	0.29	0.18	0.08	0.05	0.07	0.11	0.05	0.1
14-Jul	0.17	0.24	0.12	0.03	0.03	0.05	0.02	-0.02
15-Jul	0.09	0.17	0.1	0.03	0.02	0.2	0.01	0.1
16-Jul	0.05	-0.09	0.1	0.2	0.06	0.12	0.04	0.02
17-Jul	0.04	-0.1	0.1	0.35	0.05	0.13	0.01	0.05
18-Jul	0.04	0.06	0.1	0.33	0.05	0.14	0.02	0.06
19-Jul	0.04	0.07	0.08	0.15	0.01	0.05	0.01	0.05
20-Jul	0.05	0.06	0.1	0.14	0	0.14	0.01	0.03
21-Jul	0.08	0.09	-0.06	0.05	0.01	0.1	0.04	0.04
22-Jul	0.13	0.12	0.04	0.06	0.01	0.12	0.01	0.02
23-Jul	0.1	0.12	0.08	0.06	0.02	0.1	0.06	0.03
24-Jul	0.09	0.12	0.12	0.14	0.04	0.1	0.1	0.03
25-Jul	0.07	0.04	0.15	0.13	0.05	0.1	0.07	0.03
26-Jul	0.07	-0.1	0.12	0.14	0.04	0.1	0.08	0.02
27-Jul	0.08	0.08	0.13	0.12	0.2	0.07	0.05	0.02
28-Jul	0.06	0.06	0.14	0.1	0.17	0.05	0.07	0.02
29-Jul	0.06	0.05	0.14	0.09	0.15	0.04	0.05	0.02
30-Jul	0.04	0.05	0.08	0.1	0.16	0.08	0.06	0.04
31-Jul	0.02	0.14	0.08	0.09	0.11	0.04	0.03	0.06
1-Aug	0.09	0.14	0.08	0.09	-0.02	0.05	0.07	0.07
2-Aug	0.04	0.18	0.08	0.08	0.18	0.06	0.04	0.07

3-Aug	0.08	0.22	0.08	0.11	0.09	0.06	0.05	0.07
4-Aug	0.07	0.1	0	0.11	0.1	0.04	0.03	0.08
5-Aug	0.08	0.02	-0.03	0.13	0.1	0.03	0.05	0.04
6-Aug	0.1	0.1	0.11	0.14	0.1	0.02	0.04	0.06
7-Aug	0.1	0.08	0.12	0.12	0.1	0.02	0.02	0.05
8-Aug	0.1	0.06	0.1	0.13	0.09	0.02	0.05	0.04
9-Aug	0.1	0.04	0.12	0.13	0.06	0.04	0.06	0.06
10-Aug	0.08	0.07	0.08	0.12	0.08	0.06	0.06	0.08
11-Aug	0.1	0.05	0.08	0.1	0.07	0.03	0.06	0.06
12-Aug	0.05	0.1	0.05	0.07	0.02	0.01	0.07	0.06
13-Aug	0.05	0.05	0.03	0.05	0.12	0.02	0.1	0.05
14-Aug	0.05	0.05	0	0.02	0.04	0	0.1	0.11
15-Aug	0.01	0.08	0	0.02	0.04	0.06	0.1	0.09
16-Aug	0.04	0	0.02	0.01	0.04	-0.03	0.11	0.1
17-Aug	0.03	0.02	0.04	0	0.02	0	0.1	0.09
18-Aug	0.02	0.05	0.02	0.03	0.02	0.02	0.09	0.11
19-Aug	0.03	0.04	0.04	0.03	0	0.03	0.1	0.08
20-Aug	0.02	0.04	0.05	0.04	0.02	0.01	0.15	0.11
21-Aug	0.02	0.04	0.05	0.08	0.01	0.02	0.1	0.1
22-Aug	0.02	0.05	0.1	0.09	0.01	0.02	0.13	0.1
23-Aug	0.04	0.05	0	0.06	0.02	0	0.08	0.09
24-Aug	0.06	0.03	0.06	0.08	0.02	-0.01	0.13	0.09
25-Aug	0.06	0.02	0.04	0.1	0	0.01	0.12	0.11
26-Aug	0.04	0.06	0.07	0.09	0.02	0.02	0.1	0.12
27-Aug	0.07	0.08	0.06	0.07	0	0.07	0.07	0.07
28-Aug	0.04	0.08	0.05	0.05	0.02	0.05	0.07	0.07
29-Aug	0.04	0.14	0.04	0.06	0.01	0.09	0.06	0.06
30-Aug	0.05	0.09	0.08	0.03	0.02	0.05	0.06	0.05
31-Aug	0.06	0.07	0.05	0.02	0	0.05	0.07	0.05
1-Sep	0.05	0.08	0.04	0.02	0.01	0.08	0.06	0.05
2-Sep	0.06	0.06	0.04	0.05	0.02	0.04	0.05	0
3-Sep	0.05	0.12	0.07	0.05	0.04	0.03	0.06	0.05
4-Sep	0.08	0.12	0.06	0.04	0.02	0.06	0.05	0.05
5-Sep	0.09	0.08	0.03	0.03	0.03	0.08	0.04	0.05
6-Sep	0.05	0.08	0.05	0.03	0.03	0.07	0.03	0.04
7-Sep	0.04	0.1	0.05	0.04	0.02	0.07	0.02	0.03
8-Sep	0.08	0.1	0.03	0.03	0.04	0.05	0.03	0.04
9-Sep	0.04	0.12	0.03	0.02	0.04	0.07	0.02	0.05
10-Sep	0.06	0.1	0.07	0.02	0.01	0.05	0.04	0.07
11-Sep	0.06	0.09	0.08	0.02	0.01	0.05	0.02	0.06
12-Sep	0.08	0.13	0.07	0.07	0.04	0.04	0.04	0.06
13-Sep	0.08	0.06	0.06	0.02	0.02	0.07	0.03	0.04
14-Sep	0.04	0.07	0.05	0.03	0.04	0.07	0.03	0.04
15-Sep	0.06	0.05	0.04	0.03	0.02	0.05	0.06	0.05
16-Sep	0.04	0.08	0.06	0.04	0.01	0.02	0.06	0.04
17-Sep	0.05	0.07	0	0.04	0.02	0.04	0.04	-0.01
18-Sep	0.05	0.07	-0.02	0.03	0.01	0.06	0.03	0.09
19-Sep	0.01	0.08	0.04	0.03	0.02	0.04	0.02	0.05
20-Sep	0.04	0.08	0.08	0.03	0.05	0.03	0.02	0.04
21-Sep	0.05	0.06	0.03	0.02	0.03	0.03	0.03	0.07
22-Sep	0.02	0.08	0.09	0.02	0.02	0.05	0.01	0.04
23-Sep	0.02	0.06	0.1	0.06	0.03	0.03	0.03	0.05

24-Sep	0.02	0.04	0.09	0.03	0.04	0.02	0.01	0.03
25-Sep	0.03	0.04	0.1	0	0.03	0.01	0	0.03
26-Sep	0.01	0.01	0.13	0	0.06	0.02	0.01	0.04
27-Sep	0.02	0.03	0.12	0.05	0.04	-0.01	0.02	0.04
28-Sep	0.02	0.03	0.08	0.02	0.1	-0.02	0.01	0.04
29-Sep	0.02	0.06	0.12	0	0	-0.01	0	0.04
30-Sep	-0.01	0.03	0.1	0.02	0.04	-0.01	0.02	0.03
1-Oct	0	0	0.14	0.01	0.03	-0.01	-0.02	0.02
2-Oct	0.03	0	0.12	0.02	0.05	0	-0.02	0.01
3-Oct	0.04	0	0.09	0.01	0.06	-0.02	0	0.01
4-Oct	0	0	0.07	0.01	0.04	-0.04	0	-0.01
5-Oct	0	-0.01	0.04	0	0.02	-0.04	0.01	0.01
6-Oct	0	0.03	0.04	0.01	0.02	0	0	-0.01
7-Oct	0	0.02	0.06	0.03	0.02	-0.03	0	-0.02
8-Oct	0	0.01	0.02	0.04	0	-0.04	-0.01	-0.02
9-Oct	-0.02	0.02	0.01	0	-0.01	-0.02	-0.01	-0.04
10-Oct	-0.02	0.08	0.01	-0.03	-0.01	-0.01	-0.02	-0.02
11-Oct	-0.02	0.07	0.01	0	0	0.01	-0.01	-0.03
12-Oct	-0.02	0.02	0	0	-0.01	0.07	0	-0.03
13-Oct	-0.05	0.02	0.01	0	-0.02	0.04	-0.02	-0.04
14-Oct	-0.04	0.02	0	-0.03	-0.01	0.01	0	-0.03
15-Oct	-0.03	0.02	0	0	0	-0.02	-0.02	-0.05
16-Oct	-0.03	0.01	-0.02	0	0	0	-0.03	-0.04
17-Oct	-0.05	0.03	-0.01	-0.01	0	0	-0.04	-0.05
18-Oct	-0.02	-0.02	-0.06	0.02	-0.01	0.01	-0.04	-0.03
19-Oct	-0.02	0	-0.01	0	-0.03	-0.01	-0.04	-0.05
20-Oct	-0.03	0	0	-0.03	-0.06	-0.03	-0.02	-0.05
21-Oct	-0.03	-0.01	-0.02	-0.02	-0.06	-0.02	-0.03	-0.04
22-Oct	-0.06	-0.02	0	-0.05	-0.04	-0.02	-0.04	-0.04
23-Oct	-0.03	0	0.02	-0.03	-0.04	-0.04	-0.03	-0.06
24-Oct	-0.07	-0.02	-0.03	-0.06	-0.06	-0.04	-0.08	-0.05
25-Oct	-0.1	-0.14	-0.03	-0.04	-0.06	-0.02	-0.03	-0.03
26-Oct	-0.06	-0.01	-0.02	-0.05	-0.04	-0.01	-0.01	-0.15
27-Oct	-0.06	0	0.06	-0.05	0.01	-0.02	0	0.03
28-Oct	-0.07	-0.13	-0.01	-0.04	0	-0.02	-0.02	-0.05
29-Oct	-0.09	-0.06	-0.01	-0.03	-0.01	-0.05	-0.02	-0.04
30-Oct	-0.09	-0.03	0.02	-0.05	-0.03	-0.04	-0.05	-0.03
31-Oct	-0.06	-0.02	0.01	-0.02	-0.03	-0.03	-0.04	-0.03
1-Nov	-0.03	-0.02	-0.02	-0.1	0	-0.03	-0.05	-0.06
2-Nov	-0.04	-0.03	-0.01	-0.06	0.04	-0.04	-0.03	-0.06
3-Nov	-0.04	-0.03	-0.02	-0.1	0.06	-0.09	-0.03	-0.04
4-Nov	-0.07	-0.06	-0.04	-0.08	0.02	-0.06	-0.02	-0.06
5-Nov	-0.07	-0.06	-0.06	-0.05	0.03	-0.05	-0.03	-0.05
6-Nov	-0.07	-0.05	-0.02	-0.04	0.01	-0.06	-0.06	-0.05
7-Nov	-0.06	-0.05	0.04	-0.08	-0.01	-0.07	-0.04	-0.05
8-Nov	-0.11	-0.03	0.01	-0.05	0.01	-0.05	-0.03	-0.06
9-Nov	-0.08	-0.08	-0.04	-0.06	0	-0.06	-0.06	-0.08
10-Nov	-0.06	-0.04	-0.07	-0.06	0.03	-0.06	-0.04	-0.05
11-Nov	-0.08	-0.03	-0.08	-0.07	0.02	-0.06	-0.03	-0.06
12-Nov	-0.06	-0.04	-0.34	-0.06	-0.01	-0.05	-0.02	-0.04
13-Nov	-0.08	-0.05	-0.04	-0.03	-0.02	-0.06	-0.03	-0.06
14-Nov	-0.12	-0.04	-0.07	-0.1	-0.02	-0.06	-0.05	-0.04

15-Nov	-0.14	-0.07	-0.04	-0.06	-0.02	-0.05	-0.02	-0.06
16-Nov	-0.11	-0.07	-0.06	-0.07	-0.02	-0.06	-0.04	-0.04
17-Nov	-0.03	-0.08	-0.06	-0.05	-0.04	-0.07	-0.04	-0.06
18-Nov	-0.08	-0.07	-0.05	-0.08	-0.01	-0.06	-0.04	-0.16
19-Nov	-0.05	-0.06	-0.03	-0.07	-0.03	-0.05	-0.04	0.02
20-Nov	-0.09	-0.09	-0.03	-0.07	-0.06	-0.06	-0.07	-0.06
21-Nov	-0.06	-0.09	-0.03	-0.07	-0.04	-0.06	-0.09	-0.06
22-Nov	-0.05	-0.06	-0.04	-0.05	-0.04	-0.05	-0.06	-0.05
23-Nov	-0.04	-0.06	-0.03	-0.06	-0.04	-0.06	-0.05	-0.05
24-Nov	-0.03	-0.09	-0.03	-0.08	-0.04	-0.07	-0.06	-0.14
25-Nov	-0.02	-0.07	-0.06	-0.07	-0.06	-0.09	-0.05	-0.03
26-Nov	-0.06	-0.08	-0.07	-0.06	-0.06	-0.04	-0.07	-0.01
27-Nov	0	-0.05	-0.07	-0.07	-0.06	-0.04	-0.06	-0.08
28-Nov	-0.05	-0.03	-0.04	-0.08	-0.04	-0.06	-0.04	-0.05
29-Nov	-0.07	-0.03	-0.07	-0.06	-0.06	-0.06	-0.05	-0.05
30-Nov	-0.06	-0.04	-0.05	-0.07	-0.06	-0.07	-0.07	-0.05
1-Dec	-0.08	-0.05	-0.07	-0.09	-0.04	-0.06	-0.04	-0.05
2-Dec	-0.1	-0.1	-0.08	-0.09	-0.06	-0.05	-0.07	-0.06
3-Dec	-0.06	-0.12	-0.04	-0.05	-0.04	-0.07	-0.06	-0.06
4-Dec	-0.08	-0.09	-0.05	-0.05	-0.06	-0.05	-0.08	-0.05
5-Dec	-0.1	-0.09	-0.03	-0.06	-0.04	-0.05	-0.06	-0.05
6-Dec	-0.08	-0.06	-0.07	-0.06	-0.05	-0.07	-0.06	-0.07
7-Dec	-0.04	-0.06	-0.06	-0.08	-0.05	-0.06	-0.07	-0.06
8-Dec	-0.06	-0.05	-0.1	-0.08	-0.03	-0.08	-0.01	-0.05
9-Dec	-0.1	-0.06	-0.07	-0.06	-0.05	-0.09	-0.08	-0.07
10-Dec	-0.08	-0.04	-0.07	-0.05	-0.06	-0.05	-0.09	-0.06
11-Dec	-0.04	-0.03	-0.07	-0.07	-0.06	-0.06	-0.07	-0.05
12-Dec	-0.04	-0.03	-0.05	-0.08	-0.06	-0.04	-0.06	-0.05
13-Dec	-0.07	-0.07	0.31	-0.07	-0.08	-0.09	-0.06	-0.07
14-Dec	-0.05	-0.07	-0.06	-0.06	-0.06	-0.04	-0.05	-0.06
15-Dec	-0.06	-0.09	-0.08	-0.07	-0.05	-0.06	-0.05	-0.06
16-Dec	-0.06	-0.04	-0.04	-0.07	-0.05	-0.06	-0.08	-0.07
17-Dec	-0.06	-0.06	-0.08	-0.07	-0.06	-0.06	-0.1	-0.05
18-Dec	-0.06	-0.09	-0.02	-0.06	-0.06	-0.06	-0.07	0.03
19-Dec	-0.06	-0.03	-0.08	-0.06	-0.08	-0.09	-0.05	-0.16
20-Dec	-0.06	-0.08	-0.07	-0.07	-0.06	-0.08	-0.09	-0.06
21-Dec	-0.04	-0.06	-0.07	-0.06	-0.06	-0.07	-0.06	-0.07
22-Dec	-0.05	-0.06	-0.06	-0.03	-0.08	-0.07	-0.05	-0.06
23-Dec	-0.03	-0.04	-0.08	-0.06	-0.06	-0.05	-0.08	-0.1
24-Dec	-0.09	-0.03	-0.04	-0.08	-0.06	-0.07	-0.07	-0.05
25-Dec	-0.07	-0.03	-0.1	-0.08	-0.06	-0.05	-0.06	-0.02
26-Dec	-0.05	-0.08	-0.02	-0.04	-0.08	-0.04	-0.09	-0.03
27-Dec	-0.05	-0.04	-0.1	-0.07	-0.08	-0.06	-0.05	-0.03
28-Dec	-0.08	-0.06	-0.07	-0.09	-0.06	-0.09	-0.05	-0.09
29-Dec	-0.09	-0.04	-0.17	-0.05	-0.06	-0.06	-0.08	-0.08
30-Dec	-0.07	-0.05	-0.02	-0.05	-0.06	-0.06	-0.06	-0.1
31-Dec	-0.06	-0.11	-0.05	-0.05	-0.06	-0.1	-0.06	-0.08

1.5.2 Kampong Chhnang weekly average water level difference

Table 21 Average weekly water level difference in Kampong Chhnang calculated from daily water level difference data (meters). The beginning and end of flooding is marked in bold..

Week	*From*	*To*	*1994*	*1995*	*1996*	*1997*	*1999*	*2000*	*2001*	*2002*
1	2-May	8-May	-0.06	0.00	-0.01	-0.01	0.05	0.03	0.02	-0.03
2	9-May	15-May	0.10	0.00	0.05	-0.04	0.02	0.01	-0.03	0.00
3	16-May	22-May	0.00	0.02	0.17	0.03	0.09	**0.10**	0.09	0.00
4	23-May	29-May	0.07	0.01	-0.12	0.05	0.06	0.16	0.01	0.08
5	30-May	5-Jun	0.02	0.00	0.09	0.06	**0.12**	0.03	**0.11**	0.05
6	6-Jun	12-Jun	**0.15**	0.05	0.00	-0.03	0.08	-0.02	0.09	0.07
7	13-Jun	19-Jun	0.13	0.08	0.04	-0.02	0.02	0.11	0.09	**0.11**
8	20-Jun	26-Jun	0.12	0.08	0.04	0.02	0.06	0.10	0.05	0.06
9	27-Jun	3-Jul	0.04	0.00	0.04	**0.17**	0.02	0.08	0.11	0.02
10	4-Jul	10-Jul	0.02	0.08	0.06	0.08	0.02	0.06	0.09	0.16
11	11-Jul	17-Jul	0.14	0.09	**0.11**	0.11	0.03	0.11	0.05	0.07
12	18-Jul	24-Jul	0.08	0.09	0.07	0.13	0.02	0.11	0.04	0.04
13	25-Jul	31-Jul	0.06	0.05	0.12	0.11	0.13	0.07	0.06	0.03
14	1-Aug	7-Aug	0.08	**0.12**	0.06	0.11	0.09	0.04	0.04	0.06
15	8-Aug	14-Aug	0.08	0.06	0.07	0.09	0.07	0.03	0.07	0.07
16	15-Aug	21-Aug	0.02	0.04	0.03	0.03	0.02	0.02	0.11	0.10
17	22-Aug	28-Aug	0.05	0.05	0.05	0.08	0.01	0.02	0.10	0.09
18	29-Aug	4-Sep	0.06	0.10	0.05	0.04	0.02	0.06	0.06	0.04
19	5-Sep	11-Sep	0.06	0.10	0.05	0.03	0.03	0.06	0.03	0.05
20	12-Sep	18-Sep	0.06	0.08	0.04	0.04	0.02	0.05	0.04	0.04
21	19-Sep	25-Sep	0.03	0.06	0.08	0.03	0.03	0.03	0.02	0.04
22	26-Sep	2-Oct	0.01	0.02	0.12	0.02	0.05	**-0.01**	0.00	0.03
23	3-Oct	9-Oct	0.00	0.01	0.05	0.01	0.02	-0.03	0.00	**-0.01**
24	10-Oct	16-Oct	**-0.03**	0.03	0.00	**-0.01**	**-0.01**	0.01	**-0.01**	-0.03
25	17-Oct	23-Oct	-0.03	0.00	**-0.01**	-0.02	-0.03	-0.02	-0.03	-0.05
26	24-Oct	30-Oct	-0.08	**-0.06**	0.00	-0.05	-0.03	-0.03	-0.03	-0.05
27	31-Oct	6-Nov	-0.05	-0.04	-0.02	-0.06	0.02	-0.05	-0.04	-0.05
28	7-Nov	13-Nov	-0.08	-0.05	-0.07	-0.06	0.00	-0.06	-0.04	-0.06
29	14-Nov	20-Nov	-0.09	-0.07	-0.05	-0.07	-0.03	-0.06	-0.04	-0.06
30	21-Nov	2-Dec	-0.04	-0.07	-0.05	-0.07	-0.05	-0.06	-0.06	-0.06
31	3-Dec	9-Dec	-0.07	-0.08	-0.06	-0.06	-0.05	-0.07	-0.06	-0.06
32	10-Dec	16-Dec	-0.06	-0.05	-0.01	-0.07	-0.06	-0.06	-0.07	-0.06
33	17-Dec	23-Dec	-0.05	-0.06	-0.07	-0.06	-0.07	-0.07	-0.07	-0.07
34	24-Dec	30-Dec	-0.07	-0.05	-0.07	-0.07	-0.07	-0.06	-0.07	-0.06

1.6 Land use

1.6.1 JICA land use classes

Table 22 Original JICA land use classes

Class ID	*Category*	*Class*
1	Urban, Built-up areas	Settlement
2	Urban, Built-up areas	Infrastructure (Airfield, factory, etc.)
3	Agricultural lands	Paddy field
4	Agricultural lands	Receding and Floating rice fields
5	Agricultural lands	Field crop
6	Agricultural lands	Swidden agriculture (Slash and burn)
7	Agricultural lands	Orchard
8	Agricultural lands	Plantation (Rubber plantation)
9	Agricultural lands	Village garden crop
10	Agricultural lands	Garden crop
11	Agricultural lands	Paddy field with villages
12	Grasslands	Grassland (Undifferentiated)
13	Grasslands	Abandoned field covered by grass
14	Grasslands	Flooded grassland
15	Grasslands	Grass Savannah
16	Grasslands	Grass with termite mounds
17	Grasslands	Marsh and swamp
18	Shrublands	Shrubland (Undifferentiated)
19	Shrublands	Abandoned field covered by shrub
20	Shrublands	Flooded shrub
21	Shrublands	Woodland and scattered trees (C < 10%)
22	Forest covers	Evergreen broad leafed forest
23	Forest covers	Coniferous forest
24	Forest covers	Deciduous forest
25	Forest covers	Dry Deciduous (Open) forest
26	Forest covers	Mixed forest from evergreen and deciduous species
27	Forest covers	Riparian forest
28	Forest covers	Bamboo and Secondary forests
29	Forest covers	Flooded forest
30	Forest covers	Mangrove forest
31	Forest covers	Degraded mangove forest
32	Forest covers	Forest plantation
33	Water features	Lakes (>8 ha)
34	Water features	Lakes (<8 ha)
35	Water features	Reservoir
36	Water features	Shrimp/Fish farming and Salt pan
37	Water features	Others (Sea, bay, etc.)
38	Soils and Rocks	Barren land
39	Soils and Rocks	Sand bank

1.6.2 Calculated land use class surface areas according to elevation

Table 23 Surface area (square kilometers) of Bayesian Belief Network land use classes depending on elevation.

Water level (m)	*Urban*	*Grass*	*Shrub*	*Forest*	*Water & Soil*	*Total*
1-2	0.23	241.18	753.81	125.59	1312.68	2433.49
2-3	0	247.82	625.21	42.33	24.86	940.22
3-4	0	347.55	810.22	6.62	29.75	1194.14
4-5	0	405.04	880.88	9.04	18.57	1313.53
5-6	0	472.48	778.24	9.27	14.99	1274.98
6-7	0	777.8	387.74	2.83	11.97	1180.34
7-8	0	1081	131.78	1.52	12.29	1226.59
8-9	0.23	1251.05	29.92	0.36	8.86	1290.42
9-10	4.36	981.1	9.09	1.03	5.53	1001.11
10-road	14.76	1477.3	74.92	17.51	14.75	1599.24
Total	19.58	7285.74	4482.83	220.53	2830.38	14839.06

1.6.3 Land use class distribution

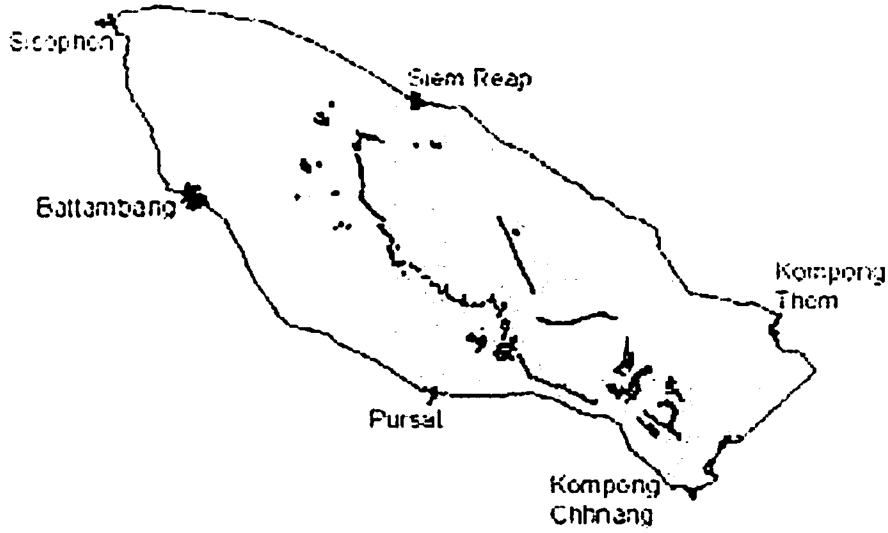

Figure 15 Spatial distribution of Bayesian Belief Network model floodplain vegetation, *Forest* parameter for the landuse node.

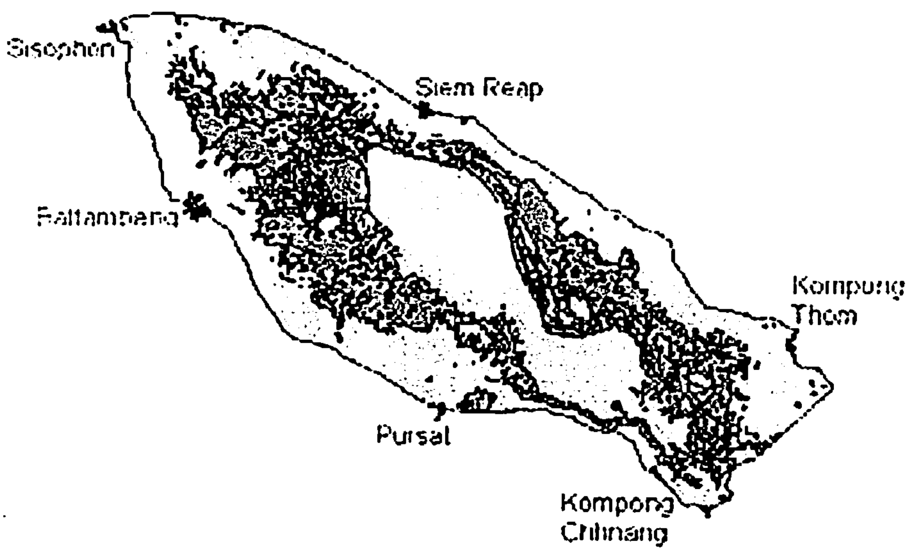

Figure 16 Spatial distribution of BBN model floodplain vegetation, *Shrub* parameter for the landuse node.

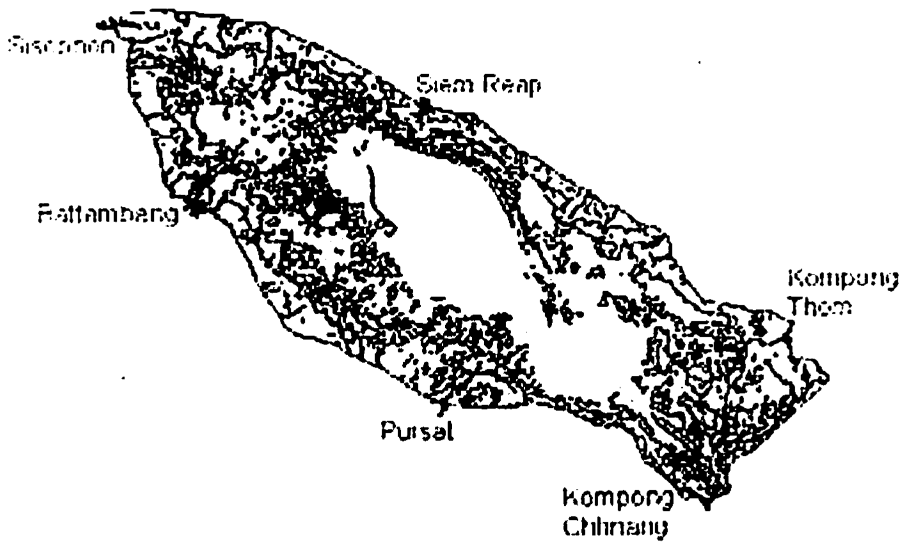

Figure 17 Spatial distribution of BBN model floodplain vegetation, *Grass* parameter for the landuse node.

1.7 Dissolved oxygen

Table 24 Dissolved oxygen (milligrams per liter) statistics by station. Comparison between standard deviation when all stations are selected and when unfit stations (marked bold) have been removed.

Station	*Average*	*Max*	*Min*	*No. of samples*	*Years*	*Notes*
PNK1	4.34	11.60	0.00	45	2001-	2001 from Jul.
PNK2	6.63	16.50	0.30	68	2001-	2001 from Jul.
PNK3	6.14	11.20	0.50	52	2001-02	2001 from Aug.
PNK4	**5.97**	**8.60**	**1.40**	**9**	**2001-02**	**Dec-Jan**
PNK6	**5.40**	**5.60**	**5.20**	**2**	**2002**	**Jan**
KGL1	5.90	13.10	0.20	136	1995-	Almost annual
KGL2	7.04	13.80	0.10	109	2001-	2001 from June
KGL3	**4.07**	**8.90**	**0.30**	**10**	**2001**	**Aug-Dec**
KCH1	5.40	8.50	2.50	90	1995-2002	Almost annual
All stations			*Total*	521		
St Dev	0.98	3.32	1.71			
Selected stations			*Total*	500		
St Dev	0.96	2.70	0.95			

Table 25 Dissolved oxygen percentages from MRCS/WUP-FIN data.

Year 2000		Percentage of Dissolved Oxygen levels			
Layer	*Vegetation*	*< 2 (mg/l)*	*2-4 (mg/l)*	*> 4 (mg/l)*	*Sum*
Vertical averages	Grass	60	25	15	100
	Shrub	69	24	7	100
	Forest	32	53	15	100
Surface	Grass	49	31	20	100
	Shrub	58	31	11	100
	Forest	19	57	24	100
Middle depth	Grass	56	27	17	100
	Shrub	65	26	9	100
	Forest	28	53	19	100
Near bottom	Grass	78	15	7	100
	Shrub	88	10	2	100
	Forest	64	32	4	100
Year 1997		*Percentage of Dissolved Oxygen levels*			
Layer	*Vegetation*	*< 2 (mg/l)*	*2-4 (mg/l)*	*> 4 (mg/l)*	*Sum*
Vertical averages	Grass	51	28	21	100
	Shrub	65	20	15	100
	Forest	27	37	36	100
Surface	Grass	39	33	28	100
	Shrub	56	24	20	100
	Forest	17	40	43	100
Middle depth	Grass	49	27	24	100
	Shrub	62	21	18	101
	Forest	23	37	40	100
Near bottom	Grass	72	17	11	100
	Shrub	82	12	6	100
	Forest	50	27	23	100
Year 1998		*Percentage of Dissolved Oxygen levels*			
Layer	*Vegetation*	*< 2 (mg/l)*	*2-4 (mg/l)*	*> 4 (mg/l)*	*Sum*
Vertical averages	Grass	54	21	25	100
	Shrub	72	16	12	100
	Forest	37	29	34	100
Surface	Grass	41	25	34	100
	Shrub	62	20	18	100
	Forest	27	29	44	100
Middle depth	Grass	51	21	28	100
	Shrub	69	17	14	100
	Forest	34	28	38	100
Near bottom	Grass	73	16	11	100
	Shrub	87	9	4	100
	Forest	59	30	11	100

1.8 Hydrological data frequency distributions

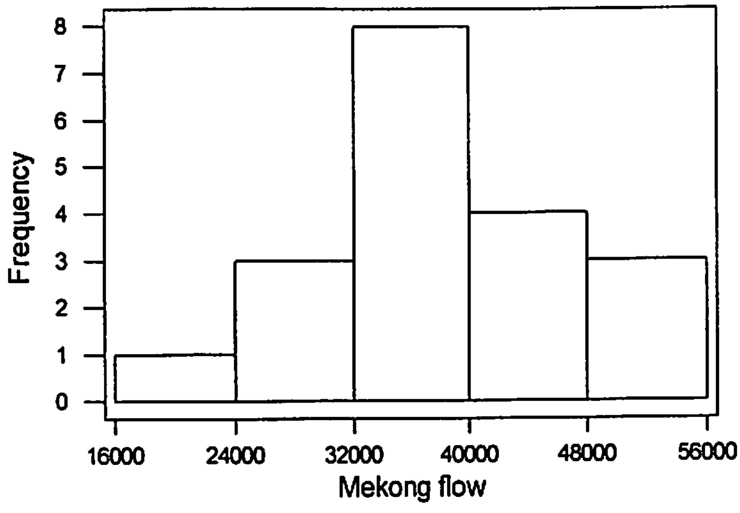

Figure 18 Frequency distribution of Mekong flow (MCM) towards the Tonle Sap Lake from 1985 to 2003.

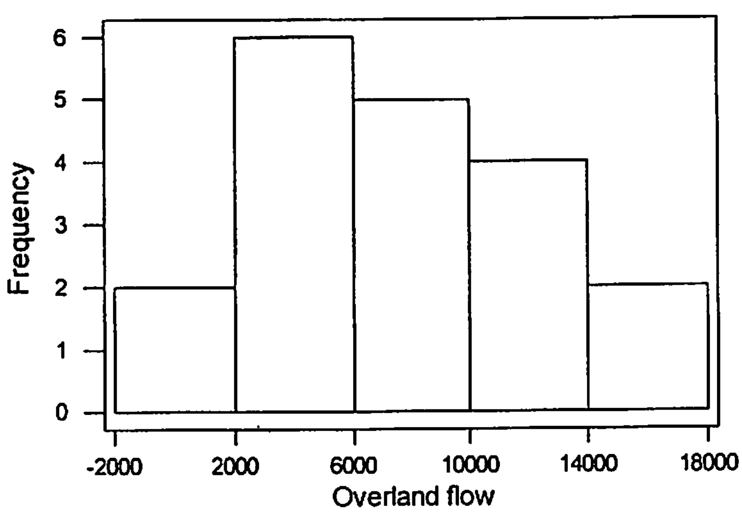

Figure 19 Frequency distribution of overland flow (MCM) towards the Tonle Sap Lake from 1985 to 2003.

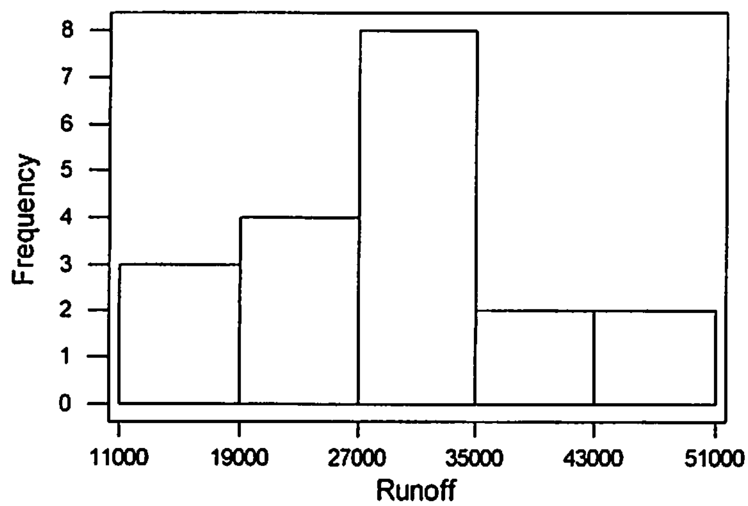

Figure 20 Frequency distribution of rainy season Tonle Sap tributaries runoff (MCM) from 1985 to 2003.

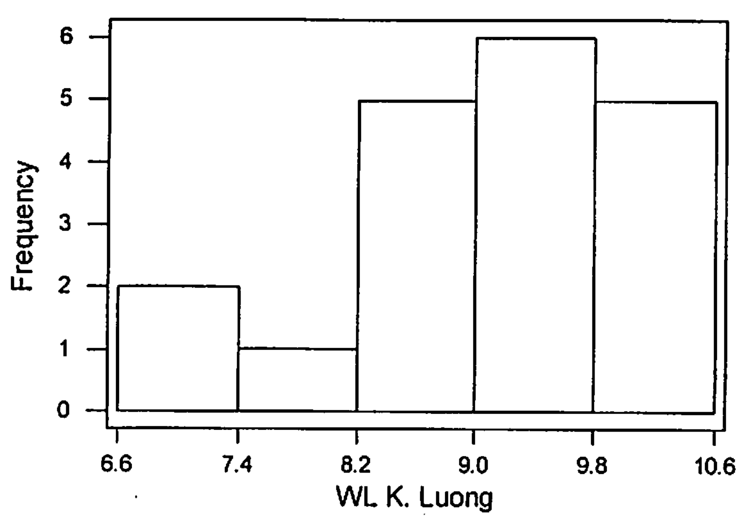

Figure 21 Frequency distribution of Kampong Loung maximum water level (m) from 1985 to 2003.

1.9 Bayesian Belief Network model output

Table 26 Bayesian Belief Network model output probabilities comparison depending on different datasets used. Only probabilities which changed have been noted in the table.

Node	*Parameter*	*Suggested*	*Long ppt*	*Daily difference*	*Weekly difference*	*Ha Tien*
Precipitation	Good	54.5	57.1			
	Bad	45.5	42.9			
Tonle Sap Runoff	Above mean	54.1	55.1			
	Below mean	45.9	44.9			
Overland flow	Above mean	42.9				
	Below mean	57.1				
Mekong flow	Above mean	47.6				
	Below mean	52.4				
Tonle Sap water level	More 9m	55	55.2			54.7
	Less 9m	45	44.8			45.3
Flood beginning	Before	47.6		60	60	
	After	52.4		40	40	
Flood duration	Longer	42.9		40	50	
	Shorter	57.1		60	50	

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Fisheries Component

INFLUENCE OF BUILT STRUCTURES ON TONLE SAP FISH RESOURCES

Prepared by

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CONTENTS

INTRODUCTION

1. Fish and fisheries in many tropical river systems are strongly affected by the natural flood regimes and factors that affect these flood regimes (e.g. Welcomme and Halls 2004; Sparks 1995; Junk *et al.* 1989). These river systems are also subject to a variety of developmental pressures, including modified flow regimes, habitat loss, land use change and intensive exploitation of aquatic resources (Arthington *et al.* 2004). It is also suggested that in many cases the planning of many such developments has focused on commercial uses of natural resources, such as agriculture, and taken much less account of other uses, such as subsistence fishing (e.g. Islam and Braden 2006; Oosterbaan 1988). In order to mitigate the negative impacts of developmental activities that involve the construction, modification or removal of structures that affect the flood regime it is important therefore to better understand the effects that they have. This study has looked at three types of structures: a large scale irrigation scheme, floodplain road construction and large scale fishing gear in order to provide some insights into these structures that could inform future decision-making.

2. Built structures have the potential to impact, both positively and negatively, all fish species through the variety of effects, both direct and indirect, that they can produce. These effects, including, but not limited to, changes in hydrology, habitats and patterns of exploitation, can impact fish locally, and even result in transboundary impacts. Evidence of the impacts of built structures have mostly centered around the effects of irrigation and hydroelectric schemes and channelling of rivers (e.g. Nguyen-Khoa *et al.* 2005; Warren 2000; Halls *et al.* 1999; Bailey and Cobb, 1984; Bernacsek, 1984). These studies suggest that these types of built structures can result in a variety of impacts, often with negative impacts on the fisheries as a result of a reduction in or change to aquatic habitat (including connectivity) or changes to and on fish migration and reproduction. However, some positive effects of irrigation and hydroelectric schemes have also been described, primarily arising from associated higher dry season water levels.

3. Roads can also affect fisheries because they can also alter hydrology and sedimentation regimes, consequently affecting the nature of the aquatic habitats and the fish associated with them (Roni *et al.* 2005; Gibson *et al.* 2005; Duke *et al.* 2003; LaMarche and Lettenmaier 2001; Sidle *et al.* 1985). Finally, large-scale fishing gears can affect the movement, migration and presence of fish (by design) but may also have less direct effects on fish by affecting water movement, retention and quality (e.g. Kurien *et al.* 2006)

4. In examining the effect of built structures on fish it is important to understand the nature of the fish species that are being affected. Fish in river-floodplain systems can be categorized as belonging to one of three groups based on their spawning and migratory behavior (see also the fish bioecology-hydrology report). These are white fish (e.g. *Cyclocheilichthys* sp., *Henichorhynchus* sp. and *Paralaubuca* sp.), which migrate upstream to spawn in the main channels and whose fry drift downstream on the currents and then onto the floodplains, black fish (e.g. *Channa striata* and *Anabas testudineus*) which are largely resident on the floodplain and which spawn on the floodplain, and finally the grey fish, a group intermediate between black-fishes and white-fishes (Welcomme 2001; Lévêque and Paugy 1999). Species of this group undertake short migrations between the floodplains and adjacent rivers and tributaries and may also make similar short migrations between permanent and seasonal floodplain water bodies (Welcomme 2001).

5. White fish, because of their more complex spawning and recruitment requirements are considered to be the group that could most easily be affected by hydrological modifications as they are widely distributed, vulnerable to changes to the main channel and, along with the other types, to floodplain modifications, and, in addition, require connectivity between habitats (e.g. Poulsen *et al.* 2002).

I METHODS AND TOOLS

I.1 APPROACH AT THE BASIN AND SUB-BASIN SCALES

6. At the Mekong Basin and Tonle Sap sub-basin levels, this project did not make plans for specific fieldwork, so conclusions are based on previous work and a literature review.

I.2 APPROACH AT THE LOCAL SCALE

7. At the local level, the fisheries component has been designed to provide information that will complement the information generated from the other components and thereby contribute to the overall assessment. Based on discussions between components, the specific objectives of the fisheries surveys were identified as:
    1. Identify how built structures have modified:
        a) habitats (created/increased/reduced)
        b) fishing opportunities, including changes in access to habitats
        c) fish catches and fish populations
    2. Generate new information on fish ecology in the Tonle Sap

8. The survey has been designed to generate general information on these aspects rather than providing detailed quantitative information. Where such quantitative information is required it was suggested that supplemental questions should be integrated into the household surveys being undertaken through the livelihoods and socioeconomic components.

9. Three sites were selected for the study: an irrigation scheme at Stung Chinit, a large scale fishing gear at Prek Toal and rural roads in Pursat. Stung Chinit was selected as there are two major environmental concerns associated with such schemes: the impact of barriers on migratory fish and the impact of the use of pesticides and fertilisers in the project area. Unfortunately, because the scheme only started operating earlier this year it is too soon to be able to look at the effect of agricultural inputs and the study concentrated on the first concern. This should provide useful information that can be used by planners considering irrigation schemes.

10. Pursat is the site of many proposed developments, including irrigation developments, roads and canals. Given the relatively flat nature of the area, constructions that divert or retain water could have quite significant local hydrological effects. Studying the effect of the rural road structure at this site could provide useful insights into the effect of such potential barriers on fisheries and how these effects can be enhanced (if positive) or mitigated (if negative), which could be useful during the implementation of the planned developments.

11. The extensive fishing gears (a 35km long bamboo barrage) at Fishing Lot #2 near Prek Toal serve to concentrate the fish leaving the floodplain making them easier to catch. Given the extent of the gears it is possible that they could significantly affect local hydrological regimes, fish species and local livelihoods (e.g. Kurien *et al.* 2006). While these gears are also present at other fishing lots, the productivity of the area around Prek Toal makes this a most suitable site at which to study the effects of the structure.

12. The type of structure and its operation meant that the approach taken by the fisheries component survey team differed at each site. For Stung Chinit, a site containing a recently completed built structure, the survey concentrated on identifying the changes and effects due to the structure by comparing the fisheries situation before and after completion. For Prek Toal, where the structure has been in use for a long time, the survey team also surveyed a nearby area that was managed without a similar structure to identify differences in fishing practices and outcomes that could be attributed to the structure. Finally, in Pursat a mixed approach was taken by comparing the situation before and after with villagers who might be directly affected by the structure, and also comparing villagers nearby who were not affected by the structure.

13. A major issue that had to be carefully considered in developing the survey methodology and content was the clear trade-off between the quantity and detail of the information collected on the one hand and the needs of the participating fishers on the other. In particular the methodology was developed with the aim of keeping the respondents engaged in order to enable discussions to develop and answers to be explained. It was important that the fishers were not allowed to get bored and were not kept too long as if the respondents get bored or restless the quality of information is likely to suffer (e.g. Silver and Campbell 2005).

14. Given this approach, a methodology was developed that could generate information related to the objectives by utilizing the detailed time and place knowledge of local expert fishers. The types of information to be collected are directly related to the objectives and based on subject areas identified by the domestic fisheries specialist.

15. In accounting for the fact that the fish fauna in Cambodian inland waters comprise a mixture of black, white and grey fish, a bio-ecological review was undertaken that involved merging the FishBase and MRC Mekong Fish databases, a method similar to that employed by Baran *et al.* (2005) for Lao PDR, and using information from a number of other sources (see Annex A). The aim of this was to identify homogenous groups ("guilds") of fish species that have similar ecological conditions and that are thus likely to be similarly influenced by built structures. With regard to fish catches, populations and ecology, the methodology incorporates the materials developed by the domestic fisheries specialist from the review of bio-ecological information on Tonle Sap Lake fish species.

I.3 METHODOLOGY AT THE LOCAL SCALE

16. It is well recognized that fishers and others dependent upon natural resources have a wealth of time and place knowledge that can be valuable for management decision-making within fisheries (e.g. Jentoft 2000; Bergmann *et al.* 2004; Dubois 2005; Garaway *et al.* 2006; Wilson *et al.* 2006). The survey methodology therefore sought to access local ecological knowledge relating to each of the specific survey objectives.

17. In gathering local ecological knowledge, experiences have suggested that the use of closed, questionnaire type surveys are less appropriate and that less structured, and more visual, participatory appraisal type methodologies have been suggested (e.g. Pido *et al.* 1996). However, these methodologies require a certain level of skill and familiarity with their use if they are to be successful.

18. As a result of pre-testing of methodologies, a survey methodology was developed that was comfortable for the data collectors to use and that included elements of both formal questionnaires as well as visual methodologies, such as mapping and the use of fish picture cards for species identification (see Annex B). The actual survey at each site was preceded by a pre-survey that was intended to see if there were any additional factors that would need to be accounted for in the full survey and to identify the respondent groups who would provide the information. The results from the pre-surveys are provided in Annex C. During the pre-survey, criteria were developed that could be used at each site to identify suitable fishers and help ensure that the information that they were able to provide covered an adequate time period and geographical area. The criteria for selection of expert fishers were as follows:
    - between 40 and 60 years old;
    - having 10-15 years fishing experience;
    - currently actively fishing;
    - well-known for fishing skills in the village, and
    - fishers selected from different locations in the same village to potentially provide information on all fishing locations.

19. The local fisheries officer and village and commune headmen were asked to identify knowledgeable fishers in the survey locations who met the above criteria, and to contact them to see if they would be willing to take part in the surveys in groups of three. This provided a total of between sixty and eighty experienced and knowledgeable fishers for each study site.

20. In order to separate the effect of the built structure from other factors that have been, and are, affecting hydrological conditions and fisheries, respondent groups were asked first about aspects of the fishery, e.g. patterns in fishing effort, changes in fish size and fish prices, and what they thought were the reasons for any observed change. They were then asked what effect they thought that the built structure had had and for their perceptions of the positive and negative impacts of the built structure and how any negative impacts might be mitigated (see Annex B).

II RESULTS

II.1 MEKONG SCALE

II.1.1 Water management basinwide

21. Water coming from the Mekong (either through the Tonle Sap River or overland during floods) represents 60% of the Tonle Sap water (Koponen *et al.* 2007 and Figure 1). This means that the development of built structures upstream of the Tonle Sap sub-system would have a significant impact on the lake's hydrology.

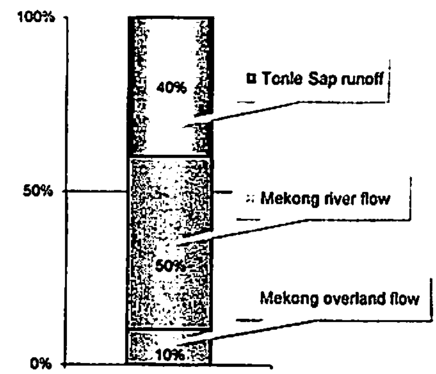

Figure 1: Contribution of the Mekong to the Tonle Sap water level (Koponen *et al.* 2007)

22. In fact Laos contributes 19 percent of Tonle Sap water, and while China and Thailand contribute 9 and 10 percent respectively. This calculation is possible knowing the contribution of each country to the Mekong annual flows (see Table I), the contribution of Mekong flows to Tonle Sap flows (see above) and the share of Mekong annual average flow at the level of Phnom Penh (i.e. 93.3 percent of the total Mekong flow).

Table I: Contribution of riparian countries to Mekong and Tonle Sap flows

	Contribution to Mekong flows (%)	Contribution to Tonle Sap flows (%)
Laos	35	19
Cambodia	18	-
Thailand	18	10
China	16	9
Vietnam	11	-
Myanmar	2	1

II.1.1.1 Mekong flows and built structure development

23. The degree of inundation in the Mekong depends on the strength of the annual monsoon, as 85-90% of the discharge is generated during the wet season. However, the average wet season discharge in the last twenty years (1979-98) appears to be at least 10% lower than in 1924-1956, while the inter-annual variations have become more extreme (Nam Sokleang 2000). The downward trend seems to be independent of fluctuations in rainfall and therefore has been linked to dam building activities that started in the late fifties in the basin (Van Zalinge *et al.* 2003). White (2000) also identified dams as the projects that pose the highest degree of systematic risk to the region, under criteria that include displacement of vulnerable people, impact irreversibility, environmental impacts on the mainstream river flow and quality, and economic impact.

24. In the Mekong Basin according to the MRC (2003), thirteen hydropower dams of a capacity higher than 10 megawatts existed in 2003: two in China on the mainstream, 5 in Laos, 4 in Thailand and 2 in Vietnam, the latter nine being on tributaries, for a total production of 4,400 megawatts (15% of the basin's hydropower potential estimated at 30,000 megawatts). Many more are under construction or being planned, including at least six in China and "a number" in Laos[1]. There is also "a positive attitude towards hydropower development" in Vietnam (MRC 2001), as attested to by the recent plans of Electricity of Vietnam to build 173 new hydroelectric power stations with a total capacity of 2,296 MW to supplement the existing 500 small and medium sized hydroelectric power stations[2]. Until recently no new major dams were planned in Thailand and Cambodia, but this is changing quickly. In Cambodia, the government "places high priority on attracting increased private sector investment and participation in electricity production and distribution"[3] and the Prime Minister of Cambodia has recently requested the Chinese ambassador in Cambodia "to attract her country's companies to invest in hydroelectric power generation"[4]

Table II: Sites with existing hydropower capacity or proposed for development in Cambodia

River/Site	Multi-site
Sre Pok	3 sites in Cambodia: 787 MW. 7 sites in Viet Nam: 841 MW
Se San	2 sites in Cambodia: 582 MW / 3042 GW; 5 sites in Viet Nam: 1516 MW
Se Kong	2 sites in Lao PDR: 390 MW / 1269 GW
O Phlai	4 sites; 21 MW / 147 GW
Stung Pursat I	4 sites: 96 MW / 485 GW
Prek Liang	3 sites: 121 MW / 581 GW
Prek Por	3 sites: 34 MW / 204 GW
Prek Ter	3 sites: 50 MW / 269 GW
Stung Battambang	3 sites: 73 MW / 384 GW
Prek Chhlong	2 sites: 31 MW / 203 GW
Prek Kam	2 sites: 8 MW / 53 GW
Prek Kreing	2 sites: 14 MW / 85 GW
Prek Rwei	2 sites: 12 MW / 128 GW
Stung Mongkulborey	2 sites: 14 MW / 97 GW

River/Site	Single site
Mekong Sambor 2	3300 MW / 14870 GW
O Chum II	1 MW / 4.4 GW
Kamchay	180 MW / 550 GW
Prek Chbar	5 MW / 32 GW
Stung Atay	110 MW / 588 GW
Stung Cheay Areng	260 MW / 1350 GW
Stung Chikreng	2 MW / 8 GW
Stung Chinit	5 MW / 23 GW
Stung Sreng	7 MW / 69 GW
Stung Staung	4 MW / 23 GW
Stung Sva Slapp	4 MW / 20 GW
Stung Tanat	4 MW / 27 GW
Stung Tatay	80 MW / 250 GW
Stung Treng	980 MW / 4870 GW
Upper Prek Ter	15 MW / 77 GW
Upper Stung Siem Reap	1.7 MW / 7 GW

Capacity installation (MW) / *Energy production* (GW)
Sources: Sources: Hydroelectricity Department, Ministry of Industry, mines and energy; MRC Hydropower development strategy 2001; Cambodge Nouveau n° 215 and 241

25. This assessment only refers to hydropower dams of medium or large size, which do not consume water but only alter the flow regime and fragment aquatic habitats. However, these dams are supplemented by thousands of small irrigation reservoirs and weirs that aim at extracting water from the river and thus reduce flow, among other impacts. These small schemes are not individually identified, although they are quite visible on remote-sensing maps, particularly in North-East Thailand (see for instance MRC 2003). In addition to existing ones, multiple smaller schemes are being considered (including 15 dams for

[1] This includes, according the Vientiane Times (28 March 2006) plans for a 240 MW dam at Khone Falls, more specifically at Don Sahong. Such dam would have a very significant negative impact on dry season migrations, since Don Sahong is the only channel that fish can use to migrate from Cambodia to Laos during the dry season.
[2] Vietnam Economic Times, 04 August 2005. This covers the whole of Vietnam, not just the share of the Mekong Basin lying within Vietnam.
[3] Rectangular Strategy, side 3, Development of the energy sector and electricity network. This approached is balanced by a commitment to "enabling a supportive fisheries and ecological system" (side 2 of the rectangular strategy).
[4] Phnom Penh Post, 1-14 December 2006

irrigation purposes, mainly in Thailand and Vietnam). The Vietnam National Mekong Committee (2003) states that currently there are 580 irrigation projects of various size within the Sesan and Srepok basins (major Mekong tributaries) in Vietnam only, servicing at least 46,180 hectares of rice paddies and coffee plantations in the central highlands. The irrigation water demand of crops in the Sesan and Srepok basins in Vietnam is estimated to grow by 36%, from 2.8 in 2001 to 3.8 billion m^3/year by the year 2010. The projected water demand in dry season represents 63% of the total runoff, an unrealistic quantity to extract without extensive water development infrastructure. Consequently, further development - and rehabilitation- of irrigation schemes are planned. About 658 irrigation works are expected to be constructed in the Gia Lai, Dak Lak and Kon Tum provinces.

II.1.1.2 Water allocation mechanisms and fisheries economics

26. To date, scientifically underpinned comprehensive water allocation mechanisms have not been set for the Lower Mekong Basin (Petersen 2003). Among the preliminary works, the model proposed by Ringler (2000, 2001) to determine the optimal allocation of water resources in the Mekong Basin should be mentioned. Unfortunately, lack of data and data unreliability hampered the predictive power of the model (Johnston *et al.* 2003). Ringler finds that artificial diversions of water from the Mekong could readily cause negative impacts on fisheries and saltwater intrusion into the Mekong Delta during the dry season.

27. Table III shows that total profits from optimal water allocation and use were estimated at USD 1.8 billion in 1990, irrigated agriculture ranking first with USD 917 million and fish catches second with USD 546 million. Vietnam obtains the greatest benefits from basin water uses, contributed chiefly by irrigated agriculture and fish production. Profits from hydropower are largest in Laos, and fish catch and wetlands are the major water-related income sources in Cambodia. One must note that this scenario is based on data available in 1999, when total Mekong fisheries catches amounted to 1 million tons, not 2.6 or 3.2 million tons as per recent estimates.

Table III: Baseline scenario profits from water use in million USD (Ringler 2001)

Country/region	Irrigation	Municipal & Industrial	Hydropower	Fisheries	Wetlands	Total
Yunnan, PRC	20	11		0.05		31
Lao PDR	38	6	33	19	5	101
Thailand	320	65	10	151	4	551
- N Thailand	52	5		10		68
- NE Thailand	268	60	10	141	4	483
Cambodia	26	7	7	188	80	301
Vietnam	513	81		188	44	825
- VN, Central Highland	29	6				35
- VN, Mekong Delta	484	75		188	44	790
Total Basin	*917*	*170*	*43*	*546*	*134*	*1,809*

28. To our knowledge no socioeconomic analysis has been done at the scale of the whole Mekong Basin. At the moment the Mekong River Commission is developing a simple resource allocation and optimization model (RAOM) similar to Ringler's model, but drawing on recent hydrological information to examine how water resources in the Lower Mekong Basin (LMB) can be allocated among various water-consuming activities and functions. The values used to run the model are simply unit estimates, and integration of environmental flow requirements is in principle possible, depending upon the progress that is made with current valuation initiatives by partners (Johnston *et al.* 2003).

29. The MRC and Halcrow Ltd. have also set up a Decision Support Framework (DSF) that consists of a suite of data analysis software and models intended to assess the magnitude and impact of changes in the water-resource system (Halcrow 2004a). These tools are supposed to allow macro-level sustainability analyses and potentially impacted population analyses. However, the nature and contents of these tools are not detailed in the sixteen volumes of documentation about the DSF, and the "*meaningful socio-economic assessment of future development scenarios will require a more detailed set of data*" than the current MRC Social Atlas, and "*significant efforts remain to assemble data sets to support socio-economic assessments*" (Halcrow 2004b and c).

30. Overall, the NSF (1998) and Smith *et al.* (in press) found that the diversity of fisheries-related livelihood strategies is poorly represented in practice by socioeconomic analyses and policies.

II.1.1.3 Water management, fisheries and livelihoods

31. In the Mekong Basin, the bulk of the catch originates from part-time and subsistence fishers rather than from those classified as full-time fishers (Dixon *et al.* 2003). According to that study, in the three Lower Mekong countries studied, the majority of full-time fishers categorise themselves as very poor, and also highly dependent on others for finance. However, they are considered relatively less vulnerable than agriculturally-based poor who are more subject to seasonal scarcity periods. The majority of part-time fishers also categorise themselves as poor or very poor. The third group of subsistence fishers includes landless labourers, women, children and small farmers. They range from very poor to rich and in most cases are not fully dependent upon fisheries for income-generation or subsistence. As such, they are less likely to be deeply impacted by a degradation of the wild resource. The fact that inland fisheries are often regarded as an activity for the poor but can also be an activity for the more wealthy was noted by Béné and Neiland (2003), which led Coates *et al.* (2004) to call for a better understanding of how fisheries and their management contribute to, or are affected by, wealth differentiation.

32. The threats to fisheries take place in a context of limited knowledge, if not ignorance, about the extent and importance of natural resources in terms of overall household livelihood strategies. The usual census approach, which consists of thinking in terms of primary and secondary occupations, conceals the importance of diversified activities and particularly of inland capture fisheries to the livelihoods of the Mekong rural poor (Dixon *et al.* 2003; Keskinen 2003)

33. Consultations with local communities (Dixon *et al.* 2003) allowed the identification of two main threats to fisheries common to the three Mekong countries: unsustainably high fishing pressure, and degradation or loss of wetlands and floodplain habitat. The latter was specified as resulting from i) increased agricultural activities (inducing deforestation and agro-chemical pollution), and ii) modification of river-flows by flood control, drainage and irrigation structures or hydropower schemes. Thus, built structures are indeed central to development options and fisheries issues in the basin.

34. Participatory rural appraisal results showed that all of the above challenges and threats to inland fisheries have already reduced the livelihood base of poor people and made them

more vulnerable to hazards from drought and flooding, natural declines in the fish population, inadequate market access and high population growth. However, the study also concluded that in terms of pressing issues, access to fisheries and threats to aquatic resources come after personal and communal poverty issues such as lack of rural infrastructure (roads, clean water sources, sanitation facilities, schools), lack of land for farming rice and crop pests. Normal flooding is not a problem, only exceptional floods are.

II.1.2 Impact of large scale built structures on the basin fisheries

35. Preliminary calculations suggesting a 20% increase in demand for fish in the LMB over the next 10 years (Sverdrup-Jensen 2002), combined with a major threat that fisheries habitats will be reduced due to barriers to migration, conversion of floodplains into agricultural and urban areas, and changes in natural·flow regimes due to dams and irrigation, make the future of Mekong fisheries uncertain. We detail below some of the major changes whose impacts have been at least partly documented.

36. The impacts of dams on Mekong aquatic resources have been highly debated (e.g. Roberts 1995, Siebert 2001, TERRA 2003, FEER 2004). Hill and Hill (1994) first attempted a thorough assessment of the consequences of dams on Mekong fish and fisheries. They highlighted the exceptional ecological importance of the Khone Falls area, the devastating consequences that a dam across the Tonle Sap River would have, the need to consider true "run-of-the-river" dams rather than blocking dams, and overall the absence of appropriate information. In fact their review itself is hampered by a systematic lack of data.

II.1.2.1 Gaps and flaws in assessments

37. Ten years later, specific information on the impacts of dams on fisheries is still lacking and/or of poor quality. In his review of the Economic Impact Assessment of the Nam Theun 2 dam in Laos, Wegner (1997) takes note of the high value of indigenous fish species and expresses concern that these have not been considered adequately in the impact assessment. Similarly the World Bank (in Amornsakchai *et al.* 2000) acknowledges the fact that for the Pak Mun Dam in Thailand the lack of detailed baseline studies on fisheries has made it difficult to estimate fishery losses in the cost-benefit analysis of the dam. Bernacsek (1997b) notes that aquatic impact assessments were carried out before impoundment in only seven cases out of 40 dams or reservoirs surveyed in the basin.

38. In a scenario analysis prepared for the MRC, Halcrow (2004d) estimated that the impact of five additional large dams in the Lower Mekong Basin would reduce the maximum longitudinal fish migration network by only 1.6%. However, among other flaws and biases, the distances computed include *twice* the length of large streams, with the argument that "*fishes migrate most commonly along either river bank*"! (op. cit., Appendix A). Of course, this bias minimizes the calculated impact of upstream dams on the whole river network open to migrations.

II.1.2.2 Recent breakthroughs

39. In 2004, Podger *et al.* assessed the impact of different water management scenarios on flows and on a number of indices, including a fish habitat availability index (HAI). The study concluded that the expected losses to the HAI range between 1% and 13% for the area downstream from Kratie in northern Cambodia. However, going beyond benign relative values, Barlow (pers. comm.) highlighted the fact that this is a fraction of a huge resource amounting to 2.6 million tons; it can be shown by a pro-rata calculation that this limited relative reduction would correspond, in Cambodia and Vietnam alone, to a loss of 15,000-199,000 tons with a monetary value of USD 10-135 million a year. The livelihood value of this fraction is not known.

40. Baran (2007) has recently detailed the consequences of flow modifications on the Mekong fish production. Several points are highlighted:

41. Development scenarios generally consider that dams will store water in the wet season and release it in the dry season. If dry season flows are indeed increased by infrastructure, then dry season migration thresholds or cues might never be reached, which will inhibit the migration of species sensitive to these low flows. As most migrations occurring in the dry season have a reproductive purpose, the biological impact of increased dry season flows might be on reproduction success. Another consequence would be that most artisanal gears designed to catch species migrating at low water levels could not be operated any longer or would be less efficient at higher water levels, hence a loss of catch and productivity even in the presence of fish.

42. A contrario, it is also hypothesized that significant water abstraction for irrigation might decrease flows in the dry season. Such reduction would have dramatic consequences in Southern Laos if the discharge in the Mekong main stream goes below 2000 $m^3.s^{-1}$, since no catches are recorded for such low discharge levels.

43. Dams, depending upon their operation rules, can also delay the flood onset by buffering the flood pulse. This delay might have a significant negative impact on the fish abundance as the flood onset is playing a strong trigger role in the migration of a majority of commercially important species. Several reports have documented a positive relationship between an early flood and a productive fishing year (cf. Baran *et al.* 2001). According to Welcomme and Halls (2003), in a system where the upstream movement of adults compensates for the downstream drift of larvae, a natural or artificial variation of the flow regime is likely to result in a very different distribution of fry and thus in a fluctuating production in downstream regions; this kind of perturbation has been documented in South America for instance.

44. The basinwide impact of rainy season flow modifications due to large scale built structures such as dams would be minor compared to dry season flow changes. Decreased flood peaks in the rainy season might slightly improve the catchability of fish, and delayed flood peaks might not have a major impact since they happen at a time when fish do not noticeably migrate or breed.

45. The impact of Chinese dams is also feared in the Mekong Delta, though according to Nguyen Minh Quang (2003), the hydrologic impacts of the Manwan Dam observed in Northern Laos are not perceptible in the Mekong Delta. However, the impact of reduced

flows and sediment input on the productivity of Vietnamese coastal fisheries is surprisingly never mentioned, although it was already highlighted by Chevey (1933) seventy years ago. The impacts of dams on coastal fisheries have proven very significant in a number of countries, and assessing them in the case of new damming plans is a recurrent recommendation (Vidy *et al.* 2000; Blaber 2002, Dugan *et al.* 2002; Arthington *et al.* 2004).

II.1.3 Specific impacts of hydrological changes induced by built structures

II.1.3.1 Hydrological migration triggers

46. The Mekong is the river featuring the highest hydrological variability in the world (Welcomme 1985) and its fish fauna display exceptional migratory behaviour. Since these migrations happen on a large scale and are well coordinated, the factors that trigger migrations in the basin have recently been reviewed (Baran 2007). The underlying question concerns the consequences of modifications to the hydrology and hydrodynamics of the river by infrastructure on the fish resource.

47. Migration cues have been documented for 30 out of the 165 Mekong fish species known to migrate; the cues are unknown for the remaining 82% of these migratory species. The literature review identified five major migration triggers in the Mekong: i) discharge, water level and current; ii) rainfall at the end of the dry season; iii) changes in water color and turbidity; iv) apparition of insects; and v) lunar phase (although its role remains unclear and is probably combined with hydrological factors).

48. Ninety percent of Mekong fish species for which migration cues are documented respond to a variation in water level or in discharge. Some fish families are extremely sensitive to hydrological migrations triggers, in particular Pangasiids (catfishes), of which 58% of 19 species are sensitive. In general, catfishes, which include several families, are the group most sensitive to migration triggers. Catfishes have a high value in commercial fisheries and also play a major role in the regional aquaculture sector. Since catfish fingerlings are caught in the wild to be raised in cages[5], the modification of triggers and of the reproductive success of catfishes might result in diminished supply for the whole aquaculture sector in Cambodia and southern Vietnam.

49. Khone Falls is the only stretch of the basin where long-term catch statistics can be coupled with long-term hydrological records. Analyses of the Khone Falls fisheries (Baran *et al.* 2005; Baran 2007) show that *ninety-six per cent* of the total fish biomass harvested year-round in Khone Falls is harvested between 2000 and 8000 $^{m3.s-1}$, i.e. low discharge levels corresponding to the dry season. The most "productive" discharge levels are 2000 and 3000 $m^3.s^{-1}$; they total more than 60% of the annual yield. This dependence of catches on low, dry season discharge levels is due i) to the fish migration waves that occur during the dry season; ii) to the dominance in catches of a few fish taxa that migrate at this season, and iii) to the better catchability of fish at these discharge levels.

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[5] In Cambodia, the aquaculture production of species whose cycle is mastered represents less than 5.5% of the total freshwater fish production. Ninety-four percent of the fish production thus originates from capture fisheries and from wild fingerlings – including catfishes – grown in cages.

50. The conclusion is that the impact, by dams or other built structures, of dry season flow alterations would be dramatic for fishers and food security. This importance makes it a priority area of research to better inform development options. The water allocation rules being developed and used by the MRC and the Mekong riparian countries should in particular integrate the information regarding fisheries and their dependence on low discharge levels.

II.1.3.2 Additional impacts to be considered

51. The evolution of the size of fish caught is a parameter that should be integrated into comprehensive assessments of the impact of built structures. Year after year, total catches seem to contain a higher proportion of less valuable small fish and a lower proportion of medium and big sized fish of high economic value. This evolution is mainly driven by fishing pressure, which tends to select and kill larger individuals or species (Welcomme 1995). However, hydrological changes or jaggedness tends to favour opportunistic fish species, whose reproductive strategy (early age at first maturity, lots of eggs) allows them to cope with environmental variability. These species happen to be small and short-lived (e.g. *Henicorhynchus spp.* or *Trey riel*), and they proliferate at the expense of larger species. The economic impact of this replacement of quality fish by low value fish is invisible in global statistics based on biomass and has never been assessed.

52. In Africa, detailed studies in the Niger Central Delta have shown that a reduction of 75% of the area of floodplains resulted in a 50% loss of the fish harvest, the two dams of the system contributing 10% of these losses (Laë 1992). However, these studies also highlighted that declining natural fish production was blurred by an increased concentration of fishes (hence a higher catchability) and increased fishing efficiency.

II.1.4 Mitigation measures and positive influence of dams on fisheries

53. The negative effects of dams on inland fisheries have been extensively described (WCD 2000) and alternatives or mitigation measures such as fish ladders have been proposed. Warren and Mattson (2000) expressed reservations about the efficiency of such mitigation measures in the Mekong context; Roberts (2001) confirmed the inefficiency of the Pak Mun Dam fish ladder and Baran *et al.* (2001b) showed that the intensity of migrations (e.g. 30 tons of fish caught per hour in the Tonle Sap River during the migration peak) makes fishways unrealistic in most main channels (Jensen 2001).

54. The creation of reservoir fisheries following the creation of a dam is often cited as a compensation for the loss of capture fish. However, out of 160 families living in freshwater, only 17 are fully lacustrine or able to live in lakes at one stage of their lifecycle (Fernando & Holcik 1982), most species having to return to free-flowing rivers to breed. Baran (2007) showed that in the Mekong Basin, nine species only are known to breed in reservoirs such as the ones that could be created behind dams.

55. On the positive side of dam building, additional water reservoirs increase fish production locally (Lagler 1976, Bernacsek 1997b). The latter author gives an equation predicting the catch of a new reservoir:

Catch in tons.year^{-1} = 1.877x(Reservoir area in km^2) – 12x(mean depth in m) + 0.03835x(Affluent inflow volume in mcm.y^{-1})

It should be noted, however, that i) this equation does not integrate the loss in wild fish production down the reservoir (as demonstrated in southern Laos by Lorenzen *et al.*, 2000), and ii) the biological productivity generated by this environmental modification is often concomitant with significant social changes in fisheries, particularly in terms of access rights, wealth distribution and equity (WCD 2000, Hirji and Panella 2003).

56. Among the beneficial impacts of damming are the increased dry season flows that would oppose the annual saline intrusion hampering rice culture in the delta (Feng Yan *et al.* 2004). However, the saline intrusion is also highly beneficial to fish production (abundant coastal fishes entering the delta) and shrimp aquaculture (one kilogram of shrimp being worth about 50 kg of rice), and the trade-offs between these different commodities and their underlying socioeconomic implications remain to be assessed.

II.2 TONLE SAP SCALE

II.2.1 Impact of hydrological changes driven by built structures

57. Observations on the *Dai* fishery for migrating fish in the Tonle Sap River during 1995–2002 indicate that year-to-year variations in maximum Mekong River flood levels strongly affect the yield of this fishery (Van Zalinge *et al.* 2003, Hortle *et al.* 2004), which is dominated by about 40% of short-lived opportunistic species (Baran *et al.* 2001c, van Zalinge *et al.* 2004). According to Starr (2004), very low water levels in 2003 caused the fish catch to decrease by as much as 50%, also causing fish prices to double around the Tonle Sap Lake. Among the 10 dominant taxa in Cambodia listed by van Zalinge *et al.* (2000), four are sensitive to hydrological migration cues: *Cyclocheilichthys enoplos*, *Pangasius spp.*, *Barbonymus gonionotus* and *Paralaubuca typus*. They represent 18% of the total catch and 14% of the commercial value respectively.

58. Some dramatic impact of dams on fisheries in Cambodia have been illustrated by the Yali Dam located in Vietnam on a river flowing down to Cambodia. McKenney (2001) estimated that the erratic flow release of this dam resulted in over USD 2.5 million in lost income in 1999 for 3,434 households. On average, livelihood income per household decreased from about USD 109 per month to USD 46 per month (-57%). Non-quantified impacts of this dam include deaths and illnesses, livestock losses due to suspected water quality problems, and rarefaction of some natural resources. The Fisheries Office of Ratanakiri province (Fisheries Office 2000) as well as Baird *et al.* (2002) confirmed these impacts while emphasizing the losses in fish catches and water quality and the total disruption of local livelihoods.

II.2.2 Impact of water quality and habitat losses

59. Among the threats to fisheries can be listed are chemicals that are widely used in agriculture schemes around the Tonle Sap Lake. Sixty-seven percent of the farmers surveyed used pesticides in 2000 (EJF 2002), with volumes as high as 72 l/ha/year for

vegetables, and 1.3 million litres of pesticides were used in the Tonle Sap catchment area (Yang Saing Koma *et al.* 2001). Many of them are highly hazardous chemicals (including DDT and methyl-parathion) imported from neighbouring countries and used indiscriminately, for instance to harvest fish or to preserve dry fish (FACT 2001, Touch Seang Tana and Todd 2003). Although one study of organochlorine residue levels based on 48 freshwater fishes concluded that Cambodian fishes are among the less contaminated of the region (In Monirith *et al.* 1999), the possible consequences of chemical pollution for the population's health as well as on the environment, have never been quantified on a large scale in Cambodia. These possible consequences were detailed in EJF (2000). Considering the on-going large-scale development of irrigation around the lake, this issue needs to be urgently tackled.

60. One of the issues that recently surfaced is the trapping of sediments and the reduced flow speed that results from dams, particularly those across the mainstream (Sarkkula *et al.* 2003, Kummu *et al.* 2005). Analyses detailed in Plinston and He Daming (2000) showed that about half the sediment reaching the Mekong Delta derives from the Upper Mekong in China. A scenario analysis showed, particularly through mapping of sediment concentrations and sedimentation rates, that flow reduction and sediment trapping by the Chinese dams on the Mekong would have a dramatic impact on the net sedimentation and productivity of the Tonle Sap Lake (Sarkkula *et al.* 2003, Van Zalinge *et al.* 2003, Sarkkula *et al.* 2004, Kummu *et al.* 2005).

II.2.3 Role of fishing structures

61. Several commentators on the fisheries in the Tonle Sap believe that the amount of fish in the lake is dramatically decreasing (e.g. Mak Sithirith 2000; FACT 2001). However, there is also strong evidence that fish stocks have not declined overall but on the contrary that the overall catches at the moment are higher than at any time in the past (Baran *et al.* 2001a, Van Zalinge *et al.* 2001). In fact, the population has increased much faster than the harvest. As a result, the catch per unit of effort or per fisher is falling, and medium and large-size species are becoming rare.

62. Fishing lots provide an example of changes in fishing patterns and conflicting interests: large-scale fishing includes fishing lots that are auctioned for exclusive exploitation of fish resources (Van Zalinge *et al.* 1998). In 1996, these fishing lots covered 80% of the Tonle Sap's shoreline (Gum 2000). Following social pressure, 56% of the total area of the private fishing lots was converted in 2000 into open access areas to allow the poor to benefit from the fisheries (Royal Government of Cambodia cited in Keskinen 2003). However, fishing lots are also regarded by biologists as a good way to combine exploitation, environmental protection (Chheng Vibolrith 1999), and even biodiversity conservation (Coates *et al.* 2003). Hence, there is a dilemma between a management system "socially unjust" (as the fruits of the resource are captured by a few operators) that contributes somehow to conservation, and an open access system "socially more fair" but likely to result in unrestricted exploitation levels jeopardizing the resource.

II.3 LOCAL SCALE

II.3.1 Description of the study sites

II.3.1.1 Pursat

63. The fisheries resources available to villagers in Pursat were dependent upon the local topography. While the entire area is relatively flat, the land slopes in two dimensions. The first is the slope of the floodplain from the main road (National Road number 5) down towards the Tonle Sap Lake. The second dimension is that the ground also slopes from beyond Krang Veng village on the one side and around Moat Prey village on the other down towards Chong Khlong and Doung Chua villages. On the other side of Moat Prey, the ground slopes down from around Moat Prey past Kampong Lor village. Both of the lower points were the site of canals that run between the canal parallel to National Road number 5 and the Tonle Sap. According to the fishers interviewed, higher areas are characterised by lower abundance of fish so that the area around Moat Prey, because of the relative height of the land, has relatively low fish abundance.

64. Generally fishers are permitted to fish anywhere around the villages and they are using a variety of fishing places including the nearby rice fields and canals. In addition, fishers from all the villages also fished further down the floodplain in flooded areas and small lakes as well as in the Tonle Sap Lake itself. In terms of restrictions, in Doung Chua there has also been a change in that fishers for the village no longer fish in Ka Cheng pond because this pond has now come under private ownership. Related to the built structure, there has been a regulation put in place by the village road committee that fishers should not obstruct the culverts and gates with their fishing gears.

65. In terms of location (see Figure 2) the villages in the area can be classified depending upon their location relative to the built structure that is enclosing a part of the floodplain. Thus, villages are either outside (Doung Chua and Krang Veng), inside (Moat Prey) or situated on the edge of the structure (Kampong Lor, Ou Ta Prok and Chong Khlong). In order to investigate the effects of the small floodplain road at this site it was decided that the views of fishers at each of these locations relative to the road would be sought, and this difference in location relative to the structure was used in the analysis of the context and effects of the structure.

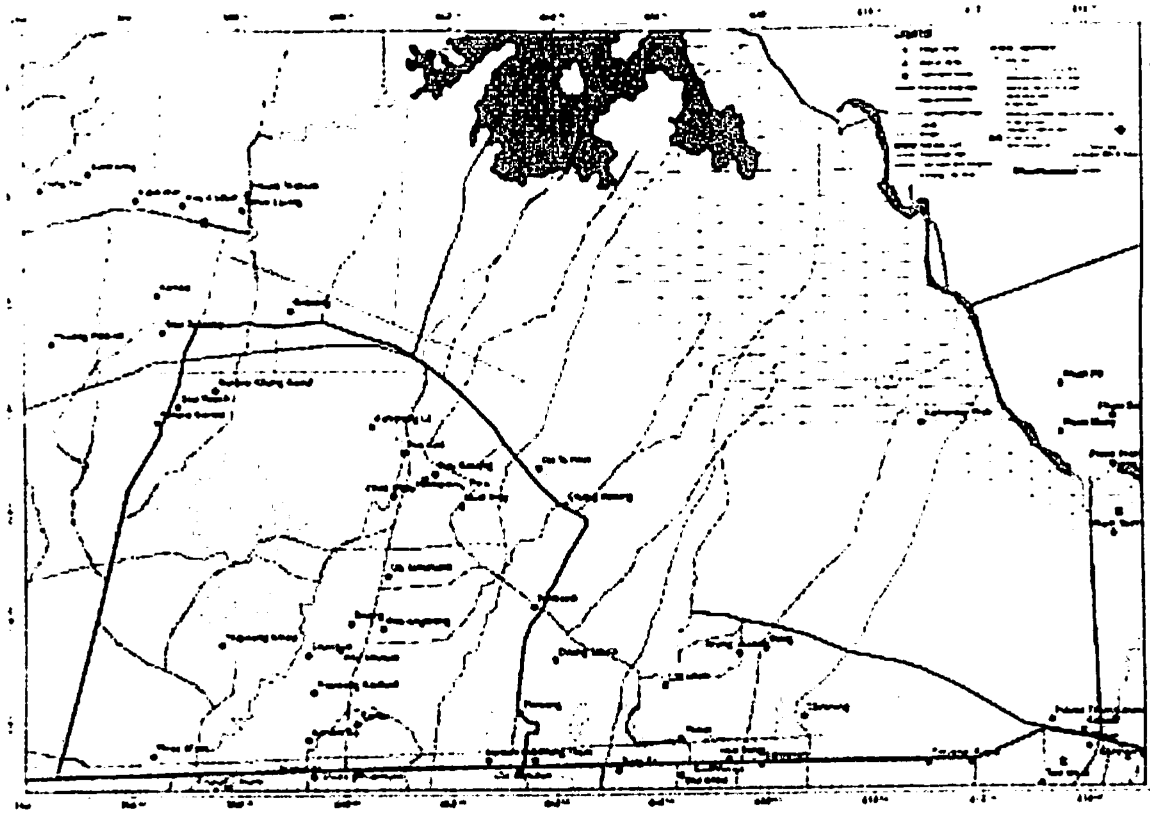

Figure 2 Location of the villages and road system at the Pursat site

II.3.1.2 Stung Chinit

66. The site is a large-scale irrigation scheme located in Santuk district of Kampong Thom Province on the Stung Chinit Tonle Sap tributary. There is a second tributary nearby: Stung Tang Krasang. The Stung Chinit irrigation scheme represents a fairly large and complex system consisting of a dam, reservoir, spillway, fish pass, a network of canals, rice fields and a number of associated roads (see Figure 3). As a result, the effects that the scheme will have on hydrology, fish and fisheries are likely to be fairly complex and spatially diverse. The scheme has been subject to quite detailed prior assessments that examined a range of aspects, including farm management, water utilisation, fisheries and navigation (e.g. OTCA 1970; MOWRAM/ADB 2003; MOWRAM/ADB 2002) and which have shown the scheme to be economically and technically feasible and developmentally desirable. The scheme has only recently started operating and for this reason the full nature of the impacts cannot yet be determined. The focus here is on the short-term impacts that have occurred during the start up of the scheme, which might serve to highlight some of the possible longer-term effects.

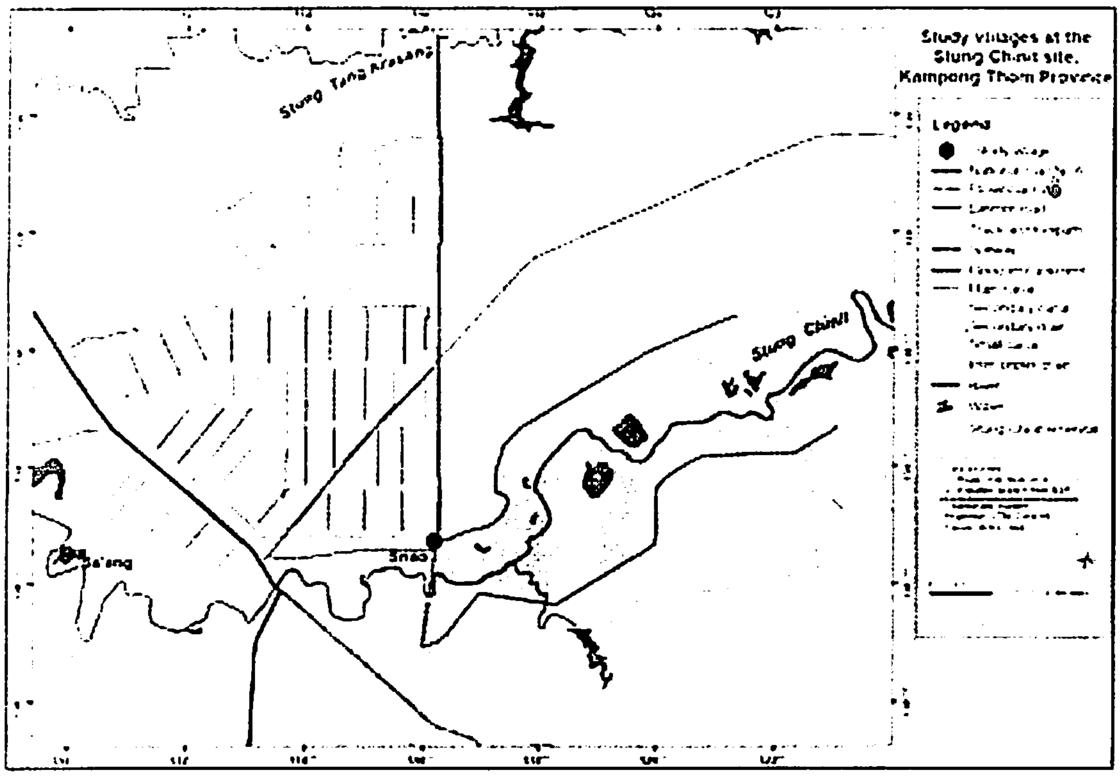

Figure 3 Location of villages and structures associated with the Stung Chinit irrigation scheme

67. Often irrigation schemes and river development plans do not take into account the effects of the development of built structures on fisheries (Grover, 1980). Destruction or alteration of the aquatic environment, the effect of flood control measures on migrations and spawning movements and triggers, and pollution of aquatic environments with sediments and agro-industrial chemicals are all commonly associated with irrigation systems. In order to capture some of this diversity, the fisheries component surveys examined the effects at villages along a transect from above the dam and main canal at the edge of the scheme to below the scheme (Figure 3). This was done as the scheme has created a large reservoir above the dam that could provide a new fishing location, a series of canals, and rice fields at the middle of the scheme, and has modified the flow of the river downstream as well as affected the connectivity to the section above the dam. Thus, villages have been classified as above the scheme (La'ak and Prey Dom), at the center of the scheme (Snao), at the lower edge of the scheme (Sa'ang), where some 30 out of 72 households will be benefiting from the access to irrigation water, and downstream from the scheme (Thnaot Chum). In addition, these locations could also be grouped as upstream or downstream based on their locations relative to the dam and main canal. Above the scheme it was also considered useful to assess the changes for villages on either side of the scheme as the availability and access to fishery resources may be particularly affected for these upstream villages.

II.3.1.3 Prek Toal

68. The site at Prek Toal consists of forest and floodplain areas that are seasonally submerged and which are managed for fishing located on either side of the Stung Sangkae, which empties into the Tonle Sap Lake. These are highly productive areas of flooded forest and floodplain that contain areas highly important to migratory birds and that have importance for fish conservation such as the Prek Toal Core Area (e.g. Davidson 2006; Goes 2005). On one side of the river along which the survey villages are located is Fishing Lot #2. This is an area that has historically been leased out on a multi-annual lease to the 'lot operator'. The conditions of the lease and area leased are described in the 'burden book' that sets out the lease conditions. During the year there is a 'closed season' from 31 May to 30 October, during which people from the surrounding area may fish in the lot using family-scale gears and methods, followed by an 'open season' from 1 November to 30 May during which access for fishing is given to the lot owner. During the open season, the lot operator may choose to sublease areas of the lot (e.g. Prek Long Ung, Prek Da, Prek Ang Krang, Prek Dem Cheu, Prek Spout, Boeung Norea and other streams and lakes, except the floodplain areas reserved for small-scale fishers). These sub-leases have been paid for in dollars but more recently the lease prices have been specified in kilograms of gold.

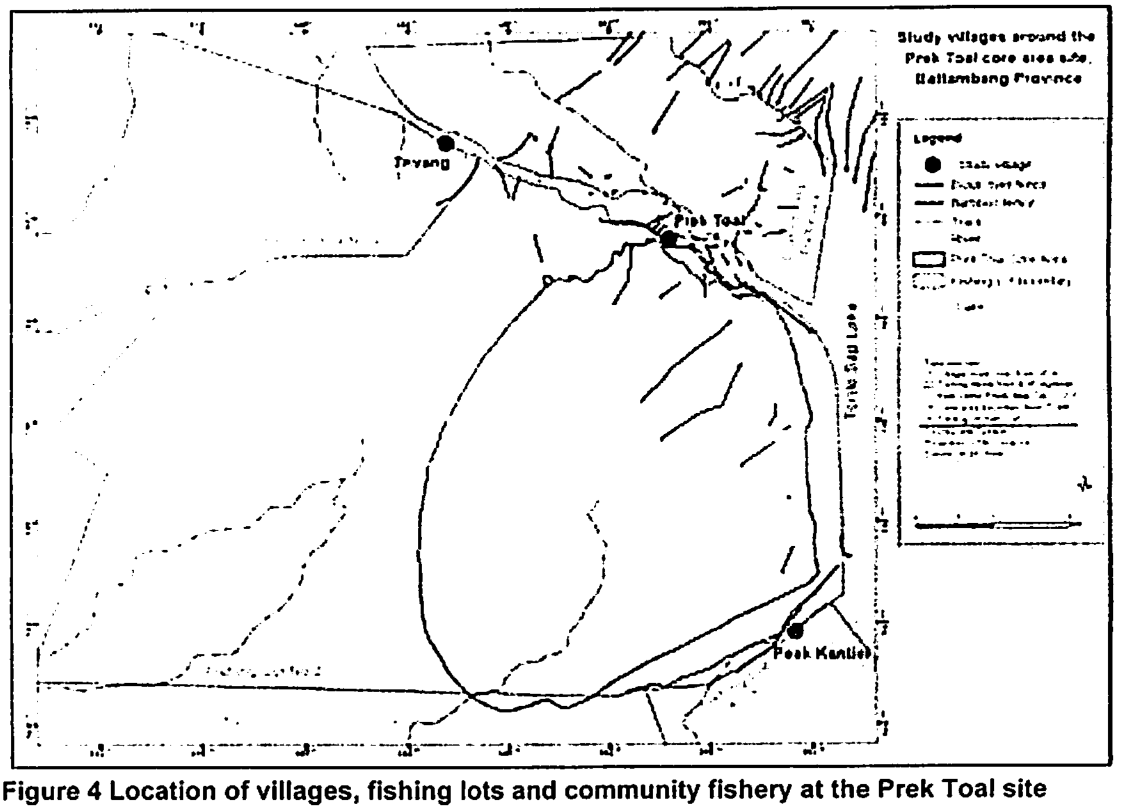

Figure 4 Location of villages, fishing lots and community fishery at the Prek Toal site

69. As one of the management measures of the fishing lot, the floodplain is enclosed from 15 November - 30 December (depending upon the flood level) until 31 May by the lot operator using a 35km long fence that is approximately 3.5m high and that runs along the edge of the floodplain, acting to channel fish into harvesting compartments. This fence has traditionally been made of bamboo but more recently fine mesh netting with a mesh size of less than 1 cm has been used. This fence is the built structure under consideration.

70. On the other side of Stung Sangkae the floodplain was managed in a similar way prior to 2001 (as Fishing Lot #3) but was considered a naturally less productive part of the floodplain. After 2001, as part of the fisheries reform process, the structure was removed and the floodplain area was given over for community management for household benefit. Exploitation within the community fishery is intended to be limited to relatively small-scale or household fishing gears.

71. The two areas of floodplain are exploited by fishers from the floating villages located along Stung Sangkae as well as fishers who migrate from Battambang and other provinces to the area to exploit the fisheries. Of the local fisher villages, closest to the edge of the lake is Prek Toal village and, moving inland along Stung Sangkae, Anlung Ta Or, Kampong Prahok and Thvang. These villages were all selected as part of the survey and interviews held with fishers in each one as well as with fishing lot workers employed to work in Fishing Lot #2, the lot operator and sub-lessees.

72. Details for each of the villages that were selected at the three sites are provided in Table 5.

Table 4 Description of the villages selected for sampling by the fisheries component at each of the sites

	Pursat					
Village	Krang Veng	Doung Chua	Chong Khlong	Ou Ta Prok	Kampong Lor	Moat Prey
Commune	Snar Ansar	Ou Sandan	Ou Sandan	Ou Sandan	Kampong Po	Ou Sandan
Location	Outside	Outside	Edge	Edge	Edge	Inside
	Stung Chinit					
Village	La'ak	Prey Dom	Snao	Sa'ang	Thnaot Chum #1	Thnaot Chum #4
Commune	Kampong Thma	Chaeng Daeng	Kampong Thma	Kampong Thma	Thnaot Chum	Thnaot Chum
Location	Upstream	Upstream	Middle	Edge	Down stream	Down stream
	Prek Toal					
Village	Prek Toal	Anlung Ta Or	Kampong Prahok	Thvang		
Commune	Kaoh Chiveang	Kaoh Chiveang	Kaoh Chiveang	Kaoh Chiveang		
Location	Lake	Inland	Further inland	Furthest inland		

II.3.2 Results of project studies

II.3.2.1 Pursat

73. As a starting point, the respondents were asked about the effect of the built structure on local hydrology. In response to this it was the universal belief among respondents was that the only effect that the built structure might have had on the water locally was a possible decrease in the rate at which water was able to move up and down the floodplain. There was no reported effect on water quality.

74. There was unanimous agreement that fish abundance had declined over time. The perception of the degree to which abundance had declined differed for the three size categories but it was again unanimous that the larger fish had declined most (see Figure 5).

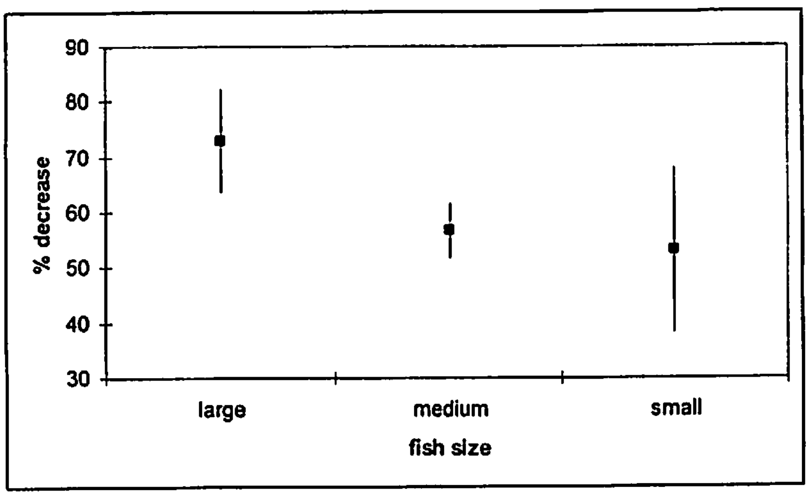

Figure 5 Mean perceived decrease in fish abundance for three size classes of fish that had decreased over time at the Pursat site (error bars indicate the standard deviation around the mean).

75. When asked what caused the changes in abundance, a variety of reasons were given for the decline in abundance that they have observed. While all the reasons given were due to human/environment interactions, the built structure was not cited as a cause by any of the respondent groups. It was stated by 42% of respondents, including 100% of those with rice fields within the boundary of the road system, that the structure had no effect because of the culverts and gates associated with it (together with the regulations related to them) as well as the presence of canals that enable fish to move up and down the floodplain. There was some variation in reasons for change by location (inside, outside and edge), although these difference do not appear to be significant (X^2, $P > 0.05$, df = 18). Considering the top two ranked reasons reported for the decline (Figure 6), it can be seen that the perception was that fishing effort, either as a result of increasing efficiency or increased numbers fishing, has been the main reason for the perceived decline.

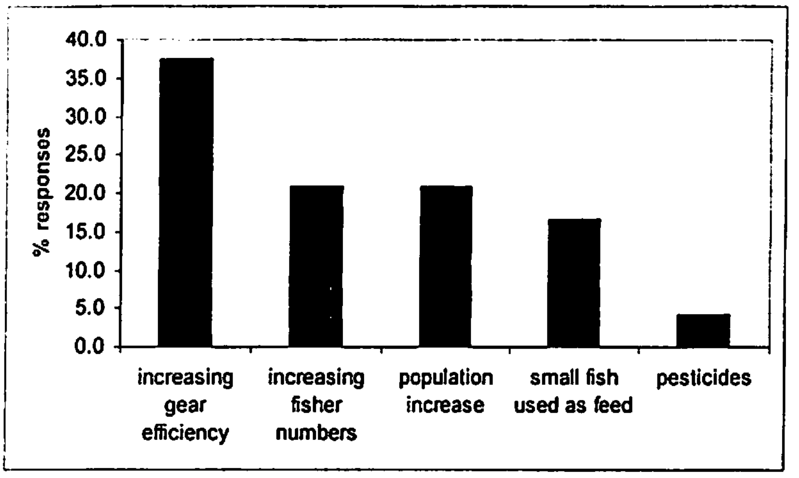

Figure 6 Top ranked reasons for the decline in fish abundance perceived by fishers at the Pursat site.

76. In relation to fishing effort, participants were asked whether the built structure was having any effect on fishing effort. There were again no significant differences in the opinions by location (X^2, $P > 0.05$, df = 4) with the road believed to have had very little effect on overall effort levels. However, patterns of effort were believed to have been affected as the canals in the area and areas around the culverts and gates were believed to have provided additional places to fish. In addition it was unanimously believed that the nature of these additional locations (i.e. deeper water and a channelling effect on fish) promoted the use of the more efficient gear types. Examples of the kinds of new and more efficient gears that were reported to be more widely used predominantly included electro-fishing and the use of fine mesh nets. At the same time the use of more traditional gears such as *angruth* and *chhneang* was widely perceived to have declined (see Figure 7). There were no significant differences in the changes in gear types used by location (X^2, $P > 0.05$, df = 8).

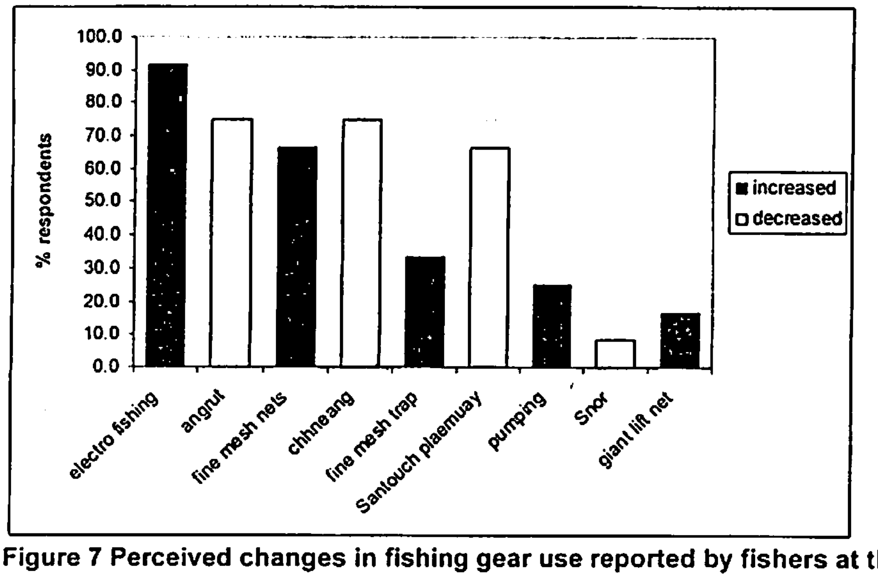

Figure 7 Perceived changes in fishing gear use reported by fishers at the Pursat site.

77. The decline in fish abundance has meant that there have been changes in the patterns of fishing effort with over 80% of respondents indicating that fishers are now travelling further from their homes in many cases and new fishing locations that had not previously been used by those villagers are being exploited. The majority of these locations are further down the floodplain towards the Tonle Sap Lake, for example Boeung Chhes, Boeung Sambok Ork, Boeung Naktavul, Trapang Khach and Boeung Kambeth Snearth and other areas including the flooded forest.

78. The decrease in abundance of fish in all categories has been accompanied by increases in price (Table 3). Interestingly, small fish had increased the most in price and also showed the greatest variation in increase. This could reflect the greater diversity in the view of the extent to which this group had declined in abundance (Figure 5) and also that the group will consist of a mixture of lower value and higher value fish species. It is also noticeable that despite large fish being perceived to have decreased the most, this was not reflected in the extent of the price increase over the period.

Table 5 Changes in fish price for three size classes of fish at the Pursat site between 2000 and 2006. Standard deviation in brackets.

	Small	Medium	Large
Mean price before (2000) (Riel/kg)	566.7 (238.7)	1833.3 (492.4)	2875.0 (979.9)
Mean price now (2006) (Riel/kg)	1958.3 (582.3)	3750.0 (891.9)	5666.7 (1557.0)
Mean difference	1391.7	1916.7	2791.7

79. A number of reasons were given for why the prices had increased and these were not significantly different between locations (X^2, $P > 0.05$, df = 12). The main reasons for the increase were high local demand (100% of respondents), decreased fish abundance and reduced fish catches (92%) and increased demand for fish for export, principally to Vietnam and Thailand (92%). The results of the socioeconomic surveys in two of the villages at the site also indicated that household catches had decreased but that the overall contribution of fishing to household income had not, likely due to the price increases.

80. The built structure was universally felt to have contributed to fish price increases by both increasing the access to the villages by middlemen (it was variously reported that visits had increased by 30-50%) and also the access to markets by villagers. This was also believed to have had a positive effect in enabling villagers to get a better price for their fish, but it was also reported that increased sales of fish meant that sometimes villagers cannot find fish to buy in their village. The main benefits of the road were, unsurprisingly, associated with better access, either access by villagers to markets and other facilities or access to the village by external agents, including traders, extension staff and NGOs. These access benefits are similar to those reported by Hettige (2006) for rural roads.

81. In terms of species, the species reported to have changed in abundance were very similar by location. There was only one species that was considered by all respondent groups to have disappeared from catches, while several others were widely believed to have declined in abundance (Figure 8). No species were reported as having increased in abundance.

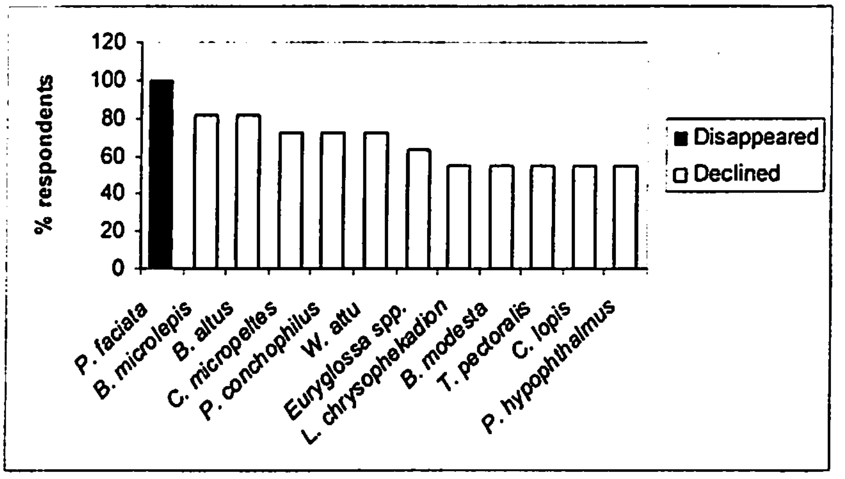

Figure 8 Changes in species abundance reported by respondents from all villages at the Pursat site.

82. In summary, the structure (road) was felt to provide benefits to locals relating to water and fisheries in that it acted as an embankment to prevent substantial flooding from water moving up the floodplain. It was also able to act to retain water in the rice fields above the road, making water available for the rice crops and for livestock. Related to fisheries, the structure was not believed to be affecting fish abundance because water connectivity has been maintained due to the presence of culverts and gates and associated regulations that enabled water and fish to move up and down the floodplain. Any blocking effect was also reported to be mitigated by the presence of canals that also enable water and fish to move up and down. The structure (and also canals in the area) has provided new fishing opportunities that have been exploited by fishers. The structure has also assisted in the marketing of the fish caught by increasing access to the villages by middlemen purchasing fish and also access of villagers to the local markets. This has had a positive effect on the prices that fishers are able to get for their catch.

83. The negative effects of the structure were mainly indirect. There was a perception, particularly among those outside of the structure, that the water retention effect might actually contribute to flooding inside the area enclosed by the structure at times of heavy rainfall. It was also felt that the new fishing opportunities that have been created may also have enabled the use of the more efficient types of gears that are perceived to be contributing to declines in fish abundance. Finally, while the increased marketing opportunities that have been provided by the structure and price increases that have been observed have benefited fishers, they have reportedly had some negative effects on those in the villages looking to purchase fish for household consumption in that sometimes fish may not be available to those in the villages who want to buy it.

II.3.2.2 Stung Chinit

84. Asked about the hydrological changes that the scheme had brought about produced differing responses by location. Around Prey Dom, above the scheme, it was noted that development of the scheme had a negative effect in that it had led to increased flooding of the villagers' rice fields and homesteads. Prior to the scheme water could be released from the nearby lake Boeung Chork into the river through the stream Ou Chork. With the development of the scheme, an embankment was created that blocked some of this flow, and the stream was channelised to create a canal linking the reservoir to the river downstream of the dam, and that could carry the water from Boeung Chork, which received water from three other upstream streams. However, the respondents reported that the canal is unable to carry sufficient water and that this has led to the flooding problems. The respondents also noted that this canal was an important part of the scheme in relation to fisheries as it allowed fish to move upstream and downstream past the dam and embankments. The reservoir was also noted as being a major hydrological effect of the scheme and it was felt that this would benefit the fisheries by providing additional habitat that would be perennially available. While the reservoir may bring additional habitat, it can be expected that fish diversity and abundance in irrigation canals will be less than in the unmodified river. For example, following the development of the Gezira irrigation system in Sudan there was a reduction in fish diversity of some 45%, with only 19 of the 34 species of fish present in the source waters (the Blue Nile) found in the minor and field canals (Coates 1984).

85. In La'ak village, above the scheme and on the other side of the reservoir from Prey Dom, the respondents indicated that the reservoir was the main hydrological change brought about by the scheme and that this enabled them to access water for rice and that the embankment associated with the reservoir prevented flooding of the village in the wet season. At the same time though this reduced flooding effect has reduced the flow of water to the rice fields. A similar effect has been caused by the new road that was built between the two rivers Stung Chinit and Stung Tang Krasang. As a result there is less water reaching the rice field areas and this has affected fish movement and abundance in these fields.

86. In both of these locations above the scheme it was reported that the scheme had also affected water quality, primarily due to the decomposition of flooded vegetation. While respondents reported that this did not appear to affect the fish or fishing, there were reports that it had negative effects on animal (50% of respondent groups) and human (25% of respondent groups) health. In other studies it has been found that anoxic waters from reservoirs containing rotting vegetation have caused mortality in river fish (Arthington 2004). However, studies by Lim and Lek (2005) suggested that there was little variation across the site in terms of total suspended solids in the water and that, according to French standards, the water quality regarding nutrients varies between "very good" and "good" quality and that in terms of organic matter the water quality is a bit lower with a "fair" water quality. The factor affecting water quality was attributed by Lim and Lek (2005) to organic inputs from the riparian villages. The water quality descriptions provided would not seem to account for the effects described by the respondent groups.

87. At Snao village in the middle of the scheme the main hydrological effects that were noted were that the scheme had created a larger flooded area above the dam, in particular the reservoir, and that these flooded areas remained flooded for longer. They also noted, as was stated in La'ak, that the physical structures that had been created had reduced the access by fish to the rice fields. As with the locations above the scheme, respondents indicated that the development of the scheme had affected water quality. In particular, the creation of the scheme had led to some flooding in the village and there was a unanimous view that during this flood period well water in the village began to become turbid and smell bad and that again this had had negative impacts on human and animal health in the village.

88. The perception of the change in hydrology was similar for all the locations downstream of the dam and canal. Here the main effect was that there had been changes in the volume and timing of water flow, resulting in reduced water flow in the river and less flooding of the downstream floodplain areas as a result. Respondent groups also noted that the water quality had also changed with water having a 'bad smell' and being more turbid. While it is possible that this is linked to the submergence and decomposition of vegetation upstream, the perception was that this change was due to the slower current in the river. Lim and Lek (2005) noted that the total suspended solids were higher in the downstream areas and that this was possibly due to an increase of the population density and an increase of soil erosion and runoff.

89. In terms of where people can fish, there has been a traditional system of access restrictions along the river that dictated who could fish and where. This access was allocated on a household basis and this access could be leased to others. With the introduction of the scheme, the traditional system above the main dam is no longer operating and the reservoir is at present a perennial open access resource. Below the dam the traditional system is still operating along the river in the same way as before.

90. There was universal agreement among the participating fishers that the development of the irrigation system has changed where people fish. This includes both fishers fishing at new locations as well as not fishing at others that were fished prior to the scheme. This is not surprising given the scale and extent of hydrological modification that has resulted. The effect that the scheme had on patterns of fishing effort depended however on where the fishers were located in the scheme (Table 4). The greatest change has, as might be expected, been above and in the middle of the scheme where the creation of the reservoir, canal and rice fields has provided a number of new fishing locations. For the villages above and at the centre of the scheme the reservoir represents an important a dry season resource as the lakes. It has also meant that fishers in these places are no longer travelling further afield to fish (e.g. in Stung Tang Krasang and Boeung Lvea) as the reservoir is much closer. However, it has been reported, particularly by the villagers in La'ak and Snao, that the reduced connection of the rice fields to the river system due to the creation of roads and embankments has led to a decrease in the abundance of rice field fish and made rice fields a less important place to fish. This could be important as in appraisals in Lao PDR, Nguyen-Khoa *et al.* (2005) found that such fields were important sources of fish and that it was therefore important to maintain the water levels and connectivity of the fields to support production.

91. There have been some benefits from the scheme for those living in Snao village in particular as fishers from there are able to fish the section of the river just below the dam, fish pass and spillway. This is a place where fish moving upstream are reported to congregate as their way upstream is blocked and many fishers take advantage of this.

92. For villages downstream from the scheme the picture is quite different and fishers in these villages are now reporting that they are traveling further afield to fish, including to the Tonle Sap Lake, because of reduced fish abundance nearby. These villages are also being affected by other changes that are related to other resources in the floodplain, for example the release of Boeung Krai Slao, Boeung Tamun and Peam Anchanh and the restriction of access to other lakes, such as Boeung Samreth and Boeung Chhkae Khamsvar, and these changes are reported as important in the downstream locations. In addition, these villages also related that the risk of gear theft also affected where they choose to fish. Both floodplain areas far from their village and the rice fields at the southern edge of the irrigation scheme were suggested as places where gear theft was an issue.

Table 6 Changes in patterns of fishing effort described by fishers from villages around the Stung Chinit scheme.

	Above	Centre	Edge	Below
Fishing locations created	Now fishers can go fishing in the lakes that are all part of reservoir in wet season and expect to be able to in the dry season also.	Now fishers expect that they can go fishing in reservoir because this will hold water in dry season.		Fishers can go fishing at some lakes at present because these lakes were released for fishing people (after fishery reform, 2001).
	Fishers can use some lakes that are part of reservoir because they will remain full in dry season and fish are more abundant in the reservoir.			Fishers have started fishing at Tonle Sap Lake due to fewer fish in nearby rice field and lakes.
	Before some of the lakes near the village dried out in dry season. Now, with the reservoir, there is a lake in both dry and wet seasons			
Fishing locations no longer used	Fishers stopped fishing after damming because this lake was far from village (50km) and fish are more abundant in the reservoir and rice fields close to the village.	No longer fishing in the rice field area under the irrigation scheme. Recently there have been fewer fish in these rice fields due to the scheme blocking fish migrations.	Location now restricted by private control for development of livestock/fish farming.	Fishers have stopped fishing at the southern rice field area of Stung Chinit because of the risk of gear theft.
	No longer fishing in two lakes that are now very deep in wet season (after damming) and fish are now more abundant in lakes near by the village.	Fishers could not fish in rice field areas next to the village after damming in wet season due to less fish or no fish found in this type of habitat.		Now fishers cannot go fishing at a lake that has been become part of Fishing Lot #10 since 1995.

93. Within the villages around Stung Chinit there was a unanimous belief that in general there had been a decline in overall fish abundance. A number of reasons were put forward for this general decline in fish abundance (Figure 9). The reasons that were given were similar by location and there was only one notable variation, which was in the issue of barrages and electro-fishing gears strung across the river. This was considered an important cause of declining abundance in those villages below the dam but was not mentioned by fishers in villages either in the middle or above the dam. As with the other sites, the main reasons being put forward were to do with human/environment interactions. Increasing fishing effort through increasing numbers of fishers and increasing gear efficiency, for example the use of smaller mesh size nets, was unanimously cited as a reason for decreased abundance. Clearing of the flooded forest was also a widely cited reason for decreased fish abundance at the Stung Chinit site.

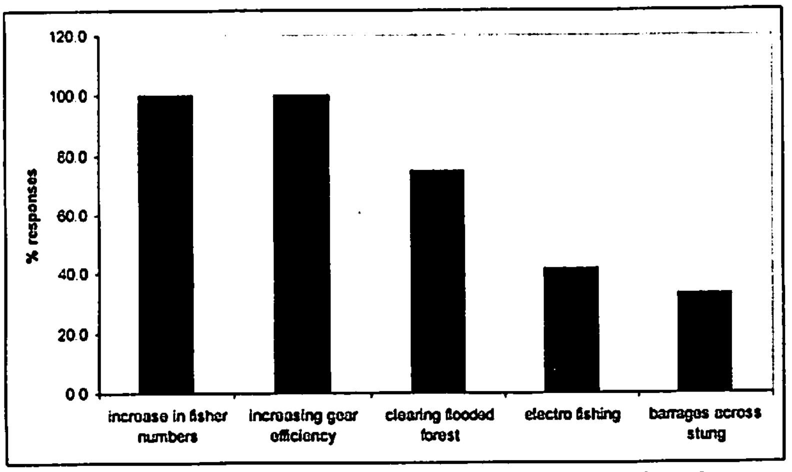

Figure 9 Top ranked reasons for the decline in fish abundance perceived by fishers at the Stung Chinit site.

94. While it was felt that there had been a general decline in fish abundance at all locations over time, it was also believed by all the respondent groups that the scheme had affected fish abundance. At the upstream locations it was stated that the scheme had led to an increase in size and abundance of fish while at the downstream locations abundance was felt to have decreased. The upstream increase was believed to be due to the increase in habitat and food availability for the fish. However, there was uncertainty as to whether the increased abundance and resulting improved catches would be maintained in the future.

95. Downstream one respondent group in Sa'ang village indicated that they felt that the reduction of fish abundance in the river was such that during the dry season in the future the river might only be used as a source of subsistence fish. The decreased abundance of fish downstream was considered by all downstream respondent groups to be due to the flow changes caused by the scheme's reduction in the number of fish that were traveling up the river from the Tonle Sap Lake. This connectedness was important, and it was also mentioned by respondents that local fish abundance was strongly correlated with the natural flooding from the Tonle Sap Lake. When there was a strong flood there would be a greater abundance of fish along the river. This is consistent with a widely found correlation between catches and flooding intensity (e.g. Baran *et al.* 2001). As well as changes in abundance it is

possible that a reduction in flow will also affect the species assemblage as the size of the stream has been identified as a potentially important factor in structuring fish assemblages (Grenouillet *et al.* 2004). Unfortunately, at this stage the structure has not been operating for long enough to be able to confirm any changes.

96. That respondents indicated that local fish abundance was dependent on fish traveling up the river, highlighting the fact that activities further downstream on the floodplain and in the main Mekong system may also be having a strong influence on fish abundance at the site. In this respect the villages at the lower edge and downstream of the scheme reported that a floodplain irrigation scheme further downstream (a structure developed during the Pol Pot time) from the Stung Chinit scheme was having a more significant effect than the Stung Chinit scheme itself. Walker (2003) has suggested that the development of such lowland irrigated agriculture often does not feature in the debate on water supply and utilization. Unfortunately, again because the structure at Stung Chinit has only started operating and because there was not enough time to also investigate the downstream structure, it was not possible to investigate this assertion.

97. The changes that the Stung Chinit scheme brought about in both hydrology and fish populations have led to changes in the patterns of exploitation with fishers in the upstream areas relating that they are now using larger mesh size nets to catch fish in the reservoir. In the downstream areas fishers relate that the reduced flow in the river due to the scheme has enabled fishers to use gears such as drift gillnets, cast nets and long lines that were used less in the past in these locations. The use of boats in the upstream and downstream area is also said to have increased with the development of the scheme.

98. There were interesting differences in the new gears that were reportedly used between the upstream and downstream locations. Downstream both electro-fishing and the use of fine mesh nets are perceived to have increased (100% of respondent groups) and it is also thought that the use of barrages across the river (50%) and the use of fine mesh traps (33%) have also increased. One group also noted that fishing with explosives was also sometimes happening. By contrast, only 50% of respondent groups upstream noted an increase in the use of electro-fishing gears or fine mesh nets. All of these gears represent an increase in gear efficiency and the differences between upstream and downstream perhaps reflect the perceived changes in fish abundance in these locations with fishers downstream increasing the use of efficient gears, such as the barrages, in pursuit of fewer fish.

99. Changes in hydrology, fish and patterns of fishing effort have also been accompanied by changes in fish price. Generally fish prices for small, medium and large fish have been increasing over time, but along with this trend there have been more local effects that were attributed to the development of the scheme. The nature of the reported local changes in fish price and the reasons for the changes also varied by location. In the downstream locations 100% of respondents reported that fish prices had increased due to the reduced catches that fishers are now getting. In the upstream locations, by contrast, 100% of respondents indicated that the development of the scheme had led to a decrease in fish price as fish were now more abundant and of a larger size (an example was given of *Channa striata* decreasing in price from Riel 7000/kg in 2005 to Riel 5000/kg in 2006). In addition it was also reported that the development of the roads associated with the scheme

meant that it was now easier for fishers to sell their catch, either by taking it to the market or selling to middlemen. In La'ak village, for example, it was reported that the roads had led to about a 30% increase in the number of middlemen coming to the village to buy fish.

100. The change in abundance in the downstream locations is also reflected through the traditional management system for the downstream locations. Decreased fish abundance downstream has meant that the price that can be charged for leasing a stretch of the river has also declined.

101. Against the backdrop of the generally perceived decrease in abundance there were some specific changes in abundance that had been observed by participants. These patterns of abundance across the Stung Chinit site were interesting. When the data on species changes was aggregated for upstream (Snao, La'ak and Prey Dom) and downstream (Sa'ang and Thnao Chum) there were significant differences between the species reported as having disappeared based on species that were reported by over 50% of respondents in either location (X^2, $P < 0.05$, df = 7). The patterns of decline in species abundance varied but not significantly (X^2, $P > 0.05$, df = 15). The spatial pattern of variation in species abundance is shown below in Table 5. These changes were attributed to the development of the scheme and in particular the dam that was constructed across the river reducing the connection between the upstream and downstream areas as well as the increase of food and habitat available upstream. In addition to the changes in abundance that had been observed it was also the view of respondents that the size of many of the species that had increased in abundance had also increased in the upstream areas. Elsewhere fish sizes were generally reported to have declined.

Table 7 Patterns of species abundance based on aggregated responses for upstream and downstream locations in relation to the dam at the Stung Chinit site.

Location	Disappeared	Declined	Increased
Upstream	*Boesemania microlepis* *Chitala lopis* *Pangasius conchophilus* *Trichogaster pectoralis* *Pangasianodon hypophthalmus* *Cirrhinus microlepis* *Amblyrhynchichthys truncatus*	*Euryglossa* spp. *Pangasius spp.* *Leptobarbus hoeveni* *Wallago attu* *Mastacembelus spp.*	*Probarbus labeamajor* *Puntioplites spp* *Barbonymus gonionotus* *Hemibagrus spilopterus*
Downstream	*Boesemania microlepis* *Chitala lopis* *Pangasius conchophilus*	*Euryglossa* spp. *Mastacembelus spp* *Pangasius* spp. *Leptobarbus hoeveni* *Trichogaster pectoralis* *Pangasius larnaudii* *Pangasianodon hypophthalmus* *Cirrhinus microlepis* *Amblyrhynchichthys truncatus* *Labeo chrysophekadion* *Channa micropeltes* *Barbonymus altus* *Hampala* spp.	

102. The species that are reported to have disappeared common to both upstream and downstream areas are predominantly white fish species. Those fish species that are reported to have increased in the upstream area are also classified as white and grey fish. As mentioned, the white fish are those that are considered most vulnerable to developments in the riverine and floodplain systems and might be some of those most affected. While it might be thought that the creation of additional upstream habitat would be likely to benefit black fish species most, it is the grey fish that have increased in abundance. There are several possible reasons for this. The first is that connectivity of the upstream and downstream has been maintained and the more migratory grey fish are still able to move up and down. Secondly, the reduced connectivity of the system to the rice fields that has been reported may have adversely affected the black fish. Finally, it may be that the blocking of the river has trapped fish in the reservoir and these fish are now being caught. The latter is possibly the most likely as fishers have reported increases in the size of these fish and also voiced concerns about the connection between upstream and downstream areas.

103. The issue of connectivity had been addressed to an extent in the design of the scheme through the inclusion of a fish pass, designed to ensure that fish could continue to move between the upstream and downstream stretches. According to MOWRAM/ADB (2002), The design of the fish pass was based on a number of ecological impact studies in the Stung Chinit site carried out by Warren (1999) and Schouten (1999), findings from successful vertical slot fish pass projects in Bangladesh (Bernacsek 1997a) and Australia (Stuart and Berghuis 1999; Mallen-Cooper 1992) where fish passes have been designed for warm-water slow-swimming fish species similar to those occurring in Cambodia. The more general aspects of the design for the Stung Chinit fishpass were prepared by using the guidelines and recommendations produced by Clay (1995) and Katopodis (1992).

104. The study by Lim and Lek (2005) suggested that the construction of fish pass will have positive impacts on migrating fish species. However, many of the fishers interviewed expressed some concern about the functioning of the fish pass and whether or not all species could easily move up and down it, particularly given the flow rates within the pass. This concern has been echoed in the report by Baran *et al.* (2001), who noted that the density of fish migrations in the Tonle Sap River means that fish passes are not realistic as a mitigation measure for dams. Respondents in the upstream areas, and in particular Prey Dom, felt that the canal that linked the reservoir and the river downstream on that side of the reservoir was in fact a more important connection between upstream and downstream for the fish and fish movement and that this connection should be maintained.

105. Respondent groups were also asked about what they felt were the effects of the scheme on fish and fisheries, how these compared with other influences and about possible mitigation measures (Table 6). This summary shows that those at the centre and upstream of the dam were the ones who were benefiting most from the development of the scheme, but that even here there were a number of concerns. Benefits to these villages (La'ak, Prey Dom and Snao) included the reservoir as a perennial fishing location and water for crops. However, there was uncertainty as to whether the benefits seen in the fisheries (larger fish and larger catches) would continue or whether the disconnection of the upstream and downstream sections of the river might affect fishing in the future. As a result most of the suggestions from these groups were about ensuring and enhancing this connection.

106. The picture downstream was less positive as while some villagers on the edge of the scheme might benefit from irrigation water in the dry season and possibly rice field fish at this time, there were no other benefits. Instead fish in the river had become less abundant and there was a fear that these would also be easier to catch and therefore vulnerable to overfishing. In addition, there was a concern within these groups that the control of the water flow in the river might also mean that their fields and villages will be more susceptible to flooding in the wet season. As a result, their suggested mitigation measures concentrated on the control of water release from the reservoir and the need to maintain flows in the river.

Table 8 Summary of the positive and negative effects of the Stung Chinit scheme on fish and fisheries, how these effects compared with others and suggested mitigation measures that could be taken to reduce the negative effects of the scheme.

	Up	Middle	Edge	Down
Positive effects of structure	Provides water for dry season crops. Fish are also more abundant in accessible perennial resource nearby.	Provides larger fishing locations and new fish habitats upstream. Provides water for rice field in dry season.	Will provide some households with water for dry season rice farming, and wild fish from the reservoir may become available in these dry season rice field areas.	No
Negative effects of structure	Blocks fish (including black fish) moving between river and rice field. Causes flooding in rice fields and houses close to reservoir and less water in some other rice fields. Poor water quality affects the health of humans and animals.	Affects fish migration to spawn and feed in the upstream area. Negative impacts on availability of fish in downstream areas and some rice fields. Affects flooding in rice field and houses, and poor water quality affects the health of humans and animals	Fish migrations during flood season and dry season refuge are affected. Fishers easily catch fish as they aggregate in small, shallow habitats and brood fish could be fished out.	Blocks fish migration from Tonle Sap Lake to upstream. Rice fields and houses may be flooded when the gate is opened in the wet season. Cannot travel by boat to cut wood and collect secondary forest in upstream part.
Comparison to other influences	Do not yet know.	Do not yet know.	The irrigation structure has less negative impacts on fish and fishing than unsustainable fishing methods. But the scheme may lead to increases in use of unsustainable fishing methods.	The irrigation structure has less negative impacts on fish and fishing compared to destructive fishing methods. But the scheme may lead to increases in use of unsustainable fishing methods.
Suggested mitigation measures	Enlarge the diversion canal and ensure functioning fish pass. If possible, re-establish the original fish route between Stung Chinit and Boeung Chork, as this lake has been a large and productive lake. Install technically appropriate number and size of culverts and gates along the main canal.	Ensure a route for upstream fish migration. Perhaps re-adjust fish pass position.	Gate should be managed to allow a reasonable amount of water to flow downstream.	Manage the release of water or create diversion canal to reduce possibility of flooding.

107. In addition to these suggestions regarding the scheme itself, the respondent groups also suggested that there should be a crack down on illegal fishing and that activities further downstream, including clearing of forests and operations of fishing lots, should be regulated to ensure that fish are still able to move up the river.

108. Because the effects of the built structure have been complex and spatially diverse, it is worth providing a brief summary of the outcomes as they were encountered at this early stage after the commissioning of the scheme (Table 7).

Table 9 Summary of the outcomes reported at the Stung Chinit site.

	Upstream	Downstream
Significant hydrological changes	Creation of reservoir; reduced connection to rice fields; reduced connection between upstream and downstream sections	Reduced flow
Water quality	Much poorer	Poorer
Fish size	Increased size of some fish	Same or decrease
Fishing effort	Fishing in reservoir; Not travelling so far to fish	Increased use of efficient gears; Fishing further afield
Fish price	Decreased	Increased
Fishing lease price	n/a	Decreased
Fish abundance	Some species increased	Declining

II.3.2.3 Prek Toal

109. It was found during the pre-survey and surveys that, while the fishing gear structures can be expected to have some effect on hydrology and fish, it is very difficult to separate the effect of the structure alone from the rules and patterns of behavior that are associated with the structure, and this should be borne in mind while reading the following sections.

110. The view was universal among the respondent groups that the structure had no effect on hydrology (in terms of flow, water retention and water quality). The same was also said of the larger *Bor* (<500 to 1000m in length) and *Nor Rav* (500 to 3-4000m in length) gears that are increasingly being used at this site. On the other hand, pumping activities and allied dyke construction by fishers, primarily by the subleasees in the fishing lots, but also in the community fishery areas, are believed by over 80% of the respondent groups to have had more significant impacts on water flow and retention. Both lakes and small streams were reported to have been emptied in this way and the result of this was a decrease in water flow in Stung Sangkae. The draining of small lakes and dyked streams is likely to reduce the available dry season habitat and this could have implications for a number of the floodplain resident species. It is also believed that this pumping affected the adjacent habitat with 100% of respondent groups saying that pumping increased the turbidity in the remaining habitat. Respondent groups also reported that the effect of this was to increase the water temperature and this was affecting fish and increasing fish mortality in refuge areas (over 80% of respondent groups) and also that the water had a "bad smell" (75%).

111. Overall, there was a unanimous view across all the villages that fish had declined in abundance in all areas with abundance estimated to have been reduced by 60-70% from levels in the past. This decline in abundance has led to changes in fishing practices in the area, and almost all of these changes to where fishers can access are due to rules and behavioral changes rather than the direct effects of the physical structure itself. There were strong differences between the community fishery and the fishing lot in terms of access to fishing grounds. The creation of the community fishery meant that villagers in all the villages (as well as migrants) now have access to fishing grounds during the dry season. In contrast, the fishing lot operation has not led to any new fishing opportunities for the villagers.

112. As well as creating opportunities, there have also been a number of examples where opportunities to fish have been reduced. In the community fishery the area of Roha Tra Num Chring was recently designed as a protected fish sanctuary where fishing is prohibited in the dry season. There was a high level of awareness of this sanctuary with over 85% of respondent groups citing it as an example of a change to where villagers can fish. This measure was taken in order to protect the fish broodstock. For Fishing Lot #2, 75% of the respondent groups related that the change in lot operator had reduced the opportunities to fish. There were three reasons for this. In the first place, the operator during the period from 1994 to 1998 allowed fishers to go fishing in many small lakes of Prek Stung Chas during open season (i.e. at a time when fish are generally more abundant), during the period of the current operator (from 1998 to present) the lot operator has stopped fishers from fishing these small lakes and instead has begun to offer them on subleases. The structure itself has had other direct effects as fishers could travel by boat to go fishing at Boeung Nob and To Tem prior to 1998 but now they cannot go fishing at these lakes because the fishing lot operator has blocked the way to these fishing locations with a long bamboo fence barrage. Finally, the fishing lot has also expanded by some 7-8 km, enclosing a larger area around Pek Kantel, making fishers' potential fishing location narrower and making it more difficult to access fishing in this area.

113. Respondents identified a number of reasons given for why abundance had decreased and many of these were common to both areas so that there was not any significant difference between the reasons given regarding the community fishery and Fishing Lot #2 (X^2, $P > 0.05$, df = 10). Common reasons, as with the other sites, were increasing numbers of fishers, an increase in the number, scale and efficiency of gears (including electro-fishing and pumping) and clearing of the flooded forest (cited by 100% of respondent groups). In addition, in the community fishery respondents also cited poor enforcement and corruption as contributing to reduced abundance (38%) by not preventing the increased use of large-scale and destructive methods, while in the fishing lot the long bamboo barrage fence (100%) and non-adherence to the conditions in the burden book (12%) were also described as contributory factors. There was also an overall perception that the activities in the community fishery, due to increased access and the use of efficient gears were having a greater impact on fish stocks than the fishing activities in the same area when it was managed as a fishing lot. An increase in the number and efficiency of the gears employed in the fisheries around the Tonle Sap has also been noted by Sithirith and Grundy-Warr (2005).

114. Respondents were asked about the changes in species abundance in the community fishery and in the fishing lot. In terms of the species that are considered to have disappeared or declined there were no significant differences between the two areas and indeed there was a high degree of correlation between the aggregated responses. Two species (*Pangassius conchophilus* and *Barbonymus altus*) are believed to have disappeared from the two areas and a number of others to have declined (Figure 10). In addition, there was one important difference between the two areas when it came to species that had increased in abundance. While no species were reported as having increased in abundance in the community fishery, there was universal agreement between respondent groups that three-spot gourami (*Trichogaster trichopterus*) had increased in abundance, or declined relatively less, in the fishing lot area.

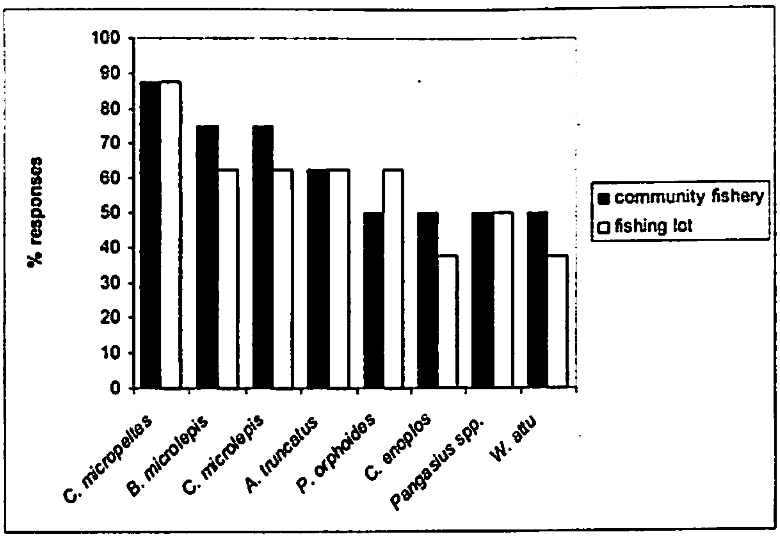

Figure 10 Declines in species abundance in both the fishing lot and community as reported by respondents from all villages at the Prek Toal site.

115. Respondents believed that the biggest local effects that were causing species-level changes were the increased fishing pressure and the destruction of fish habitat, for example through clearing of flooded forest. Gears in both areas, and particularly the structure in the fishing lot and the increasing use of *Bor* and *Nor Rav* fishing gears in the community fishery, are considered to be affecting the migration of fish from the lake to the floodplain and off the floodplain to the lake.

116. The reduction in access and perceived decline in abundance of fish has led to changes in fishing practices beyond where people fish. In all areas respondents indicated that there had been an increase in the introduction of larger-scale and more efficient gears including the nylon mesh *Bor* and *Nor Rav* gears, pumping out of sections of the floodplain, electro-fishing and giant lift nets. However, while the trends and changes were similar in the first instance there were important differences in the institutional aspects between the community fishery and fishing lot that, when combined with the structure, suggest that there may be different outcomes for the fish populations.

117. Respondents complained that in the community fishery there was a lack of enforcement and that this, combined with availability and affordability of efficient gears (e.g. the nylon mesh *Bor*) and ease of access to the fishery, meant that fishing was effectively uncontrolled. The lack of enforcement together with fishing pressure has led to conflicts between different fishers, typified by an increased incidence of gear theft. On the other hand, the fishing in the fishing lot was described as very effective and well organized and the main complaint regarding the fishing activities was that the lot owner did not always control instances of illegal fishing gear use.

118. These changes, together with the increase in demand for fish over time, have had an effect on the price of fish. Generally, the price of fish has been increasing over time and it was noted that the price of fish from the community fishery during the period when it was operated as a fishing lot was lower than it is now (see also Table 8).

Table 10 Changes in fish price of fish for three size classes of fish at the Prek Toal site between 2000 and 2006. Standard deviation in brackets.

	Small	Medium	Large
Mean price before (2000) (Riel/kg)	400.0 (115.5)	1687.5 (439.5)	2531.5 (670.0)
Mean price now (2006) (Riel/kg)	1000.0 (103.3)	3000.0 (258.2)	4250.0 (632.5)
Mean difference	600.0	1312.5	1718.8

119. As can be seen, it is the smaller fish that have increased most in price (by a factor of 2.5). One contributory factor to this increase is the reduced availability of these smaller fish locally. In the past, villagers used to be able to buy small, low value, fish from the fishing lot (Lot #2) to make *Prahok*. As the price of this fish rose the villagers changed what they did with the fish and began to sell this to fish traders at a slight profit. Most recently, in the last couple of years, the lot operator has decided to stop selling these fish species and they are instead kept by the operator to make *Prahok* himself.

120. Respondent groups all gave the same reasons for the increasing price of fish of all sizes. These were increasing demand, both locally and from Vietnam and Thailand, increasing fisher numbers and, consequently, smaller catches and lower catch rates and a general decrease in the size of fish caught. There was no difference between the community fishery and Fishing Lot #2 in terms of responses, and the structure was not considered to have any direct effect on fish prices.

121. There were interesting responses regarding the positive and negative aspects of the two management systems (Table 9). None of these related to the structure itself but centered more on issues of equity, accountability and sustainability.

Table 11 Perceptions among respondent groups of the positive and negative aspects of the two management systems at the Prek Toal site.

	Community Fishery	Fishing Lot
Positive aspects	People can access the fishery all year round and this provides opportunities for outsiders to fish (e.g. Battambang, Siem Reap, Banteay Meanchey, Pursat and Kampong Thom).	Flooded forest, birds and wildlife are better protected than in the community fishery, and fish habitat is more abundant. Fishing lot system provides better control over fishing activities than community fishery.
Negative aspects	Decline in flooded forest (suggested to be at least 60%) because of use for firewood and increase in large-scale and illegal fishing gears and activities. Corruption, limited capacity and poor accountability of managers, inability to enforce regulations and lack of support from government.	Intensive fishing, expansion in fishing lot area and blocking fishers' routes across Lot #2 to go fishing in public areas. Burden book not enforced (e.g. use of legal fishing gears, legal fishing time/periods, percentage of the fishing lot area that can be subleased)

122. Interestingly, fishers in the respondent groups indicated that they felt that the fishing lot system provided better control over the fishery than the community fishery but that the lack of accountability of the lot operator meant that illegal fishing activities, the timing of fishing activities and expansion of the effective lot area (e.g. around Pek Kantel and the exclusion of fishing activities several hundred meters outside the fence in the Tonle Sap Lake) remain unchecked.

123. Respondent groups had similar recommendations for the improved management of the two areas. Again, none of the recommendations involved the structure itself but focused on the negative aspects that were highlighted in Table 9 above. Thus over 90% of respondent groups advocated the banning of the nylon *Nor Rav* and larger, fine mesh *Bor* gears from both areas. They also wanted to see less corruption in, and increased cooperation between, the fisheries administration, police and local authorities (70% of respondent groups), better enforcement of the burden book, laws and by-laws (46%) and measures to prevent the clearing of flooded forest, including possible provision of alternative fuel sources (39%).

II.3.3 Outcomes of studies at the local scale

124. Because of the differences in the sites and in the nature of the structures, it is unsurprising that the outcomes were, in many cases, quite different. It is worth therefore dealing with each of the sites in turn before highlighting some of the common elements.

II.3.3.1 Pursat

125. The main effects of the road were on access and not directly on fish stocks. In comparison with other effects on the fishery, such as the demand for fish and use of destructive fishing methods, it was the perception of all respondents that the impacts of the road on fish abundance and species composition are insignificant. Any negative impacts attributable to the road were considered to be mitigated by the presence of gates and culverts that maintained water movement up and down the floodplain. Any impacts are also perhaps mitigated by the background trend of fishers tending to fish further down the floodplain. Respondents did indicate that the culverts and gates and canals have provided additional fishing locations but that these were often exploited using more efficient gears. It was also suggested that the road affected the hydrology locally by increasing water retention in the area enclosed by the road and that this was beneficial for rice production in that area.

II.3.3.2 Stung Chinit

126. It is too early to say what the full effects of the development at Stung Chinit will be and, from the evidence of this survey, it is likely that these will be spatially varied. Particular areas of importance would seem to be the reduced flows and connectivity of the system and the effect that this will have in the longer term on water quality and on fisheries in the main stream, reservoir and rice fields. It was also not possible at this stage to note the effects of the dry season rice culture. Increased use of agricultural inputs such as pesticides and fertilisers should help to boost agricultural production but could also very well negatively affect the fisheries (e.g. Nguyen-Khoa *et al.* 2005). The flows are an important consideration as studies have indicated that decisions related to water allocation and flow can be a primary source of conflict between fishers and farmers (e.g. Islam and Braden 2006).

127. What can be said at this stage is that at Stung Chinit there was a belief among all respondents that the structure had significantly affected the abundance, relative abundance and catches of fish. These changes had also affected local fish prices and the prices that could be obtained for leasing access to fishing in the river. However, the nature of the changes differed by location. In the downstream areas close to the dam many fish, in particular the migratory species, are reportedly aggregating as they cannot easily pass through the spillway, canal and fish ladder. While this may have negative effects for these species in the locality in the longer term, these aggregations currently provide a useful fishing opportunity. However, further downstream there are few benefits other than to those households that have access to irrigation water. Here the belief is that the structure has negatively

affected water quality, fish abundance and catches because the connection between the upstream and downstream areas has been broken and that this has had a negative impact, particularly on the migratory species. There are also concerns about the control of the release of water from the reservoir and the risk of flooding.

128. In the area above the dam, the most significant change is the reservoir and this has provided an important new fishing location, particularly as it is a perennial resource. It is too early to say what the final effects of this reservoir will be as the dam has only recently been closed but initial reports are that migratory fish species in the catches from the reservoir are larger sized. All fishers who were interviewed and who were living above the dam believed that the reservoir could become a productive fishing location as it provided a large perennial water body comprising a variety of fish habitats that could also provide more food for fish. The nature of the reservoir and the larger size of some of the fish have caused changes in the way that the resource is exploited with larger mesh nets now being used and an increase in the number of people now using boats to fish from. However, there are also a number of concerns, and among these was uncertainty over the longer-term effects of the scheme. Fishers in the upstream areas were concerned that the immediate gains in production may be a short-term effect due to the retention and growth of fish above the dam and that in the longer term the reduced connectivity to downstream areas will lead to a reduction in production. This is a very real possibility (e.g. FAO 2001; Bernacsek 1997a; Petrere 1996). The fish pass was another area that fishers highlighted during the surveys as they were not entirely convinced that it was working as it was designed to and they believed that this should be assessed.

129. Nguyen-Khoa *et al.* (2005) found in their study of irrigation systems that the reservoirs created by irrigation schemes did in fact boost fisheries production and that the increased reservoir production more than offset the reduced downstream production. However, in a scheme the size of Stung Chinit the distribution of these benefits and losses needs to be considered as it is not the same villages and households that are receiving the increased opportunities and benefits and bearing the costs.

II.3.3.3 Prek Toal

130. The situation in Prek Toal is also interesting from a management point of view. On the one hand, there is the fishing lot where there is an emphasis on productivity from the fishery and the fishing is considered by respondents to be comparatively well managed by the lot operator (although not all the management decisions favour sustainability or access) and very intensive (see also Sithirith and Grundy-Warr 2005). On the other hand there is the community fishery where access is much less of an issue but where enforcement is difficult and there is evidence that there is an increase in the use of destructive practices and in conflict between fishers and that the efficiency and, consequently productivity, is lower. A similar pattern was noted between an inland fishery in Indonesia where the fishers hold rights to fish and a more open access floodplain fishery in Bangladesh. As with the fishing lot, the fishing in Indonesia was more efficient and less competitive and, as with the community fishery, the fishing in Bangladesh involved fishers competing with one another (Hoggarth *et al.* 1999).

131. Productivity in the fishing lot comes at a cost to equity in that only those who can afford to fish there during the open season are allowed to. By contrast, in the community fishery there are, by design, fewer equity issues (this is not to say that such issues do not actually exist in practice, or that they do not actually affect the poorest to a far greater degree) but this means that there is competition for fish and, with a lack of enforcement, widespread use of illegal gears and gear theft. Thus, the community fishery is likely to be a less productive or efficient system overall than the fishing lot.

132. What cannot yet be said is how the systems compare in terms of sustainability with regard to the fish stocks. On the one hand the community fishery area would appear to be more 'porous' to fish than the fishing lot, i.e. to provide greater connectivity of the system overall, primarily because of the lack of the fence structure. On the other hand, there are considerable destructive gears and less controlled use in the community fishery, which is affecting fish and their habitats and may be affecting sustainability.

II.3.3.4 Common elements

133. The study highlighted one key aspect that is of importance and that is the common belief that fish abundance, species diversity and household catches are declining. While it may be that overall catch levels are actually remaining steady, the distribution of fish may be changing if there are increased numbers fishing (reducing individual household fish) and more export of fish (both reported by respondent groups at all locations). The effect therefore is to decrease the asset base of the rural households, potentially affecting livelihood options and strategies and increasing their vulnerability. The responses to this reported by the respondent groups have been that fishing pressure has increased though the use of larger and more effective gears (including illegal and destructive gears), exclusion of fishers from certain areas and exploitation of new fishing locations, often further from the fishers' homes. These aspects and their implications are explored in more detail in the livelihoods report.

134. The study also highlighted the importance of habitat connectivity in fisheries. The level of connectivity of riverine and floodplain habitats can have a direct effect on fish abundance and species composition (Welcomme and Halls 2004; Miranda and Lucas 2004; Berrebi-dit-Thomas *et al.* 2001; Halls *et al.* 1998). All three of the structures that were considered in this study have the potential to reduce connectivity and in the cases of Stung Chinit (water and fish) and Prek Toal (fish) this connectivity was seen to be affected. This issue of connectivity is an important consideration and should be considered at a number of scales. As the results from Stung Chinit indicate, fishers were aware that what was happening downstream of them was affecting local fish abundance. In all three cases it was also found that there were similarities in the species that were cited as having reduced abundance and that these were mainly white fish species, fish for which connectivity at larger scales is of particular importance.

135. The importance of connectivity and flows is also important to consider given the vital role of water flows as a distributor of fish larvae and juveniles through passive

drift (Poulsen *et al.* 2002). Four types of flows have been identified in relation to fish fauna in river and floodplain systems: population flows, critical flows, stress flows and habitat flows (Chea *et al.* 2006; Welcomme and Halls 2004). Population flows influence biomass through density-dependent interactions with parameters such as growth and mortality; critical flows trigger lifecycle events such as migration and spawning; stress flows endanger fish either through excessive flow rates or insufficient water, and habitat flows are needed for maintenance of environmental quality including temperature, sedimentation and nutrient levels. However, it is more difficult to identify what percentage of flow needs to be maintained. This is because the relationships between flow and ecological conditions (e.g. fish abundance) can be linear or curvilinear over a wide range and thresholds and have not been established (e.g. Acreman 2005; Sheldon *et al.* 2000; Extence *et al.* 1999).

136. Another aspect emphasized by the study sites that again highlights the importance of connectivity and flows is the issue of stress flows and the need to maintain dry season habitat because built structures can potentially affect this habitat. The dry season is a stressful period for many species and maintaining adequate water in these habitats and protecting these species from excessive fishing pressure is considered an important conservation measure (Welcomme and Halls 2004; Halls *et al.* 2001). In Prek Toal these habitats were primarily affected by the clearing of the forest and pumping. Pumping is affecting dry season habitats directly by drying out areas and indirectly by increasing the turbidity in others.

III CONCLUSIONS AND RECOMMENDATIONS

137. Development planning should consider connectivity and the maintenance of critical habitats in time and space prior to development and the introduction of mitigation measures that can preserve sufficient flows to maintain ecosystem integrity. This is a recommendation that can apply to all planned structures. This will also potentially provide more predictable outcomes as it relies on preserving existing habitat and system characteristics rather than enhancing habitats or creating new habitats (Roni *et al.* 2005; Roni *et al.* 2002).

138. This recommendation echoes the points made by Poulsen *et al.* (2002) and Coates (2001) who suggest that environmental management, and consideration of how development measures might affect water and fish, should be a prerequisite for fisheries management. Given that connectivity exists across a range of geographic scales and varies across a range of time scales, it important that the planning processes for built structures consider the wider environmental context in which they will operate. There is also a requirement that information that can support such considerations needs to be made more widely available.

139. The case studies illustrate some of the particular requirements in relation to this recommendation. For example, the Pursat case study highlighted that for roads it is important that the effects of the road on the hydrological regime are considered. In this study there were no negative impacts on fisheries attributed to the road but this was believed to be because the road design included gates and culverts that enabled water to move up and down the floodplain. However, it was also reported that these culverts and gates were being used as fishing locations and that more efficient gears were being employed in these areas. It is therefore recommended that road building should carefully consider the existing hydrological regime and how culverts and gates can best be placed to maintain this regime and preserve environmental flows. Because these locations may be exploited it is also recommended that attention be given to fisheries issues, such as the use of fishing gears in the culverts, by the road management committees that are responsible for the maintenance of the roads and culverts.

140. Water management regimes at Stung Chinit should consider the needs of fishers (across the scheme but particularly in downstream locations) and balance the flow requirements for fisheries against the water requirements for agriculture. Further information is needed on the effects of flows. At Stung Chinit maintaining environmental flows was again important for fisheries. Access and flows between the upstream and downstream sections of Stung Chinit appear to be important. These issues have been raised for irrigation schemes by a number of authors (e.g. Nguyen-Khoa *et al.* 2005; Welcomme and Halls 2004). While we know that there is a negative impact on fisheries downstream of the reduced flow, it is not possible to describe the relationship between the flows and the fisheries. The effectiveness of the connections between the downstream and upstream sections of the river should also be assessed. Access to the upstream areas by fish downstream (and *vice versa*) should take into account aspects such as water volumes and flows that will trigger or hamper movement, for example, the fact that the maximum short-term swimming speed of many fish species is less than 0.5 m/s (Clay 1995 – quoted in Nguyen-Khoa *et al.* 2005; Arthington *et al.* 2004).

141. Managing flows between the upstream and downstream sections should explicitly address the balance of benefits from water management to the upstream rice farmers and downstream fishers. In the first place, management that will benefit the downstream fisheries will require that water flows account for past natural hydrological variation as much as possible by releasing appropriate amounts of water at the right times. However, determining the appropriate amount is not straightforward as water releases potentially come at a cost to agricultural production or to fisheries in the reservoir upstream. Given that the downstream villages appear to have borne a number of costs of the scheme and received fewer benefits, at least in terms of the fishery, these trade-offs need to be carefully considered.

142. Within the upstream area flows between the main channel and reservoir and the rice fields have been identified as important. While it is still rather too early to conclusively determine, the rice field fisheries appear to have suffered from poor flows, and modifications to water management practices may be able to improve the production potential of these fisheries.

143. The level of sustainability of the fishing practices in Fishing Lot #2 and the community fishery is uncertain and should be established to inform management decision-making. At Prek Toal there were issues with both maintenance of flows and maintenance of critical habitats (flooded forest and dry season refuges). While the structure did not appear to affect the environmental flows in terms of the hydrological regime, there was a clear effect on fish movement. What is less clear in this case is the overall effect on fish and levels of escapement of fish and fish larvae that would provide an indicator of the sustainability of current management practices. It is therefore a recommendation for the Prek Toal site that the relative sustainability of the fishing systems used in the Tonle Sap Lake in terms of their effect on fish recruitment and escapement be investigated.

144. In terms of dry season habitats, pumping in both the community fishery and the fishing lot appears to be a particular issue as far as illegal or intensive gears are concerned in that it seems to be a fairly destructive method. Habitat being modified to facilitate pumping, i.e. through the creation of dykes and dams across streams, and pumping also has wider effects, including increased turbidity in other water bodies and reduction in dry season habitat. These dry season habitats provide important refuge areas, particularly for grey and black fish, and structures and associated management measures that effectively reduce dry season habitats can result in a decline in fish production, as has been suggested by the respondents in this study and the results of Halls *et al.* (1999).

145. Flows and fisheries are not just a result of the physical structures but also of how these structures are managed and utilised. It is therefore important to examine the associated institutional arrangements. This is highlighted by examples from each of the study sites.

146. In Prek Toal there is a need to ensure the accountability of the management decision-makers and to improve the contact and collaboration between the various actors including fishers, management committees and the Fisheries Administration. In the fishing lot there has been an increase in activities such as pumping and expansion of the effective area of the fishing lot that require some form of control. At

the same time, there is a good deal of unregulated activity within the community fishery and an intensification of fishing as well as conflicts between fishers. There is a need also to develop a cost-effective enforcement system within the community fishery area. This will require cooperation and collaboration between the main fisheries stakeholders in the area and will be a challenge.

147. At the Stung Chinit site there was also clear evidence of the potential for conflict. Downstream villages are concerned about water management and how this will affect the fisheries and flood regimes and evidence from the pre-survey has highlighted that there have been conflicts between water use for agricultural use and for maintaining fisheries and this had been given as one reason that the scheme fell into disuse in the past. The potential for these water use conflicts has also been highlighted in other studies elsewhere (e.g. Nguyen-Khoa *et al.* 2005 and Huq 2005). Because of this potential, as well as the issue of how the increase in agricultural intensity and inputs affects fish production, it will be important to revisit the site in the future in order to assess the relative agricultural production gains and changes in fisheries.

148. The situation in Pursat was that the introduction of the road, gates and culverts provided new fishing opportunities. While there have been rules introduced by the road management committees that prohibit the blocking of these culverts by fishing gears these were not always adhered to and more intensive fishing gears have been deployed in these places.

149. Access to fisheries and to the benefits from fisheries is likely to become an increasingly contentious issue and requires an explicit consideration of what benefits are required from fisheries and how these should be shared within society. The investigation into built structures also highlighted some wider questions that it is worth drawing attention to. The almost unanimous response from respondent groups is that fishing effort is increasing through a combination of the increasing numbers of people fishing and the increasing scale and efficiency of the gears being used. The use of efficient gears, and in particular those classified as illegal such as electro-fishing, is reportedly widespread and there have been calls by many of the respondent groups for improvements in enforcement and clamp downs on illegal fishing. While this again highlights the issues around enforcement and how this can be achieved, there are some broader implications for decision-makers in this trend.

150. Clearly the fish resources themselves cannot sustain ever-increasing pressure and still maintain biological integrity. There are already concerns over a number of species including the giant river catfish and giant carp. However, there are also a great many people who are dependent on the resources for food and/or income. Thus, maintaining the productivity of the fishery and ensuring an equitable, or at least acceptable, sharing of the benefits is also a key consideration. Even so, increasing fishers chasing possibly fewer wish will mean lower individual catches, increasing the individual pressure to use more effective gears and raising the potential for conflict. At some point decisions will have to be made about access to fisheries. This point is highlighted by the contrast between the two fisheries in the case of Prek Toal.

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ANNEX A: AN EVALUATION OF FISH SPECIES AND GENETIC DIVERSITY OF THE TONLE SAP GREAT LAKE

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Summary

Fish has long been critical to all Cambodians. It is a major source of nutritious food in the daily diet, a primary source of income and has strong cultural and religious significance. Fisheries matter a great deal to the millions of people who live on the banks of the country's rivers, particularly those living in and around the Tonle Sap Great Lake. Cambodians are considered one of the highest per capita consumers of freshwater fish in the world (a recent estimate of 67 kg per person per year from household surveys). Freshwater fisheries contribute 10 to 12% of Cambodia's GDP accounting for 31% of the GDP contribution of the primary sector. Since 2000 Cambodian freshwater capture fisheries rank fourth in the world in terms of total catch (i.e. 400,000 tons per year). This is considerable as the country is rather small (181,035 km^2) and its population is also small (13.6 million in 2005). Actually, with an average 30 kilograms of freshwater fish caught per Cambodian per year, the country has the most intense freshwater fisheries in the world.

The contribution of various ecotones to global biodiversity in Southeast Asia reaches the status of hotspot. The Indo-Burma region, including the Mekong River Basin, is no exception. The aquatic resources of the basin represent enormous biodiversity with at least 1,200 fish species. Its extremely diverse fish community reflects past climatic and geological processes, which have brought together the fauna of several river systems, and places the Mekong among the top three rivers in the world (after the Amazon and the Zaïre/Congo). Cambodia's Mekong River Basin harbors approximately 500 fish species, of which, about 200 fish species are found in the Tonle Sap Great Lake (the largest and most productive lake in Southeast Asia, being formed by subsidence about 5,700 years ago). The Tonle Sap Great Lake is the center of Cambodian fish production and it is globally significant ecologically, being nominated as a Biosphere Reserve in 1997 under the Man and Biosphere Program of UNESCO.

Fisheries from the Tonle Sap Great Lake contribute over 60% of the total freshwater fish catch in Cambodia. The Tonle Sap Great Lake has some of the smallest and largest freshwater fishes in the world, from the minute carp *Oreichthys parvus* (maximum length 2.5 cm), to huge species such as the Mekong giant catfish *Pangasianodon gigas* (maximum length 300 cm) and the giant barb *Catlocarpio siamensis* (maximum length 200 cm). The more familiar fish groups comprise carps (Cyprinidae – 39%), catfishes (Akysidae, Ariidae, Bagridae, Clariidae, Pangasiidae, Siluridae and Sisoridae – 24%), herring (Clupeidae – 3%), snakeheads (Channidae – 2%), featherbacks (Notopteridae – 2%), gouramis (Osphronemidae – 2%), and climbing perch (Anabantidae – 1%). The remaining 27% consists of needlefishes or garfishes, tongue fishes, soles, leaf fishes, archerfishes, drums, threadfins, snooks, anchovies, eels and many other fish species. A very recent first research result is that "white" fish species constitute about 37% of the total number of Tonle Sap Lake fish species, "grey" fish species 50%, and "black" fish species 13%. The catch composition of "white" fishes and "grey" fishes is about 60% of total

catch, while "black" fishes contribute about 40% to total fish catch. The previous estimates of composition of catches of top ten fish species (i.e. *Henicorhynchus lobatus/siamensis*, *Channa micropeltes*, *Cyclocheilichthys enoplos*, *Labiobarbus spp.*, *Osteochilus spp.*, *Cirrhinus microlepis*, *Pangasianondon hypophthalmus*, *Barbonymus gonionotus*, *Paralaubuca typus*, and *Channa striata*) in commercial fisheries (i.e. large- and middle-scale fisheries) by the Mekong River Commission – Fisheries Program reveal that "white" fishes (i.e. six of the top ten fish species) contribute about 45% of total catch and 27% of total value, "grey" fishes (i.e. two of the top ten fish species) 7% of total catch and 4% of total value, and "black" fishes 11% of total catch and 25% of total value.

The many fish species of the Tonle Sap Great Lake encompass 90 genera and 32 families with a diversity of form, feeding habits and modes of reproduction. As a result of the high diversity in the Tonle Sap Great Lake, fish occupy all available aquatic habitats and exploit many kinds of foods. Biodiversity is a crucial element in high fishery production, providing to some extent a natural "safety-valve" each season, so that loss of any species (e.g. from a disease or over-fishing) will be compensated for by increased production of other species. The high diversity of species, the great range of habitats, and the variation in catches over time and space make wild freshwater fish available to a wide range of people, thus a high degree of participation in Cambodian fisheries.

Within fish species, diversity might be partitioned into variation within and among populations. It is necessary to maintain both types of variation to minimize the frequency of extirpation of local populations and to sustain species stability since genetic diversity is a requisite for evolutionary adaptation to a changing environment. So far, genetic stock structure and differentiation at the population levels has proven to be the best method to manage the conservation of species, including fisheries. However, their application, particularly in tropical regions, is still in its infancy. In Cambodia, there is very little scientific knowledge of fish population genetics (i.e. genetic diversity and stock structure). The first research study is on population genetics of the two large migratory Pangasiid catfish species *Pangasianodon hypophthalmus* and *Pangasius bocourti* in the Mekong River (including Cambodia, Laos, Thailand and Vietnam) using both mtDNA and microsatellite markers by Cambodian DoF/KULeuven. The recent study on mtDNA stock structure of the two small migratory Mekong River carp species *Henicorhynchus siamensis* and *H. lobatus*, collected throughout Cambodia, Thailand and Vietnam, was conducted by MRC/QUT/ACIAR. In addition, there is an on-going mtDNA phylogenetic study on the Mekong giant catfish *Pangasianodon gigas* by NACA.

So far in the Mekong region, there are nine microsatellite markers in the SE Asia catfishes *Pangasianodon hypophthalmus* (4) and *Claria batrachus* (5) developed in 1999, twenty-seven microsatellites for the migratory Asian catfish family Pangasiidae (i.e. five species: *Pangasius krempfi*, *P. bocourti*, *P. conchophilus*, *P. pleurotaenia*, and *Helicophagus waandersii*) developed in 2002, and recently twenty-four microsatellites in the captive Mekong giant catfish *Pangasianodon gigas* developed in 2006. In the past decade, there have been several studies on population and phylogeographic structure in SE Asia fish, i.e. the catfish *Hemibagrus nemurus* in SE Asia using mtDNA markers published in 1995, the climbing perch *Anabas testudineus* in Thailand using allozymic markers in 2000, Pangasiidae catfishes in SE Asia using both allozymic and mtDNA markers in 2000 and using mtDNA markers in 2003, the four species of the catfish genus *Clarias* (i.e. *C. batrachus*, *C. macrocephalus*, *C. gariepinus*, and *C. meladerma*) in Thailand using allozymic markers in 2002, the river catfish *Hemibagrus nemurus* in Malaysia using microsatellite DNA markers in 2003, and the cyprinid fish *Barbonymus gonionotus* in SE Asia using mtDNA and microsatellite markers in 2004.

To date, the genetic approach for identifying discrete gene pools (i.e. stocks or populations) of fish, and hence effective management units, has not been trialed in Cambodia and so the basis for developing management principles and practices is limited. Therefore, population genetics programs are needed to (1) demonstrate the utility of molecular population genetic data for fisheries and aquaculture management in Cambodia, particularly in the Tonle Sap Great Lake and (2) develop both human (expertise) and physical (DNA laboratory) capacity in Cambodia in undertaking and interpreting such programs. This approach will provide a major boost to the level of scientific knowledge available to managers for developing successful long-term management plans for Tonle Sap Great Lake fish species. In parallel it will develop expertise in Cambodia in the practice and interpretation of such data sets in fisheries and aquaculture management where previously it was largely absent. Together this should provide a powerful impetus to develop and apply similar technologies more widely on Lower Mekong River Basin fish species and ultimately promote the level and quality of fish stock management in the region.

ANNEX B. SURVEY FORMS

Built Structures Fisheries Survey Form

COMPLETE 1 FORM FOR EACH INTERVIEW

Section A. - DETAILS OF THE INTERVIEW

Date	
Location	
Structure type	
Village name	
Commune	
District	
Province	

Respondents	Gender/Age

Who identified them?

Section B. - TYPE OF INVESTIGATION

	Yes/No?
B1. Is this a before/after investigation?	

If answer to B1 is "Yes" then fill in sections	C, D, E and F
If answer to B1 is "No" then fill in sections	C, E and F

Section C. - MAPPING THE CURRENT SITUATION

Guidelines:

We get the respondents to draw a map of the area as it is now (use large piece of paper).
Important aspects to include are:
1. types of habitat (e.g. canals, paddy fields, ponds, rivers, streams, swamps etc.) that might be important for fish and/or fishing. Highlight which ones are new or have changed. Location name
2. Distances, estimated areas and depths and seasonality of the resource (mark these on map)
3, Any rules that are in place regarding access to and use of resources. Mark these with the letter private or protected areas on the map.
4. Gear and main gear types in each fishing location.
Now go to section D or E.

Section D. - MAPPING THE SITUATION BEFORE THE BUILT STRUCTURE

Guidelines:

We get the respondents to draw a map of the area as it was before the built structure was put in place (use large piece of paper). Important aspects to include are:

1. types of habitat (e.g. canals, paddy fields, ponds, rivers, streams, swamps etc.) that might be important for fish and/or fishing. Local name
2. Distances, estimated areas and depths and seasonality of the resource (mark these on map)
3. Any rules that were in place regarding access to and use of resources. Mark these with the letter private or protected areas on the map.
4. Gear and main gear types in each fishing location.

Now go to **section E** and to ask about changes.

	Yes/No?
D1. Is there anywhere that you are fishing now that you were not fishing before?	

If D1 = yes then describe why?

	Yes/No?
D2. Is there anywhere that you were fishing before that you are not fishing now?	

If D2 = yes then describe why?

Section E. - CHANGES IN THE FISHERY

E2. For each of the locations that are still being fished, what changes have there been in catches and fishing and why, e.g. change in depth, number of fishers, gear types, scale of the gear, species etc.
1. total catch - how much changed in %? overall, small- and big- sized fish groups and why changed?   Did/does the built structure affect catches? What level?   2. fish size - how much changed in %? overall, small- and big- sized fish groups and why changed?   Did/does the built structure affect fish size? What level?

Section E continued

3. catch composition -how much changed in %? overall, small- and big- sized fish groups, by species and why changed?

Did/does the built structure affect catch composition? What level?

4. fish movement and migration - why changed? (white, grey and black fishes)

Did/does the built structure affect movements and migrations? What level?

Section E continued

5. fishing effort - why changed?

Did/does the built structure affect fishing effort? (gear types used)

6. fish price - how much in %?: overall, small-sized fish group and big-sized fish group. Why changed?

Did/does the built structure affect fish prices?

Section F. - EFFECT OF THE BUILT STRUCTURE ON HYDROLOGY & HABITATS

F1. How do the fishers feel that the built structure has affected/affects the water flow and water quality? For examples: extent and uration of flooding, amount of fish disease, water colour and turbidity.
1. How water flow affected?
2. How water retention affected?
3. How flooding areas affected?
4. How water quality affected? (e.g. fish disease, water collour and turbidity)

F2. How do the fishers feel the built structure has affected/affects the habitats or fishing locations?

For example: new habitats or fishing locations created, change in size/area, acess to fishing locations

1. New habitat or fishing location created?

2. In the past could you access to many locations easily?

F3. Is there any other information about the built structure or the fishery that the fishers would like to share with us?

Recommendations/suggestions for protecting your fisheries resources

Are built structures having positive or negative impacts on fisheries resources? Why?

In case of negative impact, how do you minimize it?

Form completed by:

Fisheries Ecology Survey Form

COMPLETE 1 FORM FOR EACH INTERVIEW

Section A. - DETAILS OF THE INTERVIEW

Date	
Location	
Structure type	
Village name	
Commune	
District	
Province	

Respondents	Gender/Age

Who identified them?

Section B. - MAPPING THE CURRENT SITUATION

Guidelines:

We get the respondents to draw a map of the area as it is now (use large piece of paper).
Important aspects to include are:
1. types of habitat (e.g. canals, paddy fields, ponds, rivers, streams, swamps etc.) that might be important for fish and/or fishing. Highlight which ones are new or have changed. Location name
2. Distances, estimated areas and depths and seasonality of the resource (mark these on map)
3. Any rules that are in place regarding access to and use of resources. Mark these with the letter private or protected areas on the map.
4. Gear and main gear types in each fishing location.
Now go to section C.

C1: For each location records gear and main gear used by season, scale and mesh size of the gear, species caught (see pictures), and catch per day

Location	Main gear	W/D season	Scale	mesh size	Species caught	kg w sea	kg d sea	kg total

C2: Record the fish species caught by season, catch per season and average size of the fish in that season

Species	Wet season (6-10)		Dry season (11-5)		Total	
	kg	cm	kg	cm	kg	cm
Riel						
Andetchhkae						
Chhkaok						
Pra Thom						
Kae						
Po						
Chhveat						
Kros						
Changva						
Prual						
Kambot Chramos						
Brama						
Ros						
Chhdau						
Srakakdam						
Kantrop						
Slat Srae						
Kanhchos Chnot						
Khman						
Ta Aon						
Linh						
Kanhchrouch						
Sanday						
Sleuk Reusei						
Ka Ek						
Kahae						
Chpin Prak						
Proloung						
Kranh						
Kantho						
Kray Sre						
Kampleanh Sre						
Chhlounh						
Kcheng						
Angdeng						
Khman						

Section D - LOCAL MIGRATIONS AND SPAWNING

D1. Use the local map and transparencies to show the location and timing of migrations and where the fisher perceives the source of young fish to be (e.g. local, tributary or Mekong).

Species	Where the young fish come from
Pra Thom	
Prual	
Riel	
Chhpin	
Ta Oan	
Kanh Chos	
Kanthou	
Kray Srae	
Proloong	

D2. Have there been any changes in migrations and movements because of the built structure? If yes, which species and why do they think this has happened?

Section E. - NEW INFORMATION ON FISH ECOLOGY

H1. Ask fishers for which species they have knowledge of spawning, nursing, feeding and migrations within the basin. For those fish that they have knowledge, complete the following table.
For the ecology type (black/white/grey) you will need to identify this yourself.

Species name	Type of Spawnin habitat	Name of Spawning location	Type of Feeding habitat	Type of nursing habitat	Ecology type
Andet Chhkae					
Kanhchos Bay					
Kanchras Thom					
Bandoul Ampov					
Reus Chek					
Kasan					
Phtoung					
Chlaing					
Ka Ek					
Angkot Prak					
Dorng Khteng					
Chunteas Phluk					
Ampil Tum					
Stuk					
Kra Morm					
Ka Uk					
Krum					
Chunluanh Moan					
Kantrang Preing					
Kampleav					
Khlaing Hay					
Kes					

Form completed by:

ANNEX C. PRE-SURVEY REPORTS

Kampong Thom Province

Objective of the trip: To select sampling locations and test the fisheries component questionnaire at Stung Chinit site in Kampong Thom province

Duration of the trip: 3 days (21-23 August 2006)

Persons involved: Dr. So Nam, Dr. Robert Arthur, Mr. Leng Sy Vann, Mr. Prum Sitha, and Miss. Pom Sok Hort.

The site:

The site at Stung Chinit in Kampong Thom Province represents an irrigation scheme comprising a number of built structures that include a barrage across a river (Stung Chinit River), sluice gates, canals (including channelised rivers), embankments, roads, a fish pass, an irrigation reservoir and paddy fields. This is an example of a development that has rehabilitated an existing, but disused, irrigation scheme that dates from the Khmer Rouge period. From the available information it seems that the scheme was in use (gates closed) between 1981/982 and 1989/90 after which the barrage was broken (gates open). There have been a number of reasons given for this including conflict between fishers and water users but the true reason remains unclear. The scheme remained out of operation until June 2006 when the present, renovated and extended, scheme came into operation (gates closed once more).

Progress report:

1. Consulting with Provincial Fishery Officers

The team met with provincial fishery officers to inform them about the purpose of the visit to Kampong Thom. This was also an opportunity to get additional information from them regarding the built structure at Stung Chinit, especially about the patterns of fishing activity for the villagers who fish in the affected river. From discussions with the livelihoods component team and with the provincial fishery officers, it was decided that the team would visit four communes: Chaeng Daeng, Kampong Thmor, Boeung Lvea and Thnoat Chum commune. Within these four communes six villages[6] were identified that would be visited:

- Tek La'ak, Snao, and Sang village in Kampong Thnor commune,
- Prey Dom village in Chaeng Daeng commune, and
- Thnoat Chum village 1, 2, 3, or 4 in Thnoat Chum commune,

1. Consulting with commune/village head and commune council members

We met with the chiefs of three communes (Kampong Thmor, Thnoat Chum) to consult with each of them about fishery situation around the irrigation scheme at Stung Chinit. This information was given by representative of each commune through mapping and interview techniques.

[6] Tek Laak, Snao and Sang villages were identified based on discussions about an earlier visit by the livelihoods component.

Kampong Thmor commune

We went to meet the Chief of Kampong Thmor commune accompanied by Kampong Thmor Fishery Inspector (Mr. Keo Sitha, phone number: 012 716 339). The head of the commune (Mr. Men Chin, phone number: 012 596 235) provided information regarding the location of fishing villages and his views on the fisheries situation at Stung Chinit.

- La'ak village is a village where villagers fish in both Stung Tang Krasang and Stung Chinit irrigation reservoir. Snao and Sang villagers go fishing mainly in the irrigation reservoir.
- Regarding the fishery situation in Stung Chinit, before the closure of the gate following rehabilitation of the irrigation scheme there were many fish in Stung Chinit upstream of the dam and fishermen could at this time catch large fish, including species such as *Mystus wyckioides*, *Wallago Leerii*, *Probarbus jullieni*, and *Catlocarpio siamensis*. These species are now rarely caught.
- The head of the commune relates that there are still many fish both below and above the gate that can easily be caught (more above than below). Some parliamentary people came recently to see how the abundance of fish had increased but he is not sure whether the abundance is due to an actual increase or just fish concentrating at these sites.
- The fish ladder is considered to be beneficial if it allows fish to get up but there is no evidence for this.
- Before any irrigation scheme was created there were many pools in the upstream area that were an important source of fish as a lot of fish congregated in these deep pools. During the period when the gate was open the pools silted up. The reason given for this was that the forests were being cleared along the river. The larger trees are prized for their wood and because the roots make good plowing implements. Removing the trees has a big effect in making the river and pools shallower and both water temperature and turbidity increase.
- Regulation of the water using the gate means that the forest downstream no longer gets inundated in the same way. This makes it easier to exploit. Development of the irrigation scheme has had an effect on trees with a lot of palm trees around Snao village being removed.

After discussions with the commune head, the team went to see the heads of each of the three villages within the commune and to discuss with groups of three fishers from each in order to get a more detailed picture of the fishing activities, and changes in fishing activities in each village.

La'ak village

La'ak represents a village upstream of the irrigation scheme, in particular the dam across Stung Chinit. According to respondents at La'ak village fish were abundant during the time when the dam of Stung Chinit was not broken (i.e. was closed). After the dam was broken in 1989/90, the number of fish declined too. With the dam closed large aggregations of fish such as *trey riel* are seen below the dam, where they can easily be caught. Everyone from the downstream areas fishes just below the dam as the fish get stuck there and cannot pass. Fish from upstream are also less able to move downstream and some have been observed spawning at the edges of the irrigation reservoir. This is a benefit for the fishers upstream. It is also good because in the dry season there were not so many places to fish but now they can fish easily because there is water in the reservoir.

Villagers have been fishing in both Stung Tang Krasang and Stung Chinit. With the dam closed again the fishers use the reservoir more because it is closer. In La'ak village there are five or six households that go to fish all the time, the others just fish occasionally with cast nets or with gillnets set overnight. Over time there have been changes in fishing with the number of fishermen increasing; in some places there is even fishing in rotation. There were two, interrelated, reasons given for this. The first is that people see that there are fish and that more fish are being caught so they also want to go fishing. Also, after planting rice, farmers have more free time so the opportunity is there and the numbers of fishers increase. The fishing gears have also changed with mesh sizes decreasing. In the past nets with 3-4 cm mesh sizes were used but now 2.5 cm mesh sizes are common and fishers are catching many more small fish.

There have been some differences identified between the two rivers with fishers mostly catching black fish species in Stung Tang Krasang. They report that *Wallago attu* is present in both rivers: Stung Tang Krasang and Chinit. There have also been changes in the composition of fish in the rivers over time; particularly notable is the decline in snakeheads, especially *Channa mircopeltes*. However, this is due more to harvesting for aquaculture than the dam. The fishers weren't able to catch much in the reservoir this year because there is a larger area of water and the fish are less concentrated so more difficult to catch. They hope to catch more next year because the broodstock were not caught this year and the increase in fish will mean that they can use larger mesh sizes and not have to set gillnets overnight. In the wet season (May/June) fish (i.e. black and grey fish) move and migrate from the stream (i.e. both rivers) to rice fields, lakes, and other floodplain areas though canals and tributaries to feed and spawn (an upstream migration according to local knowledge). In the dry season (November/December) fish move from the rice fields, lakes, and other floodplain areas to the stream through canals and tributaries (a downstream migration according to local knowledge) in order to find refuge (e.g. in deep pools) where the fish can hide and feed. When the dam was open fish (i.e. white fish) moved and migrated down the river to feed in the floodplain and lake.

Snao village

Snao village is adjacent to the irrigation scheme dam and therefore represents a village in the middle of the scheme. Fishers from the village fish for household consumption and have generally been fishing below the dam. This is a general thing that people downstream of the dam do not really fish above the dam and the fishers report that there is some sort of unofficial regulation that if you are from downstream you fish downstream and if upstream you stay upstream. (According to the fishers, there was also an allocation of fishing locations along the river with traditional family locations that were all identified a long time ago. This was all along the river and this fishing location system is still in place in the downstream areas). The main fishing gear used in this village was the cast net.

When the dam was closed this changed as there became a large area upstream to fish all year and fewer opportunities downstream. The fishing downstream was affected as there was less water and the fishing was only good while there was water, particularly from November to January, while fishing upstream could continue all year round. It is the opinion of the fishers that fishing will become better upstream compared to down for this reason and already they say that there are generally more people fishing upstream compared to down. The effect of the closure was that the larger area upstream meant that there were no longer regulations there and fishers from downstream could fish in the reservoir. However, the restrictions remain in place downstream where there is still partitioning and it can get quite crowded but where the catches can be quite good for the few months that there is sufficient water. Fishers from upstream are still not allowed to fish in this area.

They were also able to inform us that there were more fish upstream than downstream when the dam was not broken, with bigger fish, for example a *Walago lerri* of up to 20 to 30 kg, and more fish at this time compared to when the dam was open. When the dam was broken (opened, the fishers say through natural erosion of the base of the dam), there were fewer fish and catches were smaller but they could catch more in the downstream areas. However, in the future they do not expect catches to return to the levels they experienced before when the dam was closed because of the modern, smaller mesh, fishing gears, the increase in numbers of fishermen and the clearing of the flooded forest. Before in Snao village some people used to buy fish and about a third went fishing after rice planting; now they all fish. In addition, before it was just adults who fished but now younger people from Snao are also fishing using hooks and line.

In the wet season the catches were lower than those in dry season because at this time the river was full of water and very deep, making it difficult to fish. In the dry season villagers always went fishing in the river's deep pools and in the irrigation reservoir, and especially in October to November they could catch a lot of fish. The reason given for people not catching much in the upstream areas at the moment is that when the dam was closed the fish in the reservoir were quickly caught. After the dam was closed, the water downstream was reduced and so fewer people were able to go and fish there at that time.

Regarding the structure, it was the opinion of the fishers that some fish are able to get up the fish ladder but these are larger fish and that smaller species such as *trey riel* cannot move up the pass as they are not strong enough.

The above information is the first information obtained from the village head only. This information may be different from that obtained from experienced fishers.

Sang village

Sang village is downstream from the Stung Chinit dam and represents a village at the edge of the irrigation scheme. Fishers at the village informed us that before the Khmer Rouge dam on Stung Chinit had been broken, there were many fish species in Stung Chinit. At that time the majority of the people living in the village always went fishing upstream below the dam where fish congregated and a few (the minority) fished around the irrigation reservoir. At this time many fish species were caught (e.g. *Morulius chrysophekadion, Osteochilus melanopleurus, Micronema micronema, Pangasius larnaudii, Henicorhynchus siamensis, Thynnichthys thynnoides, Barbonymus gonionotus, Mystus wyckioides, Wallago attu, Hampala spp, Channa striata, and Channa micropeltes*).

Fishers report that they are now catching less and using more gears or fishing for longer.

After the dam was broken, some fish species were no longer caught (e.g. *Mystus wyckioides and Channa micropeltes*) and some were caught in smaller numbers than before (such as *Wallago attu, Hampala spp., Channa striata, Henicorhynchus spp., and Thynnichthys thynnoides*). Overall fish abundance is believed by the fishers in this village to have declined since the time before the dam was broken. Reasons given for why fish abundance has declined included: increasing numbers of fishermen, increasing fishing effort (i.e. time spent fishing and number of gears), and new and potentially unsustainable fishing gears (including gears made from filamentous mesh net).

The fishers were also able to provide some information on fish movements and migrations, reporting that there are two peak periods of fish migration: (1) upstream migration in November/December and (2) downstream migration (May/June). Interestingly, according to them, the migration patterns in Stung Chinit are completely different from the patterns in Stung Tang Krasang due to its different water regime.

Boeung Lvea village/commune

We met with the chief of the commune to consult with him about the general situation in the commune. He told us that this commune started out as a single commune but is now divided into two parts (Old Boeung Lvea (in the upland area) and New Boeung Lvea (this village). New Boeung Lvea was established around 1980 and is situated along the main irrigation canal leading from the irrigation reservoir and, as such, represents a village in the middle of the scheme. According to the commune chief, the main occupations of villagers are related to collecting secondary wood and non-timber products from the upland areas around Old Boeung Lvea and rice cultivation around New Boeung Lvea. The reason for this is that they do not have much land. According to him only about 30% of households are engaged in fishing activities and mostly in Stung Tang Krasang although they also use the reservoir area of Stung Chinit when the dam is closed as anyone can fish there. The villagers thus split their time between the two locations and, according to the chief of the commune, would continue to do so even with the operation of the irrigation scheme. Because there was not a high degree of reliance on fishing in the village and villagers did not have long fishing experience it was decided not to include Boeung Lvea as a study location for the fisheries component.

Chaeng Daeng commune

We met first with the vice-chief of the commune and the secretary of the commune at the commune office. We informed them of the purpose of our visit and asked for information about the commune, especially about villages within the commune that were particularly dependent on fishing or were recognized as having particular knowledge about fish and fishing. We were informed that Prey Dum village is an active fishing village and that this village was located about one kilometer from the river. Because it is also a lowland village, the village is at risk from flooding due to the dam that can affect the rice fields every year. Before the new scheme was developed, there was a large natural canal that allowed water to escape from the land around the village to the river downstream of the dam. During the renovation of the scheme the canal was channelised and when the water is high this canal does not transfer the water away sufficiently and local flooding occurs affecting both the village and surrounding rice fields.

When the dam was not broken (post Khmer Rouge period), there was a high abundance of fish and many big fish also. For example, a *Wallago leerii* could weigh o to 20 kg. Since the dam was broken fish abundance has declined strongly and some fish species were not found in some places, in particular they mentioned *Barbonymus gonionotus* and *Hampala spp*. The commune officials thought that with the reconstruction of the scheme fish stocks may recover in the future.

Prey Dum village

Prey Dum is similar to La'ak village in being upstream of the dam. However, it is located on the other side of the river and irrigation reservoir, away from Stung Tang Krasang, and instead near the channelised canal. The village is comprised of 182 households according to the village chief. He complained that his village and the nearby rice fields get flooded due to the dam because the new channelised canal is not able to take away sufficient water. Last year households in the village lost some rice through flooding and this year it has been much worse and they expect that this will be the case also in the future. The canal used to be a tributary that ran from a lake in the flooded wetland area to the river downstream of the dam and water would move quickly down this tributary. With the development of the scheme this tributary became a canal that now acts as a link between the irrigation reservoir upstream and the river below the dam. The villagers would like to enlarge the canal so that it is able to remove the water more effectively to reduce the flooding and, according to the village chief, the MoWRAM is considering this. However, the MoWRAM had also apparently agreed to compensate villagers between 1000 (productive lowland areas) and 500-700 (less productive areas) US dollars per hectare for the damage that might result to their fields from the renovation of the scheme. Up to this point the villagers complain that they have not received this money from the MoWRAM.

The village chief considers that the overall the scheme provides more benefit for people living downstream because they can do 2-3 crops from their rice fields, but upstream people get less benefit from their rice fields, which are irrigated by rain water rather than from the reservoir, and indeed suffer from the flooding. During the dry season there is some irrigated rice cultivation with water pumped from the reservoir but not much. The general feeling is that the scheme provides very little benefit.

In this village people go fishing mainly for subsistence purposes rather than commercially, although they may sell a small amount at the local market. Traditionally many in the village have been growing rice and collecting forest products and making baskets. There are also some who move down to the lake and who either fish in the fishing lot after the lot owner, work as fishing a lot owner or take the opportunity to buy cheap fish there. When the dam was open there were many small water bodies around the village (including many lakes such as Chung Keang, Takeng, Ambeksrov, Rolouch, Tangbang and Ptachas). These water bodies were easy to fish and gears used in them included small scale fishing gears such as cast nets, gill nets, hooks and lines and bamboo traps. When the dam is closed these water bodies become part of the irrigation reservoir and in the dry season villagers go fishing mainly in the irrigation reservoir where the fishing gears used were similar to those in the water bodies and the upstream river. In the wet season fishing is mainly in rice fields and the flooded wetland areas that are created. Most of the villagers do not like fishing in the reservoir because they can catch less fish. However, there are two families (with boats) who have to go fishing there a lot because they have little or no land for rice fields.

Most of the fish that villagers catch are black/grey as they move and migrate. In general there was a perception that fish abundance has been declining over time. The village headman thought that when the dam was closed in the past this resulted in plenty of fish in the upstream area because the flooded forest provided habitat for the fish. However, while he thinks that this will also be the case in the future he believes that it will be less because a lot of the flooded forest has become rice field. He thinks that perhaps after the dam has been closed for two or three years the fish will have become more abundant. However, species diversity has decreased over time and now the diversity of fish species is less than it was in the past. This, and the decline in abundance, is due to two factors: firstly, there is illegal fishing activity using electro-fishing, dynamite and small mesh nets and, secondly, there has been the effect of the changes in hydrology over time. Before the dam fish could move freely. When the dam was closed the upstream area benefited, while fish from downstream could not move up. When the dam was broken, the fish could move again and there was also a benefit to the people downstream.

Related to the current irrigation scheme, the headman informed us that almost all fish species can continue to move upstream and down because of the canal, particularly important for upstream movement. The canal, which is always open, means that fish can get to the irrigation reservoir as well as to the wetlands around the village and to the deep pools further upstream. In the rainy season fish migrate down from the river to rice fields, floodplains (also through the network of irrigation canals) and lakes. These species include the climbing perch (*Anabas testudineus*), *Mystus wyckioides*, *Channa striata*, *Hemibagrus spilopterus*, *Henicorchynchus siamensis*, *Dangila spp.*, *Barbonymus gonionotus*, and *Clarias spp*. Fish moving upstream reach the dam and either aggregate below the dam or else move up through the canal. This aggregation effect is a benefit to those downstream who have more fish to catch during this period. Generally, the village is not worried about the fish but is concerned at the loss of rice production.

Thnot Chum commune

We met with the chief of the commune and Thnot Chum villages to consult with him about the fishery situation in Thnot Chum commune and impacts of the irrigation scheme in Stung Chinit. This is a commune located downstream of the dam and outside the irrigation scheme. Thnot Chum itself is made up of four villages (1^{st}, 2^{nd}, 3^{rd}, 4^{th} Thnot Chum village) and consists of a total of 550 households. There is a researcher from the GRET project to monitor the fish catch in the village. Some 40% of people from these villages fish regularly (either part-time or full-time) and 20% fish all year round. Fishing is generally local and fishers don't go downstream very much. As with Snao village, it was reported that in the past the fishing area downstream of the dam was subject to access restrictions. Households had their own particular fishing areas that were passed down and spots where people fished, using cast nets and gill nets, were often signposted. As the numbers of fishers has increased over time (due to population increases) this system has stopped. As a general rule the number of fishers increases as one moves downstream. Before, when the dam was closed, households also used to fish above the dam, but not much as it is quite a long way away. At present, with the dam closed again, they are not sure whether the fish are very abundant in the reservoir yet so they have not started fishing there again yet. Generally, the river is preferred as flowing water is different to standing water and the river is nearby and has fish in it.

The dam broke in 1985/86. Before this, when the dam was not broken, fishing in the river was better than when the dam became damaged because the water level was lower and the river was narrower, making it easier to catch fish. There were not really any problems with the fishery then because the upstream area had enough water for spawning fish. Fish in the river generally came from upstream although there was also another dam lower down in the floodplain that kept water in the floodplain and which meant that fish could travel upstream to Thnot Chum. After the downstream floodplain dam broke there were fewer fish traveling upstream.

The river at Thnot Chum provides something of a nursery area and there are usually plenty of *Wallago attu* because of the many small fish in the area. This year there has been a lot of *trey riel* in the river, more than last year although in general the abundance of *trey riel* has been declining over time. The reason for the abundance this year is not clear but someone has suggested that it is because there are fewer predators and another reason that has been suggested is reduced fishing with mosquito netting that has allowed more of the fry to survive.

Regarding this, the DoF patrols have meant that there is less illegal fishing but if the patrols were to stop there would be lots. They have wanted to try to create a community fishery for conservation and to improve production. There are a number of small water bodies near the villages and they have created some regulations to help manage these resources. While it is still allowed for people to fish in these there are regulations such as conservation zones in place.

On the 20th of January 2006, the southern embankment was broken and at that time water was shallow, making the water very turbid. As a result, a lot of fish, especially *Wallago attu* (with a single fish of 5-8 kg) died and could be found with silt in their gills. There are many deep pools and they are 4-12 m of depth in the downstream part of the village (e.g. Ta Ouk, Ta Tra and Prek Ampov deep pools), and deeper than 12 m in the upstream part (e.g. Thnot Chum deep pool with 15 m in depth). These pools represent important refuges because they are difficult to fish (depth and water eddies) even in the dry season.

In terms of the effect of the built structures for Thnot Chum the downstream dam had a larger effect for fisheries as it made the floodplain area larger and so more fish would come into the river. The upstream dam did not affect the fish abundance so much but when it was closed it affected the river and also meant that fish would concentrate in the river. There will always be water in the river and fish will still be able to move up and down the river when the dam is closed so they expect that there will be no negative impact on the fishery in Thnot Chum. With the closure of the dam this year the village will benefit from the concentration of fish but they will not benefit from the irrigation. However, it is planned that another canal will be built during a second phase and they expect to benefit from this.

Battambang (Prek Toal)

Objective of the trip: To select sampling sites for the project area of Prek Toal and pre-test the questionnaires in Prek Toal village of Battambang province

Duration of the trip: Two days (24-26 August)

Persons involved: Dr. So Nam, Dr Robert Arthur, Mr. Leng Sy Vann, Mr. Prum Setha, and Miss. Pom Sok Hort.

Progress report:

The site:

The site at Prek Toal village of Battambang province provides a different sort of built structure from the other sites. Here the structure is a fishing gear consisting in a large part of a large bamboo fence (36 km long) that is in place from January to June in order to channel fish returning to the lake from the floodplain area as the water recedes into fishing gears. This type of structure is associated with the fishing lot system where the enclosed area of the lake and floodplain is leased for fishing. This lot system and the fence gear is a traditional system of management. Prek Toal provides an opportunity to examine an operational fishing lot (Lot #2, the largest (50,134 ha) and most productive lot in Cambodia) and a fishing lot (Lot #3) where the structure was removed and the management system changed to a 'community fishery' system that has fewer access restrictions in 2001 in order to examine the effect of the structure. This is slightly complicated by the fact that the management system and structure are so closely related, making it difficult to clearly separate the impacts of the two.

1. Consulting with Provincial Fisheries Officers, Village Heads and Commune Council Members

We met and discussed Prek Toal with the local Fishery Inspectors: the First Vice-chief of Koh Chivang commune (Mr. Kuy An, his phone number, 016 715 986) and heads of Kampong Prohok (Mr. Keo Sovann) and Prek Toal (Mr. Pum Chin, his phone number, 016 328 721) at the Prek Toal Fishery Inspection Unit in order to discuss our plans for information collection, introduce ourselves, distribute the criteria for the selection of fishers for the interviews we would be conducting and also gather some general information regarding the fishery situation around Prek Toal. At this site there are four floating villages along the Stung Sankae: Prek Toal village, Anlung Taour, Kampong Prahok, and Khvang. In addition, there is a further village, Prek Kanteal, that is not officially recognized and which is located on the other side of Fishing Lot #2. During the discussions they were able to inform us that:

- This source of water around Prek Toal village is from the Stung Sangkae and Mekong River during the wet season. At the start of the wet season (June to August), the standing water in the floodplain area also starts being described as having a bad smell. The water's smell is reduced as fresh water flows into the floodplain area as the flood level rises. The bad smelling water is also described as being present again in November and December when the inflow of fresh water stops. This spoiled or bad smelling water in June and August results from flooded water from Stung Sankae and the rain over grasslands, and the water's smell is reduced when the Mekong River arrives.
- The Mekong River is a major factor relating to the abundance of fish in the Prek Toal area. When flooding from the Mekong River arrives late, i.e. starting in July/August, the abundance of fish is low. In contrast, when the flooding arrives early (June/July) then the abundance of fish in the area is much greater.
- There are a variety of fishing locations in the Prek Toal area but these can be summarized as being Fishing Lot #2, the community fishery (formerly Fishing Lot #3), the Tonle Sap Lake and the Stung Sankae main channel. Where people go fishing is not fixed and is instead related to the gear and resources of the fishers, access to the fishing lot and the flood level (see Table 1). Small-scale fishers are allowed to fish in the fishing lot area up to 15th October, after which access is restricted and the area comes under the control of the holder of the lease. The area controlled by the lease-holder includes the floodplain and also the lake area adjacent to the built structure (bamboo/nylon net fence) extending some 1 km into the lake. Within the fishing lot and community fishery fishers gradually move inland across the floodplain from the lake with the rising water and movement of the fish. Areas within the lot are subleased after 15th October so there is still some fishing activity within the fishing lot after this date. In the wet season fishers go fishing in the lake from May to July, and in the four community fisheries (previously Fishing Lot #3) and Fishing Lot #2 from August to the middle of October. Fishing is much more difficult during the months of November and December because in those months there is the bad smelling water from the Tonle Sap Lake that affects the fish and the water level is still high, making it difficult to fish. The bad smelling water causes fish to die, especially white fish and grey fish. In the dry season (in particular from January to May) they go back fishing in the Tonle Sap Lake and Stung Sankae main channel.

Table 1: Fishing location of Community Fisheries Members by Season

Community Fisheries	Closed Season May-October		Open Season October-May	
	% of CF members	Fishing location	% of CF members	Fishing location
Khvang	- 20 - 30 - 50	- CF's fishing domain (ex-Fishing Lot No.3) - CF's fishing domain (ex-Fishing Lot No.4) - Fishing Lot No.2	- 80 - 20	- CF's fishing domain (ex-Fishing Lot No.3) - Open access around the village, including Stung Sangkae
Kampong Prahok	- 70 - 30	- CF's fishing domain (ex-Fishing Lot No.3) - Fishing Lot No.2	- 80 - 20	- CF's fishing domain (ex-Fishing Lot No.3) - Open access around the village, including Stung Sangkae
Anlung Taour	- 50 - 50	- CF's fishing domain (ex-Fishing Lot No.3) - Fishing Lot No.2	- 50 - 30 - 20	- CF's fishing domain (ex-Fishing Lot No.3) - Go fishing at the lake - Leasing fishing location of Fishing Lot No.2 (Dong) from middle of December to May
Prek Toal	- 50 - 50	- CF's fishing domain (ex-Fishing Lot No.3) - Fishing Lot No.2	- 30 - 40 - 30	- CF's fishing domain (ex-Fishing Lot No.3) - Go fishing at the lake - Leasing fishing location of Fishing Lot No.2 from middle of December to May

Source: field trip, August 2006

The fishing gears that are used in the floodplain areas are *Bor* (small or big barrage with mesh net), gill net, and long hook and line. Over 90% of the gears used are *Bor*, and gill nets and long lines make up the rest. This *Bor* gear can be divided into three categories based on the scale of the gear: small scale (100-500 m); medium scale (>500-1000 m); and large scale (>1000 m). Table 2 provides a summary of fish catches by gear and location.

Table 2: Fish catch by *Bor* gear around the Lake and Fishing Lot No.2

Scale of *Bor* Fishing Gear (m)	Fishing Location		
	Total catch/day In TS Lake (Kg/time)	Total catch/day In Fishing Lot Number 2 (Kg/time)	
	May-July	August	Sept.-middle October
100-500	10-20	20	100-200
>500-1000	50-60	50	300-500
>1000	400	100	500-1000

Source: field trip, August 2006

A wide range of fish species are caught at the Prek Toal site including from the three ecological groups (i.e. black, grey and white fish, for the details see Table 4). When these fish species are caught depends on the season (see Table 3). During the closed season (particularly from May to July), grey and white fish are caught in the lake while black fish are caught in Fishing Lot #2 and the community fishery from August to October. White fish are again caught in the open season from the middle of October to November and grey fish are also caught from November to December. Fish species from all the ecological groups are caught from December to May, both in the floodplain areas and in the lake.

Table 3: Fish Species Caught by Season and Location

Closed season		**Open season In fishing lot No.2 and lake**		
Lake	Fishing Lot #2/CF	Fishing Lot #2/CF	Fishing Lot #2/CF	Lake and floodplain
May-July	August-October	Middle October-November	November-December	December-May
Grey and white fish	Black fish	White fish	Grey fish	Mixed fish species

Source: field trip, August 2006

In addition to fishing, some of villagers also go to work for the lease-holder of Fishing Lot #2 from February to May.

2. Discussing with knowledgeable fishermen

Two groups, comprising a total of six fishers, were convened to discuss local fish ecology and their perception of the effect and impact of the built structure. This discussion was held in Prek Toal village and the information was obtained through a combination of interviews based on the fisheries survey form and mapping.

Prek Toal village has been in existence for a long time and the fishing lots themselves were developed during the French regime. Within the fishing lots, as the water starts receding, the lease-holder of the fishing lot starts subleasing fishing locations along natural canals and lakes within the lot (from the middle of October to December/January). Other locations along the edge of the Tonle Sap Lake are similarly subleased from January/February to June. The reason for this subleasing is that the fishing lot lease holder does not have enough labor to be able to fish all these locations himself. However, fishing lot operators also go fishing with bamboo fences (i.e. a fence barrage of > 30 km long) installed at the Tonle Sap Lake from February to June. The fishing lot lease-holder starts putting up the fence barrage from middle of January and this remains in place until June. In Lot #2 the fence has a length of 36 km, stretching from Koh Chinuk (10 km), along the edge of the Tonle Sap Lake (20 km) and up to Pak Kanteal (6 km).

The people in the Prek Toal area informed us that they face serious problems in fishing. During the closed season (June-October), the provincial fishery officer does not allow them to fish in both the floodplain and the fishing lot, and in the open season (middle of October-June) the owners of the fishing lots do the same too within and around the boundary of their fishing lots. Several fishing gears are used in this area and these gears are classified into 3 types based on their fishing scale. Members of the community fishery use fishing gears such as gill nets, long hooks and lines, cast nets, *Lae*, *Bor*, *Samras*, and giant dip nets as well as various illegal gears, including electro-fishing. Lessees (*Dong*) always use middle-scale barrages, long gill nets, *Bor*, pumping machines, and electro-fishing. Fishing lots use large-scale barrages and electro-fishing.

A wide range of important fish species were caught in both seasons in Fishing Lot #2 and the community fisheries (before 2001 called fishing Lot #3 adjacent to Lot #2). They include white, grey and black fish species (for details see Table 4). On average, fish catch by species varied from 0.5 kg to 8 kg per day per household.

Table 4: Fish species caught at Prek Toal

Scientific name	Khmer name
Henicorhynchus siamensis	Riel Top
Henicorhynchus cryptopogon	Riel Angkam
Euryglossa spp.	Andetchhkae
Cyclocheilichthys enoplos	Chhkaok
Pangasianodon hypophthalmus	Pra Thom
Pangasius conchophilus	Kae
Pangsius larnaudii	Po
Pangasius spp.	Chhveat
Osteochilus waandersi	Kros
Labocheilos melanotaenia	Changva Ronoung
Rasbota tornieri	Changva Moul
Cirrhinus microlepis	Prual
Amblyrhynchichthys truncatus	Kambot Chramos
Boesemania microlepis	Brama
Channa striata	Ros
Channa micropeltes	Chhdau
Cyclocheilichthys apogon	Srakakdam
Pristolepis faciata	Kantrop
Notopterus notopterus	Slat Srae
Mustiid spp.	Kanhchos Snot
Hampala macrolepidota	Khman
Ompok hypophthalmus	Ta Aon
Thynnichthys thynnoides	Linh
Botia modesta	Kanhchrouch Krahorm
Wallago attu	Sanday
Paralaubuca typus	Sleuk Reusei
Morulius (Labeo) chrysophekadion	Ka Ek
Barbonymus altus	Kahae
Barbonymus gonionotus	Chpin Prak
Leptobarbus hoeveni	Proloung
Anabas testudineus	Kranh

Trichogaster pectoralis	Kanto
Chitala lopis	Kray Sre
Trichogaster trichopterus	Kampleanh Sre
Macrognathus siamensis	Chhlounh
Mastacembelus favus	Khcheng
Clarias batrachus	Angdeng Reung
Clarias macrocephalus	Angdeng Tun
Hampala dispar	Khman

Source: field trip, August 2006

Fishers informed us that fish catch and size drastically declined due to an increase in fishers, more gears, including small, medium and large-scale barrages bamboo/nylon net fences and illegal fishing gears such electro-fishing, filamentous nets and pumping, new gears (i.e. *Bor*, mosquito net fence traps), and good security (no fear of Khmer Rouge soldiers). Some fish species have not been seen in the catch such as *Amblyrhynchichthys truncates, Puntius orphoides, Belodonthichthys dinema,* and *Dasyatis laosensis.* The giant snakehead *Channa micropeltes* declined very much in the catch because of an increase in the use of electro-fishing and collection of its juvenile for stocking the floating cages; however, there was an increase in the murrel snakehead *C. striata* due to its proliferations and multiple spawning, and difficulties from catching in the wet season, and clarrid catfishes because currently its juveniles have not been collected for aquaculture. It was stated that the number of fishers increased in the past years because of a lack of job opportunities and alternative livelihoods for the floating village households, and these people have to depend solely on fishing as their main occupation. The price of all fish species has dramatically increased in the recent years due to an increase in demand for household consumption and both internal and external markets, and in price of other goods.

Lots of flooded forests have been cleared to create new fishing locations by both small- and medium-scale fishers, and large-scale fishers (fishing lot operators). In past years fishers did not go fishing in many small natural lakes, in which, they are fishing now due to the increase in the number of fishers and fish demands, and the decrease in fish productivity in Fishing Lot #2. They complained that some locations particularly in the core zone areas were restricted to fish in the wet season by the environmental sector due to biodiversity conservation. Moreover, fishers informed us that there is a complaint from Fishing Lot #2 that core zone areas within the lot were also restricted to fish in the dry season (i.e. open season) by the environmental sector.

Regarding the fishers' perceptions of the effect and impact of the built structure (i.e. large barrage or bamboo/ nylon net fence) on:

(1) fish migration, this gear had a significant impact on fish migration and spawning of all groups of fish species (i.e. black, grey and white fish) to the lake during the early dry season when water recede to the lake from the floodplain and from the lake during early wet season when the water enters the floodplain from the lake. This leads to retarding the spawning and foraging time of the adult fish and rearing/nursing time of the young of black and grey and white fish species. However, the level of such an impact cannot be measured.

(2) water flow, the barrage had little effect on water flow at Prek Toal.

(3) flooding areas, furthermore the pumping method accompanied by partitioning of the tributary (another type of built structure made by lessees) to harvest fish, especially in Fishing Lot #2 has a significant effect on the level of flooding by preventing water flow

into the floodplain in the early wet season, and fish migration into the lake in the early dry season.

(4) water quality, harvesting fish by the pumping method causes many fish, particularly small fish species, to die due to water turbidity as silt is sealed their gills. Bad-smelling water caused by rain water is found in the floodplain (dry grassland in dry season) in the wet season (May/June); this water does not cause fish to die as grey and white fish can stay in the lake, tributaries, and floodplain lakes away from the bad-smelling water on the floodplain and can enter the floodplain when the Tonle Sap Lake water enters the floodplain or mixes with floodplain water to remove the bad smell (i.e. buffering). Bad-smelling water entering from the Tonle Sap Lake is found in the floodplain in the dry season (November/December); such light brown colored water causes fish to die, particularly grey and white fish.

Interestingly, fishers provided their perceptions of the advantages and disadvantages of the built structure (i.e. Lot #2) and community fisheries management system as follows.

Fishing Lot # 2

- Advantage:
    - Flooded forest, fish and other aquatic animals and plants, and birds in the lot were well protected by the lot as the lot operator can hire may guards to patrol the lot;
    - Fishers can have access to some far distant fishing locations to fish if they ask the lot for permission to fish there; and
    - Prevents fishers from using electro-fishing method to fish in the lot.

- Disadvantage:
    - The lot harvested fish using pumping method;
    - The lot owner expanded the boundary of the lot;
    - The lot harvested fish using large-scale bamboo/nylon net fence trap (i.e. barrage); and
    - The lot fished with electro-fishing device.

Community Fisheries

- Advantage:
    - Small-scale fishers had more freedom to fish.

- Disadvantage
    - During the transitional period, fishers fished with illegal fishing gears such as electro-fishing, filamentous nets and brush park fishing, and other most effective fishing gears, e.g. the *Bor*; and
    - Fishers had too much right to use all types of new and unsustainable fishing gears.

Pursat

Technical Assistance Built Structures Project
TA 4669-CAM
Fisheries Components

FIELD TRIP PRESURVEY REPORT
31 August to 1st September 2006 at Pursat site, Pursat province

Objective of the trip: To select sampling sites for the project area and test the questionnaires in Ou Taprok and Chong Khlong village of Pursat province.

Duration of the trip: 2 and half days.

Persons involved: Dr. So Nam, Dr Robert Arthur, Mr. Leng Sy Vann, Mr. Prum Setha, and Miss. Pum Sok Hourt.

Activities of the trip:

1. Consulting with Provincial Fishery Office

We met with provincial fishery officer to inform him of the purposes of our visit to Pursat province and then we consulted with PFOs to select the sites within the project area through the map of Pursat province. Six villages within three communes were selected that would be visited during the field trip. All the villages are located close to National Road No. 5 in the south of Pursat province. They consist of:

- Ou Sandan commune, Ou Tabroak, Chong Khlong, and Doung Chhua villages);
- Snar Ansar commune, Krang Veng village; and
- Kampong Po commune, Moat Prey and Kampong Law village.

2. Consulting with Commune Council

We went to meet the chiefs of each of the three communes to consult with them and get information about general situation in each commune. This information was given using mapping combined with interviews:

Ou Sandan commune

We met and consulted with the chief of Ou Sandan commune as well as the head of all the three villages in the commune. The villages within this commune are Chong Khlong (158 HH), Ou Taprok (195 HH), and Daung Chhua (99 HH). They provided general information about Ou Sandan commune:

- Ou Sandan is a commune located 150 m from National Road No. 5 and consists of seven villages.

- In this commune there are plenty of small streams, lakes, canals, track roads and cow roads and these structures have existed since ancient times. There are two main canals that are used for rice field irrigation, as fishing locations, and as a route for fish migration from the mountains during the wet season, getting water from Stung Thlea Ma-orm. These canals have water in the wet season with 1 m depth and are dried up during the dry season.
- The commune is divided into two parts. The top part is in the upland area and the living standard of people in this area is lower than the bottom part (lowland) because people in the lowland area are able to cultivate rice in both wet and dry seasons and are getting high rice production. In addition, they are able to fish in both the dry and wet season. People in the upland areas go fishing in the wet season and the majority of their fishing locations are in the rice fields.
- In the wet season, approximately 30% of villagers go fishing around the rice fields, 20% of them go fishing along the small streams and canals, and the other 50% go fishing in the floodplain areas and in the lakes. In the rice fields, canals and small streams the fishing gears being used are similar and are small-scale fishing gears such as cast nets, gill nets, long line hooks, and bamboo traps. But there are different gears used in the floodplain and lakes where they use small barrages, electro-fishing, gill net with big mesh net (5-10 cm), and trawls.
- In the dry season, there is fishing in the lake (10%) and Tonle Sap River (90%) only.
- Fish species caught along the canal include *Barbonymus gonionotus, Notopterus notopterus, Henicorchynchus siamensis, Hemibagrus spilopterus*, and many other fish species.
- The built structure (road) does not affect fish migration because fish can migrate through the gates and the culverts (holes of cement) along the road. These gates are not allowed to be blocked and people are not allowed to fish with nets or bamboo barrages. This has been prohibited by the commune council.

Snar Ansar commune

The team met with the first vice chief of the commune as well as the head of Krang Veng village to consult with them about the general situation, especially fishery resources in the commune. This information was obtained through mapping. Krang Veng village has 162 HH. Then they informed us that:

- Snar Ansar is a commune located along National Road No. 5 bordering the west of Ou Sandan commune, the east of Anlung Thnaot commune, and the north of the Tonle Sap Lake.
- This commune is not different from other communes where there are canals, small streams, and roads from ancient times. Some roads were renovated in 2002 and 2005. There was also a new canal dug in 2002. This canal dries out in the dry season and in the wet season it has a depth of 1.5 m.
- Besides cultivating rice and fishing, they have other jobs such as collecting palm juice, collecting vines, making bamboo baskets, weaving mats, and raising livestock.
- In this commune, there are three villages that are professional fishing villages both dry and wet season. These villages are Beng, Krang Veng, and Kampong Prak (floating house). However, if we compare ethnic villages (i.e. Cham or Islamic villages) they are still lower than these villages in terms of fish caught. For example, in the dry season Beng village went buying *Prohok* (fermented fish paste) from ethnic villages but Ou Taprok and Chung Chlong village went back buying palm sugar from Beng village. In other words, ethnic villages also become suppliers for livestock to other villages and their living standard is better than other villages.

- In the dry season villagers go fishing at small streams, canals, floodplains, and the lake but especially rice fields. They use different fishing gears in the different fishing locations. In rice fields they always use cast nets, bamboo traps, and long line hooks, but at the lake and floodplain they use cast nets, gill nets, and barrages with bamboo traps.

Kampong Po commune

We met with the secretary of Kampong Pou commune and the head of Moat Prey and Kampong Lor. We consulted with them through asking and mapping in the commune. In this sense two villages are proposed for the survey: Moat Prey (183 HH) and Kampong Lor (264 HH). They informed us that:

- This commune is located along National Road No. 5 and borders the west with Anlung Vil commune, the east with Ou Sandan commune, and the north with the Tonle Sap Lake.
- The east area of this commune is better than the west area because the east is a lowland area. This lowland area gets higher rice production and can also produce more fish because it is closer to the Tonle Sap.
- This commune has three primary canals (Prolay 17 Mesa), which get water from either Stung Pursat or Stung Thlea Ma-orm. These canals were built during the Pol Pot regime (1976). So far they are still useful for irrigation and fish migration from upstream and are a fishing location for the villagers during the wet season. But they are dried out during dry season. Moreover, Kampong Lor commune has a new canal that was dug in 2000 crossing Prolay 17 Mesa from Stung Thlea Ma-orm and it gives more benefits for rice farming and fishing, especially fish migration from upstream. In May through June fish migrate upstream, and they migrate downstream from October.
- The commune also has some big lakes and a lot of small lakes. These lakes are not dried out during dry season and they are advantageous for villagers fishing there because they can be used in both dry and wet seasons.
- The main occupations of people in Kampong Lor are rice field cultivation and fishing. Fifty percent of Kampong Lor villagers do both rice farming and fishing, and the other 50% do fishing only. As for Moat Prey village, the majority of villagers make their living both fishing and rice farming, but the minority do fishing only.
- Villagers in this commune always go fishing during the wet and dry season. In the wet season, they go fishing at rice fields, small streams, streams, canals, floodplains, and the Tonle Sap Lake with small-scale fishing gears. However, these gears are used in a different manner depending on the fishing location. Rice field gears consist of long line hooks, cast nets, and bamboo traps. Cast nets, bamboo traps, and small barrages with bamboo traps are used in streams and canals. Gill nets, cast nets, and small barrages with bamboo traps are used at the floodplain areas and Tonle Sap Lake. During the dry season, they go fishing in the lakes, Ou Taprok stream and the Tonle Sap Lake with different fishing gears based on fishing locations. *Samras*, bamboo traps, cast nets, circular seine nets and small barrages with bamboo traps are used in floodplain lakes. Cast nets, gill nets and bamboo traps are used in streams. Circular seine nets, *Samras*, cast nets, and long barrages with bamboo traps are used in the Tonle Sap Lake.
- For fishing gears, they bought them from Cham villages (Ou Taprok and Chung Chlong villages) and sometimes they went to buy fishing gears in Pursat town.
- They thought that before there were plenty of fish, but now there is a dramatic decline in both the quantity and size of fish. Moreover, some fish species have disappeared, especially larger fish.

3. Discussing with fishermen groups

We have two groups (a total of six fishermen) to discuss fish ecology and fishing information related to the build structure in their villages. The first group is in Chong Klong village, talking about the built structure, and another group is in Ou Taprok, talking about fish ecology. This information is detailed as below:

Chong Klong village

This village is a village close to Ou Taprok village, which is in the east of Ou Taprok. This village has some primary and secondary canals which were built during the Pol Pot regime and they were renovated in 1996 and 2003. In addition, there are some rural roads that were built in 1994 and renovated in 2002 due to the flooding from 2000 to 2002. Another road linking Ou Sadan road was underwater during the flood from 2000 to 2003.

Chong Khlong village is a village that favors fishing because of the many floodplain lakes. These are Boeung Tro Chek, Veng Tun, Pro Lakva, Charb Kul, Kbal Skouv, Tys Peay, Tro Borklun, Kouch, Locheung, Tro Pengkros, Tro Pengksarch, Pseurt Knung, Chhes, Dach Krolech, and Boeung Bath Pdil. In the wet season villagers always go fishing in rice fields, small streams, canals, and floodplain areas with family-scale fishing gears and their fishing gears are different owing to fishing location. At rice fields they like to use gill nets and hooks and line. Cast nets and bamboo traps are used in small streams and canals. Gill nets, bamboo traps, and circle grill nets, electro-fishing (September to November) is used in floodplain areas. But in the dry season villagers go fishing in floodplain lakes and the Tonle Sap Lake only and their fishing gears consist of cast nets, circular seine nets, electro-fishing, and *Samras*.

Ou Taprok village

Ou Taprok village is next to Chong Khlong village and is also a professional fishing village. This village also has many floodplain lakes, and these lakes have permanent water. Villagers always go fishing in rice fields and canals in the wet season, and the floodplain and Tonle Sap Lake in the dry season. The fishing gears they are using are not different from Chong Khlong village in both dry and wet seasons.

Fishers' perceptions of fish and fishing in Chung Khlong and Ou Taprok villages

In general, there has been a dramatic decline (i.e. 50-70% from the past catch rate) in either fish abundance or fish size in both villages. Several similar reasons for the decline are (1) use of illegal fishing gears such as electro-fishing, fine mesh nets and brushparks, (2) clearing flooded forests, and (3) illegal fishing activities such as collection of snakehead eggs. It was reported that there is an increase in the abundance of other aquatic animals such as small shrimp (i.e. *Kampeus*) and mollusks. However, amphibians (i.e. frogs) similar to all fin-fish species had declined. It is clearly reported that the price of fish is increased over time due to a decline in fish abundance, high market demand, and population growth. Interestingly, the price of small-sized fish has dramatically increased compared to big-sized fish.

Fishers' perceptions of the effect of the built structures (i.e. roads and canals) on hydrology, fish, and fishing in Chung Khlong and Ou Taprok village

It is strongly believed that the built structure (i.e. road) has no negative effect on water flow and water quality in the villages as water gates and culverts have been installed along the roads. Fish can move up and down the floodplain through these gates and culverts. The structure provides more fishing opportunities in terms of new fishing locations and different fishing gears used, especially around water gates and culverts. Canals are another type of built structure that could create new fishing locations, fish habitats and/or migration routes.

Appendix 4 Environment Component Technical Reports

- Impact Of Built Structures On Tropical Floodplains Worldwide

- Review Of Tonle Sap Built Structures Environmental Impact Assessments (EIAs) With Regard To Fisheries

Asian Development Bank
TA 4669-CAM

Technical Assistance to the Kingdom of Cambodia
for the Study of the Influence of Built Structures
on the Fisheries of the Tonle Sap
(financed by the Government of Finland)

Environment Component

IMPACT OF BUILT STRUCTURES ON TROPICAL FLOODPLAINS WORLDWIDE

Prepared by

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Biota BD, Finland

December 2006

TABLE OF CONTENTS

ABBREVIATIONS

ADB	Asian Development Bank
IEE	Initial Environmental Examination
EIA	Environmental Impact Assessment
CIA	Cumulative Impact Assessment
SEA	Strategic Environmental Assessment
INPA	National Institute of Amazonian Research
IUCN	The World Conservation Union
MRC	Mekong River Commission
FAP	Flood Action Plan
WCD	World Commission Dam
PCB	Polychlorinated Biphenyls
DDT	Dichloro-diphenyl-trichloroethane
ICOLD	International Commission on Large Dams
WB	World Bank
WRI	World Resource Institute
MRAG	Marine Resource and Fisheries Consultants
SIA	Social Impact Assessment
IIRSA	Integración de la Infrastructura Regional Suramericana
SEMRY	Secteur Expérimental de Modernisation de la Riziculture de Yagoua (later renamed to Société d'Expansion et de Modernisation de la Riziculture de Yagoua)
BCAS	Bangladesh Centre for Advanced Studies
PIRDP	Pabna Irrigation and Rural Development Project
FCDI, FCD/I	Flood control, drainage and irrigation scheme
CPP	Compartmentalisation Pilot Project
IRN	International Rivers Network
SEARIN	Southeast Asia Rivers Network
SEI	Stockholm Environment Institute
CBD	Convention on Biological Diversity
NEPA	National Environmental Policy Act (USA)
EMS	Environmental Management System
FAO	The Food and Agriculture Organization of the United Nations
GEF	Global Environment Facility

LIST OF FIGURES

LIST OF TABLES

ANNEXES

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

This review discusses the recorded impacts of built structures on the environment and fisheries of tropical floodplains worldwide.

Riverine floodplains cover more than two million km^2 globally. The floodplains in various parts of the globe vary considerably in terms of their physical, chemical and biological characteristics. However, the majority of all floodplains share one quality; they are highly productive due to the exchange of energy and nutrients between different groups of organisms, terrestrial and aquatic. Moreover, all literature describing floodplains mentions their undisputable importance for fisheries.

Floodplains are among the most biodiverse environments known. Apart from being biodiverse, tropical areas also display a high percentage of endemism. Tropical riverine fauna generally include a large number of migratory species, which are highly vulnerable to human impact, including modifications of lateral or longitudinal connectivity to their habitat. Many of these species are both riverine and lacustrine, depending on the season, and therefore dependent on the availability of both habitats.

Floodplains are rapidly being destroyed through reclamation of the land for other purposes. Today, rivers and wetlands are valued with regard to all ecosystem goods and services they provide, and as such are estimated far higher in value than e.g. forests or grasslands. In Europe and the USA, where most floodplains have been lost, restoration of regulated wetlands is increasingly taking place, and at a great cost, to return these long-term benefits and ecosystem services provided by the wetlands.

One of the highest valued "direct use value ecosystem services" of floodplains is fish, while inputs to agriculture (nutrient rich deposits) and nursery functions of fish and other organisms, are considered the most important "indirect use value services". Some, albeit few, studies concerning the value of specific ecosystem services in tropical floodplains have been carried out, and these studies make it clear, that the conservation of the flooded forest habitats is of critical importance, also financially, to ensure a sustainable future for local economies.

Predictions suggest that in the near future, the most threatened floodplains will be those in Southeast Asia, Sahelian Africa and North America. Without beginning to preserve existing floodplains and to restore hydrological dynamics, sediment transport and riparian vegetation to those rivers that retain some level of ecological integrity, dramatic extinctions of aquatic species and ecosystem services will be faced within the next few decades.

Hydrology is clearly the single most important driving variable in tropical floodplains, based on which the flood pulse concept defines the river and its floodplain as an indivisible unit. Any long-term change to the pulse affecting the hydrodynamics of the flood, such as timing, height, duration, amplitude, smoothness or the rapidity of change of the flood pulse, will result in fundamental ecological changes in the affected areas and also influence the living conditions of the local human population. It is now generally accepted that the conservation of most species in the aquatic system, as well as biodiversity in its broader sense, depends on the maintenance of the flood pulse.

Impacts of different types of built structures such as embankments, roads, canalization, and mining and fishing gears, is discussed in this review. Of these, dams and canalization have been discussed most in literature, due to their significant impacts on floodplain environments, fish and fisheries.

The main effects of dams include changes in discharge downstream, desiccation of floodplains, riverbank erosion, changes in water quality, and changes in flora and fauna.

The following effects of stress caused by built structures, such as dams or levees, on fish have been identified:

- Obligate migratory species will tend to disappear in systems where the main channels are locked by large dams.
- Floodplain spawners are selected by chanelisation or other stream regulation processes that reduce or eliminate the annual flood.
- Within modified channels there is a tendency to lose obligate migratory species although management is usually directed at their protection through installation of fish pass structures or through stocking.
- There is a tendency for dominance in fish assemblages to shift from floodplain spawners toward main channel spawners.

Because of the negative impacts, and the difficulty in finding effective mitigation measures, the environmental flow requirements methodology (which includes managed flood releases) is increasingly used to reduce the impacts of changed stream flow regimes on aquatic, floodplain and coastal ecosystems downstream.

Recorded impacts of built structures on floodplain environments have been reviewed based on case studies worldwide.

In the South American floodplains, deforestation has, and continues to be, the most severe and debated threat to the vast floodplains. Built structures are still relatively few, and the impacts thereof less discussed. However, large-scale infrastructure projects are increasingly planned, and feared to have major impacts on the floodplains. The most significant threats to the Amazon floodplains are summarised as 1. modification of the hydrological regime, 2. large-scale destruction of plant communities, 3. reduction of populations of plant and animal keystone species and 4. pollution. Examples of projects for which impacts have been recorded are discussed.

In Africa, water needs for irrigation, domestic and industrial uses have caused construction of numerous reservoirs affecting the downstream flow and floodplains. The changed hydrological regime of rivers has adversely affected floodplain agriculture, fisheries, pasture and forests that constituted the organising element of community livelihoods and culture. In many cases, the desiccation caused by dams has been enhanced by natural drought.

Impacts of flow alteration on fish species have been documented for numerous artificial reservoirs in Africa, which have replaced running water habitats resulting in the disappearance of lotic species and the proliferation of species adapted to lentic systems. Many of these species are exotic, which has had further impacts on the ecosystem.

The case of the Waza Logone floodplain is discussed in detail due to it being an important example of a successful initiative to restore the lost ecosystem services of a floodplain impacted by dams. The restoration was based on an ecosystem approach and carried out through planned releases of water. The return of the flood was of greatest value to pasture and fishing, while it has also significantly benefited agriculture, the state of other natural resources and surface water reserves.

In general, there are many lessons to be learnt with regard to the restoration of floodplains in Africa. Opening of structures unnecessary changing flooding patterns, as well as artificial flood releases, in connection with a participatory approach utilising local knowledge, have achieved successful results. Despite these experiences, it has been shown that it is extremely hard to recover the complete variety of ecosystem services, once lost.

In Australia, wetland habitats are decreasing mainly due to modified flood regimes, floodplain isolation and increasing salinization. The following factors have been listed as key pressures on the aquatic ecosystems:

- changes in natural flow regimes due to water extraction and supply
- direct modification or destruction of important habitats
- barriers to the movement of plants and animals upstream
- effects of poor water quality
- competition from introduced and exotic animal and plant species

Common built structures in Australia include dams, weirs, regulators, farm dams, floodgates, causeways, culverts, pipes, channelised streams, bridge footings, and erosion control works. These barriers have been observed to isolate fish communities, restrict passage and result in changes in the fish community structures as many native fish need to migrate up and down river systems to breed, disperse and travel to spawning grounds.

Bangladesh has one of the richest and largest floodplain systems in the world, floodplains constituting about 80% of the country. Because of the large damage to the human population caused by floods, many flood control programs have been built to mitigate the adverse impacts of flooding. These structures have affected the floodplain environment and fisheries, most strikingly through the drastic reduction of floodplain area by over 2 million hectares in the past 30 years, which has severely impacted floodplain dependent fish species.

Numerous studies carried out in Bangladesh point to decreasing inland fish catches due to water resources development projects, as well as decreasing fish diversity. In general, whenever flood control projects reduce the area of flooded land, there will be a loss of habitat for fish production and a subsequent loss in annual fish yields or catch per unit area. Flood control programmes have been found to affect reproduction and larval fish drift, block fish migration and dispersal routes, and reduce species diversity by up to 30%, most of which is due to the loss of the more valuable white fishes. Sluice gates have proven to be fatal for many fish species. Water control projects have substantially reduced fisheries on the floodplains. Flood control, drainage and irrigation schemes have been found to negatively affect fish species assemblages and stock values by reducing the accessibility of impounded floodplains to migratory fish. The fish production from inland capture fisheries has been in decline in Bangladesh for some time. A major reason is the flood control projects, while pesticides and industrial pollution are also mentioned as important factors impacting the fisheries. Flood control and drainage projects have been implemented partly to increase rice production, but it has turned out that they have been of little value for rice production, whereas their effects on fisheries have been devastating (in some cases reducing indigenous floodplain fisheries by over 70%).

In the Mekong area, several large dam projects have brought insights into their impacts on the environment. As in Africa, there are some encouraging examples of participatory approaches in connection with the rehabilitation of lost ecosystem services through managed releases of water. However, better management of environmental and social safeguard perspectives are commonly called upon to avoid impacts on the environment and fisheries. Suggested management practices are discussed based on the knowledge base collected through this review.

Final recommendations are as follows:

Modification of the hydrological regime has been found the first and foremost threat toward floodplain ecosystems, based on numerous experiences in tropical floodplains worldwide. Therefore, any structure affecting the all-important hydrology of a floodplain should be assumed to influence the environment, and treated with consequent caution. Most impacts are directly or indirectly combined with aspects of changing hydrological regimes, and cannot be separated from this. Any assessment must take into account impacts on integrative processes such as the flood pulse and alterations to any aspect of it; these include its **magnitude, timing, amplitude, duration, modality, smoothness and rapidity of change.** In general, the loss of flooded areas and hydrological connectivity should be minimized.

Another general recommendation concerns the importance of a systematic, professional and serious EIA process. This entails, among other things, to accommodate adequate **baseline collection** (to be extended over at least two years) and present a comprehensive collection of proposed **mitigation measures**, to ensure that these be taken into account in the design phase of the project, rather than later at a significantly greater expense. The incorporation of an **Environmental Management System** (EMS) is a central part of the EIA process and the resulting EMS must be adhered to throughout the project cycle, including setting of milestones, response plans to detected changes and an evaluation of the functioning of the EMS. Also, **Strategic Environmental Assessments** should be developed for relevant sectors.

The following recommendations have been drawn from the case studies considered in this review:

1. **Indirect impacts** of large-scale construction sites may be enormous in comparison to the actual structures. Land-use change, potentially induced by project activities in the area surrounding the project site, and their impact on the environment should be considered in EIAs.
2. Small-scale canals and natural water channel modifications are possibly the most common type of built structure and therefore lead to many **cumulative impacts.** Taking these into account in connection with new built structure assessments is of importance.

3. The main causes of freshwater aquatic **biodiversity loss** have been identified as flow modification, habitat alteration, water pollution, introduction of exotic species and over-exploitation of certain species. All these issues are, directly or indirectly, linked to built structures, and therefore EIAs relating to built structures should include a component considering biodiversity issues at as many levels of the ecosystem as possible.
4. In connection with river regulation such as dams, as well as other large structures blocking migration routes and causing fragmentation of habitats, **fish biodiversity** has decreased in most reported cases. In connection with new built structures it is therefore of importance to consider this probable impact at an early stage and prepare mitigation measures during the entire project cycle. Planning of structures should take into account the **movement of fish**, as well as securing the presence of **sanctuaries/protection times**. The design of sluice gates and other modified passages should take into account that for many fish an overshot mode regulator is less destructive than an undershot one, while e.g. various designs of turbines for hydropower differ with regard to the mortality of passing fish.
5. Lessons learnt have shown that the destruction of floodplains affects specialized artisanal-type fisheries, often operating on a small-scale. This type of **small-scale fisheries** livelihood is very hard to replace and it is therefore of importance to **assess and value** in the course of the EIA process. The spread of invasive plant and animal species (often occurring as a result of changed hydrology or intended introductions of e.g. fish to reservoirs) can lead to surprising and dramatic losses/changes and also affects local livelihoods that depend on other ecosystem goods than fish.
6. When assessing the impact of built structures on e.g. fish catches, it is of importance to **evaluate the distribution of the catches between subsistence fisheries and professional fisheries**. In many cases, it has been shown that e.g. flood control structures have benefited groups of people that have the ability to invest in fish farming, while the opportunities for natural open water fisheries have diminished, either through changes in species composition or fish production in the affected area. Unlike land, floodwater usually belongs to all. Therefore, **the risks connected to reduced floodwater availability are significant especially for non-land owners**, the poorest section of the rural population.
7. The **value of other ecosystem goods**, such as forest and plant resources, pasture, wildlife etc. are often underestimated until these are lost with degenerating floodplain conditions. Even though fisheries are indisputably the most significant resource of the floodplains, other natural resources are of great importance in view of **diversification of food resources and livelihoods**, and often play an important part especially for the poorest people. Also e.g. the value of wetlands as natural purification filters for water is surprisingly high. **The use of integrative approaches, such as the ecosystem approach, is highly recommended in complex environments such as floodplains.**
8. **Valuation of ecosystem services** should be developed and integrated into project planning and EIA procedures. This type of valuation yields figures and a numerical measure that can be integrated into more conventional economic cost benefit analyses of the proposed investment, and allows a more thorough economic analysis of the predicted returns for different investment options.
9. Lessons learnt have demonstrated the **sensitivity of tropical floodplain** environments to **increased nutrient runoff**. Recent research has illustrated the

importance of phytoplankton to tropical floodplains in Australia and South America. This has important implications for the management of floodplains. Attention should be directed to the control of water quality changes (nutrients, but also turbulence, herbicides, metals, etc.) influencing phytoplankton productivity and species composition of the floodplains, which could have a profound impact on the entire food chain including the species composition of fish.

10. In connection with road construction, it is of importance to assess how to reach a **compromise between construction costs** and the need for including e.g. culverts and other **means to facilitate floodwater flows and the passage of flora and fauna**. In many cases where the needs of the ecosystem functions have not been taken into account during the planning phase of the construction, fitting of culverts has been done at a later stage (and at a significantly higher cost) to e.g. enable fish passage.
11. In connection with any built structure in floodplain areas, the effects of **increased access to the wetlands** should also be assessed. It has been shown that improved access due to lessened flooding, improved road networks and consequent increased human habitation in the floodplain areas will inevitably lead to increased destruction of forest resources and habitats through increased commercial activities facilitated by road accessibility. Increased access has also had drastic effects on wildlife due to intensified poaching in areas previously less accessible. Similarly, the newly accessible areas will be subject to new agricultural activities or improved agricultural methods (including irrigation, flood control works, and other infrastructure, as well as new crops or varieties), which in turn will cause changes in the hydrology and increased runoff of pesticides and herbicides.

1. INTRODUCTION

This report forms part of the ADB TA 4669, "Study of the Influence of Built Structures on the Fisheries of the Tonle Sap" project, presenting part of the Environmental Component. The intention of this component is to assess the side-effects of built structures on the (aquatic) environment.

The key outputs of this component are:

1. Literature review (this product, references in Annex 1) including recommendations based on lessons learnt in tropical floodplains worldwide.
2. Table of data concerning recorded, and quantified, impacts (in the form of an Excel file with collected metadata on selected reference cases, Annex 2)
3. Review of IEEs and EIAs in the Tonle Sap Basin (to be produced by Sophie Nguyen Khoa, available in November 2006)
4. Synthesis report based on this review and the analysis of IEEs and EIAs on the Tonle Sap Basin.

This report reviews documented short-term and long-term influences of built structures on selected tropical floodplains worldwide, from an environmental and social safeguard perspective. It reviews mainly impacts recorded after a built structure project has been realised, while predictive information such as Environmental Impact Assessments (EIAs), Cumulative Impact Assessments (CIAs) and Strategic Environmental Assessments (SEAs) are only dealt with occasionally when information on post evaluations have not been found in the literature. Lessons learnt and recommendations based on this literature review will be combined with the second part of the environmental component, which aims to synthesize the findings and recommendations from EIA processes conducted for development projects in the Tonle Sap Basin. The final output will be a joint effort to produce a set of recommendations based on this literature review and the findings from the EIA analysis. These will feed into the policy briefs to be produced as part of the "Informing policy and decision makers" component.

2. METHODS AND SUMMARY OF MATERIAL

2.1. Methods used

The following approaches were used to identify literature and other materials concerning the impacts of built structures:

- Internet based search engines
- Library searches at the University of Turku, Finland, and especially in the Amazon library hosted at the same university
- A questionnaire (Annex 3) sent to experts identified during the preliminary literature review
- Correspondence with floodplain experts through the email, phone and other means (Annex 4, Persons Consulted)

2.1. Summary of Information Sources Reviewed

Information on general aspects of floodplains is extensive and readily available. However, quantitative information is scarce. The review collected quantitative information (presented in Annex 2), but qualitative data has also been reviewed and summarised in this report. The review concentrates on selected, important and well-documented floodplains around the world.

- >300 journal articles/reports were reviewed
- 9 books were reviewed
- A number (>120) of web pages were reviewed

The questionnaire contained 10 questions (Annex 3 displaying questions and a summary of quantitative answers) regarding floodplains and observed impacts of built structures within them was sent to altogether 62 recipients, mainly scientists known (through the review process) to have worked in floodplain environments. Twenty-three replies were received (of which 19 answered most questions) out of the 62 recipients (31% response rate). The replies received considered floodplains on all continents and major river basins.

3. FLOODPLAINS – GENERAL ISSUES

3.1. Definition

The most common and referred to definition of floodplains is: "Areas of low lying land that are subject to inundation by lateral overflow water from rivers or lakes with which they are associated" (Junk and Welcomme 1990). The "Glossary of terms related to floodplain management" defines floodplains as "low lands adjoining the channel of a river, stream or watercourse, or ocean, lake or other body of water, which have been or may be inundated by flood water, and those other areas subject to flooding" (FMA website *http://www.floodplain.org/glossary_of_terms.htm*). In the literature, several more specific definitions are used for different types of floodplains. The terminology varies, including names such as floodplain, flooded forest / shrub land / savannah, inundated forests, *várzea* and *igapó*, seasonal floodplain and wetland, being used depending on flooding characteristics, geographical area, and vegetation of the floodplain or other characteristics of the environment. In the Amazon, the floodplains are defined according to the origin and type of the water flooding the forest; *várzea* forests are fed by sediment rich "white water" rivers, *igapó* forests border the blackwater (high humus content) and clearwater tributaries (Goulding *et al.* 1995). The *várzea* forests are the most common, the most nutrient rich, and have the tallest trees, and therefore are probably the ones that correspond the closest to the nutrient rich Asian monsoon-driven floodplains.

This review concentrates mainly on tropical riverine freshwater floodplains (thus excluding e.g. marine and brackish deltas and mangrove swamps) that are, or have been, regularly inundated by seasonal floods, and where development has taken place and the impacts thereof have been recorded. The review concentrates on some well studied and documented areas, and it does not by any means present an exhaustive inventory of floodplains or structures built on them.

3.2. *STATUS OF KNOWLEDGE REGARDING TEMPERATE VERSUS TROPICAL FLOODPLAINS*

Riverine floodplains cover more than two million km^2 globally (Tockner and Stanford 2002). The tropical floodplains of the world are scattered over all continents with tropical areas, occurring along numerous tropical rivers and lakes. The floodplains in various parts of the globe vary considerably in terms of their physical, chemical and biological characteristics. However, the majority of all floodplains share one quality; they are highly productive due to the exchange of energy and nutrients between different groups of organisms, terrestrial and aquatic (Junk 1997). Moreover, all literature describing floodplains mention their undisputable importance for fisheries.

Another trait shared by most floodplains is their rapid destruction through reclamation of land for other purposes. Due to the special features of the floodplains, oscillating between aquatic and terrestrial phases, they have proved difficult environments for human utilization, and for this reason they have been eliminated or strongly modified by human activities. In highly industrialised countries in North America, Australia and Europe, most floodplains have been lost to agriculture, industries, infrastructure and housing; all the while the understanding of the importance of floodplains and other wetlands has increased. Today, rivers and wetlands are valued with regard to all ecosystem goods and services they provide, and as such are estimated far higher in value than e.g. forests or grasslands. According to Constanza *et al.* (1997) the estimated average global value for ecosystem goods, services, biodiversity and cultural considerations of wetlands is US$14 785 million while forests are estimated at US$969 and grasslands at US$232 million respectively. In both the USA and Europe, restoration and recovery of regulated wetlands is increasingly taking place, and at a great cost, to return these long-term benefits and ecosystem services provided by wetlands. The restoration efforts have even included decommissioning of dams due to environmental concerns. Much of the restoration effort has concentrated on rehabilitation of wetland habitat and fish migration routes. A recent example is the restoration plan for the Everglades Wetlands in Florida. The documented negative impacts of water diversions through dikes and canals included diminished water retention capacity of the watershed, topsoil loss, runoff from developments leading to raised phosphorus levels, salinity intrusion, loss of biodiversity and proliferation of invasive species. The first phase of the restoration plan is estimated to cost US$7.8 billion, mainly due to the restoration of natural hydrological patterns to increase the capacity for storing water within the watershed. This includes the removal of long stretches of canals and levees, and the installation of gates and culverts to roads presently interrupting the ability of many animals to find suitable habitats timed to their lifecycle (WRI 2000).

> *In the near future, the most threatened flood plains will be those in SE Asia, Sahelian Africa and North America. There is an urgent need to preserve existing, intact flood plain rivers as strategic global resources and to begin to restore hydrological dynamics, sediment transport and riparian vegetation to those rivers that retain some level of ecological integrity. Otherwise, dramatic extinctions of the aquatic and riparian species and of ecosystem services and faced within the next few decades.*
>
> Tockner and Stanford 2002

Apart from restoration programs, research activities are also currently taking place in connection with e.g. flood control and its implications for fish and fisheries in temperate areas (e.g. the Living Murray initiative in Australia, the recent symposium in Austria on the topic "Hydropower, flood control and water abstraction: implications for fish and fisheries" held in June 2006). The abstracts submitted for presentations during this conference indicate that a clear majority of the work in temperate rivers and floodplains reports decreasing fish catches, increased larval mortality, reduced or strongly altered species diversity as common consequences of built structures on rivers and floodplains. To remedy these losses, fish passes, bypass channels, spawner transportation, flood simulation and weir operation have been studied in connection with migratory fish rehabilitation programmes.

Research concerning implications of flood control and other built structures on floodplains in tropical areas, mostly located in less developed countries, is in comparison with temperate floodplain research in short supply. In addition, given the differences between tropical and temperate riverine systems, theories and conservation strategies that have been developed based on studies in temperate environments may not be applicable or effective in tropical environments (Pringle 2000). For example fish ladders, which have been developed and used extensively in temperate regions to facilitate the migration of especially economically important fish species, have on many occasions proven to be a failure in tropical regions (Roggeri 1995 and references therein).

There are well-studied exceptions, however. The Amazon floodplains have long received much attention from both natural and social scientists. Research has been conducted especially in the areas of Manaus, Brazil, due to the presence of the National Institute of Amazonian Research (INPA), while other, more remote, parts of the basin remain largely unexplored. Extensive studies have been done by the tropical ecology group of the Max Planck Institute on the floodplains of Brazil, but also the Pantanal in the Paraguay River Basin. In Africa, floodplain related research is mostly quite recent, with the exception of some thorough studies carried out in the 1970s by e.g. Welcomme and colleagues, who demonstrated the relation between the fish catch per kilometre of river related to the floodplain area in km^2, and discussed the importance of floodplain development to the variation between catches (Welcomme 1975). Some recent and valuable efforts have been made by independent researchers as well as research organisations such as the IUCN (water and wetlands programme) in Africa. Environmental research including aspects of floodplains has been done extensively in the Senegal valley, Barotse floodplains in Zambesi, Tana River floodplains in Kenya, Waza Logone floodplains in the Niger Basin, and in Kenya and Tanzania on eastern African wetlands (Duvail 2004), while the Congo Basin is largely unexplored. In Asia, recent studies on floodplain ecosystems and their fisheries have been carried out for instance in Bangladesh (in connection with the Flood Action Plan studies) and the Greater Mekong region (MRC work, other ADB projects on the Tonle Sap / Mekong floodplains).
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3.3. TROPICAL FLOODPLAINS - HYDROLOGY AND PRODUCTION

Hydrology is clearly the single most important driving variable in tropical floodplains (Tockner and Stanford 2002), based on which the flood pulse concept defines the river and its floodplain as an indivisible unit (Junk 1997). Any long-term change to the pulse affecting the hydrodynamics of the flood, such as timing, height, duration, amplitude, smoothness or the rapidity of change of the flood pulse, will result in fundamental ecological changes in the affected areas and also influence the living conditions of the local human population (Junk and Cunha 2005).

A positive correlation between the height of flood pulse / inundated area of the flood and fish catches has been reported for a number of tropical floodplains (Welcomme 1979, de Graaf 2003a and de Graaf 2003b and references therein, Halls and Welcomme 2004, and Tockner and Stanford 2002). Studies in both the Amazon and Africa have shown that the growth of tropical floodplain fish is maximal in the high water season (Hoggarth *et al.* 1999). However, not only the height of the flood pulse (amplitude) is of importance, but also other flood pulse characteristics such as timing, continuity, rapidity of change and duration of flood, as well as dry season water levels, have been shown to be related to fish production (Welcomme and Halls 2004). The productivity of floodplain environments in indisputable in comparison to any other freshwater system: Jackson and Marmulla (2000) conclude that while shallow, managed reservoirs yield on average 30-150 kg/ha/year of fish, deep reservoirs 10-50 kg/ha/year, and slow flowing rivers 30-100 kg/ha/year, floodplains averaged 200-2000 kg/ha/year. Baran (2005) summarises the productivity of some known floodplains in Asia and South America, reporting yields varying between 25 and 230 kg/ha/year.

Much is still unknown concerning tropical floodplain ecosystems. The high biodiversity and intricacy of the environment leads to complex ecological interactions. For example, only recently has the evidence of the importance of autochtonous (produced within the system) carbon, and especially microalgae, in tropical riverine systems increased, as opposed to the earlier belief that allochtonous carbon was the driver of floodplain ecosystem functions (Douglas *et al.* 2005). In the Amazon, it has been shown that some plant groups contribute more to the primary production of a floodplain in comparison to others, which are more important as food resources for adult fish (Forsberg *et al.* 1993). Flooded forest trees, certain macrophyte leaves, periphyton and phytoplankton as a group produced only 48% of the organic matter of the floodplain, but accounted for 82-98% of the carbon in adult fish, due to selective feeding by the fish themselves, or by herbivores and detrivores lower in the food chain. In numerous other tropical rivers it has been shown that microalgae are the main driver of aquatic food chains (Douglas *et al.* 2005 and references therein). Therefore, algal production in floodplain lakes may play a critical role in sustaining commercial fish production (Forsberg *et al.* 1993). Algae are sensitive to even small changes in nutrient loads (Douglas *et al.* 2005). In case of high light and temperature conditions, increases in nutrients are likely to trigger rapid increases in primary production and lead to changes of species composition, thereby affecting the entire food web productivity. This means that attention should be directed to the control of water quality changes (nutrients, herbicides, some metals like copper especially) influencing phytoplankton productivity and the species composition of floodplains (especially in connection with structures involving aqueous effluents), which would have a profound impact on the entire food chain including the species composition of fish.

3.4. Floodplain Biodiversity

Floodplains are among the most biodiverse environments known, due to the high level of spatiotemporal heterogeneity as well as the diversity of habitat types, representing a variety of successional stages (Ward *et al.* 1999). Junk *et al.* (2000) regard the floodplain forest to be the system with the highest biodiversity, since it consists of many endemic highly adapted tree species, which offer habitat and food for a highly diversified, but mostly unknown, community of invertebrates. This applies most probably to the Tonle

Sap area as well, not only regarding the fish diversity but also other floodplain organisms.

Apart from being biodiverse, tropical areas also display a high percentage of endemism. In the Amazon, 90% of the over 2000 known fish species are endemic, and in the Congo, 70% of the 700 species are endemic. The corresponding figures for temperate rivers are significantly lower; in the Mississippi River 30% out of 250 species are endemic, and in the Danube only 10% out of 70 species are endemic (Pringle 2000). This entails that even local disruption of a habitat in tropical rivers and floodplains can lead to devastating impacts for certain endemic populations. In the Amazon it is thought that damming of rivers has most likely resulted in numerous species extinctions, especially of highly confined endemic species (Goulding *et al.* 1995.

Tropical riverine fauna generally include a large number of migratory species, highly vulnerable to human impact including modifications of lateral or longitudinal connectivity to their habitat. Many of these species are both riverine and lacustrine, depending on the season, and therefore dependent on the availability of both habitats (Pringle 2000).

> *The ichtyofaunas of North America (about 1500 species), Europe (about 360), and Australia-New Guinea (about 500) are the most thoroughly documented, but new species continue to be described based on discovery of previously unseen forms and species-level taxonomic splits of known species. The ichtyofaunas of tropical Asia (perhaps >3000), Africa (perhaps >3000) and South and Central America (perhaps >>5000 species), are species-rich yet incompletely known. Tropical freshwaters are hot spots of recent and likely future ichtyological discoveries. Especially in the tropics, discoveries of species that signal new generic-level taxa are common, and new family-level groups are found occasionally. Everywhere ongoing phylogenetic studies often suggest or reveal unsuspected relationships. These are times of exciting discovery and advancement of knowledge in freshwater ichthyology. New discoveries beckon us to seek the many remaining unknowns in the diversity of life on our planet. These are also times of rapid and destructive change in freshwater habitats around the globe. These threats alert us to the increasing potential for permanent loss and ignorance of much of our planet's rich aquatic biota.*
>
> Lundberg *et al.* 2000

According to Bayley (1998), it is now generally accepted that the conservation of most species in the aquatic system, as well as biodiversity in its broader sense, depends on the maintenance of the flood pulse. It also depends on the maintenance of connectivity, both longitudinally within the river channels and laterally between the main river and the floodplains. Longitudinal connectivity is necessary to keep migratory pathways open for the long and medium distance migrants. Lateral connectivity is necessary so that the floodplain environments, including the associated higher vegetation, are sustained and fish can move from their dry season habitats to the wet season spawning and feeding areas. Generally, the effects of excessive fishing are insignificant relative to the damage that can be caused by changes in connectivity, and water quantity, quality and timing (Bayley 1998). Conservation of the biodiversity of floodplains is also of importance for retaining other ecosystem services. Recently, experimental research provided proof of the importance of one single migratory fish species to the carbon flow in a tropical river in South America (Taylor *et al.* 2006). The authors showed that *Prochilodus mariae* modulates the carbon flow and ecosystem metabolism of a river in the Orinoco Basin. Removal of the species decreased downstream transport of organic carbon and increased primary production and respiration. Therefore, besides being an important harvested species, *Prochilodus* is a critical ecological component of South American rivers, and dependent on both latitudinal and longitudinal access to floodplains (spawning during wet season) and the river (feeding in dry season).

It has been shown in temperate rivers and floodplains that the impoundment of river channels does not have a significant impact on the species richness of molluscs, crustaceans or insects, but the species composition changed. However, disconnecting the floodplain from the main river channel led to a severe impact on biodiversity, reducing the species richness in all studied groups from 494 species in a connected floodplain to 149 in a disconnected floodplain (Ward *et al.* 1999). Moyle and Leidy (1992), and later numerous other researchers (summarised in Dudgeon *et al.* 2006 categorised the causes of the loss of freshwater aquatic biodiversity into five broader units (built structures relating to these units in parenthesis):

1. Competition for water / flow modification (most built structures, dams, impoundments, dikes, levees, irrigation, canals),
2. Habitat alteration, destruction or degradation (impoundments, canals, irrigation),
3. Water pollution (all built structures with effluents, but also irrigation, dams),
4. Introduction of, and invasion by, exotic species (canals, dams, reservoirs) and
5. Commercial (over)exploitation (selective fishing gears).

Each of these five causes can be connected to built structures; thus built structures will impact biodiversity. The first three causes mentioned often act in concert, and are the principal causes of the loss of aquatic biodiversity, but are often exacerbated by the introduction of exotic species and overexploitation. The effects of all of these factors are also both additive and cumulative.

3.5. ECOSYSTEM VALUE OF FLOODPLAINS

Ecosystem valuation (as presented by Barbier *et al.* 1993 and Constanza *et al.* 1997) has fairly recently been introduced in connection with ecosystem services provided by wetlands, including some floodplains. According to Constanza *et al.* (1997) wetlands are one of the most valuable landscape types in the world. One of the highest valued "direct use value ecosystem services" of floodplains is fish, while inputs to agriculture (nutrient rich deposits) and nursery functions of fish and other organisms, are considered the most important "indirect use value services" (e.g. Turpie 2000). Destruction of floodplains has been found to lead to diminished water storage during floods (Junk 1997) and subsequently reduced release of stored water during the dry season, another important ecosystem service of all floodplains, which is hard to value without complicated hydrological models. Dudgeon *et al.* (2006) conclude that freshwater biodiversity in general provides a broad variety of valuable goods and services for human societies, some of which are irreplaceable. Nonetheless, there is a paucity of empirical data showing how the value of goods and services derived by retaining habitats in relatively natural conditions compares with that obtained when they are converted for human use. The uses of fresh water, including non-consumptive use, underscore the importance of considering the perspectives of a wide range of stakeholders in environmental valuation and in the development of effective conservation policies (Dudgeon *et al.* 2006).

> *African floodplains provide a host of goods and services; these include floodplain recession agriculture, fish production, wildlife services and goods, livestock grazing, ecotourism, biodiversity as well as natural products and medicine. Not one of these goods and services has been valued completely. Estimates abound for individual floodplains, but no systematic evaluation for the economic valuation of floodplain services has been carried out continent wide, nor has this been linked to floodplains resilience to stress. It is this lack of information on the economic value that has been a major contributory factor in the destruction of floodplains. Decision makers and politicians see floodplains, as areas without use, to be "developed".*
>
> Christopher Gordon, 2002

In the Amazon floodplains in Brazil the annual flooded forest revenue related to *Tambaqui* production has been estimated (Araujo-Lima *et al.* 1998) at US$13 million, of which US$8.2 million originated from floodplain areas. As such, the revenue from this one specific species of fish was larger than the concomitant poultry and rubber production in the Amazonas State, and close to the value recorded for the logging industry in 1992 (US$9 million). In Cambodia, a valuation of the flooded forests in Kandal Province (Navy *et al.* 2001) estimates that the flooded forest brings a 33% higher net income (predominantly through fishing, but also including fuel wood and vegetables) compared to converted land (mainly through rice and some other crops). In the Waza Logone floodplains in Nigeria, the economic loss of a decrease of 30% in flooding was estimated at US$2.4 million per year. These studies make it clear that the conservation of the flooded forest habitats is of critical importance also financially, to ensure a sustainable future for local economies.

This type of quantification of ecosystem services can contribute significantly to more accurate calculations of actual benefits created by a certain built structure, taking into account both losses and benefits of ecosystem services and natural resources resulting from the development.

4. IMPACTS OF BUILT STRUCTURES ON TROPICAL FLOODPLAINS

In this section, impacts recorded in connection with certain types of structures are briefly discussed. More specific impacts of certain selected structures are discussed in the following chapters dealing with specific floodplains.

Major human impacts on tropical floodplains are according to Tockner and Stanford (2002) caused by hydrological change and urbanisation.

Rosenberg *et al.* (2000) summarised the environmental effects of large-scale hydrological alterations in general as follows:

- habitat fragmentation within dammed rivers,
- downstream habitat changes, such as loss of floodplains, riparian zones and adjacent wetlands and deterioration and loss of river deltas and ocean estuaries,

- deterioration of irrigated terrestrial environments and associated surface waters and dewatering of rivers, leading to impaired water quality because pollution cannot be adequately diluted.

Furthermore, he mentions the following less conspicuous impacts:

- genetic isolation through habitat fragmentation,
- changes in processes such as nutrient cycling and primary productivity,
- impacts in biodiversity,
- methylmercury contamination of food webs and
- greenhouse gas emissions from reservoirs.

4.1. DAMS

The largest and most discussed and debated built structures affecting floodplains are indisputably large dams. Much has been said on the topic, while few quantified and objective studies have been made. According to an inventory made in 2002 there were over 45,000 large dams (dams over 15 m height, or with reservoirs containing 3 million m^3 of water), and total annual freshwater withdrawals were estimated at 3800 km^3, twice as much as 50 years earlier (de Sherbinin 2002). Existing dams retain approximately 10 000 km^3 of water, the equivalent of five times the volume of all the world's rivers (Dudgeon *et al.* 2006). Dams are constructed for hydroelectric power, flood control, irrigation, and water supply, and many dams serve multiple purposes. Even though dams *per se* make up only a small percentage of total land cover, these artificial water bodies often facilitate other forms of land cover change, such as development of large-scale irrigated areas and urbanization, which impact far larger areas.

4.1.1. Impacts of dams

Since the 1980s there has been a well-organised international movement opposing dam building which does not comply with the San Francisco Declaration of 1988[1], resulting in much discussion concerning the costs and benefits especially of larger dams. The World Commission on Dams (WCD) collated a significant pool of information on issues regarding dams during its activities since 1998 until the release of the WCD report in 2000. According to this report, large dams have numerous impacts on ecosystems. These include:

- the loss of forests and wildlife habitat, the loss of species populations and the degradation of upstream catchment areas due to inundation of the reservoir area;
- the loss of aquatic biodiversity, of upstream and downstream fisheries, and of the services of downstream floodplains, wetlands, and riverine, estuarine and adjacent marine ecosystems; and
- cumulative impacts on water quality, natural flooding and species composition where a number of dams are sited on the same river.

Furthermore, dams and reservoirs impact the hydrological cycle by increasing evaporation (dams in arid areas can lose 5% of total withdrawals to evaporation) and

[1] *In June 1988 the International Rivers Network sponsored an international conference in San Francisco for citizens organizations concerned with protecting rivers and water resources from their most immediate threat – construction of large dams. The position statement adopted by the conference and subsequently extended by network organizations forms the San Francisco Declaration, including 22 points which can be accessed at e.g. http://www.irn.org/basics/ard/index.php?id=sfdeclaration.html*

loss of downstream aquifers due to reduced replenishment (de Sherbinin 2002). The extension of irrigation systems has also been shown to lead to habitat fragmentation and destruction, e.g. in the Senegal valley floodplains and delta (Daffé web citation).

Bernacsek (1984) summarised the main effects of dams as changes in discharge downstream (volume, timing and amplitude), desiccation of floodplains, riverbank erosion, changes in water quality (especially low oxygen conditions), and changes in flora (including aquatic macrophytes) and fauna (especially changes in fish biodiversity and composition).

In a synthesis based on studies presented at the international symposium concerning large rivers, Welcomme *et al.* (1989) summarised the effects of stress caused by built structures, such as dams or levees, on fish:

- Obligate migratory species will tend to disappear in systems where the main channels are locked by large dams, while
- Floodplain spawners are selected against by chanellisation or other stream regulation processes which reduce or eliminate the annual flood.
- Within modified channels there is a tendency to lose obligate migratory species although management is usually directed at their protection through installation of fish pass structures or through stocking.
- There is a tendency for dominance in fish assemblages to shift from floodplain spawners (phytophilous species) toward main channel spawners (mainly litophils).

More recently, in a contributing paper to the World Commission on Dams, Bernacsek (2000) reviews the impacts of dams on fish and fisheries. He lists the following direct and indirect impacts:

- Clogging or creating hazards to migration in upstream and downstream directions, and by mortality or damage when fish pass through dam discharge structures.
- Indirect impacts on fish biodiversity, fish stocks and fisheries through modifying and/or degrading the upstream and downstream aquatic environments, such as floodplains, including: (i) thermal stratification of the reservoir and release of cool and anoxic hypolimnion water downstream; (ii) downstream flood alteration and termination of inundation of downstream floodplains; (iii) sediment and nutrient trapping in reservoirs; (iv) release of contaminants from trapped sediment into the reservoir food chain; (v) infestation of the reservoir with floating aquatic plants; (vi) ghost fishing by nets snagged on drowned trees in the reservoir; (vii) long distance recession of the shoreline during drawdown; and (viii) pesticide contamination arising from agriculture on the reservoir drawdown zone.

The potential of reservoir fisheries is often listed as one of the benefits of dam construction, creating new fisheries opportunities in the area affected. However, the yields obtained from reservoirs are very variable, and tend to be higher in smaller reservoirs than in larger impoundments. On average, reservoir fisheries are far less productive than river fisheries on a per unit area basis (Jackson and Marmulla 2000).

Petrere (1996) points out the potential benefits of dams with regard to water quality in the river, if constructed in a highly polluted river (example River Tietê in Brazil), where downstream dams can have a positive effect through deposition of dissolved solids in the reservoirs and forced water aeration through spillways. However, the author acknowledges the detrimental effects of large dams on floodplains both above and downstream of the dam. He also discusses fish ladders, lifts, canal locks, transportation of spawning schools and spawning channels as mitigation measures for the impacts of dams on fish migration. However, fish ladders have been shown to have a low efficiency even for the selected species that can, at all, use them. In addition, fishways designed to promote fish passage past dams are in many instances used by fishers to capture fish (Jackson and Marmulla 2000). Fish lifts are not very common as they are expensive to build and operate. Canal locks may have a marginal effect on assisting in fish movements. The transportation of spawning schools is comparatively inexpensive but requires short distances and efficient water oxygenation apparatus in the transporting vehicles. Spawning channels have been found to be effective but require much maintenance and care taking (Petrere 1996).

Because of the negative impacts recorded, and the difficulty in finding working mitigation measures, the environmental flow requirements methodology (which include managed flood releases) is increasingly used to reduce the impacts of changed stream flow regimes on aquatic, floodplain and coastal ecosystems downstream (de Sherbinin 2002).

> *There is a need for fundamental research linking abiotic processes to changes in ecology, particularly in tropical environments, where much of the remaining potential for "new" river regulation resides. For all new large dams pre and post construction studies should be conducted in order to assess the environmental impacts and to determine the effectiveness of mitigating measures.*
>
> McCartney *et al.* 2000

4.1.2. Impacts of dams on fisheries

In Africa, studies have been made on the sequence of events after damming. According to Lévêque (1997), the results of these studies conclude that in general, and in tropical areas (as opposed to temperate, where the consequences of dams can be quite different), the closure of the dam is followed by a marked increase in fish populations favored by the new lacustrine conditions. After some time, the fish biomass decreases sharply as predators reduce the inflated population. The change in species composition is marked, and hard to predict, but the obvious change is the disappearance of riverine fish in the reservoir, while species adapted to life in open waters, such as small clupeids, become abundant. Although the number of species in a reservoir may be equivalent to the number inhabiting the original river at the reservoir site, native forms often disappear (Lévêque 1997). Apart from changes in fish diversity, the reservoirs are often subject to a succession of increasing pollution, eutrophication, algal blooms, extensive growth of water weeds, deoxygenation of the water and subsequent fish kills.

4.1.3. Water-related diseases and chemical pollution

An important indirect effect of dams is the increase in water-related diseases through the creation of suitable habitats for vectors in reservoirs and irrigation schemes. Well documented examples include the Akosombo and Kainji dams, man-made lakes of the

Tana River, Lake Volta regions after the construction of the dam, and the Senegal River Delta after the construction of the Diama Dam (Roggeri 1995). Irrigated agriculture worldwide is by far the largest user of freshwater and, consequently, impacts on freshwater ecosystems and the fisheries they support are stronger than for most other human activities (Nguyen Khoa *et al.* 2005). Irrigation, in combination with the potential increase in the use of pesticides (such as PCBs, DDT, dieldrin, chlorodan) and other chemicals related to increased agricultural activity, can lead to indirect impacts on the environment and fisheries. The bioaccumulation of these compounds through the food chain and their persistence in nature also impacts people using fish as a resource.

4.1.4. Environmental standards for dam construction

Regarding dam construction, environmental standards have been set both by institutions related to the construction (such as ICOLD, International Commission on Large Dams) as well as those which facilitate funding for construction (e.g. World Bank). ICOLD calls for a "comprehensive EIA" to be standard procedure as part of dam construction (ICOLD web pages, accessed in June 2006) but guidance on what should be included in this is not provided, except mentioning that "special attention should be paid to any effects on biodiversity or the habitat of rare or endangered species". The WB applies the same environmental standards to any project, i.e. pre-project environmental assessments. The only specific guidelines applying to dams seem to relate to water quality standards, implying that releases from reservoirs must comply with acceptable water quality standards (McCartney *et al.* 2000).

4.1.5. EIA on dam construction

In connection with Environmental Impact Assessments related to dam construction, only recently has attention been drawn to the downstream impacts of dams (much as a result of the work done by the WCD, including the impact on floodplains), while most attention is still given to the direct impacts of dams and the reservoirs created upstream. Indirect impacts such as infrastructural works in connection with dam construction (such as clearance of forest for accommodating machinery, temporary or permanent roads to enable access to the building site, temporary housing for staff working on the building site, etc.), as well as the general development of socio-economic activities connected to dam construction that tends to attract people and industry, are still largely ignored, especially in connection with developments in tropical areas. Generally, river ecosystems containing dams and other built structures must contend with pollution and increased exploitation of their resources, pressures independent from, but adding to, the direct influence of dams and reservoirs (Jackson and Marmulla 2000). The same applies, even more so, to the assessment of cumulative impacts, even though in connection with impoundments it is generally agreed that several impoundments in the same river catchment can result in synergistic negative impacts on downstream fisheries. E.g. Roberts (1995, cited in Jackson and Marmulla 2000) discussed impacts from 12 hydropower projects in the mainstream of the Mekong River and stressed that the combined impact on fisheries from these dams is greater than the sum of the individual impacts.

4.2. Embankments, Roads

Embankments are, like dams, structures opposing water flow. Roggeri (1995) lists at least the following types of embankments: dikes (submersible or not, with water inlet and outlet, or without), river embankments (man-made levees along a watercourse, raising the riverbanks), water–body embankment (for flood-control, creation of a stable water-body), basin embankments (floodwater storage in an annual or seasonal, man-made lake), floodwater storage dikes (often built in a crescent-shape to increase the dry-season agricultural area by storing water when the flood recedes, common in west Africa), controlled flooding dikes (usually for shortening of the flood pulse through delaying the flood), horseshoe dikes (open embankments), polders (closed embankments protecting land against flooding altogether), groynes (stone or gabion dikes, decreasing flow velocity and increasing filtration into the soil and sedimentation), bunds (usually constructed of local materials such as earth or stones) to increase flood duration or spread floodwater, for irrigation or aquaculture basins, and for infiltration purposes, and contour bunds and water spreading bunds. All these structures affect the water flow in some way, and have been used for centuries to manage floodplain hydrology for human needs. Some embankments occur in most inhabited floodplain environments. The cumulative effects of these types of structures must be significant, but have not been studied much, based on the literature reviewed. However, embankment of long stretches of major rivers, such as the Senegal River, has been documented and the negative effects of drying out of agricultural and pastoral land noted (see details in chapter 5.2.3). Collectively, the impacts of drainage by various means, embankment and subsequent landfilling, often results in worsened flood problems due to reducing the volume of floodwater which can be stored and evenly released later on (Roggeri 1995). Another effect can be reduced filtering and natural water purification of the water due to reduced floodplain vegetation.

Roads crossing floodplains are typically built on an embankment, and hence they have a similar impact on the floodplain environment and fisheries. Roads, forming long and continuous barriers to the natural movement of aquatic organisms, lead to fragmentation of habitat. The construction of roads along embankments has been argued to be a cheaper alternative compared to alternation between roads and bridges, or including culverts in the road construction (Vaz 2000). Roads crossing floodplains have been recorded to disturb natural migration routes of floodplain organisms amongst other things in Florida, USA (WRI 2000), India (Mathur *et al.* web citation) and Mozambique (Vaz 2000). Little specific information is available on the impacts of roads in tropical floodplain environments, but potential impacts in Ireland have been listed as follows (O'Neill, J. web citation): increased sediment runoff or loading, interruption of (ground)water flow, channel straightening, deepening and widening, stream flow/water level changes, loss of riparian and wetland associated vegetation, severance of habitat, increased risk of toxic runoff, modification of faunal behavior, spread of alien species and loss of spawning habitat.

4.3. CANALIZATION

Canalization (also called, especially in connection with larger-capacity canals, channelization) typically involves the realignment, clearing, widening, and lining of the stream channel, usually for flood control through improvement of flows and drainage of land. When a river is channelized, it is usually also embanked (Roggeri 1995). Canalization can also entail the construction of completely new canals for bypass, water transfer, drainage, flood control and recession or inundation purposes (Roggeri 1995). Among other effects, canalization may reduce stream length, create uniform habitat conditions, modify the hydrological cycle, drain adjacent wetlands, eliminate instream cover and riparian vegetation, degrade water quality and alter trophic relationships

(Moyle and Leidy 1992). In the industrialised world, many temperate rivers have been canalized along vast stretches. For instance in the USA, the Minnesota and Missouri Rivers are channelized for much of their lengths, which has led to the elimination of shallow-water habitats as well as adjacent riparian habitats that flooded annually, resulting in agricultural, urban and industrial encroachment on wetland habitats on 95% of the former floodplains of the Missouri River, and shortening the river by at least 120 km. Construction of the floodplain and reservoir structures has reduced the input of organic matter by 65%. Channelized sections of river have fewer fish and lower species diversity. In general, habitat alteration encourages the invasion of "weedy" fish and exotic species, with high reproductive rates and aggressive behaviour which allows them to invade adjacent less disturbed habitats and displace native species (Moyle and Leidy 1992). In the Mississippi River floodplain 80% of the hardwood forests have declined and the land has been turned into farms. As a consequence, only 20% of the floodplains can sustain fish populations, and standing biomass within this area declined from 170-340 kg/ha in undisturbed streams to 13 kg/ha. The cumulative effects of channelization and forest or wetland clearing are a watershed-level phenomenon not limited to the immediately adjacent floodplain. Rather, such activities often negatively affect hydrology, deposition of sediments, water quality, productivity and biotic diversity of all downstream aquatic habitats. In the Mississippi River Basin, these activities have increased catastrophic flooding, silted reservoirs, and eroded coastal wetlands, often creating the perceived need for further canalization and levee construction (Moyle and Leidy 1992). Similar experiences have been reported from Australia (Ball 2001).

4.4. Mining, Industrial Plants

Pollution in the form of chemical pollutants stemming from human constructions (in the form of effluents and sewage) is widespread and serious in all parts of the world. This type of impact is fairly well monitored in temperate regions, while information on the type and magnitude of aquatic pollution is in many tropical environments non-existent. In the Amazon, one of the main concerns with regard to fish populations, apart from habitat destruction and over exploitation of certain species, is the mercury pollution of rivers, caused by gold and tin mining. It is estimated that more than a thousand tons have been released in the Amazon in just two decades (Araujo-Lima and Rufino 2003). In Mexico, it has been shown that unique freshwater fishes and fisheries are in sharp decline due to environmental degradation caused by pollution from human settlements and water competition. Of 44 native fishes, 3 are extinct, and 23 greatly reduced in abundance or range. The fisheries for several valuable native species have declined or collapsed, and exotics constitute a major portion of the catch. In the Ayuquila River, several species have been locally eradicated, and major untreated industrial and municipal discharges, coupled with substantial water withdrawals for irrigation, preclude fish life during the dry season in 20 km of river that once supported an important subsistence fishery (Lyons *et al.* 1998). In the Everglades wetlands in Florida, increased runoff from agriculture and irrigation water, and effluents from industry and settlements have lead to serious eutrophication causing repeated algal blooms (and resulting fish kills), and *Typha* invasions in areas previously dominated by indigenous grasses (WRI 2000).

4.5. Small Structures, Fishing Gears

Smaller built structures, such as small-scale irrigation channels, small dams and weirs, floodwater storage systems, waterspreading dams, and fishing weirs, have received little attention regarding their impacts on the environment and fisheries.

Research carried out regarding flood control and regulator structures (sluice gates, weirs) has shown the structures to have a lesser impact on larval fish mortality if operating in an overshot mode rather than in deeper layers (de Graaf *et al.* 1999). In cases where it is not possible in the short to medium term to modify weir height or flow regime, consideration should be given to installing regulators on important wetlands and operating these structures to mimic natural wet and dry regimes (Living Murray, web citation)

Fishing gears left permanently or semi-permanently (e.g. during a certain season) in the water, may be considered built structures, and naturally have a marked effect on fisheries. In many areas selective fishing has lead to a decrease in the most valuable (often also the largest) species, and a shift toward smaller species has occurred. Due to the natural variability of floodplains, the gear types used are also adapted to this variability and include numerous different types. Baran *et al.* (2005a) describe at least 41 types of fishing methods commonly used in Laos and Cambodia. According to a study done in Bangladesh, Indonesia and Thailand, twenty different gear types were observed within nine broader classes (namely: Static barriers/Fykes, Active Filters/Seines, Lift Nets, Gill Nets, Cast Nets, Portable Traps, Hoods, Dewatering and Spears), and used according to the flood cycle. Some of these gears form static filtering barriers, fykes, which can form barriers for long stretches at the floodplain-river margin, the catch representing up to 32% of the total fishery (MRAG 1994). In cases where the floodplain environment has been reduced due to impacts from structures altering the hydrology of the area, this type of intensive and targeted fishery may have destructive results on species migrating from the floodplain back into the main river channel.

4.6. IMPACTS OF BUILT STRUCTURES – RESULTS OF QUESTIONNAIRE

During this desk review, a questionnaire regarding impacts of built structures was sent to 62 recipients (details in Annex 3). The recipients were selected based on the review. Only 23 replies were received, of which 19 answered most questions (31% response rate). In some instances it was reported that no built structures were present on the floodplains the recipients were working on, and therefore they could not answer the questions. This concerned especially floodplains in Venezuela and Peru. However, based on the few replies received, some general conclusions can be drawn. The number of answers per question is very low and can therefore be considered of indicative value only.

- Replies considered floodplains on all continents, with a small majority from Brazil. Floodplains mentioned included Amazon, Pantanal, Orinoco and Rio Mapire in South America; Gagnes, Brahmaputra and Meghna, Bangladesh, Mekong and Tonle Sap in Asia; Senegal, Okavango and Kafue flats in Africa and several floodplains of Australian tropical rivers (4 responses).
- Most floodplains considered had seasonal flooding, and consisted of large river floodplains with slow, ample and predictable floods, or flooded forests.
- Concerning ecosystem goods in the floodplains considered, fish was reported very significant or significant in all cases. With regard to other ecosystem goods and services, most suggested options scored "significant" except for game, rubber and medicinal plants, which were mainly classified as "not significant".
- Of ecosystem services, nutrients and fertile soils for agriculture were valued the most, followed by ecotourism potential and transport and navigation. Recreational and aesthetic value was considered less significant.

- The dispersal of answers regarding ecosystem goods and services illustrates the variety of ecosystem goods and services that different floodplains provide.
- Regarding built structures recorded in the floodplains, the following were listed: structures related to flood protection, mining, hydroelectric plants, chanellization, dikes, "*hydrovia*", large roads, dams, irrigation schemes, raised canals, gas storage facilities, levees, weirs, seasonal sand dams, bridges, culverts, and caseways.
- Regarding EIAs and SIAs most answers reported either no assessments made, or not in sufficient detail. Environmental Management Strategy was suggested to be incorporated into any built structure proposals. One reply indicated that a growing number of assessments are being done, but several pointed to weak implementation of the recommendations made during assessments.

All (12) respondents indicated that fish were impacted by structures, and 92% (11) noted that the environment had been impacted.

5. CASE STUDIES AND LESSONS LEARNT IN SPECIFIC FLOODPLAINS

This section gives an overview of some important tropical floodplains in South America, Africa, Australia and Asia.

A list of specific built structures and their environmental impacts, if quantified, is attached in Annex 2. This section discusses some of these cases in more detail, or other cases where only qualitative impacts have been recorded.

5.1. SOUTH AMERICA

5.1.1. Amazon floodplains

About 20% of tropical South America is wetlands (Junk 2002), including a great number of floodplains occurring in areas with low population and in remote areas where little human impact has taken place (Figure 1). In total, 6% of the entire basin area is periodically inundated. Flood control measures *per se* do not exist in the Amazon floodplains due to the high flood amplitude of the Amazon River (between 4 and 20 meters). Sometimes small, very local, flood protection measures are taken but they do not affect the ecosystem (Junk *et al.* 2000).

5.1.1.1. Large structures

Roads and other built structures are still scarce in large parts of the Amazonian floodplains. Despite this attempt to intensify the utilisation of natural resources have led to the construction of roads and other infrastructure to stimulate the agroindustrial development of the region. Operation Amazonia in Brazil (1966-1967) led to a significant increase in the road network in the Amazon to facilitate the occupation of northern parts of Brazil. These road constructions have been reported to have impacts on the floodplains through e.g. increased turbidity of rivers due to increased erosion from deforested areas. Waters of the previously Clearwater Rio Ji-Paraná became milky in colour after the construction and colonisation along the Cuiabá-Porto Velho Highway, which cut across its headwaters.

Many of these construction projects have demonstrated the vulnerability of the region especially to erosion and subsequent sediment loading of rivers and floodplains (Junk 2005). One of the major indirect impacts discussed in connection with e.g. road and gas pipe construction through remote and isolated floodplains is the introduction of the floodplains to human impact in general, introducing previously pristine areas to immigration and development of settlements, agricultural activities and ranching with livestock.

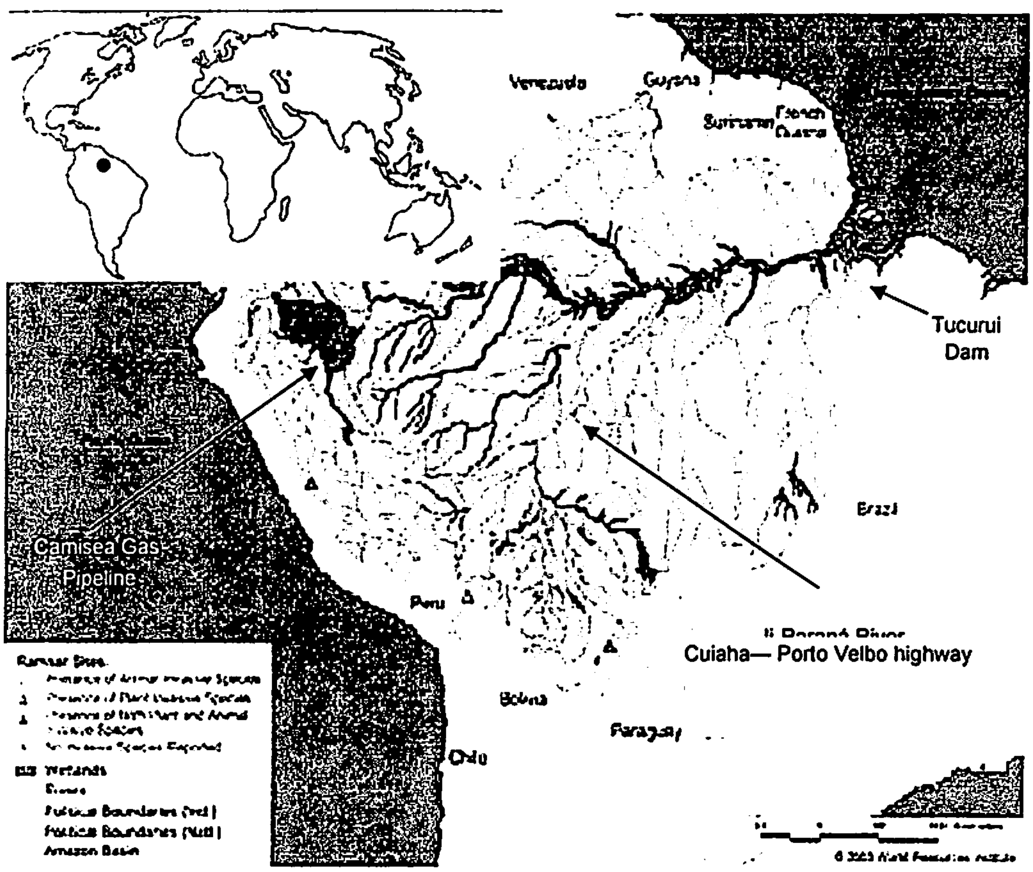

Figure 1. Map of the Amazon rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: *www.iucn.org/themes/wani/eatlas/index.html*

Comparatively few hydropower plants have been built in the Amazon region, and even fewer have had complete pre- and post-filling evaluations done regarding their impact on the environment and fish. One of the most documented cases is the Tucurui Dam. Recorded impacts include a reduction in species richness of fish and catch per unit of effort both in the reservoir as well as downstream of the dam, an increase in the abundance of piscivorous species and a decrease in frugivorous and detrivorous species, while migratory species disappeared all together (Araujo-Lima and Ruffino 2003). The situation was unstable for a number of years after construction, improving somewhat in the reservoir, while downstream fisheries did not show a similar recovery. Anoxic environments were created through decaying vegetation left in the reservoir (Fearnside 2001). Assessing the impacts of the dam is made complicated due to the differing points of view and impacts reported by different authors (see Annex 2 with list of impacts recorded). Araujo-Lima and Ruffino (2003) conclude that the impacts of the reservoir on fish varies between fish species, some being negatively affected while others respond positively to the habitat change. However, a common trend observed was the reduction in fish diversity. The only mitigation measure that has been generally adopted seems to be the establishment of hatcheries to stock the reservoirs with native species, but little follow up has been done to monitor stock densities (Fearnside 2001).

One of the most controversial, discussed and disputed construction projects in South America, apart from large dams, has been the Camisea Gas Project in Peru. The 731 km-long Camisea pipeline runs from the Amazon, over the Andes, to the Pacific Coast. EIAs and independent reviews by local organisations point to massive erosion caused by the construction and operation. The erosion causes loss of topsoil, siltation pollution of the aquatic river systems and landslides on inclines. As of March 2006 there have already been 5 spills along the Camisea pipeline since it became operational in August 2004 (Wikipedia internet encyclopaedia[2]).

The experiences related to the gas pipe constructions in the Amazon has led to attention being directed toward the social and environmental impact assessments involved. The Bank Information Centre USA prepared (Hamerschlag 1999) a set of recommendations based on the experiences derived from a 3000 km gas pipe construction from Bolivia to Brazil. The recommendations point to emphasis of information, public consultations, environment and indigenous peoples, project monitoring and compliance. However, specific instructions for consideration of different ecosystems, such as floodplains, are not specified.

Despite difficult experiences during massive infrastructural construction projects, the future of the Amazon Basin will still include several extensive projects focussing on fluvial transportation and road construction, e.g. within the programme "Iniciativa para la Integración de la Infrastructura Regional Suramericana" (IIRSA web citation).

5.1.1.2. Identified threats to Amazon floodplains

According to Goulding *et al.* (1995) the main threat to the remaining floodplain forest in the Amazon is deforestation, which has already affected most areas of the floodplains. The area of flooded forests on the floodplain has decreased dramatically. Intensive logging of valuable species in the flooded forest, as well as clearing of land for cattle farming, are the main reasons for the deforestation. Clearing of trees is also the first step in agriculture and mining.

Bayley and Petrere (1989) consider that in the case of the Amazon *várzea*, hydrological alteration due to hydroelectric dams may lead to more severe impacts on fisheries than deforestation during the next 10-20 years. The well-documented cases in Africa (Bernacsek 1984), in particular the inability of reservoir production to replace losses of floodplain fisheries and agriculture production downstream, have according to Bayley and Petrere (1989) been largely ignored in connection with the planning of new reservoir developments in the Amazon.

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[2] *http://en.wikipedia.org/wiki/Camisea_Gas_Project* citing *El Comercio*, accessed March 6, 2006 - *http://www.elcomercioperu.com.pe/EdicionOnline/Html/2006-03-05/onlPortada0467113.html*).

Bayley (1998) summarises the major threats to Amazonian aquatic biodiversity as follows:

- The conversion of *várzea* floodplain to pasture and crop agriculture;
- Changes in flood regimes and system connectivity through hydropower dams and navigation channels ('*hidrovias*'); and
- Deterioration of water quality through mercury used in gold mining, petrochemical effluents, drug processing wastes and sewage discharges.

Of these, Bayley (1998) considers *várzea* conversion to be the greatest short term threat, while the most fundamental long-term threat is unsustainable water-use, principally construction of navigation channels and dams, which reduces biological productivity by altering the floodplain inundation regime and curtails longitudinal and lateral connectivity. Junk *et al.* (2000) classifies (the same) human impacts on the *várzea* in different categories, with decreasing destructive effects: 1. modification of the hydrological regime, 2. large-scale destruction of plant communities, 3. reduction of populations of plant and animal keystone species, and 4. pollution.

5.1.1.3. Threats to Amazon fish and fisheries

Large-scale ranching with cattle and water buffalo is at the moment a serious threat to the primary economic resource of the floodplain: the abundant and diverse fish. The number of known fish species in the Amazon is around 2500 species (Araujo-Lima and Goulding 1997) of which only a fraction, mainly economically important species, have been studied. The impact of development on the Amazon fish fauna is therefore still poorly understood. The main impacts apart from over fishing (of certain high value species) are, according to Araujo-Lima and Ruffino (2003), mercury pollution and deforestation caused by gold and tin mining and habitat destruction including built structures such as dams and reservoirs. Although most of the Amazon fish catches are harvested in the main river channels and far downstream, they ultimately rely on the floodplain for spawning areas, food and cover (Goulding *et al.* 1995). The location of a built structure in the river channel is of importance, and can lead to a stronger impact on some species than others. For instance some larval fish species are predominantly transported into floodplains during rising waters, mostly along the riverbanks, in which case a structure changing riverbank attributes will affect migration patterns (e.g. canalization creating abrupt and steep riverbanks), while others are flushed out of floodplains more evenly during the water recession (Araujo-Lima and Oliveira 1998).

5.1.2. Floodplains of the Paraguay/Paraná River Basins

The "El Gran Pantanal" or the larger La Plata Basin is an expanse which encompasses more than 2 million km^2 and a population of more than 100 million inhabitants, and extends through Brazil, Bolivia, Paraguay, Argentina and Uruguay in the Paraguay River Basin (Swarts 2000). The Pantanal is the largest South American seasonally flooded land, composed of the floodplains of the Paraguay River and effluents (Figure 2). During the dry season, the Pantanal is covered by dense to open savannah and riparian forest at river edges, while during the flood, the plains are covered by water up to two meters deep that stays for several months (da Silva *et al.* 2000). The Pantanal is increasingly threatened by large development programs, including agroindustries and hydropower reservoirs, plans for canalization of the Paraguay River (hidrovia) and increasing industrial and livestock developments. These developments negatively affect habitat and species diversity, scenic beauty and also the hydrological buffer capacity of the Pantanal (Junk and Cunha 2005).

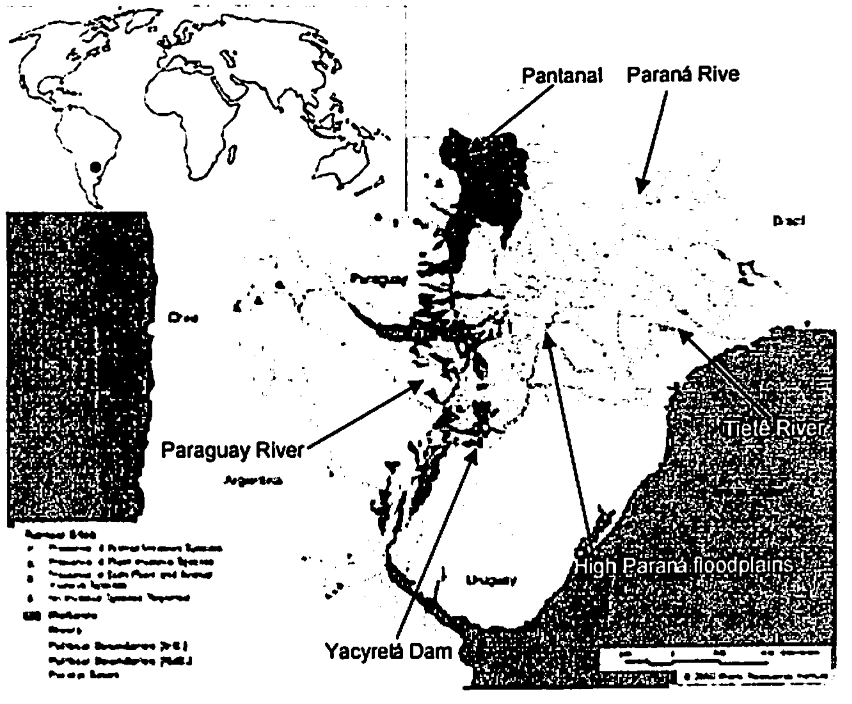

Figure 2. Map of the Paraná rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: *www.iucn.org/themes/wani/eatlas/index.html*

The high Paraná floodplains in Brazil cover an area of 230 km between Itaipu and Porto Primavera reservoirs, with a width of about 20 km. The floodplain has been affected by intensive reservoir constructions (25 reservoirs larger than 100 km^2), but due to water from several unregulated tributaries, the flood regime still maintains and this remaining stretch of the high Paraná floodplain ecosystem still supports considerable biodiversity (Agostinho *et al.* 2000). This floodplain area is the last unimpounded section of the river within Brazilian territory. In Argentina, the Paraná River is highly regulated, the water in reservoirs of the Upper Paraná Basin currently comprising more than 70% of the mean annual discharge at its confluence with the Paraguay River (Quirós 2004). The expansion of hydroelectric generation in the Upper Basin has brought with it an increase in industry, agriculture, transport and settlements. These in turn have resulted in significant increases in deforestation, soil erosion, changes in water quality and reduced fisheries opportunities in both the Upper and Lower Basins (Quirós 2004). A study done by Terraes *et al.* (1999) in connection with the Yacyretá Dam, located in the Upper Paraná River, confirmed that the reproduction of many species of fish was negatively affected by the dam through a change in the male-female ratio, as well as a shortened reproductive period. The fisheries in the Paraná River Basin were traditionally based on large potamodromous fish caught from a fish community containing a relatively high frequency of the detritivorous *Prochilodus* (Quirós 2004). The catch per fisher per day now ranges from 11 to 30 kg for reservoirs situated in the Brazilian Upper Basin to more than 110 kg in the Lower Middle Parana River. Striking differences in the fish species structure of the catch are noticeable between reservoir and floodplain fisheries and among floodplain fisheries themselves. Quirós (2004) identified three main fishery states in the Plata Basin across broad temporal and spatial scales:

1. A relatively undisturbed state corresponds to the unregulated river, when fishing effort was relatively low to moderate, the catch being mainly dominated by high value large siluroids and characins. This state is represented by fisheries at the Pantanal floodplains and the Parana-Paraguay confluence and to a lesser extent by some of the remnant lotic reaches at the Upper Parana.

2. A second fishery state corresponds to the developed river, with floodplains disturbed by river regulation and other developmental activities. Here the fisheries are still supported by potamodromous fish but fish size at capture is usually lower. Fishing effort is usually higher. The contribution by weight to the catch of less valuable *Prochilodus* has increased, and exotics are usually included in fish catches. The disturbed floodplain fishery state is represented by fisheries of most of the Lower Basin and at the few unregulated reaches of the Upper Parana.

3. Fisheries in riverine reservoirs represent a third, relatively highly disturbed fishery state. The catch of potamodromous fish frequently descends well below 50% of the total catch and fish catches are often dominated by blackfish species, less dependent on river flows, and with an increasing importance of exotic fish species. Fish size is lower as well as fish value at landing.

The Plata Basin fisheries represent almost all of these states at the same time in different parts of the basin, and provide a unique opportunity to study different stages of disturbance and its effect on floodplain fisheries.

5.2. AFRICA

Nearly all African rivers are accompanied by large fringing floodplains and several internal deltas occur. Forty-three large floodplains have been reported and described to some extent (Junk 2002). In most parts of Africa, water availability is sufficient only in the moist equatorial belt. Therefore, water needs for irrigation, domestic and industrial uses have caused construction of numerous reservoirs affecting the downstream flow and floodplains (Junk 2002). Most large rivers of Africa have at least one main stem dam and some, such as the Nile and the Zambezi, have more. There are also a large number of medium-sized dams (reservoir sizes 10 -100 km^2) for irrigation, urban water supply and small-scale power generation. The larger dams are the major causes of degradation of the aquatic environment and disruption of the livelihoods of communities dependent upon farming, fishing and grazing along the river valley (Welcomme 2003). The changed hydrological regime of rivers has adversely affected floodplain agriculture, fisheries, pasture and forests that constituted the organising element of community livelihoods and culture (World Commission on Dams Report 2000). In many cases the desiccation caused by dams has been enhanced by natural drought.

Impacts of flow alteration on fish species have been documented for numerous artificial reservoirs in Africa, which have replaced running water habitats resulting in the disappearance of lotic species and the proliferation of species adapted to lentic systems. Many of these species are exotic, which has had a further impact on the ecosystem (Revenga and Kura 2003). Only in a few cases has remediation action taken place, e.g. in the Phongolo (South Africa), Senegal and Waza Logone (Cameroon) floodplains.

5.2.1. Congo River Basin

The Congo River Basin is the largest watershed in Africa, and the second largest (after the Amazon River Basin) in the world. Due to the unstable political situation that has prevailed in the area for a long time, little information is available on this vast floodplain area. Only minor infrastructure development is present and therefore it is probable that large parts of the wetlands are still intact (Junk 2002).

5.2.2. Niger River Basin

The Niger River traverses four countries, but the basin covers 9 countries of West Africa (Figure 3). The Niger has been comparatively well studied. Welcomme has conducted comprehensive studies in many African floodplains, including the Niger. Already in 1975 Welcomme published calculations showing the importance of floodplains for fish production in the Niger and Benue Rivers, indicating that the floodplain area of a river accounts for 72% of the variance of actual catch per km of river. This relationship has been improved and extended in newer literature (e.g. Laë 1992, Laë 1994). Differences in the yield within one river system can thus be attributed both to the development of the floodplain in the various river reaches and to differences in the water chemistry of the various tributaries (Welcomme 1975).

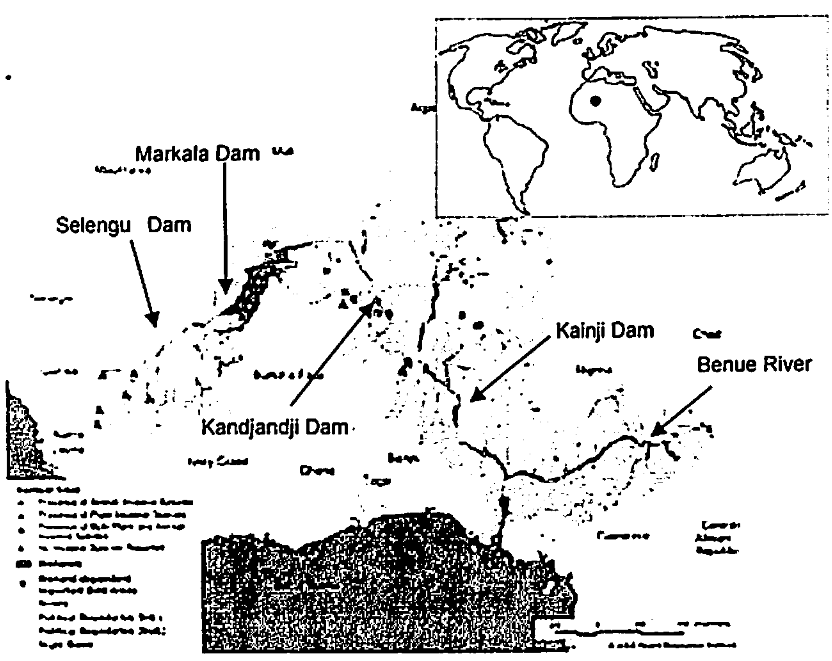

Figure 3. Map of the Niger rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: *www.iucn.org/themes/wani/eatlas/index.html*

The floodplains along the Niger River have been much affected by built structures, especially the building of dams which has reduced the area of large floodplains and floodplain lakes. According to Laë *et al* (2003), there are four major dams built on the Niger, as follows:

- A hydroelectric dam was built in 1980 in Selengue on the Sankarani River upstream of Bamako to provide electricity for the Mali capital. The reservoir surface area is 400 km^2 and during the flood the flow rate of the river entering the reservoir is estimated at 123 $m^3 s^{-1}$.
- The Markala Dam was built in 1943 250 km downstream of Bamako in Mali in order to store water for gravity irrigation of a depression that was formerly an arm of the Niger. This new area, known as the "Office du Niger", allowed a significant development of agriculture and currently produces rice and sugar cane. For this purpose up to 158 $m^3 s^{-1}$ of water is used, representing 5 percent of the river flow during the flood. There is only one hydroelectric dam in Niger at Kandaji, except for a submersible dam that provides the capital Niamey with drinking water. As the hydrological cycle is disrupted downstream, a co-operation agreement between Mali and Niger allows for artificial flood releases at low waters to maintain a minimal flow.
- The only mainstream impoundment on the Niger River is Lake Kainji in Nigeria, located about 1200 km upstream from the mouth of the river. The hydroelectric dam was built from 1962 to 1968 and the surface of the reservoir when full is about 1300 km^2.
- The upper course of the Benue River was impounded in 1982 for hydroelectric power generation, irrigation and fisheries. The surface of the reservoir covers 700 km^2.

All these structures have had an impact on the natural dynamics of the river downstream of the dams and on fish abundance and diversity (Laë *et al* 2003). According to Laë (1994) the effects of the dams is felt especially during highwater, when the filling up of especially the Selengue and Markala dams leads to a deterioration of the flooding through decreased expanse and duration of flooding. This in turn has lead to a decrease in recruitment and fish catches. The yearly production loss has been estimated at 5000 tons (10% of fished volume) of which 2000 are directly attributable to the Selengue dam.

A fairly well documented example of the impacts of dams on the Niger is the Kainji Dam. As a result of diminished downstream flows, the floodplain lake Ndakolowu, downstream of the dam, has been strongly reduced in area (Bernacsek 1984). The Kainji Dam has been reported to also have positive effects through changed fisheries opportunities in the reservoir of the dam, the Kainji Lake, second in size in West Africa to Lake Volta. A report on small-scale fishery studies done by a Nigerian-German project stated that "Although the lake's primary function is for hydroelectric generation, an important small-scale fishery has developed that in 1999 supported some 9502 fisherfolks using a wide range of gears including gill nets, cast nets, beach seines, fishing traps and longlines" (Alamu *et al.* 2003). However, earlier studies in the area pointed to the opposite. Welcomme (1985) reports a fish loss of 6000 tons per year due to the Kainji Dam. Later studies showed a 30% decrease in fish catches, and a reduction in commercially important *Mormyridae* species from an average of 20% of the catches to just 5% (Jackson and Marmulla 2000). It is not a simple task to weigh the gains and losses of a certain large project, even retrospectively. However, in the presence of floodplains downstream of a dam, losses in flooding will inevitably lead to major changes to the rich floodplain ecosystem, and the losses of these should be compared to the gains received from the artificial lacustrine environment created through the reservoir.

For many decades (especially between 1970 and 1985) the Sahelian drought has caused decreased annual inflows to many rivers in West Africa. EIA's prepared in connection with dam constructions in regions affected by this drought suggest that the dam, and possibilities for increased flows during at least part of the year, will counteract the impacts of the drought. For example, the EIA prepared for the proposed construction of the Kanjandji Dam in Niger suggests mostly positive impacts of the dam through rehabilitation of floodplains (that have decreased due to drought), including fish passes in the dam and creating new habitats (Kimba 2003, Lahmeyer Int 2002).

5.2.3. Chad River Basin

The Waza Logone floodplain in Cameroon is an exceptionally well-documented case, where promising experiences in the rehabilitation of the floodplain have been collected. The Waza Logone floodplain covers an area of about 8000 km^2 (5000 in dry season). It is located in the North Province of Cameroon (Figure 4), where the floodplain comprises about 10% of the total surface area of major riverine wetlands in the West African Sahel (Emerton 2005). It therefore represents a critical area of biodiversity and productivity in an otherwise arid area. Sixty percent of the inhabitants of the region rely on floodplain and wetland resources for their basic income and subsistence (Emerton 2005).

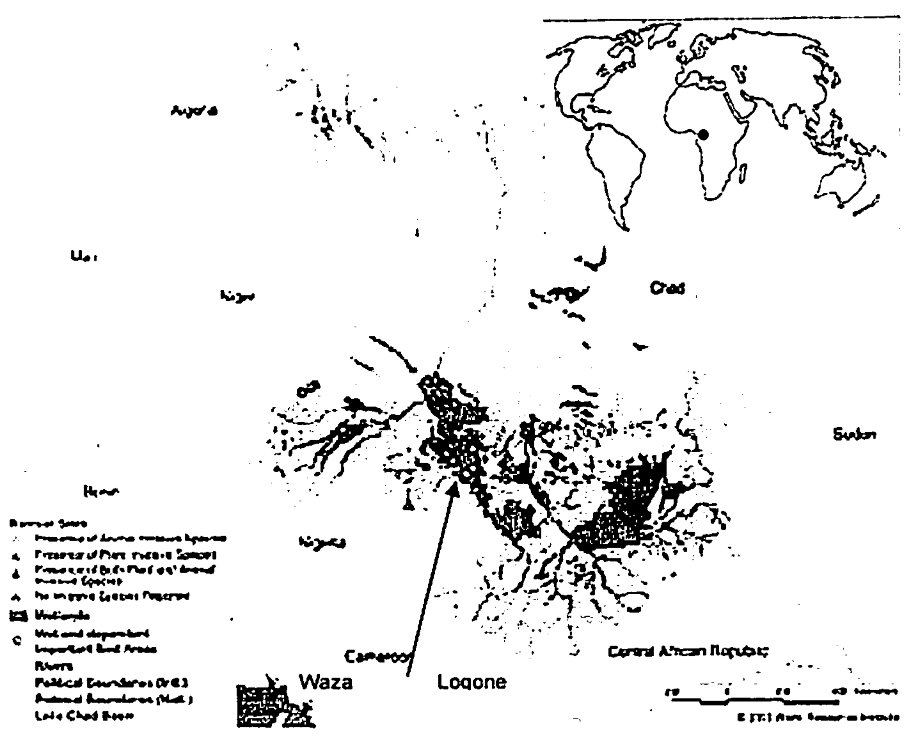

Figure 4. Map of the Chad rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: *www.iucn.org/themes/wani/eatlas/index.html*

The high productivity of the Waza Logone region depends to a large extent on the overbank flooding of the Logone River (tributary of the Benue and Niger) and three seasonal rivers. Since 1979 the inundated area has been reduced by 964 km^2 representing almost 30% of the original flooded area, due in large part to the construction of a rice irrigation scheme (SEMRY) including a 30 km long dam creating a 400 km^2 reservoir (Maga Lake), as well as extensive embankments along the Logone River (Loth 2004). The construction works resulted in a 70% reduction of water supply to the floodplain from the Mandara Mountains, and an almost complete curtailment of the water supply from the Logone.

According to Loth (2004), the reduction in inundated area had a number of negative impacts on the ecology, biodiversity and socio-economy of the Waza Logone floodplain, including:

- Reduction in crop agriculture, mainly floating rice and floating sorghum, and flood recession sorghum.
- Loss of fisheries, including an estimated 90% decline in fish yields within flood-fed wetlands, and reduction of the capacity of the area to provide nursery for fish stocks in the wider river systems of the Logone and Chari. Decrease in dry season pasture: floodplain pastures (especially *bourgou* (*Echinochloa stagnina*), a high-quality floodplain grazing area in the dry-season, which has been replaced by expanding rice cultivation. However, rice crop residues are a poor substitute for the loss of *bourgou* pasture (Wagenaar *et al* 1986).
- Loss of plant resources, including grasses, shrubs and trees that were used for house construction, beekeeping, handicraft production, wood-fuel, wild foods and medicines. Grasses from the flooded areas were harvested and used for thatching houses and constructing fishing baskets.
- Decrease in wildlife populations, which has indirectly decreased economic activities within the tourism, sport and subsistence hunting sectors.
- Reduction in surface water availability, affecting water holes and water courses that are used for domestic and livestock water supplies and for water transport.

In response to the droughts which affected the Sahel in the 1960s and 1970s, many countries opted for large-scale, intensive irrigation schemes to meet their food security needs and to provide export opportunities. Unfortunately, until the early 1990s, these schemes were premised on overly optimistic economic forecasts and, even worse, implemented without any assessment of their impacts on downstream ecosystems and livelihoods. Today, a wealth of evidence demonstrates that, in many instances, these engineering projects ... have not delivered the food increases anticipated during pre-commissioning phases. It has therefore become apparent that full floodplain conversion to irrigated agriculture is economically risky because the traditional farming, herding and fishing activities which such projects replace require no capital investments and often generate higher and more regular (and thus safer) returns per unit of water used.

Loth 2004: The Return of Water

Due to all these losses in the natural floodplain ecosystem services, it was decided to carry out restoration of the floodplains, which started in 1988 and continued until 2000. The restoration of the floodplain began with two pilot releases of water, which coincided with above average rainfall during the period 1994 to 1997. In these years a larger surface area was flooded than during the years immediately following the rice-irrigation interventions. The ecological monitoring programme initiated by the project showed that as a result of re-flooding, perennial grasses returned, and since grazers prefer perennial grasses, the number of wild herbivores increased. Socio-economic data showed improvements in fishing yields and livestock production as a result of increased flooding (Loth 2004). The restoration also led to a marked increase in the number of waterbirds, mammals, fish production, improvement and extension of pasture and changed agricultural opportunities (Emerton 2005). The return of the flood was of greatest value to pasture and fishing, while it also significantly benefited agriculture, the state of other natural resources (such as grass and *bourgou*) and surface water reserves (Loth 2004). The environmental, social and economic impact of the restoration project, as well as the methods used e.g. for the valuation of the re-inundation of the ecosystem, and the planning framework for managed flood releases etc. have been described in detail in Loth (2004).

5.2.4. Senegal River Basin

The Senegal River is accompanied by fringing floodplains along nearly its entire main course (Figure 5).

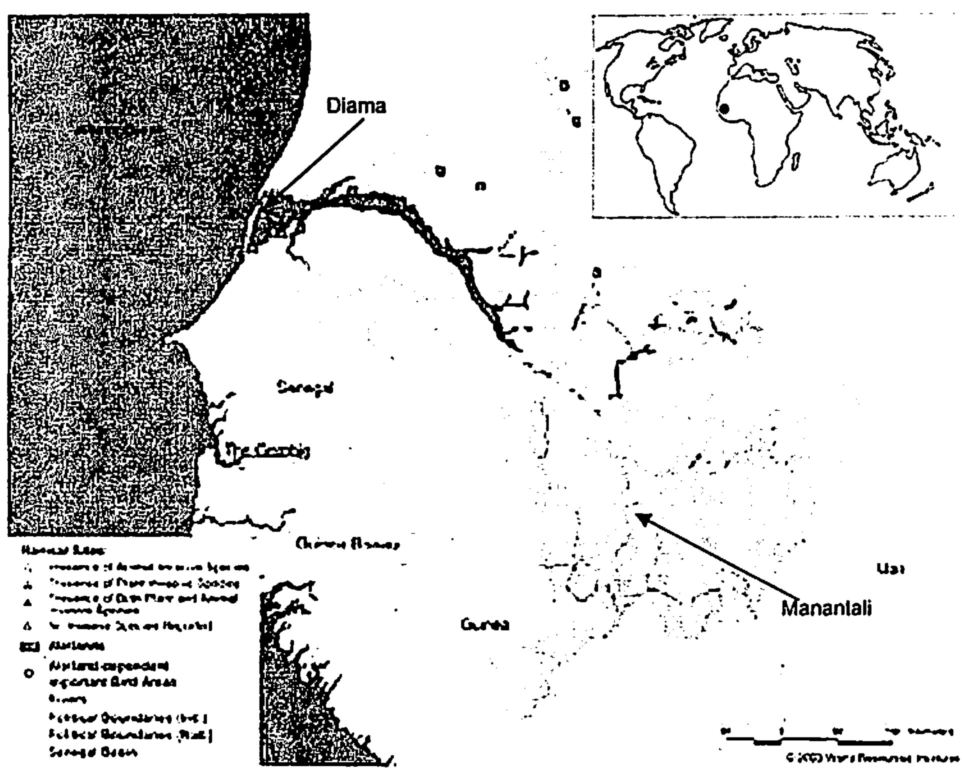

Figure 5. Map of the Senegal rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: *www.iucn.org/themes/wani/eatlas/index.html*

The Senegal floodplain received, in a natural state, floods during the high-water period between June and October. During this high water period the river overflows its banks and floods the broad alluvial plain of the middle valley. This enables farmers to practice recession agriculture, growing crops during the dry season, after the waters have receded and the low-water period has started (Finger and Teodoru 2003).

In response to the droughts of the seventies, two major dams were built in the Senegal River, the Diama and Manantali dams. Water management policies were mainly dictated by the needs of new production systems, such as irrigated farming, hydropower and fluvial transport while traditional recession farming was considered old fashioned (Kloff and Pieterse, webcitation). The first dam to be completed (in 1986) was the Diama Dam, located 27 km upstream from St. Louis (Senegal). It was built to stop the dry-season intrusion of seawater. The impoundment reservoir became fully operational in 1992, after the completion of the embankment on the Mauritanian side. The second is the storage dam at Manantali in Mali (completed in 1990) on the Bafing, the main tributary of the Senegal River (delivering approximately 50% of the annual flow). The reservoir is theoretically capable of stocking 11 billion m^3 of runoff from the strongly seasonal rainfall in the mountains of northern Guinea. The water can then be gradually released over a longer period than the natural flood (Hamerlynck *et al.*web citation).

Most of the environmental and social impacts [of the Diama and Manantali dams] have stemmed from the physical separation of the river bed from the floodplains by the building of longitudinal embankments. The original ecosystems now either have too much water (the reservoir and the lowest lying parts of the floodplains) or too little water (the higher parts). Special impacts have occurred in the former estuarine part downstream of the Diama dam which became hypersaline, a common problem with dams in tropical areas. The changed hydrology in the regions has led to salinisation and loss of top soil, hampering the agricultural sector. Areas previously affected by floods and droughts, have now a stable water level which has led to the invasion of Typha domingensis, *a reed that has perfectly adapted to the new water management regime.*

In the agricultural sector, on top of the salinisation and loss of soil fertility mentioned previously, production has been hampered by the increase in the populations of granivorous (grain eating) birds. It is thought that this population explosion is linked to the permanent availability of fresh water which has eliminated the important dry season mortality. Another factor may have been the creation of inaccessible breeding and resting areas in the tens of thousands of hectares of former floodplain invaded by Typha domingensis. *Another major problem is that the land available for the previously largely practised recession agriculture, a sustainable type of agriculture, is now insufficient.*

The fish species living in the main rivers of the Sahel have a life cycle that is adapted to the characteristic seasonal flooding, migrating into the floodplain to spawn and returning to the river bed with the new generation at the water's retreat. Through history, the different communities of fishermen in the Sahel have learned to exploit this life cycle by allowing the spawning migration to go through virtually without intervention, and by concentrating their effort on the fish trying to regain the permanent waters of the river bed. Many techniques exist for the blocking of the return channels with different devices. There is a very clear relationship between flood extent and fish capture, estimated at around 50 kg per ha. Fish catches in the delta of the Senegal River were estimated to be around 30 000 tonnes in the pre-dam era and most of this production has been lost *subsequently. This loss has been very extreme in the formerly estuarine part downstream of Diama and probably this has also impacted on marine fisheries through the loss of nursery functions for mullets (*Mugilidae*), shrimp (*Penaeidae*), shad (*Ethmalosa fimbriata*) and other species having an obligatory estuarine life history stage.*

*Though catches in the Manantali reservoir have increased this is certainly not a compensation for the losses in the rest of the valley. It is likely that a change in species composition has occurred in the Diama reservoir, with a decrease of the typical migratory species and a relative increase of the more sedentary, opportunistic species (*Claridae, Cichlidae*) but no joint surveys have been done in the international waters of the river and no data have been made available from surveys carried out by Senegal. Fishing in the Diama reservoir is seriously hampered by the dense stands of* Typha, *and by the floating invasives,* Pistia stratiotes *and (since 1999)* Salvinia molesta *that are blocking the channels.*

The conversion of the floodplains of the Senegal valley for irrigated agriculture has considerably reduced the quality and quantity of dry season pasture. This loss is more extensive than the surface area actually converted to rice fields because of the hydraulic infrastructures used for the control of water supply to the paddy fields. The irrigation systems target paddy fields only, while the surrounding floodplains have dried out and been subjected to wind erosion removing the topsoil causing sedimentation problems in the tributaries, blocking water transport.

Floodplain forests, especially those of [the indigenous] Acacia nilotica *and* Borassus aethiopium, *are of great value. Most of the natural floodplain forests of the valley had already suffered from the drought and overexploitation but after the dams losses have been compounded. The forests have died because of lack of water (on the higher grounds) or waterlogging (in the low-lying areas. The impact on* Sporobolus robustus *stands, a perennial grass used in mat weaving, which incidentally was the main source of income of the local women, was also devastating. Another important species that used to occupy the seasonal pools in the floodplains is the water lily* Nymphea lotus, *which was used locally as a cereal substitute and for its pharmaceutical properties. Most of the original habitat is now covered with* Typha.

Summarised from Hamerlynck *et al.* 2000

These impacts, summarised above as presented in Hamerlynck *et al.* (2000), finally led to restoration projects, including the Diawling National Park projects. The construction of the Diama Dam in 1986 affected also the floodplain and estuarine areas on the Mauritanian bank by the absence of floods. In 1994, managed flood releases were initiated in the Bell Basin (4000 ha) of the Diawling National Park, as part of a rehabilitation effort. The basin was designated as a joint management area between traditional users and the Park authority and a revised management plan was developed through a participatory approach based on topographical, hydro-climatic, ecological and socio-economic data. Hydraulic modelling was developed as a tool to support stakeholder negotiations on the desired characteristics of the managed flood releases. The volume of flood release required to restore the delta did not affect hydropower generation, navigation or intensive irrigation, for which the dams in the basin were constructed. This project provides an example of implementation of the recommendations of the World Commission on Dams through ecologically and sociologically beneficial operation of a dam-based infrastructure within the basin, agreed through stakeholder participation (Duvail and Hamerlynck 2003).

5.2.5. Zambezi Basin

Compared to many other river basins in Africa, the Zambezi (Figure 6) is for much of its length relatively little affected by human activities.

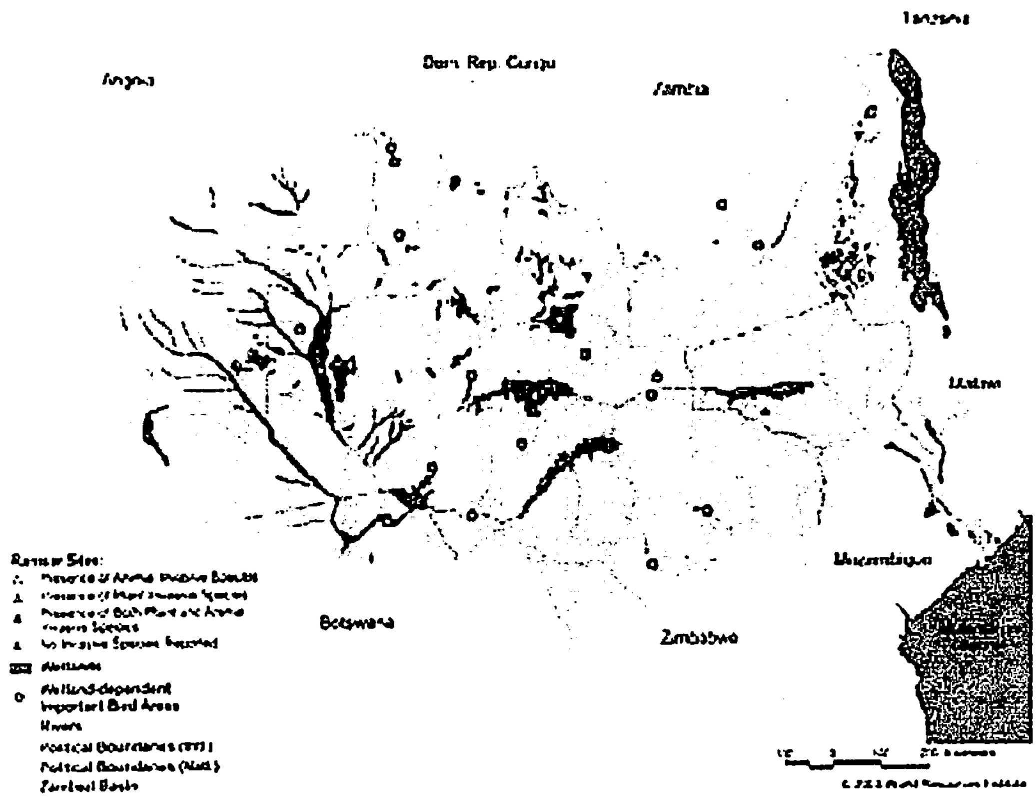

Figure 6. Map of the Zambezi rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: *www.iucn.org/themes/wani/eatlas/index.html*

The major changes in land use affecting biodiversity in the Zambezi Basin over the last 100 years have been the construction of the two major dams at Kariba in 1958 to form the 5361 km² Lake Kariba and at Cabora Bassa in 1974 to form the 2665 km² Lake Cabora Bassa (Timberlake 1998). However, due to inadequate or non- existent baseline data, as well as the absence of EIAs on species composition and abundance, it is impossible to assess the change deriving from these major developments (Timberlake 2000). Prior to these impoundments a series of dikes was built to keep the Zambezi floodwaters out of the sugar plantations. This regulation of river flow and flooding events has almost certainly had a major impact on species abundance and distribution, but the extent of these changes, given a naturally variable and changing environment, is still not clear (Timberlake 2002). Lesser dams that have had major effects on biodiversity are

Itezhi-Tezhi and Kafue Gorge, both on the Kafue River in Zambia, situated at the upstream and downstream ends of the Kafue Flats floodplain, respectively (Timberlake 1998). These two dams have altered and now strongly regulate flooding patterns on the Kafue Flats. The area flooded during the rainy season is now smaller (4340 km^2) and more regular. Flood duration is longer and slightly delayed. During the dry season a larger area remains permanently flooded (about 1000 km^2). The amplitude of water level fluctuation has been reduced from a mean of 5.1 m to a new mean of 3.3 m (Bernacsek 1984). Other dams are much smaller and situated on the upper reaches of tributaries. Two further dams are planned for the Zambezi: at Batoka Gorge below Victoria Falls, and at Mepanda Uncua below Cabora Bassa (Timberlake 2002).

The construction of these dams has resulted in regulation of the previously-vast annual Zambezi floods below Victoria Falls. Kariba Dam reduced the flood magnitude of the Zambezi River by an average of 24% in eight out of ten years (1970–80 period), which in turn reduced flooding on the downstream Mana Pools floodplain (Bernacsek 1984). Cabora Bassa Dam prevents flooding of the Lower Zambezi floodplain, resulting in drying of floodplain lakes (Bernacsek 1984). The reduction in the flooding has caused radical changes in the fish fauna of the Middle and Lower Zambezi, e.g. a dramatic decline in two commercially important cyprinid fish species (*Labeo congoro* and *L. altivelis*), due to their spawning migration routes being blocked (Lévêque 1997). New fisheries opportunities were expected to be created in the reservoir of the dam, Lake Kariba, which however turned out to be unproductive. This caused the introduction of an endemic sardine-type fish from Lake Tanganyika, which now accounts for over 80% of the commercial catch of the lake (Revenga and Kura 2003 and references therein). The reduction in flooding has also led to the modification of riparian and wetland vegetation by encouraging woody growth at the expense of grassland and, obviously, the large-scale development of lacustrine environments and benthic fauna (Timberlake 1998). Unfortunately, owing to the lack of a good series of pre-impoundment data on biodiversity and ecology, it is difficult to reliably determine the magnitude and exact cause of these changes. However, already in 1970, Attwell reported that the Kariba Dam had both directly and indirectly a great influence on the ecological deterioration of the Mana floodplains, due to the alterations in the flood regime. He mentions effects of flood releases at abnormal seasons affecting the regeneration of vegetation due to the decrease in silt-load in the alluvium caused by the dam, as well as the reproduction of many animal species, such as frogs, crocodiles, water leguaans and terrapins that breed in backwaters and small pools, and several bird species nesting on the riverbanks, where the eggs and larvae are swept away. The lack of flooding during the wet season again has severely affected especially higher lying areas where the vegetation has changed markedly, and species adapted to standing water have become more common. Some of these species, such as water ferns and water lettuce, create considerable problems due to clogging of waterways, and consequent habitat alteration for several key species (e.g. hippopotamuses and crocodiles). In general, Attwell draws attention to the requirement of diversity rather than stability in environmental conditions to maintain a healthy floodplain ecosystem.

Further downstream along the Zambezi, Bento and Beilfuss (2004) have studied the environmental flows for the sustainable development of the Zambezi Delta and the Marromeu complex Ramsar site. They found that the construction of the Cabora Bassa Dam has led to a change in the magnitude of Zambezi flows, the timing of the annual peak to the discharges, and duration of the inundation of the Zambezi Delta, all of which has led to a marked change in vegetation cover in the pre- and post-dam conditions. The area covered by typical savannah species, such as *Acacia* sp. and certain types of palms had increased by up to 24%, while typical wetland species, such as certain types of grass and shrubs adapted to seasonal inundation had declined markedly. The density and distribution of larger wildlife, such as water buffalo and antelopes, had changed clearly, with a concentration of animals on isolated patches of wetlands left, while the areas left dry after the building of the dam had been abandoned. This leads to heavy grazing pressure and probable land degradation in the limited wetland areas preserved.

A number of mitigation measures have been proposed to ameliorate the changes in the flooding regime, mainly prescribed flood releases from Cabora Bassa, opening up by means of culverts or bridges the major distributor channels coming off the main Zambezi River that feed important floodplains and swamp areas, and ensuring that the forested areas important for the maintenance of the watershed functions are not further deforested (Timberlake 2000).

5.3. AUSTRALIA

In general, wetland habitats are decreasing in Australia mainly due to modified flood regimes, floodplain isolation and increasing salinisation (Ball 2001). Australia has at least 446 large dams (>10 m crest height), most of the stored water being diverted upstream of floodplain wetlands, while 50% of floodplain wetlands on developed rivers may no longer flood (Kingsford 2000). In the State of the Environment Report for Australia (Ball 2001), the following factors have been listed as key pressures on aquatic ecosystems:

- changes in natural flow regimes due to water extraction and supply
- direct modification or destruction of important habitats
- barriers to the movement of plants and animals upstream
- effects of poor water quality
- competition from introduced and exotic animal and plant species

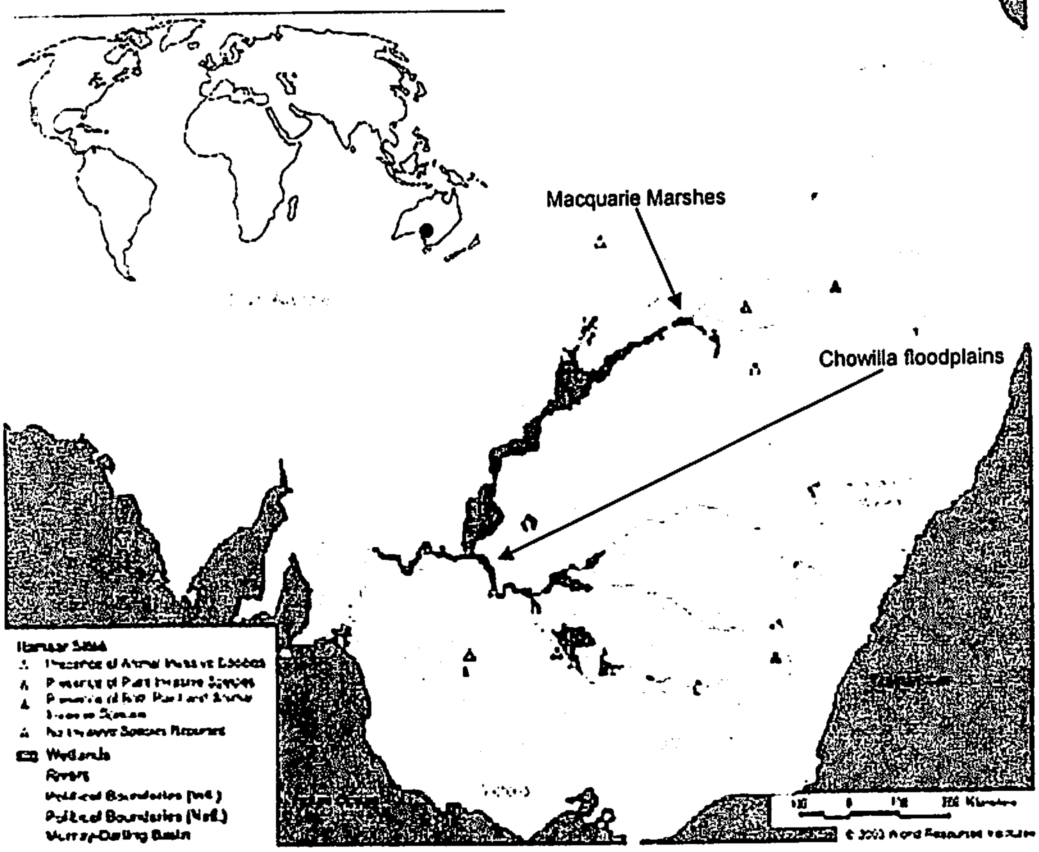

Figure 7. Map of the Murray-Darling rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: *www.iucn.org/themes/wani/eatlas/index.html*

While figures concerning the construction of major dams and water storages since 1990 are not readily available, it is clear that the growth in total water storage has declined significantly since the mid-1980s. This is partly because the most economically efficient sites for water storage have already been developed and because attitudes have changed towards major storages and their potential effects on river flows and floodplain habitats (Ball 2001). The Murray-Darling Basin in the temperate South-East of Australia is highly developed, and the most studied floodplain in Australia (Figure 7). The Murray-Darling Basin has most of its annual runoff diverted and the second highest number of dams with storage capacity exceeding mean annual runoff, as well as 87% of divertible resources extracted (Kingsford 2000). Irrigation is a major water demand sector in Australia, and has led to severe water shortages in many parts of the country. Development of the Murray-Darling Basin has resulted in 9 801 000 million l/yr of water being used for irrigation, therefore reducing flows that would have naturally inundated floodplain wetlands. Floodwaters, which used to reach the Chowilla floodplain about every 1.2 years, now reach the floodplain every 2.5 years. Moderate flooding now only occurs every three years and lasts half as long. Large floods that previously inundated the floodplain every three years and lasted for three months now occur every 10 years and last for two months (Ball 2001 and references therein). This reduction in flood frequency has had a considerable impact on native floodplain plant and animal species in the Murray-Darling Basin floodplains. In the Chowilla floodplain, populations of 18 species of snails in the Lower Murray River have declined in the last 50 years. Snails are important foods for native fish species and waterbirds and therefore their decline in population may also affect these species. Reduced flows have allowed dense littoral plants, reeds (*Phragmites australis*) and cumbungi (*Tyhpa* spp.) to become established in weir pools, displacing other naturally occurring species (Ball 2001 and references therein).

The Macquarie Marshes are located on the Lower Macquarie River, also in the Murray-Darling Basin, and represent an area of approximately 130 000-200 000 ha, part of which (18 000 ha) is listed under the Ramsar Convention. The marshes contain a number of wetland types and their important ecological features include waterbird habitat, inland reed swamps and floodplain woodlands. Since the 1960s there has been a loss of over 50% of the original marsh area, the primary cause being a 30% reduction in annual river flows since the construction of Burrendong Dam in the late 1960s. These losses correspond to a decrease over the same period of 40-50% in the area inundated by large floods and have resulted in a decline in the waterbird population. Grazing and irrigated agriculture are common activities in the wetland catchment, and some reclamation of the marshes for farming has also taken place. Prolonged inundation and alienation of floodplain areas from the river by levees and erosion of river channels have also had significant impacts. The reduction in wetland area in the marshes has had additional downstream impacts including increasing salinity and erosion. The management of the Macquarie Marshes is focused on achieving a sustainable balance between water supply for irrigation, erosion control and environmental values (Ball 2001).

Also other artificial in-stream barriers have proved to have a significant impact on native fish populations. Common built structures in Australia, apart from dams, include weirs, regulators, farm dams, floodgates, causeways, culverts, pipes, channelised streams, bridge footings, and erosion control works (Ball 2001 and references therein). Major barriers isolate fish communities, restrict passage and result in changes in fish community structures, as many native fish need to migrate up and down river systems to breed, disperse and travel to spawning grounds. Of the 55 species of native freshwater fish in New South Wales, 32 are known to be migratory and require free passage to sustain populations (Ball 2001 and references therein). In Victoria, 2438 existing barriers to fish movement and migration have been identified, while there are over 1700 barriers to fish movements in New South Wales rivers systems of the Murray-Darling Basin, with three rivers having over 300 separate barriers to fish movement. Also floodplain isolation, due to flood mitigation through the construction of e.g. levees along the riverbanks is common in most large Australian rivers.

The greatest impacts of dams and other built structures on floodplain wetlands in Australia are predicted to continue within the Murray-Darling Basin, while in the tropical areas of Australia, the impacts of built structures on floodplain environments are less well known (Kingsford 2000). Recently, a review by Douglas *et al.* (2005) examined ecological functions of wetlands and rivers of tropical Australia, which have received international and national recognition for their high ecological and cultural values. Unlike many tropical systems elsewhere in the world and their temperate Australian counterparts, they have largely unmodified flow regimes and are comparatively free from the impacts associated with intensive land use, while plans exist for high investments in new dams, weirs, channels and potential areas for irrigation on many river systems in the northeast coast basin (Kingsford 2000). Also, the growing demand for agricultural development and existing pressures, such as invasive plants and feral animals, threaten their ecological integrity. According to Douglas *et al.* (2005), there are five general principles about food webs and related ecosystem processes that both characterise the tropical rivers of northern Australia and have important implications for their management. These are: (*1*) the seasonal hydrology is a strong driver of ecosystem processes and food-web structure; (*2*) hydrological connectivity is largely intact and underpins important terrestrial–aquatic food-web subsidies; (*3*) river and wetland food webs are strongly dependent on algal production; (*4*) a few common large species have a strong influence on benthic food webs; and (*5*) omnivory is widespread and food chains are short.

5.4. Asia

Intensive seasonal flooding occurs in many parts of Asia, and despite natural flooding events being recognised as an important mechanism essential to maintain natural resources, the devastating effects of extreme floods also cause concern. Frequent flood and drought events continue to dominate the mindset of water resource managers, and engineering solutions are easily used as the tool for flood control (Gopal 2002). Non-structural approaches, such as flood forecasting and protection and restoration of floodplains, in comparison to structural approaches in general, are a good alternative to flood control through the use of large constructions (Gopal 2002) such as dams and extensive embankments, unless the construction can be justified due to other purposes (irrigation, water storage, hydropower). However, numerous large dams as well as other flood control structures have been built, their impacts being a subject of intensive debate.

5.4.1. Bangladesh

Bangladesh is one of the lowest lying countries in the world, and has historically been hard hit by flooding, while at the same time being much dependent on normal seasonal flood levels to sustain the fisheries and other natural resources that a large part of the population depends on. Bangladesh has one of the richest and largest floodplain systems in the world, floodplains constituting about 80% of the country (BCAS 2004, referring to several sources). Because of the large damage to the human population caused by floods, many flood control programs have been built to mitigate the adverse impacts of the flooding. These constructions have affected the floodplain environment and fisheries, most strikingly through the drastic reduction in floodplain area of over 2 million hectares in the past 30 years (Parveen and Faisal, 2003), which has severely impacted floodplain dependent fish species (constituting 60% of the 251 fish species found in Bangladesh).

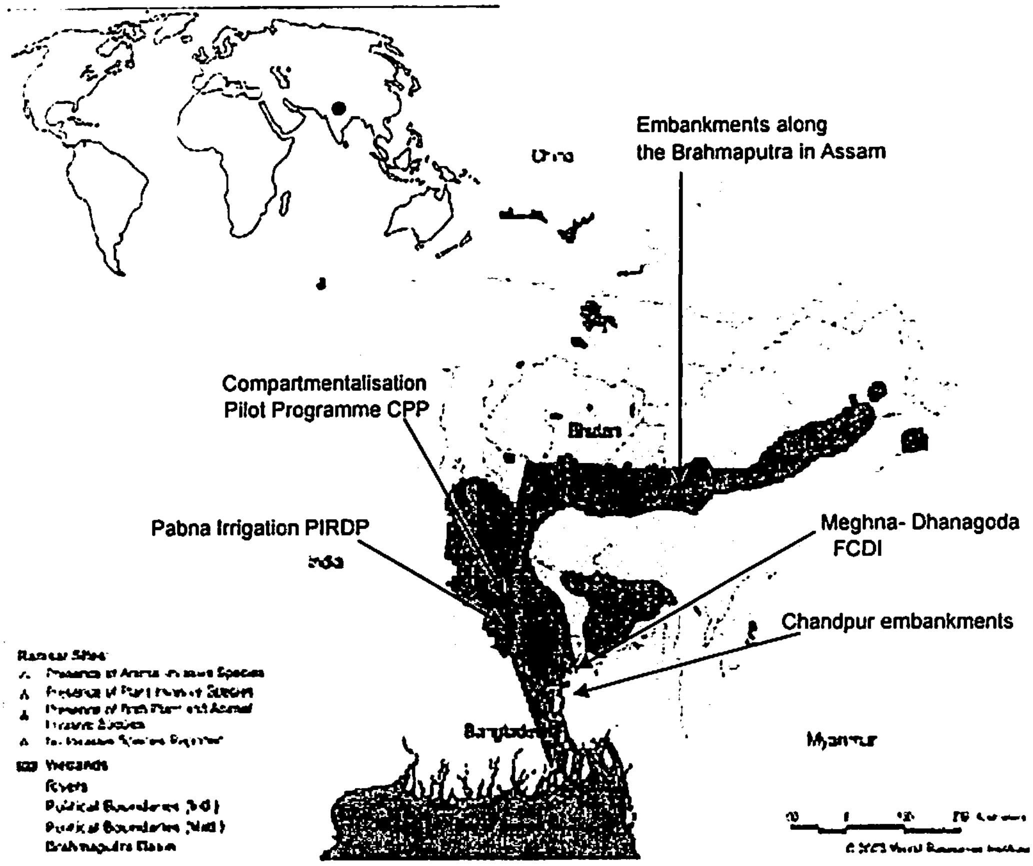

Figure 8. Map of the Brahmaputra rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: *www.iucn.org/themes/wani/eatlas/index.html*

Numerous studies carried out in Bangladesh point to decreasing inland fish catches due to water resources development projects, as well as decreasing fish diversity (BCAS 2004). The Flood Action Plan was a collaborative international study comprising 26 components since 1990, developing long-term flood control policies and an action programme for Bangladesh (Figure 8). The results of these, as well as various other studies carried out on inland fish production in relation to the flood control, drainage, irrigation and compartmentalisation projects, indicate that fish catches and fish diversity are declining in inland water bodies of Bangladesh, while production has increased in culture fisheries (BCAS 2004). In general, whenever flood control projects reduce the area of flooded land, there will be a loss of habitat for fish production and a subsequent loss in annual fish yields or catch per unit area. Flood control programmes have been found to affect reproduction and larval fish drift (de Graaf *et al.* 1999, de Graaf 2003c), block fish migration and dispersal routes (Mirza and Ericksen 1996), reduce species diversity by up to 30%, most of which belong to the more valuable white fishes (BCAS 2004). Sluice gates have proven to be fatal for many fish species, e.g. carps (white fish) of which only small numbers can get through sluice gates (BCAS 2004) and fish larvae and hatchlings, of which 25% died when passing the sluice gates (Marttin and de Graaf 2002). The authors found that there was a difference between the mode of operation of the regulating sluice gate: when operating in an undershot mode (water passing underneath the gate door) up to 44% of released hatchlings died, while only 11% died when passing the regulator when operated in overshot mode (water flowing on top of the gate door).

Mirza and Ericksen (1996) report the impacts of one of the embankment projects, the Chandpur project. The project is one of the major water resource development projects of Bangladesh, and covers an empoldered area of 56 655 ha, designed to provide flood protection, drainage and irrigation to the empoldered area. It was found that the open-water fishery in the project area has undergone great losses (83%) while the closed-water culture fish farming has benefited from the project, creating suitable stable conditions for fish culturing. However, the benefits for fish culturing opportunities have not compensated for the loss in natural open-water fisheries, and the total fish production has decreased by nearly 30% as a consequence of the Chandpur project. These developments have indirectly led to another impact: the fish consumption per capita in the area has dropped markedly (to half of the national average in 15 years) as a result of lower fish production and catches, higher population numbers and higher cost of buying farmed fish (the production of which has increased, and which is being exported out of the local area to a large extent), affecting especially the poorest people. Mirza and Ericksen (1996) note that water control projects have substantially reduced fisheries from floodplains, recommend that environmental considerations be taken into account and suggest that all new projects should collect baseline data on all fishery related issues for the benefit of future impact assessments. Annual losses of between 300 and 3000 metric tonnes of net fish production was estimated in connection with another FCDI project in the Southeast region of Bangladesh, the Meghna-Dhanagoda FCDI. The losses were mainly due to drainage and loss of floodplains and *beels* in the area, as well as the closure of internal canals inside the project (BCAS 2004).

In the Pabna Irrigation and Rural Development Project (PIRDP) site in northwestern Bangladesh, studies were carried out by Halls *et al.* (1998) concerning fish migration and movement through sluice gates in a flood control, drainage and irrigation (FCDI) scheme. It was found that *Catla catla, Channa striata* and *Wallago attu* migrated through the sluice gates, both with and against prevailing currents in different seasons, while the smaller *Anabas testudineus, Glossogobius giuris* and *Puntius sophore* did not. Species assemblages were significantly different inside and outside the FCDI schemes, with up to 25 species absent or less abundant inside compared to outside. The majority of these species were large predators or conspicuous members of the highly prized migratory 'whitefish' category, including the silurid catfish, Indian major carps, mullets and clupeids. In their absence, species inside FCDI schemes were dominated by much smaller resident 'blackfish' species. Assemblages inside FCDI schemes thus had both a reduced species richness, and a unit value reduced by up to 25%. It was concluded that FCDI schemes such as the PIRDP negatively affect fish species assemblages and stock values by reducing the accessibility of impounded floodplains to migratory fish. Though some fish are capable of penetrating existing sluice gates, management measures are required to encourage the passage of more species (Halls *et al.* 1998).

FAP 20 was a study developing a compartmentalisation approach to flood hazard mitigation. The concept includes an embanked area that would provide a comprehensive water control system to allow controlled flooding without causing damage to crops, fisheries, infrastructure or urban land. Built structures include main river embankments, existing road and railway embankments, inlet and outlet control structures and improved waterways for controlled flooding, drainage and navigation. De Graaf (2003b) summarises the results of the Compartmentalisation Pilot Project (CPP), maintaining that no difference in fish catch before and after the CPP was noted, attributable to the project not significantly altering the average flooded area. De Graaf (2003c) concludes that this type of controlled flooding is a better option than complete flood control, from a fisheries perspective.

As a summary, evidence suggests that fish production from inland capture fisheries has been in decline in Bangladesh for some time. A major reason for this decline is the flood control projects, while pesticides and industrial pollution are also mentioned (BCAS 2004) as important factors impacting the fisheries. FCDI projects have been implemented partly to increase rice production, but it has turned out that they have been of little value for rice production, whereas their effects on fisheries have been devastating (reducing indigenous floodplain fisheries by over 70%), due to built structures such as embankments, sluice gates, and culverts preventing floodwater from entering the floodplains (BCAS 2004). The results of FAP-17, designed solely to address inland fisheries issues and the impact of different types of FCDI projects on fish resources, as well as mitigation measures to prevent harmful effects, listed the following impacts of flood control on fisheries in Bangladesh (Ali and Fisher 1997):

- Loss of fish catch through loss of habitat
- Reduction in catch per unit area
- Reduced fish density/abundance
- Increased fishing effort
- Reduced biodiversity
- Reduction in the numbers of migratory fish and the number of fish migrations
- Disruption of fish community structure
- Increased capture at regulators
- Reduced opportunity for mitigation measures and
- Reduced potential for stock enhancement.

The local people were found to be highly dependent on fisheries related activities, especially the small and landless farmers in agricultural communities. The flood season was especially important for the fisheries, and it was found that reduction in flooding and floodplain area led to significant losses in income, a cheap source of animal protein and employment opportunities.

5.4.2. India

The main rivers in India, Ganges, Brahmaputra and Indus, are extensively regulated for water diversion, flood control and hydropower by a series of dams, barrages and embankments. The Indo-Gangetic floodplain is the largest wetland regime in India, but up to 70-80% of individual fresh water marshes and lakes in the Gangetic floodplains have been lost to developments after the 1950s (Ramachandra 2001). According to Mathur *et al.* (web based reference) there are over 4000 big dams in India, submerging over 37 500 km^2 and having displaced at least 42 million people in India. High population density leading to high domestic and industrial pollution, and the numerous activities in the catchments, floodplains and within the river channels have seriously decreased the quality of water. Rehabilitation of the floodplains of India to remedy the grave pollution of the rivers has been suggested by Gopal (2003).

Development of the water resources of the Brahmaputra Basin has caused concern. Fazal (web based reference) points out that the raising of embankments in India without adequate measures for the restoration of ecological balance in the catchment areas has led to increased siltation of rivers and reservoirs. In several cases riverbeds are now higher than the ground level in their vicinity. Indiscriminate use of land along the river banks has also resulted in the formation of ravines and gullies. Ravine formations are estimated to have damaged about 3.67 million hectares in Uttar Pradesh, Madhya Pradesh, Rajasthan, Gujrat, Maharashtra, Punjab, Tamil Nadu and West Bengal. Nearly 2.3 million hectares have been rendered almost useless on the banks of the Chmnbal, the Yamna, the Mahi and some other rivers. Boruah *et al.* (2000) draw attention to the importance of *beel* (deeper parts of the floodplains where water is trapped when the flood recedes) fisheries and the ecological degradation of the *beels* in the Brahmaputra River Basin in Assam. Problems have been encountered due to eutrophication caused by the construction of embankments along almost the entire length of the Brahmaputra River and many of its tributaries in the 1950s. The establishment of embankments considerably reduced the flooding and the flushing of the *beels*, and the impact has since been aggravated by human activities such as buffalo and cattle grazing, agriculture and over fishing. Boruah and Biswas (2002) summarise the impacts of the Brahmaputra embankment and dike constructions, escalating the problems caused by deforestation and subsequent erosion of the riverbanks. The embankments trap the sediment load, which is now deposited on the riverbed, making the level rise on a daily basis while the land has remained the same, except for losing the natural manure normally received during floods. Furthermore, the embankments are responsible for the shrinkage of the spawning and feeding grounds of many riverine fishes, leading to a decline in e.g. major carp species.

Kaziranga National Park in the Brahmaputra River floodplains in Assam is a small national park with important biodiversity related to the floodplain environment. Management plans for the national park draw attention to the impacts of planned developments for the area, including suggested construction of highways and expressways, harnessing of water resources for hydroelectric potential through a series of dams on Brahmaputra River (with no large dams so far, but extensive embankments constructed for flood control, Mathur *et al.* web based reference), and developments in the fields of agriculture, and oil and gas production. Main threats identified include changes in the river flow and barrier effects created by the construction of roads through or along ecological corridors connecting other areas with the floodplains (Mathur *et al.* web based reference).

5.4.3. Mekong region

The impacts of dams have been debated for a long time in the Mekong region. The Mekong has been subject to intensive dam building, the effects of which in many cases have been little studied. Despite the impacts of dams being better known now, tens of new dams are either currently under construction or planned on the Mekong and its tributaries (MacLean *et al.* 2004). According to MacLean *et al.* (2004) nearly one-third of the river's total sediment load originates in the Chinese sections of the Lancang/Mekong (Figure 9). Numerous dams in the Upper Mekong are reported to have severe impacts on downstream environments, including floodplains. These include (according to IRN 2002)

- Agriculture: Greater regulation of the flood cycle means that there will be less frequent floods, which will decrease sediment and nutrient deposition and hence reduce soil fertility. Without a massive program of artificial fertilizer use, long-term agricultural yields will decline.
- Fish and fisheries: Spawning sites may be drastically reduced in the dry season and in the rainy season lower water levels in the flooded forests of southern Laos and Cambodia will affect important fish feeding, spawning and nursery grounds. This may result in a major decline in fisheries in the Mekong Basin, including possible extinction of some species.
- Erosion: Water released from the lowest dam in the scheme will have less sediment than before and will therefore scour and erode the bed of the river downstream. This erosion could alter the Mekong's course and width, weaken supports for buildings, piers and bridges, and cause financial loss to downstream areas.

Amornsakchai *et al.* (2000) prepared a case study on the impacts of the Pak Mun Dam. The dam is built on the Mun River, 5.5 km upstream from its confluence with the Mekong, in Northeast Thailand. The dam has a maximum height of 17 m and total length of 300 m. The reservoir has a surface area of 60 square km at normal high water level of 108 meters above the mean sea level and a capacity of 225 million cubic meters. None of the EIA studies performed predicted that fisheries issues would become problematic during construction or implementation. After the completion of Pak Mun Dam, however, the Lower Mun River experienced a decline in fishing yields with an estimated value of US$1.4 million per annum at 20 Baht/kg. In the post-dam period fishing communities located upstream and downstream of the dam reported a 50-100% decline in fish catch and the disappearance of many fish species. The dam has especially affected several migrating and rapid-dependent fish species. A fish pass was built but this has apparently not been functioning as anticipated. Assessment of project impacts, like the assessment practices in past dam projects, remained focused on inundated areas and resettlement issues. The Pak Mun project happened to be the first run-of-river type dam, with no reservoir and thus impacts due to flood and resettlement were not assumed to be as serious as those of other big dam projects in the region. Thus, fisheries impacts were overlooked.

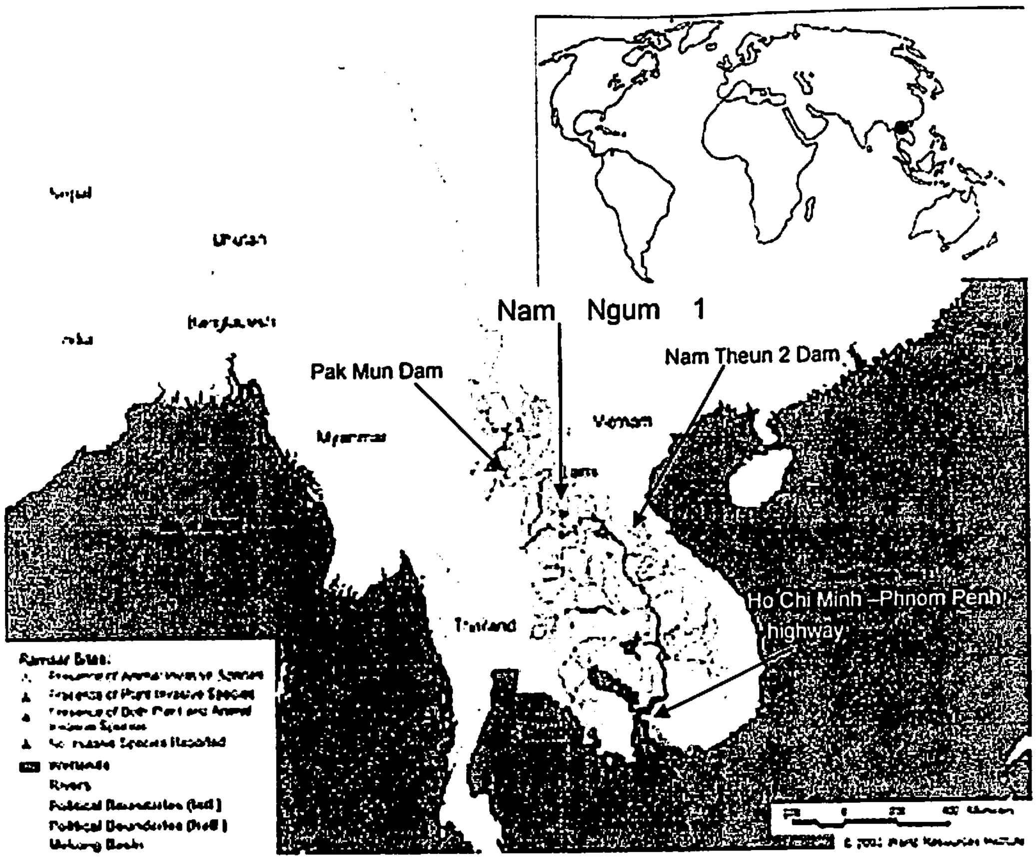

Figure 9. Map of the Mekong rivershed (grey area) showing wetlands in purple. Floodplains and built structures discussed are marked with arrows. Source of map: *www.iucn.org/themes/wani/eatlas/index.html*

In order to demonstrate the impacts of blocking the flow of the Mun River caused by the Pak Mun Dam, the local villagers requested the government to open the sluice gates for a year in order to assess the impacts on fisheries and their livelihoods from the dam. The Thai government agreed to open the dam gates on June 14, 2001 for four months to conduct studies on fisheries, social impacts and the impact of the dam on electricity supply. A participatory research project was carried out as a collaboration between Pak Mun villagers and researchers from South East Asia Rivers Network ("*Thai Baan* research"). Selected results from the report are presented below.

When the Dam was built, villagers found that only 45 out of 265 fish species indigenous to the Mun and Mekong rivers remain in the Mun river in Pak Mun area. The reservoir submerged perennial plants that typically grew in the rapids, riverbanks and islands (Don) *and allowed the invasive alien weed, giant mimosa, to thrive and dominate the riverbanks. The still water also created an environment where new types of aquatic weeds and microorganisms proliferated, such as hyacinth, "itchy snails" and the fish parasite* Mae Pla.

Villagers found that opening the dam gates for one year had dramatic impacts, bringing much of the fishery and associated ecosystem back to life. When the dam gates were opened, a large number of fish once again migrated from the Mekong to the Mun River, *laying eggs from the mouth of the river upstream to the river's tributaries. Village researchers found that 129 species of fish returned to the Mun River during the period between June 2001 to May 2002.*

The opening of the Pak Mun Dam gates restored the diversity of fish species in the Mun River. Among the native species of fish, village researchers documented that 104 species migrate from the Mekong River to the Mun River, and 25 species live and migrate within short distances within the Mun River. The migratory fish from Mekong to the Mun River include some endangered species, such as the Mekong giant catfish, or Pla Buek, Pla Dtong Grai Pla Kae Hin *and* Pla Eian Hu *or* Too Na Hoo Khao.

The opening of the dam gates has restored the fertile ecosystem near to its state before the dam was built. When sluice gates were open, the still body of water began running again, cleaning the river and sweeping away water hyacinth plants within the first month. Gradually, rapids began to reappear in the river, however, they were covered with sediment, or Aon. *After three months, the river washed away the* Aon *from the rapids. After five months, the populations of the* Mae Pla *fish parasite decreased and then disappeared. Eventually, the Mun River's fisheries, ecosystem, and vegetation returned to near to the normal state before the dam was built.*

SEARIN 2004

Riverbank vegetable gardens are a form of highly productive and important seasonal farming practised by tens of thousands of families from Yunnan down to the Mekong Delta region in Vietnam. It is an agro-ecosystem which has traditionally relied on the rich sediments carried down by the Mekong and its major tributaries, and deposited each year on the floodplain and banks to maintain soil fertility (Blake 2004). The growing of the numerous crops in riverbank vegetable gardens requires almost no fertilizers (Roberts 2001). In the northeast of Thailand large-scale dams, water extraction schemes and deforestation have radically altered the hydrology and geomorphology of the rivers draining the Khorat Plateau, resulting in mass abandonment of this sustainable farming system on a massive scale. According to Blake (2004), riverbank vegetable gardens are still relatively common in Laos and Cambodia, both along the mainstream Mekong and its many tributaries, providing vital nutrition and livelihood income to villagers and communities. Here too it is threatened by massive irrigation, flood management and hydroelectric schemes, like along the Sesan river in Northeast Cambodia and the Xe Bang Fai River, which would be impacted by the planned trans-basin diversion Nam Theun 2 Dam in central Laos (Blake 2004).

The planned Nam Theun 2 Hydropower Project is the largest infrastructure developments project in Lao Peoples Democratic Republic, including a 48 m high dam creating a reservoir covering an area of 450 km^2 in the wet season (Norplan and EcoLao 2004). A cumulative impact assessment was carried out regarding added and induced impacts. Regarding environmental impacts, the CIA pointed to possible indirect impacts regarding increased pressure on wildlife, migration of fish by the establishment of the reservoir, better protection, but also threats to biodiversity from extractive activities, hunting and general population increases, leading also to increased untreated wastewater possibly causing oxygen depletion, increased logging activities causing increased threats to biodiversity, agricultural activities causing eutrophication and higher levels of pesticides in the water (and consequently fewer fish), lowered biodiversity and fish production due to changes in flow regime, while an increase in back swamps may also increase floodplain area, reduced discharge in the flood season, negative impacts on fisheries in the Great Lake of the Tonle Sap, and positive impacts through dampening damaging flood incidents and reduced salt intrusion in the Mekong Delta.

Schouten (1998) has studied the downstream impacts of Nam Ngum 1 Dam in Laos. The dam has had positive impacts through increased fisheries in the reservoir; however, water quality downstream of the dam has deteriorated due to low levels of oxygen in the deeper layers of the stratified dam. The dam also blocks fish from upstream spawning areas and has hence impacted especially migratory fish.

A report by the Stockholm Environment Institute (SEI 2002) analyses five case studies in the Greater Mekong Sub-region dealing with various infrastructure projects (roads and dams). Out of five projects involving large-scale built structures, one had a cumulative assessment carried out (Theun-Hinboun hydropower project in Laos), while none had an economic evaluation of environmental impacts done. One of the analysed projects had no EIA process carried out whatsoever (Kinda Dam in Myanmar). The integration of social and environmental issues on a regional scale was found to be weakly carried out. The Theun-Hinboun hydropower project has been considered an environmentally friendly project due to its run-of-the-river design, absence of reservoir and hence absence of resettlement issues involved. However, the EIA process (which started too late to be able to change the design of the project) pointed to impacts on fish migration, but little consideration was given to downstream losses and potential mitigation measures to avoid these. Loss of fish biodiversity due to hydropower dams was found to be the single most important ecological issue in connection with the Theun-Hinboun hydropower project (SEI 2002), and loss in fish catch the single most important socio-economic issue. The cumulative assessment, which considered further ongoing and planned hydropower projects, indicated that these impacts would be exacerbated through further decreased flows downstream of the developments.

The SEI (2002) study also pointed to the Ho Chi Minh City – Phnom Penh highway, which in Cambodia separates the Mekong River from the Bassac Marshes, as a habitat for a diverse and abundant population of water birds. The road currently disrupts the flow of flood waters from the Mekong River to the Bassac Marshes due to the poor design of drainage structures. By improving the drainage structures, such as culverts, along this section of the road, the project will contribute to restoration of ecosystem functioning and productivity in adjacent areas (SEI 2002).

6. REVIEW OF GUIDELINES AND RECOMMENDATIONS FOR MANAGEMENT OF FLOODPLAINS

While this review did not specifically concentrate on EIA procedures in connection with the case studies, it was noted that guidelines for EIAs do not generally include instructions for how to consider specific floodplain variables and the interconnections between different environmental sectors. Therefore, few recommendations are available for how to assess the environmental impacts of a project on these integrated features of floodplain ecosystems, or how to include economic valuation of lost ecosystem services. The nature of various floodplain systems differs from river to river, and therefore the results of detailed studies done on one floodplain cannot be directly applied in another. This underscores the need for baseline information collection, even if this would be done immediately prior to project design while the site is still undisturbed. It is, however, important to make sure that the time available for data collection spans at least two years and analysis of data is given proper attention (SEI 2002). Similarly, the importance of designing and implementing environmental and social management plans and the regular monitoring of impacts and results of mitigation measures are emphasised.

Despite a general lack of guidelines with regard to floodplain environments, specific guidelines with regard to dam construction, design, and management of fisheries impacted by dams have been prepared. McCartney *et al.* (2000) and Ledec and Quintero (2003) propose a set of key indicators of likely environmental impacts of dams (see Table 1) in different situations. This should be noted as a guideline in connection with EIAs and could be developed to apply also when considering other built structures than dams.

Table 1. Indicators of likely environmental impacts in connection with the construction of dams and other impoundments (according to McCartney and references therein, 2000)

Indicator	**Comment**
Reservoir surface area	The area flooded by the reservoir is a strong proxy for many environmental and social impacts. A large reservoir area implies the loss of much natural habitat and wildlife, or the displacement of many people or both. Very large reservoirs are typically in the lowlands and often impound large rivers. Large rivers tend to be characterised by a greater range of habitats and food sources associated with greater fish diversity and a wide range of trophic adaptations.
Water retention time in reservoir	Mean water retention time (calculated as a function of reservoir volume and mean river flow) during normal operation is very useful in estimating the extent to which a reservoir will have long-term water quality problems.
Biomass flooded	The greater the amount of biomass flooded the greater the implications for reservoir water quality. Flooding native forests also harms biodiversity conservation and releases greenhouse gases (carbon-dioxide and methane) into the atmosphere.
Length of river impounded	To conserve aquatic and riparian biodiversity (including riverine forests), dam sites should minimise the length (kilometres) of river (main stem plus tributaries) impounded by the reservoir (measured during high flow periods).
Number of downstream tributaries	The greater the number of tributaries of the dam site, the better, in terms of maintaining a) accessible habitat for migratory fish, b) the natural flooding regime for river ecosystems and c) nutrients of sediment inputs needed for the high biological productivity of estuaries.
Access roads through forests	Where the risks of induced deforestation are high, project siting should minimise the kilometres of required new or upgraded access roads passing through or near natural forests.

Bernacsek (2000) specified a series of management procedures to facilitate sound management of fish biodiversity, fish stocks and fisheries in connection with all stages of dam construction (Table 2). The adoption of these procedures in the identification, design, appraisal, construction and operation phases of dams would facilitate a systematic approach to mitigation measures for fisheries management.

Table 2. Capacity and information base requirements for effective management of fish biodiversity, fish stocks and fisheries threatened or affected by dams during different phases of the project cycle, modified from Bernacsek (2000.)

Phase of project cycle	Requirements
Dam identification	Community-based or user group fisheries management systems should be put into place in the impacted area for commercial and recreational fisheries. An Initial Environmental Examination should be carried out. A data base should be assembled, providing detail on the aquatic environment, fish biodiversity, fish migration, existing fisheries upstream and downstream, likely impacts of the dams and possible mitigation measures
Dam design	Community-based fisheries management should be continued. An Environmental Impact Assessment should be carried out. The information base should be made more comprehensive. An assessment of the level of impacts on, and the risks for, fish and fisheries, and a statement with regard to the degree of suitability and acceptability or need for rejection, of the project from a fisheries point of view should be prepared. A set of mitigation measures and an environmental management plan should be prepared.
Dam project appraisal	CBM should be continued. The worth of the project should be examined. A set of questions and criteria concerning the fisheries impacts and mitigations should be satisfied before approval for dam construction is given.
Dam construction	Fisheries management activities need to be carried out which aim at preventing damage to fish biodiversity and fish stocks arising from construction activities, such as soil erosion and silt runoff, siltation of key fish habitats downstream, blast damage from explosives and blockage of fish migration. Real time data required. Management activities need to be rapidly responsive to the construction schedule. Special attention needs to be given to reservoir preparation with regard to clearing forests in a manner which will reduce problems of snagged nets and ghost fishing yet still allow sufficient surface area for periphyton growth for fish forage. Information needs focus on suspended solids, sediment transport, fish mortality, fish migration and fish biodiversity.
Dam operation	Needs for fisheries management in four impact areas must be addressed: 1) the reservoir and its affluent streams, 2) the fauna passage facilities, 3) the downstream river channel and floodplain and 4) the delta, estuary and adjacent sea. The downstream river fisheries management concerns focus on aeration of anoxic discharge water from the dam, provision of effective fish passes to allow broodstock and juveniles to migrate across the dam, reduction of turbulence in the stilling pool, and mitigation of fish losses on the floodplain. The release of artificial mini-floods and the provision of adequate dry season flow is crucial to maintaining a suitable environment for migratory fish species, especially endangered species.
Dam decommissioning	Fisheries management should focus on rapid recovery of fish stocks that have suffered impacts during dam operation. Measures should be implemented to prevent damage to fish stocks during dam demolition as well as enhancement measures, e.g. river rehabilitation, for the aquatic and related terrestrial environments. Fish biodiversity and migrations, as well as sediment loads, should be carefully monitored. CBM should be continued.

Some recommendations have been presented in the literature, based on lessons learnt in various tropical floodplains/wetlands. Lessons learnt in Senegal have shown that the combined use of modelling and thorough participatory methods involving local communities and stakeholders to explore various mitigation scenarios and options in a specific floodplain environment has led to successful results. In connection with the Waza Logone restoration project, the ecosystem approach was used extensively and throughout the project. The project provided an example of the sound practice of integrating ecosystem conservation and sustainable development, and the results from the project have been adopted by many international organisations including the World Bank and IUCN, as well as Multilateral Environmental Agreements such as the CBD.

Based on experiences from dams in Laos, Schouten (1998) recommends that feasibility and design studies for hydropower projects consider variable-level reservoir intakes that allow water to be taken continuously from the reservoir (better quality) surface water layer. Variable-level intakes avoid release of water from the (anoxic) hypolimnion and associated negative downstream effects. He also points to the importance of paying attention to downstream effects and the cumulative impacts of dams in the Mekong region. Schouten (1998) recommends hydrological and water quality monitoring and modelling, as well as fish surveys and fisheries monitoring, as a necessary baseline for hydropower development that should also lead to the formulation of mitigation measures and appropriate watershed management planning.

Lessons learnt in Australia (Douglas *et al.* 2005) have given rise to recommendations regarding management of tropical wetlands. According to these principles, one should avoid developments that would:

- Disrupt the flood pulse
- Reduce hydrological connectivity
- Impact factors influencing the production or composition of algae, such as turbidity and increased runoff of nutrients, herbicides, pesticides or metals into the water
- Disrupt the species composition and especially the occurrence of key species of the food webs.

As management options for Indian rivers and floodplains, Boruah and Biswas (2002) recommend the use of an integrated ecohydrological approach through e.g. modelling the impacts of anthropogenic activities on fish stocks (commercial and endangered species especially), emphasising mitigation measures such as control of riverbank erosion through phytoremediation, identifying the main factors impacting fish migration, and interaction between stakeholders.

The growing awareness of the cumulative negative impact on inland capture fisheries of the progression of flood control embankment and polder type projects throughout Bangladesh has led to management plans being developed (Hoggarth *et al.* 1999, Nishat 1997), suggesting e.g. the further study of the potential of closed water fisheries (resident black fish especially), as well as adapting hydraulic structures used in FCDI projects to fish-friendly models (overspill of sluice gates, fish passes, etc.) to enhance natural migration (Nishat 1997). Ali and Fisher (1997) recommend stock enhancement schemes, increased future research activities, as well as the following mitigation measures:

- Production of deep water *aman* (rice fields)
- Habitat rehabilitation and protection
- Increased fish migration across flood control structures

- Fisheries conservation: *Beel* management
- Fisheries conservation: Prohibited fishing zones at regulators
- Fisheries conservation: Protection of river fisheries
- Fisheries conservation: Establishment of fish sanctuaries
- Conversion of full flood control to partial control
- Provision of flood pathways in extensive areas protected by submersible embankments
- Increased fish migration across rural roads
- Strengthening of technical assessments and planning capabilities of concerned institutions
- Establishment of a national database on FCD/I projects
- Improvement in data collection by national monitoring agencies
- Establishment of water-user groups
- Institutional training
- Development of flood modelling techniques

Based on lessons learnt in Bangladesh (Ali and Fisher 1997, Hoggarth *et al.* 1999) especially in connection with flood protection schemes on floodplains, the following recommendations have been extracted:

- Ensure fish migration routes through structures
- Protect fisheries and habitats through protected areas/times
- Minimize loss and degradation of flooded areas
- Strengthen management institutions, and develop monitoring, forecasting and information dissemination.

Hoggarth *et al.* (1999) recommend the following management implications for floodplain river environments:

- Managers of fisheries and other resources must discuss their impacts on each other
- The impacts of floodplain modifications must be investigated and managed at both catchments and local levels
- Variability in habitats between localities necessitates local involvement in management
- Uncertainty in hydrological regimes necessitates local involvement in management
- Quantity and quality of flood water must be maintained for high fish productivity
- Diversity of floodplain habitats must be maintained for high fish biodiversity
- River channels must be maintained for fish migrations and access to spawning grounds.

Increasingly, CIAs and SEAs are called for with regard to developments involving large structures. There are few environments where a built structure will be an isolated structure impacting the environment, and the final consequences for the environment rarely add up to the simple additional value of each structure. To study the synergistic effect of many built structures, the cumulative impact, is naturally a complicated task. According to the Council on Environmental Quality regulations, cumulative effects are defined as "the impact on the environment which results from the incremental impact of the action when added to other past, present and reasonably foreseeable future actions regardless of what agency or person undertakes such other actions (40 CFR § 1508.7)" (NEPA 1997). A selection of studies including or referring to the cumulative impacts of dams has been listed on the WCD web pages (*http://www.dams.org/kbase/submissions/showsub.php?rec=ENV130*) some of which report promising approaches to the assessment of cumulative impacts in connection with e.g. impacts of dam tailings on dissolved oxygen levels downstream of dams. Modelling has been utilised in some of these studies and has shown encouraging results for assessing impacts as well as mapping potential mitigation measures.

SEI (2002) recommends that the need for Strategic Environmental Assessments be considered and developed for certain sectors, as stated in the Paris Declaration on Aid Effectiveness (OECD-DAC 2005) and recommended in the Strategic Environmental Framework for the Greater Mekong Sub-region, and a set of guidelines developed based on the results of these.

7. CONCLUSIONS AND LESSONS LEARNT

Information on floodplain ecology and functions in general is abundant, detailed studies on ecosystem functions having been conducted in the Amazon floodplains as well as the West African floodplains. However, studies concerning impacts of built structures are not as abundant, with the exception of large dams. A general conclusion is that there has been a marked increase in the awareness of the value of floodplains in past decades, as well as the impacts of constructions in these environments, but there is clearly a gap between this general awareness and the amount of research done on the type, magnitude and consequences of the impacts.

Tropical floodplains are diverse, complex and productive environments where hydrology and the flood pulse determine the seasonal succession. They support high numbers of endemic species. The high fisheries potential in these productive ecosystems is recognised in all tropical floodplains. Recently, other ecosystem services supplied by floodplains have been increasingly appreciated, with the decreasing state of remaining floodplains ones. Floodplains are now ranked amongst the highest valued landscapes in the world.

Increasing human impacts on floodplain areas, including various built structures, has led to flow modification, floodplain habitat alteration or destruction and water pollution, factors also defined as the three main causes for loss of freshwater biodiversity. A built structure rarely occurs in isolation, but rather attracts and induces developments beyond the control of the project developer, potentially causing additional impacts on the environment.

Most studies reviewed, regardless of location, emphasised the importance of the floodpulse and the protection of both lateral and longitudinal connectivity of floodplains. Isolation of the floodplain through e.g. embankments leads to a complete loss of floodplain ecosystem services.

In connection with pre- and post-valuation of tropical floodplain ecosystems, it has been shown that when a floodplain has been "reclaimed" for other uses, such as agriculture, the economic benefits gained rarely reach the same level as the ecosystem services provided by the floodplain when it was intact. Compensating for lost floodplain ecosystem services, such as recession and dry-season agriculture and natural pasture for livestock, is hard, if not impossible, to do through alternative land-uses.

Large dams have caused much discussion concerning their impacts on the environment, both upstream and downstream of the dam. However, any structure causing large-scale hydrological alteration will have many of the same impacts as dams, such as habitat fragmentation, change, deterioration and loss, as well as genetic isolation, changes in biogeochemical processes, impacts on biodiversity and pollution. The water quality changes caused by dams can strongly affect downstream floodplain environments, especially if acting in concert with other structures causing similar, or synergistic, effects. The construction of large dams or other large infrastructure usually attracts further developments, leading to higher pollution loads. The combination of the effect of the dam and the reservoir on the water quality being released downstream, and increased runoff from industry, agriculture and settlements possibly aggravated by erosion caused by these developments, can lead to severe cumulative impacts. These effects will be further exacerbated if the volume of released water is reduced.

Smaller, but numerous, built structures such as the various types of embankments, channels and dikes that are an integral part of most floodplain related livelihoods in tropical floodplains have similar, although more localised effects. The large number of this type of localised flood control construction, as well as canals, small dams and weirs built for irrigation purposes, most probably lead to significant cumulative impacts, which have not been studied to any large extent. Canalization (for e.g. improved navigation) of floodplain rivers is of concern due to the probability of cutting off the lateral connectivity to the adjacent floodplains, causing isolation and subsequent deterioration thereof. Pollution of the water caused by mines, industrial or urban structures can have long-term effects, as illustrated by the mercury pollution of Amazonian floodplains caused by mining activities.

In the Amazon floodplains built structures are still scarce, with the exception of large dams, road and gas pipe constructions. The major impacts of human activities on the *várzea* floodplain forests are classified, with decreasing destructive effects, as: 1. modification of the hydrological regime (e.g. by hydropower dams and navigation channels), 2. large-scale destruction of plant communities, 3. reduction of populations of plant and animal keystone species and 4. pollution. Decreases in fish catch and species richness, as well as significant changes in the species composition due to the disturbance of floodplains were often reported. Most of the documented cases concern very large size projects. The documentation is coloured by the strong opinions of different stakeholders and often refer to mere "enormous impacts" without specifying the type or magnitude of these said impacts. Much attention has been focussed on social impacts since these have, historically as well as presently, been significant and difficult in the case of Latin America.

In Africa less baseline information is available and much of the continent's water resources have been little studied until the last few decades of the previous century. In most parts of Africa, water availability is sufficient only in the moist equatorial belt. Therefore, water needs for irrigation, domestic and industrial uses have caused the construction of numerous reservoirs affecting the downstream flow and floodplains. Changed hydrological regimes of rivers has adversely affected floodplain agriculture, fisheries, pasture, forests and plant resources that constituted the organising element of community livelihoods and culture. Deterioration of floodplains has in many cases also had a devastating impact on wildlife, which in turn has severely impacted the important tourism industry in Africa. Drought has often exacerbated the negative impacts of built structures affecting floodplains, and much attention has thus been directed toward rehabilitation of the impacted floodplains. Therefore, most of the limited number of projects dealing with the rehabilitation of floodplains to restore former floodplain ecosystem services stem from the African continent.

Positive results in efforts to rehabilitate floodplains through managed flood releases have also been achieved in Africa (e.g. Senegal, Waza Logone and Zambezi floodplains). These rehabilitation efforts have shown that through (artificially) reintroducing floods to a former floodplain environment, it is possible to partly recover ecosystem services lost, while the complete variety of floodplain ecosystem services may be hard to restore.

In Australia five principles concerning the ecosystem processes of tropical wetlands have been recommended to improve the management of floodplains and large river systems. These include avoiding developments that would 1. disrupt the flood pulse, 2. reduce hydrological connectivity, 3. increase the input of nutrients into the water, or 4. disrupt the species composition and 5. disrupt the occurrence of key species of the food webs. Increased use of hydrological models to include connectivity to floodplains, and generally increased collaboration between scientists and management to improve the integration of river, river basin and floodplain management is also recommended.

In Asia severe floods have created much damage to human populations living in very low lying areas, such as Bangladesh, which has prompted applied research into ways of mitigating the hazards of flooding, while simultaneously preserving the beneficial functions of flooding. In this respect there is a pool of experiences from e.g. the Flood Action Plan studies. Different types of flood control structures have repeatedly been proven to impact fish, both in terms of acting as barriers for normal fish movement and migration, as well as decreasing fish diversity. To remedy this situation, a number of specific management and mitigation measures have been formulated and proposed, as well as structural approaches allowing controlled flooding (see chapter 5.4.1.). In India, extensive embankments and dikes along major river channels have caused problems with sedimentation and elevation of river channels, erosion of the riverbanks, and deterioration of the water quality in the *beels*, affecting the important *beel* fisheries.

Guidelines and recommendations for management practices in floodplain environments have been collected from the literature reviewed and presented in chapter 6. Based on these, and on the general knowledge base collected through the literature reviewed, a set of recommendations has been prepared and is presented in Chapter 8.

8. RECOMMENDATIONS FOR ENVIRONMENTAL ASSESSMENT AND MANAGEMENT OF FLOODPLAIN ENVIRONMENTS

Modification of the hydrological regime has been found the first and foremost threat to floodplain ecosystems, based on numerous experiences in tropical floodplains worldwide. Therefore, any structure affecting the all-important hydrology of a floodplain should be assumed to influence the environment, and treated with consequent caution. Most impacts are directly or indirectly combined with aspects of changing hydrological regimes, and cannot be separated from this. Any assessment must take into account impacts on integrative processes such as the flood pulse and alterations to any aspect of it, including the **magnitude, timing, amplitude, duration, modality, smoothness and rapidity of change**. In general, the loss of flooded areas and hydrological connectivity should be minimized.

Another general recommendation concerns the importance of a systematic, professional and serious EIA processes. This entails, amongst other things, accommodating **adequate baseline collection** (to be extended over at least two years) and presenting a comprehensive collection of proposed **mitigation measures** to ensure that these be taken into account in the design phase of the project, rather than later at a significantly greater expense. The incorporation of an **Environmental Management System** (EMS) is a central part of the EIA process and the resulting EMS must be adhered to throughout the project cycle, including the setting of milestones, response plans to detected changes and an evaluation of the functioning of the EMS. Also, **Strategic Environmental Assessments** should be developed for relevant sectors.

The following recommendations have been drawn from the case studies considered in this review:

1. **Indirect impacts** of large-scale construction sites may be enormous in comparison to the actual structure. Land-use change, potentially induced by project activities in the area surrounding the project site, and their impact on the environment should be considered in EIAs.
2. Small-scale canals and natural water channel modifications are possibly the most common type of built structure, and therefore lead to many **cumulative impacts**. Taking these into account in connection with new built structure assessments is of importance.
3. The main causes of freshwater aquatic **biodiversity loss** have been identified as flow modification, habitat alteration, water pollution, introduction of exotic species and over-exploitation of certain species. All these issues are, directly or indirectly, linked to built structures, and therefore EIAs relating to built structures should include a component considering biodiversity issues at as many levels of the ecosystem as possible.
4. In connection with river regulation such as dams, as well as other large structures blocking migration routes and causing fragmentation of habitats, **fish biodiversity** has decreased in most reported cases. In connection with new built structures it is therefore of importance to consider this probable impact at an early stage and prepare mitigation measures during the entire project cycle. Planning of structures should take into account the **movement of fish**, as well as securing the presence of **sanctuaries/protection** times. The design of sluice

gates and other modified passages, should take into account that for many fish an overshot mode regulator is less destructive than an undershot one, while e.g. various designs of turbines for hydropower differ with regard to mortality of passing fish.

5. Lessons learnt have shown that the destruction of floodplains affects specialized artisanal-type fisheries, often operating on a small-scale. This type of **small-scale fisheries** livelihood is very hard to replace and it is therefore of importance to **assess and value** in the course of the EIA process. The spread of invasive plant and animal species (often occurring as a result of changed hydrology or intended introductions of e.g. fish to reservoirs) can lead to surprising and dramatic losses/changes and also affect local livelihoods that depend on other ecosystem goods than fish.
6. When assessing the impact of built structures on e.g. fish catches, it is of importance to **evaluate the distribution of the catches between subsistence fisheries and professional fisheries.** In many cases, it has been shown that e.g. flood control structures have benefited groups of people that have the ability to invest in fish farming, while the opportunities for natural open water fisheries have diminished, either through changes in species composition or fish production in the affected area. Unlike land, floodwater usually belongs to all. Therefore, **the risks connected to reduced floodwater availability are significant especially for non-land owners**, the poorest section of the rural population.
7. The **value of other ecosystem goods**, such as forest and plant resources, pasture, wildlife etc. are often underestimated until these are lost with degenerating floodplain conditions. Even though fisheries are indisputably the most significant resource of the floodplains, other natural resources are of great importance in view of **diversification of food resources and livelihoods**, and often play an important part especially for the poorest people. Also e.g. the value of wetlands as natural purification filters for water is surprisingly high. **The use of integrative approaches, such as the ecosystem approach, is highly recommended in complex environments such as floodplains.**
8. **Valuation of ecosystem services** should be developed and integrated into project planning and EIA procedures. This type of valuation yields figures and a numerical measure that can be integrated into more conventional economic cost benefit analyses of the proposed investment, and allows a more thorough economic analysis of the predicted returns for different investment options.
9. Lessons learnt have demonstrated **the sensitivity of tropical floodplain** environments to **increased nutrient runoff.** Recent research has illustrated the importance of phytoplankton to tropical floodplains in Australia and South America. This has important implications for the management of floodplains. Attention should be directed to the control of water quality changes (nutrients, but also turbulence, herbicides, metals etc.) influencing phytoplankton productivity and species composition of the floodplains, which could have a profound impact on the entire food chain including the species composition of fish.
10. In connection with road construction, it is of importance to assess how to reach a **compromise between construction costs** and the need for including e.g. culverts and other **means to facilitate floodwater flows and the passage of flora and fauna.** In many cases where the needs of the ecosystem functions have not been taken into account during the planning phase of the construction, fitting of culverts has been done at a later stage (and at a significantly higher cost) to e.g. enable fish passage.

11. In connection with any built structure in floodplain areas, the effects of **increased access to the wetlands** should also be assessed. It has been shown that improved access due to lessened flooding, improved road network and consequent increased human habitation in the floodplain areas will inevitably lead to increased destruction of forest resources and habitats through increased commercial activities facilitated by road accessibility. Increased access has also had drastic effects on wildlife due to intensified poaching in areas previously less accessible. Similarly, the newly accessible areas will be subject to new agricultural activities or improved agricultural methods (including irrigation, flood control works, and other infrastructure as well as new crops or varieties), which in turn will cause changes in the hydrology and increased runoff of pesticides and herbicides.

ANNEX 1. LIST OF REFERENCES

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ANNEX 2: STRUCTURES ANALYSED IN DETAIL

Structure type is classified roughly according to size:
1 = dams and reservoirs

2= irrigation related smaller structures, weirs, regulators, dykes, levees

3= roads, railways, gaspipes, canals, flood control, polders
4= mines and other structures impacting water quality

5= fishing gear

Structure type	Size	Built	Location	Continent	Type of Impact	Main findings	Social Impact	Economic Impact	Recommendation	Time of study	Ref
1. 5 Hydropower reservoirs; Kindaruma, Kamburu, Gitaru, Masinga, Kiambere	Kamburu: Area: At upper storage level 15 km^2, cumulative surface area 40 215 km^2.	1968,75, 78, 81, 88	Kenya, Tana River	Africa	Downstream flow and physical characteristics, decreased frequency and magnitude of flooding.	Changes include reduction in area and composition of floodplain grasslands, currently much used for pasture, increasing grazing pressure. Lowering of surface and groundwater, loss of fertile riverbank sediment depositions, reduction in swamps and ox-bow lakes.	Increasing grazing pressure has lead to conflict beween pastoralist and floodplain agriculturalists over land and resource use.	The total costs of the existing dams estimated at nearly 27 mill US$, additional (proposed Mutonga Grand Falls) dam construction 19 mill US$ in flood loss related costs. Over 1 million people have been affected.	Further reservoir construction would lead to a cessation of bi-annual flooding, increasing the net cost of the dam building with 19 mill US$. Dam design options including e.g. constriction of the reservoir and dam to allow for bi-annual flood simulation would lead to a higher economic net value and rate or return.	1994	23
1. Aswan Dam	111 m high, 3600 m long, 43 million m^3, reservoir area 6000 km^2, volume 150-165 km^3.	1902	Nile River, Egypt	Africa	Change in hydrology	Prior to impoundment by the Aswan High Dam tilapia constituted 35% of the fish catch but rose to 75% afterwards, probably due to decrease in current velocity and increased macrophyte growth. Loss of floodplain habitat depresses recruitment of migratory taxa such as mormyrids, cyprinids, characoids, catfish and Nile perch. The number of fish species recorded from the lower Nile has decreased from more than 70 species to between 20 and 30.					81

1. Bakolori Dam		1970's	Nigeria	Africa	Reduction in extent, depth and duration of flooding	Reduction in the area of rice cultivation from 60 to 14% of plots in study area. Corresponding rise in amount of early millet and sorghum. Dryseason cultivation was reduced with up to 73%. Substantial decline in fishing in both dry and wet seasons.	In many villages fishing was stopped altogheter in the floodplain, and in others there was a shift to fishing in the main river channel. Five villages (24%) reported no fish catches at all, eleven reported fish to be of smaller size and twelve the absece of certain species, e.g. Nile Perch. The number of fishermen leaving the villages increased from 33% to 67% after dam closure.	Estimated loss of cropping in the Sokoto Valley in total for wet season - 0.74 and dry season - 3,06 million Naira. (Ref 18) or 7 million US$ (ref 86)	Since dam construction can have important effects on the viability of traditional floodplain livelihoods and bring considerable losses of agricultural and fishery procution downstream, effort should be put into predicting them in advance of dam construction. It is one problem to recognixe adverse enviromental and socio-economic effects, but another to get them taken into account in decision over the future of proposed porjects.		18, 86
1. Cahora Bassa Dam	Area: At upper storage level 2 665 km^2, cumulative surface area 27 675 km^2	1975	Mozambique	Africa	Elimination of flood cycles in the Zambezi River downstream of the dam	After the construction of the dam, the previous floodplains of the Marromeu have ceased nearly completely, and the complex is much drier at the end of the dry season than under natural conditions. The stagnant waterways are infested with exotic vegetation, and intrusion of saltwater. The dessiccation of the floodplain has opened the area to aggressive poaching of wildlife species and widespread frassland fires.					39

1. Construction of dams in northern Cameroon; also Sahelian drought		In past 30 years (1970 onward)	Lake Chad Basin, Nigeria	Africa	Reduction of riverine discharge and floodplain; major reduction in size of Lake Chad, but creation of fringing floodplain; change in species diversity; change in fish migrations & distribution; catch rates stable; increased demand/ prices from nonlocal markets;	The impact of environmental change has been widely characterized in the literature as a drastic decline of the fishery. In this study it is hypothesised that while the nature of the fishery has changed, the total economic value may have remained relatively stable.		No change			44
1. Construction of dams on headwaters; (ii) smaller irrigation dams elsewhere; (iii) Sahel drought (70s/80s)		In past 30 years (1970 onward)	Nguru-Gashua Wetlands, Nigeria	Africa	Reduction of riverine discharge and floodplain; reduction of fish stock size abundance and diversity; falling catch rates; increased regional demand and prices.	The study assumes that the relatively low reduction in economic value of the fishery (11%), in the face of drastic reduction in the aquatic environment, is only a temporary phase. It is anticipated that the fishery in the Nguru-Gashua Wetlands will not be able to sustain the present level of activity, and that it will become overexploited (biologically and economically) in the near future. The situation will be exacerbated by the inability of local authorities to manage water releases from the major headwater dams.		Estimated change in value of fishery -11%			44

1. Construction of Lagdo and Gongola River dam; also Sahelian drought		In past 30 years (1970 onward)	Upper River Benua, Nigeria	Africa	Reduction of riverine discharge, size of annual flood, less inundation of floodplains, reduction of fish biodiversity and stock size; falling catch rates; prices stable; stable local demand	The reduction in the size of the River Benue and its floodplain over 20 years since the construction of the Lagdo Dam upstream in Cameroon, coupled with low and only local demand for the available fish, has produced a fishery of low value to the local economy overall.		Estimated change in value of fishery -96%			44
1. Dam and irrigation constructions in Nigeria		In past 30 years (1970 onward)	Nigeria	Africa	Altered hydrological patterns and drying up of floodplains	Fisheries have been impacted by environmental change, mainly as a result of natural (e.g. Sahel drought) and manmade (e.g. dam construction) disturbance. The impact of change has in all cases led to a reduction in the aquatic environment – rivers and floodplains have been reduced in size. Lake Chad has shrunk and been replaced by a large swamp – and by and large, as a consequence, fish stocks have been reduced in size, diversity and distribution.					44
1. Dam construction for large-scale irrigation			Hadejia Jama-are River basin, Nigeria	Africa	Losses of benefits from intact floodplain system	Agricultural, fishing and fuelwood benefits lost through reduced flooding downstream against the gains from increased irrigation production upstream.		Irrigation benefits can only partially replace the lost benefits from reduced floodplain inundation	Regulated flood releases is the best hope of minimizing further losses of floodplain benefits. Further expansion of large-scale irrigation within the river basin should also be avoided.		24

1. Dam, Brokopondo Reservoir	1500 km^2 reservoir area	1964	Surinam	America	During dam building, vegetation was not cleared which led to deoxygenation of water, affecting the levels of oxygen 110 km downstream of the dam, causing massive fish kills	In tropical areas it may take many decades of even centuries for the organic matter to decay within impounded reservoirs due to the high amount of plant biomass (while in temperate areas this may take just one decade).			Clearing of vegetation in reservoir site in of importance in tropical areas.	1964-1970	76
1. Dams			Sokoto and Rima floodplains, Niger	Africa	Decrease in floodplain area from 100 000 ha in 1960 to 50 000 ha in 2020	Expected loss of production in fish, pasture and acgriculture 50%					72
1. Dams			Hadejia Komadugu, Nigeria	Africa	Decrease in floodplain area from 380 000 ha in 1960 to 38 000 ha in 2020	Expected loss of production in fish, pasture and acgriculture 90%					72
1. Kainji Dam		1968	Niger River	Africa	The flooding of the "fadamas" on either side of the Niger River has been reduced since the construction of the dam.	The fadamas are no longer suitable for fry-season cultivation because soil moisture is insufficient. 50-70% of the surface area of each fadama has been lost for agriculture. Natural soil fertilisation has been significantly reduced, leading to a 20% drop in the rice yields.					86
1. Kainji Dam		1968	Niger River	Africa	Decrease in fish catches after filling of dam	Fish catches from the system were reduced by 30%, and the commercially important Mormyridae were reduced from about 20% of the catch to around 5%.				1970s	107

1. Kainji, Bakolori and Tiga Dams	Kainji Dam: Area: At upper storage level 1 260 km^2, cumulative surface area 32 035 km^2.	1968	Niger River	Africa	Altered flow regime, stabilistation of flow in downstream area of dams, eliminating much of the seasonal inundation of the floodplains.	Fish catches declined to between 39 and 75% of their original values. Changes occurred in species composition, decline of swamp dwelling and herbivorous fish and increase in predators, finally reducing stock as a whole since not sustainable. (4) Productive pools and swamps, previously flooded in the downstream area, became dry (73). Dramatic change in species composition (78).					4, 73, 78
1. Kariba Dam	Area: At upper storage level 5550 km^2, cumulative surface area 20 670 km^2	1958	Zimbabwe/Zambia	Africa	Reduced flood magnitude of the Zambezi River by an average of 24 percent in eight out of ten years (1970–80 period)						
1. Kariba dam	Area: At upper storage level 5550 km^2, cumulative surface area 20 670 km^2	1958	Zimbabwe/Zambia	Africa	flooding of preferred habitat	Labea congoro and Labeo altivelis were important commercial fihses in the Zambezi and abundant in the Kariba area before the closure of the dam. They used to have well marked annual spawning migrations up the tributary rivers. The decline in the Labea stocks after closure of the dam was expected.				1958-1967	73
1. Kariba dam and Cabora Bassa dam	At upper storage level 5550 km^2, cumulative surface area 20 670 km^2 Cahora Bassa: At upper storage level 2	1958 and 1974	Zimbabwe/ Mozambique	Africa	Changes in hydrology	"The effects of human activities on wetland and aquatic biodiversity across the Zambezi Basin are still rather speculative when it comes to detailed assessments. The major reason for this is the shamefully inadequate or non- existent baseline data on species composition and abundance; thus an assessment of change deriving from a major			(a) prescribed flood release from Cabora Bassa, (b) opening up by means of culverts or bridges the major channels coming off the main Zambezi River that feed the swamp areas, and (c) ensuring that the forested Cheringoma Plateau which is an		48

	665 km^2, cumulative surface area 27 675 km^2					development, such as a dam, is not possible."			important source of runoff for the southwestern parts of the delta wetlands is not deforested.		
1. Maga dam including 28 km of embankments creating a reservoir and 80 km of dykes along the Logone River to control the flooding of adjoining floodplains to allow rice cultivation and irrigation		1979	Logone River, Cameroon	Africa	These schemes seriously modified the floodplain regime leading to an acceleration of the degradation of the environment caused by drought. These modifications are also thought to have eliminated the flooding of some 59,000 ha of floodplain and seriously reduced another 150,000 ha which were important breeding and nursery areas for fishes.	IUCN Waza Logone restauration project started in 1993. The economic impact of pilot flood releases in 1994 and 1997 was an added value of over 800000$ a year through restoring floodplain goods and services. Relating these changes to further recovery of floodplain ecology and biolgogy showed an incremental economic benefit of between 1,1 million and 23 million US$.		Total catch reduction would be an estimated 6,700 t/yr, total direct lost of 120 US$ million over the 21 years during which the flooding pattern has been significantly affected (1979-2000) (ref 44). Economic costs of flood loss in the Waza Logone regione estimated as 1.31 mill US$/year in pasture losses, 0,47 mill US$/year in fisheries losses, 0,32 mill US$/year in agricluture losses, 0,29 mill US$/year in grass losses and 0,02 mill US$/year in surface supply losses (ref 71)			44. 71

1. Manantali and Diama dams			Senegal valley floodplains, Senegal	Africa	Decrease in floodplain area from 550 000 ha in 1960 to 55 000 ha in 2020	Expected loss of production in fish, pasture and acgriculture 90%. Filling of the reservoir behind the Manantali Dam has reduced the volume and duration of the annual floods, which in turn has diminished the inundation of the flood plain and resulted in weakened ecosystems depending on prolonged seasonal submersion, a reduced area suitable for flood-recession cropping and curtailed groundwater recharge. Diama Dam has been invaded by dense growth of aquatic plants which hamper fishing efforts and access to the water. Reference 107: There was a net loss of 11250 tons (representing approximately 50%) of fish from the system due to intrusion of salt waters and changes in hydrological regime.	The increase in aquatic plant species offer habitat for vectors of water-borne diseases. An explosion of mosquito and snail populations has brought malaria and bilharzial to epidemic proportions.				72, 74, 107
1. Pak Mun Dam	Max height 17 m, total length 300 m.	post 1981	Mekong River, Laos	Asia	Number of fish species declined from 121 fish species in 1967 to 66 species in 1981 and 31 in 1990.	EIA done in 1981 predicted that fish production from the reservoir would increase considerably, while the opposite has happened.	Livelihoods of fish dependent households affected. The number of households dependent on fisheries in the upstream regions declined from 95,6% to 66.7% , but no alternative viable means of livelihood has been identified, requiring financial compensation by the government.	Decline in fishing yields downstream estimated to USD 1,4 million per annum. Upstream losses due to cloosure of Tum Pla Yon traps estimad USD 212000 per annum.		2005	119

1. Reservoirs in the Amazon			Amazon floodplains	America	Migratory patterns of fish	Building of reservoir affected species differently: some seem to be negatively affected by habitat change, while others respons positively. However, a common trend is the decrease in species diversity and abundance of frugivorous species. The impact on the fish community in Tucurui was more severe for migratory species. Five years later the fisheries situation had improved and catches had increased to pre-filling levels, but downriver the fisheries did not show the same recovery probably due to recruitment failure in the absence of floodplain habitat.					40 and refe ren ces ther ein
1. Selenge and Markala Dams, Niver River	Selenge Dam: Area: At upper storage level 409 km^2, cumulativ e surface area 34 900 km^2.	1943 and 1980	Niger River, Mali	Africa	Decrease in highwater level, decrease in flow and duration of flooding, leading to a decrease in recruitment and fish catches	Loss in catches between 1600 to 4000 tons annually due to Markala, 5000 tons (10% of fished volume) since Selenge was built. However, only 2000 tons can be attributed to the dam, while 3000 ton losses are due to drought.	Fishermen have had to pursue complementary livelihood activities such as agriculture, and part of the family may have moved to other parts of Mali or to other countries				25
1. Several dams on the Niger and tributaries			Niger valley floodplains, Niger	Africa	Decrease in floodplain area from 300 000 ha in 1960 to 150 000 ha in 2020	Expected loss of production in fish, pasture and acgriculture 50%					72

1. Tucurui Dam			Brazil	America	Decrease in fish bidoversity in the reservoir, upstream and downstream of the dam	Fish diversity decreased between 30-50 species following impoundment. 11 species have dissappeared in total. Piscivorous species have increased instead of detrivorous species in the reservoir and to a lesser extent upstream of the reservoir.					11
1. Tucurui Dam			Brazil	America	Changes in fish catches	Increase in fish catch in reservoir (from 400 to 3200 tons annually) and upstream (from 400 to 1000 tons) of dam, decrease downstream (wih half, from 1000 to 500 tons annually)					11
1. Tucurui Dam		1984	Brazil	America	Blockage of fish migration, creation of anoxic environments due to decaying vegetation left in the reservoir.	Because of decomposing vegetation in the impoundment, both from remains of the forest left uncut when the lake was filled and from aquatic weeds that proliferated on the surface, the water become acid and anoxic, which rendered the water unsuitable for many fish species.The diversity of fish species declined drastically, with the communities becoming dominated by a few species. While primary consumers had been most abundant, the population of predators exploded immediately after closing: in the first					41 and references therein

						year piranhas (Serrasalmus spp.) made up 40%– 70% of fish caught. The dominance of predators was maintained during the three first years, although some primary and secondary consumers were able to make a partial recovery. The biomass of fish present fluctuated strongly in the first three years: by January 1986 fish biomass had increased to a level above that present prior to closing, followed by a crash in the third year. This is probably due to the predatory fish that made up much of the biomass starving for lack of prey.					
1.Dams			Logone floodplains, Cameroon		Decrease in floodplain area from 1 100 000 ha in 1960 to 660 000 ha in 2020	Expected loss of production in fish, pasture and acgriculture 60%					72
2. Dikes		?	Pantanal, Brazil	America	Attempts to enclose areas of the Pantanal in the Camargo de Correia Island with dikes led to a prolonged moisutre period within the dikes (rather than keeping the water out as expected).	Growth of woody weeds made the area unusable for cattle ranching.			"Floodplain-friendly" philosophies recommended: utilising the unique adaptations and life strategies of organisms originating from floodplain environments.		22

2. Flood control, drainage and irrigation schemes (FCDI)			Bangladesh	Asia	Control of water levels, avoiding rapid inundation and preventing extreme flood events	Benefits to agricultural sector can be significant, while fish production and species richness is lowered by the structures. Fish yields inside a flood control compartment can be 50% lower compared to outside, with up to 25 species of fish absent or less abundant. Biodiversity, measured in fish species richness, was 6-35% lower inside than outside of fully functional FCDI schemes. Lower rates of recruitment of migratory whitefish species whose lateral migrations are obstructed by the embankments is largely responsible for these changes.		Unit value of fish catches inside FCDI schemes dropped with 25% due to changes in stock species composition from white fish dominated to smaller, black fish dominated.	Mitigation measures for the combined impacts of FCDI and incrasing dry season irrigation on fish procuction and biodiversity suggested : 1) improving passage of migratory species, 2) improving production of resident fish species based upon improved sluice gate management and alternative cropping strategies.	1996 onward	27, 28, 32
2. Floodplain levees			River Murray, Australia	Australia	Reduced floodplain connection and area of floodplain inundated				An audit should be undertaken of all floodplain levees and other structures (block banks, roads) that alter the natural movement of water across the floodplain. Unnecessary and illegal levees should be removed as a matter of priority.	2002	31
2. Regulator		1992-1998?	Lohajang River, Bangladesh	Asia	Mortality of hatchlings	Hatchling densities highest in surface layer and near the embankment. Spawning of major carp during first 8-10 weeks of the flood. 44% of fish larvae passing a regulator operated in undershoot mode die within 2 hours, while only 11.8% die if passing in overshot mode.			Fish gates should be overflow and close to shore. Fish passes should be open during spawning time.	1992-1998	1,2, 3

2. Several, including rice irrigation scheme, establishment of embankments and the Maga Dam	30 km long dam, 400 km^2 reservoir (Maga Lake), as well as extensive embankm ents along the Logone River	1979 onwar ds	Waza Logone, Cameroon	Africa	Inundated area reduced by almost 30%	Reduction in crop agriculture (floating rice and sorghum, flood recession sorghum. Loss of fisheries, including an esitmated 90% decline in fish yields. Reduction of capacity of the floodplains to provide nursery for fish stocks in the river systems of Logone and Chari. Decrease in dry-season pasture by sedentary farmers and nomadic pastoralist from northern Cameroon as well as neighbouring countires. Loss of plant resources used for construction, beekeeping, handicraft production, woodfuel, wild foods and medicines. Decrease in wildlife populations impacting tourism and subsistence hunting. Reduction in surface water availablitity.	Many families have left the villages to settle in other areas where this influx of immigrants has lead to the over-ecploitation of resources. (Ref 86)	Original value contributed by the flooding (area 3383 ha) was over 19 mill US$, or 3000/km2 flooded area. Economic costs of flood loss of 30% was estimated at -2,4 million US$ per year, including losses in pasture (1.31), fisheries (0,47), agriculture (0,32), grass (9.29) and water supply (0,02). According to ref 86, the watering of wildlife of the Waza National Park amounted to 1.8 million US$ in 1983, fish catches in the surroundings of the park have fallen to less that 10% of former values, the loss of 900 km2 floodplain pasture represents a loss of 2,5 mill US$, and increased migrations by	Flood re-release was recommended and carried out in two pilot releases in 1994 and 1997, resulting in an annual increase in the flooded area of 200 km2 and led to recovery in the number o wildlife, increase in fish production, improvment and extension of pasture and changed agricultural opportunities.	2001	19, 86

								elephants due to vegetational changes has lead to major damages caused by the elephants to hundreds of hectares of agricultural land, amounting up to 850 US$ per farmer.			
2. sluice gates or pumps positioned along earth embankments or levees			Bangladesh	Asia	Dnnual inundation of approximately 2–3 million ha of floodplain in Bangladesh has been either prevented altogether, or controlled.	The reduction in floodplain area is one of the reasons for declining floodplain fisheries in Bangladesh but over-exploitation of inland fish stocks has also been reported					37
2. Small dams for irrigation		betwe en ` 1965 and 1997	Khammoua ne, Savannakh et and Champassa k provinces, Laos	Asia	Reduced water flow in wet season, increased dry season flows	Significant reduction in riverien habitat area, increased lacustrine and dry-season rice-field areas. Redistribution of catch and fishing effort from riverine to reservoir fisheries. No significant impact on species richness or relative abundance of functional feeding groups. Synthesis: Small to medium scale irrigation schemes in rain-fed rice-farming landscapes have only moderate impacts in fisheries. Changes in agrucultural practices in the wet season are likely to have greater effects on fisheries than dry-season irrigation.				1999-2001	53

2. Weirs			Murray Darling River, Australia	Australia	Mortality of fish larvae	The percentage of fish larvae dying while passing the weir was significantly higher in the undershot weir than in overshot. Both species were affected but golden perch had greater mortality rate while passing.			Based on this and other studies on the impact of different types of weirs it seems that overshot weirs have less damaging effects on fish larvae and hatchlings, compared to undershot weirs creating much turbulence and water velocities.	2004-2005	26
2. Weirs			River Murray, Australia	Australia	Unseasonal flooding, wetlands permanently drowned by weir-pools				In cases where it is not possible in the short to medium term to modify weir heights or flow regime, consideration should be given to installing regulators on important wetlands and operating these structures to mimic natural wetting and drying regimes.	2002	31
2. Weirs for irrigation	Irrigated land area average 155 ha, associated paddy area average 93 ha	between 1965 and 1997	Khammouane, Savannakhet and Champassak provinces, Laos	Asia	Diversion of water flow	Weir schemes had no significant impact on aquatic habitat, but caused significant decline (-36%) in fish catches that was partly explained by fishing effort. Weirs had no effect on species richness, but were associated with a significant increase (+17%) in the relative abundance of omnivores. Synthesis: Small to medium scale irrigation schemes in rain-fed rice-farming landscapes have only moderate impacts in fisheries. Changes in agricultural practices				1999-2001	53

						in the wet season are likely to have greater effects on fisheries than dry-season irrigation.					
3. Constructed canals to bypass the convoluted river channels to facilitate navigation			Barotse floodplain, Zambia	Africa	Vegetation changes, increase of throughflow of flood water reducing the extent of flooding	Reduced flooding significantly reduces breeding grounds for fish, since these are located in the shallowest areas.					14
3. Cuiaba-Porto Velho Highway		1970s	Rondonia, Brazil	America	Increased turbidity, milky color of water	Turbidity was mainly caused by erosion from agricultural activity along the new highway and its feeder roads in the watershed.					6
3. Dredging and excavation of river channel		?	Boro River, Okavango Delta, Botswana	Africa	Increased surface outflow to meet human needs	The dredgning led to significant encroachment of terrestrial plant species onto the floodplain					22
3. Empolderments for water control programs to mitigate flood hazard		after 1980	Chalan Beel Polder D project, NW Bangladesh	Asia	not known	Open water fisheries dropped in the project area from a pre-project 3300 tonnes/year (1980) to a post-project 786 tonnes/year (1992) (-76% in 12 years).				1992	54 and references therein
3. Empolderments for water control programs to provide flood protection, drainage and irrigation	Empoldered area 56655 ha, embankments for 30,4 km in north-south direction and 25,6 km across.	1978	Chandpur Irrigation Project between Meghna and Dakatia tivers	Asia	Restriction of floodplains, modification of timing and amplitude of flooding. Inhibits movement and migration of fish and prawns. Limits the availability of the floodplain area for grazing, feeding and growth of juveniles of riverine and	Production of floodplain fish was substantially reduced. Prawn species were affected variously, some benefiting form the regulated freshwater environment inside the project, others failed to disperse from inside of project area to outside through the regulator, possibly due to greater velocity of water during the period of operation. Some species received little adverse	Fish consumption has decreased from 36 g/person/day pre-project (1972) to 19g/person/day post-project (1992), and the increase in exported fish from closed water culturing has decreased the intake per capita even more. Especially the			1991	54

					estuarine breeding fish, reduction of the size and quantity of stocks. Destruction of riverine character inside embankments, restricting the passage of fry, juveniles and adults of migratory species. Blocked connection and passge to the Dakatia River.	effects while some riverine species have almost disappeared inside the project area. Also the sex rations of some prawn species have been affected with the ratio of male to female increased. Tidal and estuarine fish have been seriously impacted by blockage of migratory routes. Coastal plain species are favoured by the stable freshwater environment inside the project area. Carp species have decreased inside the project area and the number of carp fingerlings has decreased and become extremely rare in the Dakatia River. *Hilsa ilisha* was found to be able to migrate into the project area through the regulator during the early monsoon season. Closed water fisheries have been impacted favorably by the project, significantly decreasing the number of exodus of fish during high water. 9 out of 47 resident shallow water fish species were beneficially affected while the rest showed no effect. 9 out of 38 jag fish species were benefited. Open water fisheries experienced a net loss in the project area 5343 tonnes/year (-83%).	poorest people in the area have suffered from the decreased open-water fish population and fish catch. Access to flooded lands have been lost due to shrinkage of the floodplains, and much of the open waters have been leased by the government to influential fish farmers. The price of the fish has gone up and cannot be afforded by the poorer people. Decrease in number of fishers was also shown over a 13-year period after the constructions. Catch per fisher within and outside the project areas was 2.55 kg/day and 4,8 kg per day, respectively.				
3. Gas pipeline		2002-2003	Peru	America	Environmental	The construction of			Environmental		15

(720 km) from Amazon to Lima					degradation of pristine, high-biodiversity Amazon jungle area; resettlement and destruction of food and water supplies of indigenous peoples (some voluntarily isolated)	the gas pipe through very remote areas of the Amazon rainforest, including floodplains, has had severe impacts on local people and their livelihoods. The main problem has been the erosion that the clearing of vegetation has had, which has in turn polluted the water and decreased fishing possibilities.			impact mitigation measures are recommended.		
3. Hidrovia, canalization of the Paraguay River		Planned, but now officially cancelled by the Brazilian government but private companies continue building infrastructure for implementation of the hidrovia (Junk 2002)	Pantanal, Brazil	America	Building of the canal will require cutting off natural meanders, deepening of the river channel, buildings to be constructed along the shores and rocky outcrops to be removed.	Changes in the hydrology will be irreversible. Lowering of the river channel depth by 10 or 25 cm could reduce the flooded area by 12 or 32%. In Northern Pantanal there are areas of high fish species diversity which would be affected by this and 40-60% of the species could be eliminated.			Natural capital of the Pantanal should be weighed against the economic benefits derived from the hidrovia construction. The predicted modifications of the flooding regime caused by the construction would not fit within the concept of sustainable development		22
3. Polders protecting rice cultivation through flood control			Bangladesh	Asia	Control of water levels	Catch per unit area was 65-104% higher outside flood control area than inside			Integrated floodplain management options to be introduced to benefit both farmers and fishermen		29
4. Gold mining structures		Late 1970s	Amazon floodplains	America	Mercury pollution of water						9
No Structure, DROUGHT			Niger	Africa	Decrease in inundated surface of floodplain, lost water volumes	Landings of fish show a decrease in production from 87000 metric tons in 1969-79 to 37000 metric tons in 1984-85. Mostly caused by a natural drought, while increased fishing effort did not have an effect on the total of the catches.	Decline in individual catches from 1900kg in 1966 to 740 kg per year in 1989.			1989	62

No Structure, DROUGHT			Sahel	Africa	Pluriannual drought in 1980' affected the fisheries in the central delta of the Niger river	Fish catches declined from 90 000 t yr-1 to 45 000 t yr-1 because of poor rainfall					23

ANNEX 3: QUESTIONNAIRE AND SUMMARY OF REPLIES RECEIVED.

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2. Details

1. Name, contact details (email preferred) and position	
View Total Respondents	23
(skipped this question)	1

3. Geographic

2. Which floodplain areas are you working or living in/familiar with?	
View Total Respondents	19
(skipped this question)	5

3. In which country (countries) is the floodplain situated?			
		Response Percent	Response Total

Australia		19%	4
Bangladesh		14.3%	3
Bolivia		0%	0
Botswana		4.8%	1
Brazil		28.6%	6
Cambodia		14.3%	3
Cameroon		0%	0
China (PRC)		0%	0
Dem. Rep. Congo		0%	0
India		9.5%	2
Laos		4.8%	1
Mali		0%	0
Mozambique		0%	0
Nigeria		0%	0
Peru		0%	0
Thailand		4.8%	1
Vietnam		9.5%	2
Zambia		4.8%	1
View Other Country		28.6%	6
		Total Respondents	**21**
		(skipped this question)	**3**

4. Description of floodplain

4. Which of the below illustrates the floodplain environment you are describing? Tick off as many as are appropriate.

	Response Percent	Response Total
Seasonal flooding	68.4%	13
Monomodal flooding (one time per year)	36.8%	7
Non-Seasonal, unpredictable flooding	5.3%	1
Flush floods of high amplitude	10.5%	2
Large river floodplains with slow, ample and predictable floods	52.6%	10
Várzea	31.6%	6
Igapó	36.8%	7
Flooded forest	52.6%	10
Flooded shrubland	26.3%	5
Flooded savannah (grassland)	15.8%	3
View Other (please specify)	21.1%	4
	Total Respondents	19
	(skipped this question)	5

5. What are the most significant goods and services provided by the floodplain?						
	Very significant	Significant	Not very significant	Not significant at all	N/A	Response Average
natural resources in general	47% (7)	53% (8)	0% (0)	0% (0)	0% (0)	1.53
fish	78% (14)	22% (4)	0% (0)	0% (0)	0% (0)	1.22
wild vegetables	7% (1)	20% (3)	40% (6)	27% (4)	7% (1)	2.93
fruit	13% (2)	13% (2)	53% (8)	20% (3)	0% (0)	2.80
game	0% (0)	15% (2)	31% (4)	46% (6)	8% (1)	3.33
rubber	0% (0)	0% (0)	15% (2)	54% (7)	31% (4)	3.78
wood	19% (3)	31% (5)	19% (3)	25% (4)	6% (1)	2.53
medicinal plants	0% (0)	23% (3)	23% (3)	31% (4)	23% (3)	3.10
Other ecosystem services such as	17% (1)	50% (3)	33% (2)	0% (0)	0% (0)	2.17
nutrients and fertile soils for agriculture	40% (6)	47% (7)	7% (1)	7% (1)	0% (0)	1.80
food for domestic animals	13% (2)	47% (7)	13% (2)	20% (3)	7% (1)	2.43
food for wild animals	7% (1)	43% (6)	29% (4)	14% (2)	7% (1)	2.54
transportation/navigation	25% (4)	31% (5)	19% (3)	25% (4)	0% (0)	2.44
recreational and aesthetic value	20% (3)	40% (6)	40% (6)	0% (0)	0% (0)	2.20
ecotourism potential	29% (4)	50% (7)	21% (3)	0% (0)	0% (0)	1.93
flood control	21% (3)	57% (8)	14% (2)	7% (1)	0% (0)	2.07
groundwater replenishment	15% (2)	54% (7)	15% (2)	0% (0)	15% (2)	2.00
					Total Respondents	19
					(skipped this question)	5

5. Built Structures

6. Have any structures been built in the floodplains? Which ones and when, and for what purpose?	
View Total Respondents	15
(skipped this question)	9

7. Has an Environmental and/or Social Impact Assessment been done before building? If so, do you think it has adequately addressed the potential or actual effects of the built structures on fisheries and floodplain ecosystems? If not, why? What improvement(s) would you suggest?	
View Total Respondents	14
(skipped this question)	10

8. Have you recorded or heard of any positive or negative impacts of these structures that have affected the

	Response Percent	Response Total
environment (e.g. flow of water, changes in water quality, silting or turbidity, changes in animal and plant species occurring)	91.7%	11
fish (species, numbers or areas of occurrence) and the fisheries (number or composition of catch, fishing areas) in the floodplain area	100%	12
livelihoods of local people in the floodplain area	83.3%	10
socio-economy of the area	58.3%	7
management of the fisheries	66.7%	8
View Other (please specify)	16.7%	2
Total Respondents	[redacted]	
(skipped this question)		

9. Please describe and, if possible, quantify the impact(s).	
View Total Respondents	11
(skipped this question)	13

10. Can you recommend a way or alternatives for the built structure mentioned, that would have less environmental or social impacts, but would still serve its purpose considering the special challenges of a floodplain environment? Please describe here. You can also point to documents recording these impacts, and recommendations, here.	
View Total Respondents	11
(skipped this question)	13

ANNEX 4 PERSONS CONTACTED FOR INFORMATION ON FLOODPLAIN RESEARCH

	Name	Date	Study area	Affiliation	Reply	Notes	Questionnaire link sent
1	Gertjan De Graaf	26.4	Bangladesh	Nefisco			X
2	Felix Marttin	26.4	Bangladesh	FAO	X	Sent articles	X
3	Professor Shinji Tsukawaki	2.5	Cambodia	Uni Kanazawa	X	Sent articles	X
4	Dr Klement Tockner	2.5	Global	EAWAG/ETH	X	Sent articles	X
5	Professor Robin Clarke	2.5	Brazil	Uni Rio Grande do sul, Brazil	X	Sent articles	X
6	Terry Boyle	2.5	Brazil (Plata basin)				X
7	Robert Naiman	2.5		Uni Washington	X	No work on floodplains	X
8	Professor Bill Adams	2.5	Nigeria	Uni Cambridge	X	Sent articles	X
9	Dr Wolfgang Junk	3.5	Amazon	Max-Planck Institute for Limnology	X	Sent articles	
10	David Dudgeon	3.5	Asia	Uni Hong Kong	X	Sent articles	X
11	Mauro Ruffino	3.5	Amazon	Coordinator of "ProVárzea"	X	Sent articles	X
12	Virginia Dale	3.5	Americas	Oak Ridge National Laboratorium, USA	X	Sent articles	X
13	Jukka Käyhkö	5.5	Amazon, Africa	Uni Turku	X		X
14	Risto Kalliola	5.5	Amazon	Uni Turku	X		X
15	Petteri Alho	5.5	Global	Uni Turku			X
16	Roberta Lossio	8.5	Latin America	Independent consultant	X		X
17	Aarnyak project	9.5	India, Brhamaputra			Reply from Partha Yoti Das, busy but will contact later	X
18	Kaziranga Protected Forests Project	9.5.	India				X
19	Dr Paul Loth	12.5	Nigeria	Uni Leiden		Acquired elsewhere	X
20	Dr Lee Baumgartner	12.5	Australia	Dep of primary industried, Australia	X	Sent articles, would like to see report when finished	X
21	Professor Isaacman	15.5	Cahora Bassa, Mozambique	Uni Minnesota		Acquired elsewhere	X
22	Brian Marshall	15.5	Zambezi Basin				X.
23	Jonathan Timberlake	15.5	Zambezi Basin	Kew Gardens, London	X	Sent CD ROM with Zambesi biodiversity book	X
24	R. Cunliffe	15.5	Zambezi				X

			Basin				
25	Olivier Hamerlynck	15.5	Senegal, Africa	IUCN	X	Sent links to articles	X
26	Madiodio Niasse	16.5	Senegal, Africa	Independent consultant	X		X
27	'Rafael Herrera Fernández'	16.5	Brazil, Venezuela				
28	Atossa Soltani	17.5	Camisea, Peru				X
29	Robert Montgomery Head	17.5	Americas	Environment and Social Unit , IADB, USA	X	Busy but will reply later	X
30	Mr Holt-Giménez	17.5	Amazon	BIC			X
31	Mr George Lukacs	17.5	Australia	Australian Centre for Tropical Freshwater Research	X	student Vern Veitch replied	X
32	Tonje Folkestad	17.5	Global dams	WWF			X
33	Mr Welcomme	19.5				Email not working	X
34	Dr Ashley S. Halls	22.5	Bangladesh	Aquae Sulis Ltd	X	Sent articles	X
35	Dr Sandra Kloff	24.5	Senegal, Mauritania	IUCN			X
36	Dr Shumway	5.6	Africa	Edgerton Research Laboratory New England	X	Will send publication	
37	Dr Frank Farqharson	15.6	global	Water Resources, CEH, UK	X		
38	Judith .Rosales	15.6	Orinoco, Venezuela	Uni Guyana	X		
39	Dr Maria Piedade	15.6	Amazon	INPA	X		
40	Karl Wantzen	16.6	Amazon Pantanal	Uni Konstanz	X		
41	Dr Kai Lorenzen	18.6	Amazon, Mekong	Imperial College London	X		
42	Ulrich Saint-Paul	18.6	Amazon, Vietnam	Center for Tropical Marine Ecology Bremen	X		
43	Dr. Michael Douglas	18.6	Australia	Charles Darwin University	X		

Additional information especially concerning the Mekong received from Matti Kummu (selected articles by Lamberts etc), Marko Keskinen (CD ROM with literature, plus fisheries database), Eric Baran, Sophie Nguyen Khoa and Yumiko Kura (World Fish Centre/Phnom Penh)

Asian Development Bank
TA 4669-CAM

Technical Assistance to the Kingdom of Cambodia
for the Study of the Influence of Built Structures
on the Fisheries of the Tonle Sap
(financed by the Government of Finland)

Environment Component

REVIEW OF TONLE SAP BUILT STRUCTURES ENVIRONMENTAL IMPACT ASSESSMENTS (EIAs) WITH REGARD TO FISHERIES

Prepared by

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December 2006

CONTENTS

FIGURES AND TABLES

ANNEXES

ACRONYMS AND ABBREVIATIONS

ADB	Asian Development Bank
CDC	Council Development of Cambodia
CDRI	Cambodia Development Research Institute
CEA	Cumulative Effect Assessment
CNMC	Cambodia National Mekong Committee
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
FACT	Fisheries Action Coalition Team
IEE	Initial Environmental Examination
IEIA	Initial Environmental Impact Assessment
JICA	Japan International Cooperation Agency
LEPNRM	Law on Environmental Protection and Natural Resources Management
MAFF	Ministry of Agriculture, Forestry and Fisheries
MOE	Ministry of Environment
MOP	Ministry of Planning
MOT	Ministry of Tourism
MIME	Ministry of Industry, Mines and Energy
MPWT	Ministry of Public, Wage and Transportation
MOWRAM	Ministry of Water Resources and Meteorology
MRC	Mekong River Commission
NGO	Non-Governmental Organization
SEA	Strategic Environmental Assessment
TA	Technical Assistance
WCS	Wildlife Conservation Society

1. INTRODUCTION

This study is part of the Environment Component of the ADB Technical Assistance (TA) 4669 "Study of the Influence of Built Structures on the Fisheries of the Tonle Sap". The objective of the 10-month study is to improve the awareness and understanding of government agencies and policy-makers of the influence of built structures on the hydrological regime of the lake and on the fisheries of the Tonle Sap (Project Proposal Report). The Technical Assistance is led by the WorldFish Center and the Cambodian National Mekong Committee (CNMC). It is composed of several components identified across disciplines: hydrology, environment, fisheries ecology, livelihoods and socioeconomics, and communication to the public and policy-makers.

The Environment Component aims to assess the state of global and local knowledge on the impacts of built structures on aquatic ecosystems and fisheries. It builds on reviews of scientific literature on the impacts of built structures on tropical floodplains worldwide, and of scientific and grey literature on built structure environmental impact assessments (EIA) in relation to the fisheries of the Tonle Sap. Results will inform and support policy- and decision-making related to built structure development.

The report presents the review of local environmental impact assessments of built structures on the fisheries of the Tonle Sap. The study focuses on EIA - including their initial forms such as Initial Environmental Examination (IEE) and Initial Environmental Impact Assessment (IEIA) - of existing and planned built structure projects implemented in the Tonle Sap area. It highlights the strengths and weaknesses of EIA processes and outputs in order to identify how best to implement adequate and effective EIAs to assess the impacts of built structures on the Tonle Sap fisheries.

The report presents the review method and activities, the evaluation of EIA reports, discussion of results and recommendations for enhanced built structure EIAs with regard to fisheries. The review was conducted mainly in Phnom Penh by an international researcher (2 months) with the assistance of a local research support officer from the Ministry of Environment (4 months), based at the regional office of WorldFish Center, Cambodia.

2. METHODS AND ACTIVITIES

The review of environmental assessments is primarily based on the collection of secondary information but it also includes informal consultation of stakeholders in relevant government institutions, NGOs and other civil society groups. Methods and activities cover the identification of the review scope, consultation of stakeholders, collection of secondary data and identification of indicators for evaluation of EIA reports.

2.1 DEFINITION OF THE SCOPE OF THE REVIEW

The boundaries of the review are defined here in terms of environmental assessment type and geographical scope, and the range of built structures.

2.1.1 Environmental assessment categories and geographical scope

EIA can be broadly defined as a process for evaluating the impact of a project on the functioning of ecosystems and the well-being of humans. Various forms of environmental impact assessments exist and are derived from EIA: initial (such as IEIA, IEE), social (Social Impact Assessment, SIA), cumulative (Cumulative Effects Assessment, CEA) and strategic (Strategic Environmental Assessment, SEA).

While EIA usually includes the assessment of socioeconomic and livelihood impacts, independent Social Impact Assessments (SIA) may be conducted to increase the depth of social studies. Some countries in the Greater Mekong Sub-region refer to SIA as a complementary but separate process to EIA; others such as the MRC assume that EIA includes adequate analysis of social impacts (MRC 200X). The review will thus evaluate coverage of socioeconomic impacts in EIA while searching for SIA reports where available.

Initial and shorter forms of environmental assessments exist in order to screen significant impacts and determine whether a more comprehensive assessment through EIA is required. They are variously referred to as 'initial EIA' (IEIA) in local official documents, and 'Initial Environmental Examination' (IEE) in donor agency (e.g. the ADB) documents. In this report, therefore, the generic term 'EIA' is used to cover available IEIA and IEE.

In order to address all potential significant effects on the Tonle Sap fisheries, the spatial scope of the review must cover all projects affecting the Lake directly and indirectly, including the tributaries flowing into the Lake. Three relevant scales have thus been identified: 1) the Tonle Sap Great Lake (TSGL), 2) the sub-catchment draining into the Lake including the Lake's associated floodplain, and 3) upstream areas up to the boundaries of the Tonle Sap Basin (TA 4669 Inception Report 2006). While built structure projects far from the Tonle Sap catchment could have an indirect effect on the Tonle Sap fisheries, a comprehensive review of the whole basin is not feasible within this review. Main issues on larger scales will be addressed in relation to built structure EIA through a general review of Strategic Environmental Assessment (SEA) and Cumulative Effects Assessments (CEA).

2.1.2 Types of built structures

The Technical Assistance study (TA 4669 Proposal 2006) defines built structures as follows: "Built structures consist of constructions that: i) oppose water outflow (e.g. dams, weirs, irrigation schemes, dykes, levees); ii) prevent water inflow (e.g. embankments, polders, flood control works); iii) alter water inflow or outflow (e.g. roads, railways, drainage canals, agricultural works, bank modifications); iv) degrade water quality (e.g. plants with aqueous effluents, mining and mineral processing facilities, sewerage systems, and dredges)."

The Law on Environmental Protection and Natural Resources Management (12 December 1996) states that all projects and activities should be subject to an EIA. Because this would not be practical and cost-effective, a list of built structure projects requiring an Initial EIA (IEIA) and/or EIA was included in the Sub-decree on the EIA Process (see also Section 3.1). All activities included in the list are potential threats to the environment and are divided into separate categories. The following categories require an IEIA or EIA: (a) hydropower; (b) irrigation systems; (c) port construction; and (d) dredging. Built structure projects that should require an EIA on the basis of the criteria defined in the Environmental Law (August 1999) and for which EIA is compulsory have been identified.

In principle most built structure projects can have an impact on fisheries, through changes to the biophysical (e.g. erosion, pollution) and social (e.g. livelihood changes, etc.) characteristics of the fishery system and the aquatic productivity of the ecosystem. Due to the short duration of the study and the difficult access to information (see Section 4.1), the review had to focus on built structures of key concern regarding the fisheries of the Tonle Sap. While structures such as airports and railways are covered by the study, they are not reviewed comprehensively. The structures identified as most relevant to this study are listed in the table below (Table 1).

Table 1: Main built structures under review

Sector or category	Built structure
Infrastructure	• Bridge and road construction (above 30 tons weight) • National road construction (longer than 100 km) • Railway construction (all sizes) • Port construction (all sizes) • Airport construction (all sizes)
Agricultural sector	• Irrigation systems (greater than or equal to 5,000 ha) • Drainage systems (greater than or equal to 5,000 ha) • Fishing ports (all sizes)
Structure degrading water quality	• Port construction (all sizes) • Irrigation systems (greater than or equal to 5,000 ha) • Drainage systems (greater than or equal to 5,000 ha) • Fishing ports (all sizes) • Industrial, waste water treatment plant

It must be noted that EIAs are not required for a range of structures likely to influence the fisheries of the Tonle Sap Basin such as small-scale irrigation and drainage systems, fishing gears, dikes and bunds in agricultural fields. These small structures contribute to the cumulative impacts on the ecosystem and thus on the Tonle Sap fisheries, which are considered in Sections 5.3 and 5.4. Large fishing gears are also included in the built structures studied by other components of the study (hydrology, fisheries and socioeconomic-livelihoods).

2.2 CONSULTATION OF KEY STAKEHOLDER INFORMANTS

The purpose of the stakeholder consultation is threefold: i) to enhance the collection of information and knowledge through key informants, ii) to increase awareness of this study, and iii) to learn the perceptions of stakeholders on the actual implementation of environmental assessments in Cambodia and improve the understanding of stakeholder issues and concerns.

Key stakeholders were identified in government institutions, civil society including non-governmental organisations (NGOs), donor agencies and to a lesser extent for such a review, local communities (see Table 2 below). The majority (but not all) of key representatives are based in Phnom Penh where most meetings were organised. Informal discussions were carried out with a few villagers and provincial and district officers during a preliminary visit of the project team in Pursat province (25 May 2006).

A brief stakeholder analysis estimated the importance of stakeholders in the project and his/her influence in decision-making for built structure projects. The Ministry of Environment has been identified as the main actor, with support or involvement of the CNMC and all respective agencies implied in a built structure project. However, in practice the MOE and CNMC do not have much influence in enforcing and monitoring the implementation of EIAs (e.g. SEI and ADB 2002) (see further details in Section 3.1).

Table 2: List of key stakeholders met during the review

Stakeholder Category	Organisation
Government institutions	• Ministry of Environment (MOE) - EIA Unit - Biosphere Reserve Unit • Ministry of Agriculture, Forestry and Fisheries (MAFF) - EIA Unit, Department of Fisheries • MIME • Ministry of Water Resources and Meteorology (MOWRAM) • Provincial and District officials
Donor agencies	• ADB
NGOs	• FACT • OXFAM Australia • Nature Conservation Society
Local communities	• A few villagers (informal interviews during field visit)

2.3 COLLECTION AND REVIEW OF SECONDARY DATA

Collection of secondary information was carried out through various mechanisms:

- Internet-based search engines and use of specific websites belonging to local organisations and donor agencies (esp. the ADB) and local websites (NGOs, etc.)
- Library searches at the JICA, CDRI, ADB, and other libraries in line ministries
- Meetings with stakeholders (information and reports provided by stakeholders and/or their organizations).

The variety of ways adopted for collecting information from different sources (Internet, libraries and local knowledge) increased knowledge and enlarged its breadth. In particular, this ensured consideration of the different perspectives and perceptions of stakeholders, and integration of various types of knowledge (e.g., local documents in Khmer language, grey and international literature). Where possible this also allowed cross-checking of information; for example the facts, views and option issues from grey literature and stakeholder knowledge, respectively.

2.4 INDICATORS FOR EVALUATION

A comprehensive evaluation of built structure EIAs would compare the predictions or evaluations of impacts derived from EIAs with actual impacts. However, since monitoring of the actual effects of built structures during and after project implementation is not recorded or has not been implemented, the present review cannot evaluate EIAs on this basis. The review evaluates the actual implementation of the EIA process and impact assessment methods, analyses and recommendations with regard to fisheries.

Indicators for evaluation have been selected through an iterative process that allowed their refinement and adequacy to Cambodia built structure EIA through increased knowledge of Tonle Sap fisheries and built structure development in the Mekong Basin. The evaluation focuses on the quality of the EIA process and the impact assessment and management recorded in collected EIA reports. Selected questions and indicators are indicated in the table below (Table 3). Indicators broadly relate to the process of EIA implementation, impact assessment methods and results, and management recommendations. Justification for the selection of key indicators is briefly explained below.

Table 3: Questions and indicators for evaluation

Category	Question or Indicator	Justification
EIA Process		
Scope of the EIA	• Are fisheries issues addressed? • Temporal and spatial boundaries of the EIA	Fisheries have often been neglected in EIA built structure projects.
Participation of stakeholders	• Degree of participation if any • Forms of participation	Public participation is generally a requirement in EIA guidelines produced by donor agencies, notably by the ADB in Cambodia. However, literature shows that the practice of EIA in Cambodia differs and operational procedures make no mention of how or when these consultations should take place (McKenney 1999).
Transparency of process	• Communication of EIA process • Dissemination of EIA outputs	Communication and dissemination of process information and outputs is a prerequisite for the participation of different stakeholders and sufficient consideration of their concerns.

Impact Assessment		
Scope of fisheries assessment	• Aspects of fisheries and disciplinary fields covered • Time and spatial boundaries of fisheries assessment	Disciplinary coverage (hydrology, ecology, socioeconomy, livelihoods, management and governance) and spatial and time boundaries.
Method for impact assessment	• Type of method selected • Adequacy to fisheries issues and local resources • Collection and use of secondary data and other sources of information • Collection and use of primary data • Baseline situation	Type of method selected among existing ones (e.g. most commonly: ad-hoc, checklist, matrix, network, simulation modelling, expert system) or innovative methods. Selected methods will be evaluated on the basis of their adequacy with respect to fisheries issues and local resources, collection of data and information and assessment of the baseline situation such as, for example, the consideration of counterfactual effects.
Level of integration	• Across disciplines • Across sectors and scales	Mainly across disciplines and possibly across sectors and scales.
Participation of stakeholders	• Degree of participation if any • Forms of participation	Level and form of participation especially who participates.
Impact assessment results	• Are results qualitative or quantitative or both? • If qualitative, what is the quality of results and degree of subjectivity and uncertainty? • If quantitative, what is the quality of results and degree of uncertainty?	Quality of impact assessment results.
Management Recommendations		
Identification of measures	• Mitigation measures • Enhancement measures	Optimising the benefits of built structure projects includes mitigating negative effects and enhancing positive effects on fisheries
Adequacy and feasibility	• Adequacy to local resources and constraints • Cost-effectiveness • Monitoring of implementation	Management measures exist and the main constraint is the suitability to local characteristics and resources. Sustainability of measures.
Support for decision-making	• Evaluation of trade-offs • Implications for policy-making	Positive and negative impacts, various costs and benefits for the different options.

3. STAKEHOLDER CONSULTATION AND SECONDARY INFORMATION

This section first presents the background of EIA procedures in Cambodia and the results of the stakeholders' consultation. It then considers the evaluation of EIA reports.

3.1 EIA PROCESS IN CAMBODIA

Until recently, EIA in Cambodia was an *ad-hoc* activity with the Council for the Development of Cambodia (CDC) providing environmental (as well as overall) clearance for major investment projects. EIA was largely limited to public sector projects normally financed by organisations whose internal approval procedures mandated an environmental assessment (the ADB, World Bank, EU, bilateral agencies, etc.). A process was implemented for: i) transferring the responsibility for EIA from the CDC to the MOE; ii) transferring the initiative for conducting EIA from outside development agencies to Cambodian authorities; and iii) ensuring EIAs apply across all new and old activities in a systematic manner. The first step has virtually been accomplished while the other two require further substantial efforts (Urwin and Wrigley 2001).

The authority for EIA is currently vested in the Ministry of Environment as provided for by the Law on Environmental Protection and Natural Resources Management (LEPNRM). The scope of EIA has been extended to all investment projects, planned or existing. For existing projects approved at the Central Level of government, a screening application to determine whether EIA is necessary followed by the preparation and submission (if warranted) of an Initial EIA (IEIA) and an Environmental Management Plan (EMP) is required.

The preliminary screening criteria are qualitative and exempt a project from EIA if:

- project activities can be expected to have non-measurable or insignificant environmental impacts,
- the project appears to be in conformity with the objectives of the LEPNRM, the National Environmental Action Plan, regional environmental development plans (if adopted) and other laws relative to NRM, and
- the risk of environmental impacts during project construction, operation and closure are considered to be small (MOE 2000, Urwin and Wrigley 2001).

The Sub-decree on the EIA Process (11 August 1999) has delegated responsibility to the Ministry of Environment for establishing the EIA Guidelines but these have not yet been produced.

There are a number of obstacles to managing and enforcing EIA requirements in Cambodia. First, environmental assessment requirements are not well known and various sector ministries and project owners do not yet apply them. The authority of the Ministry of Environment to enforce the requirements appears to be limited by these circumstances. Another constraint is the limited capacity to conduct EIAs. There are few in-country specialists with experience in EIA reporting, and international consulting firms often have to be contracted, which is expensive and does not automatically increase local capacity to do this work.

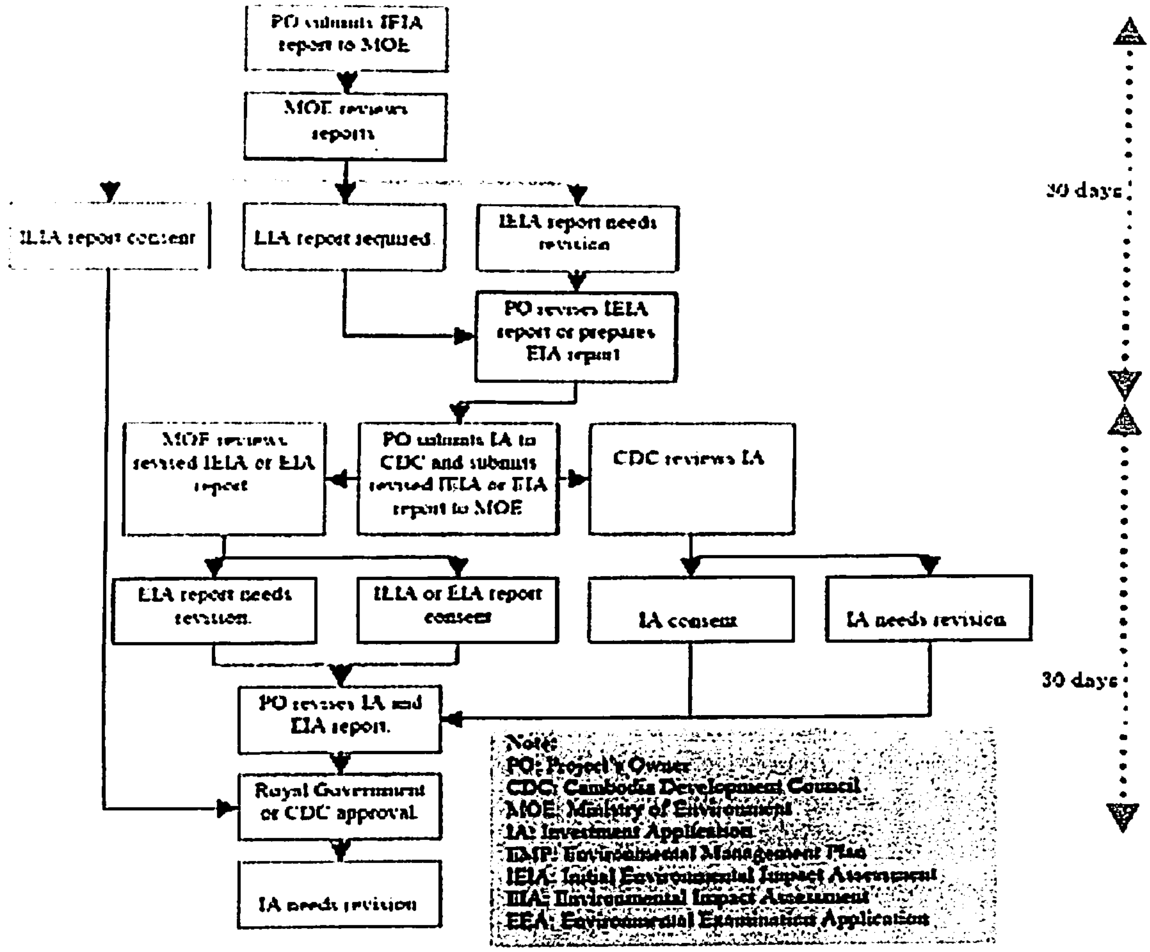

Figure 1: EIA process in Cambodia – Source: MOE 1999

The EIA principles of the donor agency (e.g. the ADB, World Bank, EU) and the host country should also be observed. The project proponent pays for the EIA, and a consultant is hired by the project proponent to conduct the EIA. The MOE reviews the documents with contribution of CDC and respective line ministries. As an example, ADB documentation (e.g. Lohani *et al.* 1997) describes EIA as a multi-step process by which a range of issues are taken into account to determine whether, or under what terms and conditions, a project should be undertaken. The screening process for the ADB categorizes loan projects into three groups, each of which requires a different level of environmental review (SEI and ADB, 2002):

- Category A: potentially serious environmental impacts, which require an EIA;
- Category B: potentially significant environmental impacts, which require an IEE but not an EIA;
- Category C: unlikely to have significant environmental impacts, which do not require an IEE or EIA.

ADB guidelines cover the environmental assessment requirements and environmental review procedures of the ADB (1993), environmental guidelines for selected infrastructure projects (1993), guidelines for incorporation of social dimensions into ADB operations (1993) and a handbook for incorporation of social dimensions into projects (1994).

3.2 STAKEHOLDER PERCEPTIONS AND ISSUES

The local review was somewhat limited and the results of the informal stakeholder consultations were not designed to be comprehensive. Instead they provide indications of key issues and concerns raised by relevant individuals and agencies involved in the EIA process at the implementation or institutional level. Results are derived from both direct communication with key stakeholder informants and the review of local and regional documents including the reports of the civil society.

Most stakeholders expressed a particular interest in the study topic, especially for improving the understanding of the impacts of built structures on the Tonle Sap in order to balance the social and economic development of Cambodia with the preservation of goods and services provided by the Tonle Sap ecosystem. Through numerous studies, awareness has increased of the potential negative impacts of built structures (especially large scale hydropower development) on the fisheries of the Tonle Sap, in particular by changing the river flow and its timing (e.g., Lamberts and Bonheur 2006). It is generally perceived that damaging the Tonle Sap ecosystem will in turn have negative social and economic impacts on communities dependent on the resources provided by this ecosystem.

Perception of impacts, issues and concerns may vary widely with the type of stakeholders (local stakeholders, civil society and government officials) interviewed. Key issues and concerns raised by stakeholders are summarised in the table below (Table 4).

Despite the increased emphasis on fisheries in development projects implemented in the Tonle Sap area, supported by the fisheries policy and EIA requirements set by donor agencies (especially the ADB and World Bank in Cambodia), the implementation and practice of built structure EIA shows insufficient consideration of fisheries issues, and no assessment has been carried out in accordance with the fisheries policy. The former ADB policy on fisheries states that the impacts of ADB projects on fisheries (notably the potential impacts of large-scale structures, especially dams) must be thoroughly assessed and eliminated or mitigated (ADB 1997).

Donor agencies and civil society call for increasing the scope of EIAs in order to address broader issues and the potential implications of project impacts at larger scales (esp. cumulative impacts). This contrasts with the general lack of financial and human resources in developing countries such as Cambodia. Beyond the issue of funding (by project proponent) and capacity building of local agencies, this review will show that there are also scientific issues in the definition of the scope (esp. boundaries) and priorities of EIAs (see also Section 4.3).

Table 4: Key issues and concerns per category of stakeholders

Stakeholder category	Issues and concerns
Local stakeholders, Civil society	• Negative impacts of built structures on fisheries tend to be underestimated • The scope of EIAs is too narrowly defined or applied; in particular social impacts, health and risk factors, and cumulative effects are generally not considered or inadequately addressed • Lack of scientific evidence, especially quantitative assessments of impacts on fisheries • Lack of participation of stakeholders in the EIA process; when stakeholders are involved, there are concerns with regard to representativeness (referring to the selection of stakeholders)
EIA implementers	• Scope of EIA is too broad • Quantitative assessments cannot be achieved
Government agencies	• cope of EIA is too broad (esp. perceived by MOE and MAFF officers) making assessment of impacts difficult • Lack of capacity to monitor and evaluate EIA implementation, analysis and results • Inadequate guidance and consistent enforcement of the EIA process • Inefficient, time-consuming, and costly EIAs relative to the benefits delivered • MOE lacks resources to conduct EIA
Donor agencies	• Lack of institutional coordination • Lack of political commitment

The various perspectives of key stakeholders highlight the need to balance the competing needs for socioeconomic development and especially the development of built structures, while preserving the Tonle Sap ecosystem goods and services, especially the benefits issued from its fisheries. This shows that positive and negative effects of built structure development urgently need to be clarified, assessed and valued.

However, the significance of EIAs is not fully recognised by many of the government ministries responsible for infrastructure or industrial and agricultural development, and environmental and social concerns are not always adequately considered in built structure project decision-making. The patron-client relationships often appear to be a more dominant force than the rule of law (SEI and ADB 2002). EIA is not sufficiently integrated with decision-making notably at the project preparation phase or with other supporting policy, planning and regulatory processes. At present there is a significant gap between public policy targets and laws and their implementation.

4. EVALUATION OF EIA REPORTS

This section first introduces the nature of the information collected and then provides the results of the evaluation in terms of the scope of EIAs, methods for impact assessment, results and management recommendations.

4.1 NATURE OF THE INFORMATION

EIA reports are scattered across various ministries, provincial and district government agencies, and with the project proponents. Access is generally difficult and very few reports are available within the MOE and other relevant ministries. EIAs are not systematically recorded and classified. As a result, a relatively small number of built structure EIA reports have been collected. Most EIA reports that are available refer to projects funded by international donors (grant or loan). No built structure Social Impact Assessments (SIAs) have been identified. The list of reviewed reports is indicated at the end of this report.

As a result of the small sample under review, the study had to broaden its initial emphasis on the evaluation of collected EIA reports in order to clarify why access to information was difficult. Possible reasons are that most EIA reports are not accessible and/or only few EIA projects have been carried out. Further stakeholder consultation showed that both were relevant for the following reasons:

- The Ministry of Environment does not access and record all EIA reports received by the various ministries and government agencies.
- Many projects are conducted with decision at the provincial level, sometimes without informing the head ministries, and local implementation of EIA is not fully controlled.
- The collection of reports from project proponents would require more time and resources to carry out field visits and further stakeholder consultations at the local level.
- A significant (but non-quantifiable) number of built structure projects do not provide EIAs. This is supported by MOE documentation (MOE 2000).
- The significance of EIA is not fully recognised by many government ministries responsible for infrastructure or industrial and agricultural development. The need for environmental assessment is still widely considered as secondary to the need for development.

In such a context, the study could not estimate the total number of existing EIAs and thus the representativeness of the study sample.

The scarcity of available EIA reports contrasts with the profusion of EIA guidelines and procedures disseminated worldwide, including specific guidelines for the Mekong River Basin and the Asia region. This reflects the discrepancy between the promotion of EIA by donor agencies and actual implementation of assessments.

4.2 PARTICIPATION OF STAKEHOLDERS IN THE PROCESS

Participation of stakeholders can occur during the EIA process and/or during the impact assessment (see Section 4.4). This section focuses on participation of stakeholders during the EIA process commonly called 'Public participation'.

Participation of stakeholders is generally very limited and there is no systematic mechanism for the involvement of stakeholders, including communities, provincial authorities, local or international NGOs. This raises issues of transparency throughout the process, of communication and dissemination of information (in both Khmer and English) at local and national levels, and of allocation of resources to these activities.

The general conclusion drawn by stakeholders is that while the requirement for participation and consultation in EIAs is clearly stipulated it does not occur in practice in Cambodia. Again the practice of EIAs in Cambodia shows significant discrepancies with guideline requirements.

4.3 SCOPE OF EIA

Most built structure projects implemented in the Tonle Sap area that may have a significant direct effect on water resources have considered potential or actual effects on fisheries in their EIAs. This reflects the awareness and well-known importance of this sector in the economy of the country, in the livelihoods of at least 2 million people and in the environment, notably its aquatic resource diversity and productivity.

The appreciation of capture fisheries has increased with the increased awareness that the threats to Tonle Sap fisheries are not only coming from the sector itself but also and possibly mainly from the development of built structures (especially large-scale irrigation, hydropower and road construction) within the catchment and Mekong River Basin, in particular upstream of the Tonle Sap. For example, the planned proliferation of dams in the Upper Mekong presents high levels of risk of irreversible negative impacts on endemic and commercially valuable fish biodiversity. In the very short-term, it is likely that the effect of proposed irrigation projects in the Tonle Sap ecosystem will be more severe than the effect of expected changes in seasonal fluctuations in lake levels from the impact of hydropower projects on the Mekong River and its tributaries (SEI and ADB 2002).

Regarding temporal and spatial scales, the scope of EIA is initially project-specific and it is assumed that the project needs to assess and manage its immediate (e.g. during construction) or short-term impacts within the immediate area (e.g. the command area of an irrigation scheme). While longer and larger scales are recommended - for example, the ADB (2004) indicates that long-term impacts should be considered prior to expanding irrigation and hydroelectric projects - they have not been considered by local EIAs. Strategic Environmental Assessments (SEA) and Cumulative Effects Assessments (CEA) would address these issues as they are conducted at catchment and river basin levels, and often have a longer-term perspective. A major SEA has been identified and recently conducted for the Mekong (SEI and ADB 2002).

4.4 METHODOLOGY FOR IMPACT ASSESSMENT

4.4.1 Coverage of fisheries aspects and scope of fisheries assessments

Coverage of fisheries aspects in EIA reports under study has been evaluated on the basis of the criteria (or 'situational variables' in the baseline situation) indicated in the table below (Table 5).

Table 5. Coverage of fisheries impact assessments

Fisheries aspect and scale of assessment	Coverage
• Physical habitat	High In most EIA reports
• Ecology of fisheries production	High In most EIA reports
• Biodiversity	Medium Focus on fish species diversity
• Ecological integrity	Very Low Only a few components of the ecosystem considered
• Exploitation of fisheries	Medium Focus on fishing effort
• Livelihood of fishers and fishing communities	Low Focus on a few livelihood assets and functions
• Institutional arrangements	Low Not much considered
• Management of fisheries	Low Not much considered
• Consideration of other key relevant sectors	Low Most EIA are sectoral
• Spatial scales	Very Low Focus on project boundaries
• Temporal scales	Very Low Focus on short-term impacts

The coverage of fisheries impact assessments tends to be sectoral and within project boundaries, and it tends to have a general focus on biophysical changes in the short-term: species diversity, hydrology, ecology and aquatic resource production. It must be noted that only a few EIAs mention aquatic resources other than fish, e.g. crab, shrimps, snails, aquatic plants, etc. despite their potential importance as a source of food for livelihoods, particularly for the poorer.

Socioeconomic and livelihood aspects are not systematically addressed and there are wide variations in EIA coverage. Overall, despite increased awareness and knowledge of the connection between biophysical and socioeconomic systems, socioeconomic effects are insufficiently considered and analysed in most EIA reports. Consideration of other sectors related to built structure development (esp. irrigation, hydropower, road construction) is limited or absent.

In terms of spatial scale, fisheries assessments are often limited to specific water bodies, essentially the main river(s) or stream(s), the Great Lake and the reservoirs for dam irrigation schemes. This provides a partial estimation of fisheries (esp. production and productivity) in the project area. Consideration of all major water bodies in the catchment, upstream and downstream of the built structure would provide a more accurate estimation of fisheries production and its significance in livelihoods at the various locations.

Assessments focus on short-term impacts and neglect longer-term effects of built structures on the ecosystem and fisheries dependent livelihoods. As a result, potential trade-offs between immediate and long-term costs and benefits are not made explicit.

4.4.2 Method for impact assessment

Checklists of impacts, with or without their estimated significance per sector or per impact category, are most commonly used. The comparison of the situation before and after the project, prediction of impacts or ex-post impact assessment, is also frequently invoked. However, since most reports do not describe the methodological steps leading to results it has generally been difficult to identify the methodological rationale underlying impact assessments.

The description of the baseline (or pre-project) situation is often a major part of the assessment. A comprehensive evaluation of project impacts requires a thorough understanding of the situational variables for the pre-project situation and how these have evolved over time. However, in most cases, there is very little collection of primary data – and none in many cases - and recycling old data and information is common. Collection of primary data is usually carried out to larger extent in donor funded projectEIAs, such as Stung Chinit and Northwest Irrigation projects.

The lack of scientific data and of baseline information in particular are often mentioned as major constraints to assessment, especially where the impact assessment method is based on a comparison of the situation before (baseline) and after the project (predicted scenario). Apart from physical changes that can be directly observed in the field, the main source of information may need to be the recall of individual or group interview respondents (see also Lorenzen *et al.* 2005). Participation of stakeholders in the assessment, e.g. in rapid and participatory appraisals, is generally limited yet higher than in EIA processes (see Section 4.2).

It may also be possible to compare the characteristics of the project and the impacted area with other similar projects for which fisheries impacts have been considered, or with comparable areas without irrigation development.

4.5 ASSESSMENT RESULTS

Evaluation of assessment results has been based on the description and analysis of the baseline situation (before implementation of the project), and the identification and prediction of possible changes or evaluation of actual changes.

4.5.1 Baseline situation

The description and assessment of the baseline situation should provide sufficient and adequate information to understand the potential impacts of built structures and causation pathways. This should support later assessment and discrimination of built structure impacts from other changes. The baseline situation is essentially descriptive and based on secondary information. Some EIAs have carried out collection of primary data for specific information in the project area. Notably due to a lack of adequate monitoring of the state of these floodplain systems, estimation of fisheries production and indicators of productivity are "incomplete at best and very problematic in most instances" (Lamberts and Bonheur 2006).

Baseline situations usually refer to the hydrological importance of the Tonle Sap system, its uniqueness and exceptional fisheries productivity. The Tonle Sap is among the most productive fishery resources in the world, and is important in terms of biodiversity, productivity and its role in livelihoods. Because this high fisheries productivity is strongly related to the specific hydrological patterns (timing of the flow, specific seasonal and daily fluctuations, flow reversal, etc.) of the Tonle Sap, these fisheries are sensitive to changes not only within the catchment but also in the Mekong Basin. The Mekong mainstream, tributaries and associated lakes are characterized by high fish biodiversity, including a substantial number of endemic species.

Increasing human impacts in floodplain areas, including various built structures (especially hydropower dams upstream on the Mekong), has led to flow modification, floodplain habitat alteration or destruction and water pollution. These factors have been defined as the three main causes for loss of freshwater biodiversity worldwide (e.g. Kruskopf in press).

The socioeconomic situation and human well-being in the Tonle Sap area are strongly connected to natural resources and other ecosystem services due to the majority of livelihoods directly and largely dependent on natural resources. Rice cultivation and fishing are the most important occupations in the Tonle Sap area (Keskinen 2003). They are supplemented by a variety of other livelihood activities of which many are directly dependent on natural resources, such as firewood collection and hunting. Therefore, a high number of poor people remain vulnerable to environmental change because of their dependence on natural resources and the lack of livelihood alternatives.

Most EIA reports do not refer to indicators of sensitivity, vulnerability and resilience of the ecosystem and livelihoods in respective areas - simply stated, a resilient ecosystem is likely to be more resistant (and thus less vulnerable) to natural or human disturbances. Notably, while the significance and importance of fisheries and the Tonle Sap ecosystem are largely recognised and documented it is not always possible to assess the degree of sensitivity of specific locations in the ecosystem (e.g. built structure projects), apart from general knowledge of sensitivity to changes in environmental flows and biodiversity.

4.5.2 Identification of impacts of built structures on fisheries

Impacts of built structures on fisheries can be direct or indirect; they may affect the ecological characteristics of the Tonle Sap fisheries, and/or the livelihoods and socioeconomic and institutional baseline situation.

Table 6: List of direct and indirect impacts mentioned in EIA reports

Impact Category	Impacts indicated in EIA reports
Direct impacts	• Blockage or impedance of fish migration • Changes in river flow • Changes in aquatic habitats • Disruption of connectivity between aquatic habitats • Changes in water quality (nutrients, agrochemicals, metals, etc.) affecting the primary productivity, fish production and species composition • Distribution and transportation of sediment • Distribution and transportation of nutrients
Indirect impacts	• Degradation of water quality • Land use changes • Distribution and transportation of sediment • Distribution and transportation of nutrient inputs, especially through changes in the flood pulse • Changes in access to wetlands and water bodies

Blockage and impedance of fish migration are the most commonly identified impacts of built structures on fisheries. However, the migratory characteristics of fish species in the impacted area are rarely identified, with the notable exception of the Stung Chinit irrigation project. The Stung Chinit EIA indicates that fish populations in the project area are both migratory and non-migratory and that estimated impacts will likely be positive on non-migratory fish (due to increased availability of water) and possibly negative on migratory fish (due to impedance of migration).

The availability and quality of aquatic habitats and the connectivity between them may result from changes in river and stream flows and from land use changes. Disrupted connectivity affects the ability of aquatic organisms to move between riverine areas. The transfer of terrestrial organic matter to the aquatic phase through the flood pulse involves a variety of pathways, including ingestion and digestion by aquatic organisms, bacterial decomposition, biofilm formation and metabolism, and leaching of photosynthesis products (Lambert and Bonheur 2006).

In Stung Chinit, two major environmental concerns associated with the project are the impacts of restored weirs on migratory fish and the impacts of pesticides and fertilizers in the project area. Pesticides are of concern not only because of their impacts on the health of farmers in the project area who work in the fields and consume the rice but also because of the impact on downstream rice-fish paddies and on livestock and waterfowl. Another threat is increased use of fertilizers and the resultant runoff into the lake and its tributaries, poisoning the fish and the people who live on them.

Impacts on livelihoods are usually deduced from changes in fisheries productivity. However, even where productivity is maintained, built structures (esp. roads, dams) may change the pattern of access to water bodies and although rarely considered, consequences on livelihoods may be more negative than productivity changes. In turn, improved access due, for example, to reduced incidence of flooding, improved road networks and subsequent increased human habitation caused by new infrastructure in floodplain areas, will lead to increased destruction of forest resources and habitats through increased commercial activities facilitated by road construction. If negative, both types of change may act to worsen the absolute position of poor people in terms of poverty, vulnerability and equity.

4.5.3 Predictive and analytical capabilities

The quality and accuracy of impact assessments are highly variable and most results on the impacts of built structures on fisheries are essentially descriptive. Most assessments focus on discrete factors or a few components of fisheries, especially fish migration and fish species diversity. Changes in connectivity between aquatic habitats and water quality and other characteristics (composition, temperature, etc.) are more difficult to assess.

Table 7: Identification of predicted or evaluated variables

Category of variable	**Predicted or evaluated variable**
Hydrological regime	Extent of water withdrawal and depletion Total flow changes
Aquatic habitats	Extent of flooded area
Connectivity between aquatic habitats	Some qualitative but no quantitative estimation
Fisheries production and productivity	For a few water bodies: - Reservoir: potential production through stock enhancement or aquaculture - Floodplain: no quantification - Lake: no quantification
Biodiversity	Fish species diversity: identification of species before and after the project
Water quality changes	Composition Temperature
Socioeconomic	Economic contribution of fisheries sector
Livelihoods	Loss of livelihood functions Income changes
Institutions	Changes in institutional arrangements

Assessments of the influence of built structures on fisheries tend to focus on the impacts as outcomes, with limited information on why they may arise as predicted, and causal explanations of impact pathways is usually lacking. When considering social and economic outcomes, the number of possible pathways that could be the root cause is even greater (see also Lorenzen, Smith *et al.* 2005). The lack of causal explanations also has implications for the identification of mitigation measures (see Section 4.6.1).

Most assessments of built structure impacts on fisheries are essentially descriptive and lack analytical and predictive capabilities. This leads to weak interpretations, and conclusions tend to be made quickly, with a high degree of subjectivity and strong reliance on expert judgement. While using expert judgement is often required at various degrees in data-scarce contexts, built structure impact assessments are not sufficiently transparent and/or detailed to allow evaluation of the degree of expert judgement. This leads to excessive use of vague qualitative statements such as 'slight eventuality', 'no major impact' without indication of their rationale and justification for such results.

Local literature indicates that EIA results are difficult to translate and weigh against the quantified net benefit of the built structure project, essentially provided by cost-benefit analysis (CBA) of built structure projects. The EIAs considered do no attempt to value environmental, social, health and other factors, and results cannot feed into CBA methodology and practice. This is critical given the central role that CBA plays in decisions about whether or not to implement a proposed built structure project (e.g. McKenney 1999 on dam projects).

4.5.4 Degree of integration across disciplines and across sectors

The degree of integration has been evaluated across disciplines (hydrology, ecology, socioeconomics, livelihoods, governance) and across sectors (fisheries and key relevant sectors, e.g. agriculture in case the of irrigation projects). Fisheries are strongly dependent on interactions with other sectors especially agriculture and all water related activities. This is especially evident in the Tonle Sap where the majority of livelihoods rely on water-related natural resources (e.g. Keskinen 2003, Nikula 2005).

Built structure EIAs mostly assess impacts on discriminate characteristics and variables of fisheries and they tend to neglect subsequent or simultaneous changes that originate from interaction between variables. This is an issue for all EIAs since the environment is traditionally divided into manageable components or categories (e.g. water quality, biodiversity, soil fertility, air quality) and such clustering underlies common checklist frameworks.

However, such EIA frameworks cannot encompass ecological processes such as floodplain processes as these can be affected by changes occurring in different components of an EIA (e.g. soil fertility, surface water quality and level, and groundwater dynamics). As a result, effects of built structures on the Tonle Sap floodplain are partially or inadequately assessed except in rare cases where potential cumulative effects between EIA sectors have been considered (Lamberts and Bonheur 2006). The authors conclude that this leads to incomplete and inaccurate assessments of the impact of man-made flow changes.

In particular, Lambert and Bonheur (2006) demonstrate that EIA methodological frameworks have been superseded by cross-cutting patterns such as the flood pulse. They propose a framework to show the variety of environmental effects on fisheries across EIA components in contrast to the important aspects of the aquatic ecosystem and fisheries omitted by other EIA frameworks. Another potential bias is that the effects of a project on each component may be small, but the overall cross-cutting damage to the flood pulse may be significant.

While the importance of the biodiversity and productivity of the Tonle Sap ecosystem has been recognised and demonstrated, the development and application of such integrative processes is a prerequisite for effective built structure EIA with regard to the Tonle Sap fisheries. Ecologists suggest developing ecosystem impact assessments (see also Section 5.3) especially where floodplains are concerned.

4.6 Management Recommendations

The evaluation of management recommendations involves analysis of the mitigation and enhancement measures identified and their utility and adequacy.

4.6.1 Identification of mitigation and enhancement measures

To compensate for the effects of built structures on fisheries, mitigation and enhancement measures have been proposed by EIA studies. A relatively wide range of mitigation and enhancement measures are proposed for the large variety of built structures, and it is likely that the review of the EIA sample does not provide a comprehensive list of existing measures. These have been grouped in relation to the mechanisms or principles of change they propose to act upon (Table 8).

Table 8: Identification of mitigation and enhancement measures

Category of measure	Measures identified in EIA reports
Mitigation measures	• Technical and engineering measures to ensure fish migration routes through structures such as fish passes and culverts (Lim and Lek 2005) • Minimise loss and degradation of flooded areas • Establish minimum dry season flow • Protect fisheries and habitats by establishing protected areas • Convert borrow pits (during road construction) into fishponds or ponds with water for gardening • Strengthen management institutions, and develop monitoring, forecasting and information dissemination
Enhancement measures	• Stock-enhancement • Aquaculture • Rice-fish farming

However, despite their potential variety, most management recommendations target two main means for action: the mitigation of river fish migration and the enhancement of fisheries production in reservoirs (for dam irrigation and hydropower schemes) and fish ponds, and to a lesser extent the establishment of minimum river flows.

To mitigate the impact on migratory fish, a fish pass structure will be constructed at the Stung Chinit weir with a minimum slope allowing fish to migrate upstream. The Stung Chinit project has also proposed establishing a minimum flow. In the absence of quantitative studies, minimum environmental flow releases of at least 10% of the mean monthly flow have been recommended to maintain healthy aquatic habitats in temperate countries. Given the diverse nature of tropical fish faunas and the generally higher temperatures, this may not be sufficient for the Stung Chinit. However, much of the water diverted from the river channel will be distributed throughout the same area through paddies, secondary and tertiary canals and drains, and some will return to the river course through this system (Lim and Lek 2005).

4.6.2 Utility and adequacy of management measures

Utility and adequacy of mitigation measures is highly variable and can only be evaluated at a general level. There is not much consideration of the location of projects and their design at the planning stage since late remedial action (at the implementation stage) is generally not feasible. Cost efficiency of management measures cannot be evaluated in this study. EIA estimates should be incorporated into the overall CBA of the project. The costs of mitigation measures, in particular, should be included in overall project costs.

In general, management measures are recommended without much consideration of the whole project and potential trade-offs between different management and development options, notably the difficult balance and complex understanding of both positive and negative impacts of built structure development. "The lack of awareness of the presence and significance of a floodplain and the inextricable unity between floodplains and their main water bodies, combined with flawed impact assessment practices, lead decision makers to believe that mitigation of negative impacts on floodplain ecosystems is possible." (Lambert and Bonheur 2006).

While standard practice in ADB activities, individual projects must be considered in the larger context within which the intervention is undertaken. Future planning should examine the cumulative impacts of individual interventions in view of overall resource management. For example, the individual and cumulative impacts of projects involving irrigation, water resource use, and rural development can be accounted for through integrated basin planning (SEI and ADB 2002) (see also Section 5.3 and 5.4).

5. DISCUSSION

The discussion aims to provide insights and recommendations for enhancing local EIAs in light of existing knowledge available locally and worldwide. Comments are made within the scope of the review, with consideration of its limitations due to both the difficulty of accessing information and the short duration of the study.

5.1 LACK OF DATA AND INFORMATION

As in many developing countries, the lack of data and information is strongly felt and it is a common constraint for research studies, especially for integrated fisheries assessments and quantitative assessment results, since these are generally resource and time consuming. While it is not feasible and practical to establish a comprehensive collection of baseline information for every project, improved data collection systems are needed, in particular the recording of all built structure projects (date, type, location, etc.) and key fisheries characteristics (gears used, main livelihood characteristics of fishers) at district, provincial and national levels.

Most EIAs do not provide any alternative to the scarcity of information such as, for example, the search for other sources of information, i.e. comparative studies, strategic analyses, and stakeholders' perceptions and knowledge (including local ecological knowledge, e.g. Baird, 2003 and Poulsen, 2003). In addition, the use of knowledge, especially local/traditional knowledge and scientific knowledge, are not optimised. While knowledge needs to increase worldwide, especially in the quantification of the magnitude of impacts (see Kruskopf, in press), significant literature now exists on the influence of certain built structures on aquatic ecosystems and fisheries, especially for large-scale dam irrigation schemes. Generic knowledge such as the ecology of fisheries, ecosystem functioning, and fisheries functions in livelihoods can be transferred and extrapolated for use in specific built structure EIAs (see further development in Section 5.3).

Therefore, the lack of data and information tends to be overemphasised as a reason for partial impact assessments that target official agreement for project implementation. Various ways for improving the accuracy and predictive capability of results have been identified. Essentially, beyond improvement of data collection systems, EIAs should enhance the use of, or identify the need to develop, methodologies and processes that are able to adapt to local conditions and optimise the use of existing knowledge and available data.

5.2 Scope of Environmental Assessments

Despite the recognition of the need for inter-sectoral and inter-institutional coordination and partnership, most EIAs are essentially sectoral and project-focused. Scientific literature on the impact of human development on fisheries in Cambodia (e.g. Lambert and Bonheur 2006) shows that EIAs insufficiently cover adequate spatial scales, especially the necessary trade-offs and potential conflicts between the upstream and downstream effects of built structures on fisheries.

However, in practice, EIA studies often face difficulties in defining the boundaries of the study area. The critical need to cover upstream and downstream areas requires a catchment perspective. At the river basin level identification of the geographical scope (Upper and Lower Mekong River Basin) would be even more complex due to potential regional effects, especially trans-boundary effects between countries, such as effects on fish migration, sediment transportation and hydrological changes. The planned proliferation of dams in this sub-region presents a high level of risk of irreversible negative impacts on endemic and commercially valuable fish biodiversity. Environmental assessments conducted in the Lower Mekong Basin have mainly focused on pollution problems but they have not been used for assessment of macro-level issues such as land use conversion, soil erosion, catchment area treatment, illegal resettlement, conflicting uses of natural resources, etc. (SEI and ADB 2002).

There is an urgent need to develop and use frameworks that can exploit the results of project environmental assessments in sectoral and regional approaches such as SEA and CEA. This is even more critical in the case of the Tonle Sap Basin (including the river, lake and associated floodplain) where extensive studies show the connections between river flow patterns and fisheries production.

5.3 ASSESSMENT OF THE IMPACTS OF BUILT STRUCTURES ON FISHERIES

The complex and dynamic ecosystem of the Tonle Sap and its fisheries (and respective livelihoods) may not be understood and adequately evaluated by existing impact assessment. Beyond the lack of information and knowledge developed in Section 5.2, the review has highlighted the potential for improvement in increased exploitation of available knowledge (locally and worldwide) and use of adequate impact assessment methods, especially those that integrate multiple disciplines and consider interactions and linkages with key relevant sectors and scales.

As introduced in Section 5.1, the potential for increased use of local and worldwide knowledge is generally neglected. Enhanced use of local knowledge including traditional knowledge involves choosing the appropriate form and degree of stakeholder participation in impact assessments. Participation may also support the resolution of conflicting issues and a commitment to solving these issues (see also Section 5.4.2). In turn, insufficient participation and use of local knowledge could have strong implications for the quality of impact assessments (especially where affected people have not been adequately consulted) and the sustainability of management measures derived from assessment results.

While key gaps have been identified in relation to built structure impacts on fisheries (see also Kruskopf in press), the worldwide knowledge base of riverine and floodplain ecosystems has significantly increased and improved the understanding of complex ecological processes. Beyond increased knowledge of aquatic ecosystems, this knowledge provides the basis for comparative analysis, e.g. cross-check comparisons between local estimates and average productions in comparable ecosystems or water bodies. It also allows the use of appropriate assessment methods and tools, such as: i) modelling tools that may support quantification of some processes and identification of impact scenarios, and ii) methods and approaches that are able to generate information in contexts of data scarcity and uncertainty such as precautionary approaches.

Traditionally, EIAs have considered air quality, water resources, wildlife and human communities as separate entities for analysis. This separation of resources and sectors has neglected linkages with key relevant sectors, e.g. agriculture for dam irrigation schemes, transport and tourism for harbour construction, and has omitted or obscured many cumulative effects (e.g. Lambert and Bonheur 2006). EIA methodologies predominantly draw from checklist frameworks, and this review has highlighted the need for more integrative frameworks. While checklists of potential effects of built structures may enhance coverage of fisheries aspects (and usually the respective relative weight of the impact) they are likely to provide discrete evaluations that neglect cause-effect relationships and other interactions between factors of influence, e.g. feed-back effects.

The resulting description of impacts tends to be a multi-sectoral but static 'snapshot' that does not reflect longer-term impacts and undervalues the chain of impact causality. Thus, it may miss possible management actions that may significantly change the outcome of a built structure development (Nguyen-Khoa *et al.* 2005). Recognition of the interconnectedness of land, water and human resources has driven several developed countries to undertake ecosystem or watershed approaches to environmental protection. The ecosystem approach explicitly addresses the ecological interactions and processes necessary to sustain ecosystem composition, structure and function. Ecosystem assessments address the full spectrum of indicators of ecological conditions ranging from the genetic to species to local ecosystem to regional ecosystem levels.

Better linkages with larger scales can be exploited through the use of natural and not just project boundaries. This leads to ecological regions, such as watersheds and eco-regions, that encompass ecosystem functioning and landscape-scale phenomena such as habitat fragmentation and that address resource or ecosystem sustainability. Increasingly, ecologists promote ecosystem approaches in order to provide the broad regional perspective needed in regional planning and the holistic thinking needed for impact assessment of fisheries and especially to address key principles of cumulative effects (SEI and ADB 2002).

5.4 Management Measures

5.4.1 Utility and adequacy of recommended measures

The management of built structures for the mitigation or enhancement of fisheries generally focuses on technical and engineering measures (esp. fish passes, fish ladders) and stock-enhancement in reservoirs for dam irrigation projects.

Often mitigation and enhancement measures are the end-product of built structure EIAs and neglect potentially effective interventions throughout the causality chain of impact, from its root causes to outcomes. As indicated in Section 5.3 on assessment, results do not provide sufficient information on cause-effect relationships and hence they do not support identification of management measures throughout key pathways of impacts. In addition, where quantifiable, the environmental, social, health and other impacts that cannot be mitigated should be added to total project costs.

Management measures are often afterthoughts, and changes in the design may not be possible. This constraint is particularly critical with technical and engineering measures. Also, proposed management measures omit or fail to adequately address local constraints to implementation, such as lack of resources or the need for institutional reforms (Nguyen-Khoa *et al.* 2005). For example, the implementation of built structures may offer a 'window of opportunity' to introduce institutional or other changes that can mitigate the problem.

5.4.2 Analysis of trade-offs and support for decision-making

Adequate design, location and management decisions with regard to built structures require appropriate analytical and decision-making processes. Competing demands are often raised by the needs for infrastructure development and the overall pressure for rapid socioeconomic development (short-term objectives) to the likely cost to the environment and natural resources (long-term objectives of sustainability). Within the fisheries sector, tensions may arise between the need for increased fisheries production and potential development of aquaculture and the conservation of aquatic resources requiring protected areas.

Present built structure EIAs in Cambodia would better support evaluation of these trade-offs if they made explicit the weight of the different environmental and socioeconomic factors and management options. This implies valuing environmental services and social preferences for the present and future through identification of trends and possible scenarios of built structure development and consequent changes in fisheries. In addition, participation of stakeholders in the selection of the most desirable or acceptable options is likely to improve the sustainability of implementation of management measures.

The local capacity and coordination between relevant agencies, especially in the ministries and in particular the MOE, needs to be enhanced in order to improve the holistic understanding of the development of built structures and their potential effects on fisheries production, biodiversity and livelihoods. At present, due to lack of information, awareness and experience, the MOE may lack critical judgement and necessary authority in the evaluation of built structure EIA reports.

5.5 Recommendations for Tonle Sap built structures EIAs with regards to fisheries

In accordance with the results of the review, recommendations are made separately for the EIA process and for the assessment of built structure impacts on Tonle Sap fisheries.

5.5.1 Built structure EIA process

- Ensure knowledge of Strategic Environmental Assessments (SEA) and Cumulative Effect Assessments (CEA) conducted in respective catchments, sub-basins (Upper or Lower Mekong) and river basins.
- Adopt a holistic approach to defining EIA scope: define spatial and time scales and key linkages between built structures impacts on fisheries and other relevant main sectors.
- Increase participation of stakeholders: strengthen public consultation in particular.
- Learning and adaptation: iteratively improve the process and integrate lessons back into the EIA process during implementation and for further EIA.
- Increase transparency of the built structure EIA process.
- Increase coordination between relevant government agencies: need for a shared commitment throughout project planning and implementation.
- Enhance and support political commitment of the Government of Cambodia.

5.5.2 Assessment of impacts on fisheries

- Adopt a holistic approach to defining the scope of fisheries assessment: to identify key issues and key interactions with relevant sectors.

- Carry out an integrated impact assessment: to understand and assess the whole fishery system and interactions, e.g. the ecosystem approach, especially for complex ecosystems such as the Tonle Sap.

- Use and develop methods (and enhancement of their use) that can deal with lack of data and scientific uncertainty

- Increase and optimize the use of available knowledge, including stakeholder knowledge and international scientific knowledge. The significant knowledge of fisheries ecology and socioeconomy in floodplain ecosystems can be better exploited.

- Promote the production and exchange of data on built structures and fisheries: design and implement simple data collection systems.

- Enhance participation of stakeholders in fisheries impact assessments.

- Improve valuation of Tonle Sap fisheries and respective ecosystem services.

- Adopt a holistic and integrated approach to identifying management measures and provide measures that are both feasible and efficient.

- Assess trade-offs between costs (including social and environmental) and benefits of built structure projects. Ultimately, this aims to inform CBA to support decision-making related to built structure development.

- Produce assessment and management results that can feed into regional assessment frameworks such as Strategic Environmental Assessment (SEA) and Cumulative Effect Assessment (CEA).

- Develop specific guidelines on assessment and management of impacts of built structures on Mekong fisheries.

6. CONCLUSION

The review of local built structure project EIAs with regard to the Tonle Sap fisheries has highlighted key constraints and limitations to performing impact assessments and processes. Limitations have been identified at various levels: some are specific to the scope and assessment of built structure EIAs, while others relate more generally to the EIA process conducted in Cambodia. The relatively short duration of this review did not allow either in-depth analysis or broad coverage of built structures because of the poor availability of information and difficulty in accessing local EIA reports. Strengthened stakeholder consultation and increased searches in relevant government agencies are critically needed.

The review shows that built structures are likely to have negative impacts on the Tonle Sap fisheries but they may also have positive impacts. Effects may originate from the built structure itself but also from the operational system (e.g. irrigation) and – although less considered in the EIAs under study - from the effects of subsequent economic development in the area (potential population increases, development of other smaller structures, etc.) triggered by the implementation of built structures, especially the construction of roads, dams and harbours. The principal negative effects arise from changes in river and tributary flows, the connectivity among aquatic habitats, and the degradation of water quality. Positive effects may result from increased production in irrigation reservoirs and decreased fishing efforts resulting from new livelihood alternatives brought by the built structure.

The review of EIA has highlighted the need for integrated assessment and management methods that can encompass the fishery system and key linkages with relevant sectors, especially farming for irrigation schemes. Management needs to assess and possibly quantify negative but also positive impacts in order to balance effects and analyse respective trade-offs. This would clarify the range of options available to stakeholders and support the decision- and policy-making relate to built structure development.

While increased integration and a holistic approach to the fishery system is required, EIA methods need to be feasible and appropriate to local resources, especially in balancing the accuracy of prediction that requires significant resources with achievable outputs and outcomes. This may be resolved in a two-speed process providing practical EIAs that assess key impacts on Tonle Sap fisheries while progressing towards more complex integrated assessments of fisheries impacts in the context of built structure development in the whole Tonle Sap ecosystem.

Increased transparency of EIA processes is urgently required, and making EIA reports widely available would be a useful first step. Public participation is needed to facilitate constructive debate, initiate resolution of difficult trade-offs and support stakeholder consensus on development choices. Increased local capacity in the EIA process should support improved monitoring of EIAs and exchange of information, as well as improved influence and authority of the MOE with the support of relevant ministries (esp. the MAFF, MOWRAM and MIME) to preserve the Tonle Sap aquatic ecosystem and fisheries.

In conclusion, improvements in EIA process and methods have a high potential for optimising the benefits of built structure projects while sustaining the aquatic ecosystem and fisheries of the Tonle Sap. This critically requires integrated impact assessment methods, enhanced participation of stakeholders, increased transparency of the process and political commitment for the institutional uptake of EIA procedures in a long-lasting way.

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ANNEX 1: List of projects that require IEE or EIA

Source: Annex of sub-decree No 72 ANRK.BK, 11 August 1999

Industry

I. **Foods, Drinks, Tobacco**
II. **Leather tanning, Garments and Textiles**
III. **Wooden production**
IV. **Paper**
V. **Plastic, Rubber and Chemicals**
VI. **Mining production other than metal**
VII. **Metal industries**
VIII. **Metal processing industries**
IX. **Other industries**
X. **Agriculture**
XI. **Tourism**
XII. **Infrastructures**

Foods, Drinks, Tobacco	
• Food processing and canning	> 500 tons/year
• All fruit drink manufacturing	> 1,500 liters/day
• Fruit manufacturing	> 500 tons/year
• Orange juice manufacturing	All sizes
• Wine manufacturing	All sizes
• Alcohol and beer breweries	All sizes
• Water supply	> 10,000 users
• Tobacco manufacturing	> 10,000 boxes/day
• Tobacco leaf processing	> 350 tons/year
• Sugar refineries	> 3,000 tons/year
• Rice and cereal grains mills	> 3,000 tons/year
• Fish, soy bean, chilli, tomato sources	> 500,000 liters/year
Leather tanning, Garments and Textiles	
• Textile and dyeing factories	All sizes
• Garment, washing, printing, dyeing	All sizes
• Leather tanning and glue	All sizes
• Sponge rubber factories	All sizes
Paper	
• Paper factories	All sizes
• Pulp and paper processing	All sizes
Plastic, Rubber and Chemicals	
• Plastic factories	All sizes
• Tire factories	> 500 tons/year
• Rubber factories	> 1,000 tons/year
• Battery industries	All sizes
• Chemical production industries	All sizes
• Chemical fertiliser plants	> 10,000 tons/year
• Pesticide industries	All sizes
• Painting manufacturing	All sizes
• Fuel chemicals	All sizes
• Liquid powder, solid soaps manufacturing	All sizes

Mining production other than metal	
• Cement industries	All sizes
• Oil refineries	All sizes
• Gas factories	All sizes
• Construction of oil and gas pipelines	> 2 km
• Oil and gas separation, storage facilities	> 1,000,000 liters
• Fuel stations	> 20,000 liters
• Mining	All sizes
• Glass and bottle factories	All sizes
• Bricks, roofing tile manufacturing	> 150,000 pieces/month
• Flooring tile manufacturing	> 90,000 pieces/month
• Calcium carbide plants	All sizes
• Producing of construction materials	> 900 tons/month
• Motor oil manufacturing	All sizes
• Petroleum study research	All sizes
Metal industries	
• Mechanical industries	All sizes
• Mechanical storage factories	All sizes
• Mechanical and shipyard enterprises	All sizes
Metal processing industries	
• Manufacturing of barbed wires, nets, etc	> 300 tons/month
• Steel, iron, aluminium mills	All sizes
• All kinds of smelting	All sizes
Other industries	
• Waste processing, burning	All sizes
• Waste water treatment plants	All sizes
• Power plants	> 5 MW
• Hydropower	> 1 MW
• Cotton manufacturing	> 15 tons/month
• Animal food processing	> 10,000 tons/year
Agriculture	
• Forest concessions	> 10,000 ha
• Logging	> 500 ha
• Land covered by forest	> 500 ha
• Agriculture and agro-industrial land	> 10,000 ha
• Flooded and coastal forests	All sizes
• Irrigation systems	> 5,000 ha
• Drainage systems	> 5,000 ha
• Fishing ports	All sizes
Tourism	
• Tourism areas	> 50 ha
• Golf courses	> 18 holes

Infrastructure

• Urbanization development	All sizes
• Industrial zones	All sizes
• Construction of bridge-roads	> 30 tons-weight
• Buildings	Height > 12 m or floor > 8,000 m2
• Restaurants	> 500 seats
• Hotels	> 60 rooms
• Hotels adjacent to coastal areas	> 40 rooms
• National road construction	> 100 km
• Railway construction	All sizes
• Port construction	All sizes
• Airport construction	All sizes
• Dredging	> 50,000 m3
• Dumping sites	> 200,000 people

ANNEX 2: List of EIA reports identified in the main relevant ministries

Ministry of Environment

Public projects (2 approvals and 4 monitoring)

1) EIA report on the Greater Mekong Sub-region (GMSR) project about communication in Kandal province, Takeo province, Kampot province and Sihanoukville of Ministry of Post and Telecommunications, which was approved on 12 January 2005.
2) EIA report on Water Supply project at Tbong Khmum village and Kangmeas village in Kampong Cham province of MIME, which was approved on 05 May 2005.
3) EIA report on the Built structure of Economic area project especially SEZ at autonomous port in Sihanoukville, which it is monitoring.
4) EIA report on Construction road 64 project from intersection of road number 6 in Kampong Thom through Preah Vihear province of MPWT, which it is monitoring.
5) EIA report on Electricity network of the Greater Mekong Sub-region (GMSR) Link from Vietnam to Phnom Penh Electricity of Cambodia, which it is monitoring.
6) IEIA report on master plan of water supply in Phnom Penh (2nd degree), which Phnom Penh Authority Supply is monitoring.

Private projects (9 approvals and 2 monitoring)

7) IEIA report on Golf course project for 18-hole golf playing at Poun village in Siem Reap for Royal report company and KANTRI Club Co. Ltd. which was approved on 13 September 2005.
8) Environmental and Social Impact Assessment report on Gem Commercial project in 3 villages are Lumphat and Ratanakiri province for Seoul Digem Cambodia Co., Ltd, which was approved on 22 September 2005.
9) Environmental and Social Impact Assessment report on Gem Commercial project at Patingthom area, Tinchak commune, Borkeo district in Ratanakiri for Ultra Marine Kiri (Cambodia Co., Ltd.) which was approved on 22 September 2005.
10) Environmental and Social Impact Assessment report at Sen Chao area in Samlot district in Battambang province for Ultra Marine Kiri (Cambodia Co., Ltd.) which was approved on 22 September 2005.
11) IEIA report on Development Eco-tourism project in Ream Park area in Sihanoukville for Yee Jia Development Company, which was approved on 23 September 2005.
12) IEIA report on Development of Eco-Tourism at Tetek Puf in Kampong Speu province for NewCosmos Development (Cambodia) Co., Ltd, which was approved on 23 September 2005.
13) Environmental and Social Impact Assessment report on alkali commercial project at Prak Mountain area, Oral district in Kampong Speu province for Future Environment Co., Ltd, which was approved on 23 September 2005.
14) IEIA report on Construction of Petroleum and Pump Petroleum project at Otre in Sihanoukville for Tela Petroleum Group Investment Co., Ltd, which was approved on 19 October 2005.
15) Environmental and Social Impact Assessment report on sand construction commercial project in Kuntheavy Island, Lekdek district in Kandal province and Check Island, Peamchor district in Prey Veng province for Khmer Dynastic International Co., Ltd, which was approved on 20 October 2005.
16) EIA report on Granted Land Project at Botum Sakor Park in Koh Kong for Greenrek Co., Ltd, which it is monitoring.
17) IEIA report on project of restaurant construction of NEXUS NAGA HOTEC in Phnom Penh for NAGA Resorts and Casinos Limited, which it is monitoring.

Appendix 5 Livelihoods Component Technical Reports

- Influence Of Built Structures On Local Livelihoods

- Enabling Alternative Livelihoods For Aquatic Resource Dependent Communities Of The Tonle Sap

Asian Development Bank
TA 4669-CAM

Technical Assistance to the Kingdom of Cambodia
for the Study of the Influence of Built Structures
on the Fisheries of the Tonle Sap
(financed by the Government of Finland)

Livelihoods Component

INFLUENCE OF BUILT STRUCTURES ON LOCAL LIVELIHOODS

Case studies of road development, irrigation and fishing lots

Prepared by

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CONTENTS

FIGURES

ANNEXES

KEY TERMS USED IN THIS REPORT

Buffer zone. A zone that usually surrounds or adjoins core areas and is used for cooperative activities compatible with sound ecological practices, including environmental education, recreation, ecotourism, and research. In the Tonle Sap Biosphere Reserve, a buffer zone of about 5,400 square kilometers (km2) surrounds the core areas up to the outer limit of the flooded forest.

Commune council. In Cambodia, an elected body that governs commune administration. In addition to fulfilling their administrative tasks, commune councils participate in informal dispute resolution, plan and implement development projects, do some agency functions for the central and provincial governments, and conduct advocacy. Development activities consist mainly of small-scale infrastructure and public goods projects.

Community management. The community-based management of local natural resources, including certain designated fishing areas, with support from relevant authorities, institutions and organizations. Examples relevant to this report include community fisheries committees, road committees as well as farmers' water user groups.

Core areas. Securely protected sites for conserving biodiversity, monitoring minimally disturbed ecosystems, and undertaking research and other low-impact uses such as education. In the Tonle Sap Biosphere Reserve, core areas are in Prek Toal (213 km^2), Battambang; Boeng Tonle Chhmar (Moat Kla) (145.6 km^2), Kampong Thom; and Stung Sen (63.5 km^2), Kampong Thom.

Chronic poverty. Describes the condition of households who remain poor over time. In this study, the "**chronic poor**" describes those households that remained poor between the period prior to the change in built structure studied and the current period, as defined by household surveys. Those "**vulnerable to chronic poverty**" were previously in the non-poor group but then fell below the poverty line; those who moved "**out of poverty**" were previously in the poor group but then managed to move above the poverty line. The "**non-chronic poor**" includes these two latter groups plus those who were above the poverty line during both time periods. See also 'Poverty'.

Flooded forest. A descriptive term for the natural vegetation that originally covered most of the Tonle Sap's floodplains. It is now characterised by low forest and shrubs that contribute to the fisheries productivity of the Tonle Sap.

Gini coefficient. A measure used to describe income inequality. In this study, it is used to describe income inequality among households within a village. The coefficient is provided as a fraction between 0 and 1, where a higher number indicates greater inequality. Here, 0 corresponds to perfect income equality (i.e. everyone has the same income) and 1 corresponds to perfect income inequality (i.e. one person has all the income, while everyone else has zero income).

Livelihood. The capabilities, assets, and activities required for a means of living. A livelihood is sustainable when it can cope with stresses and shocks and maintain or enhance itself in the present and in the future without undermining the natural resource base.

Livelihood approach. A way of thinking about the objectives, scope, and priorities for development. It reinforces positive aspects and militates against constraints or negative influences. Its core principles are that poverty-focused development should be people centered, responsive, and participatory; multilevel; conducted in partnership; sustainable; and dynamic. It puts people at the center of development.

Poverty. The state of being deprived of the essentials of well-being such as adequate housing, food, sufficient income, employment, access to required social services and social status. Poverty is usually measured with reference to a **poverty line**; if a household earns an income lower than a set amount, that household and its members are deemed to be living in poverty. In this study, the measure of poverty includes cash income as well as a dollar-value equivalent for household production (such as rice or fish catch) consumed by the family. See also 'Chronic poverty'.

Social capital. The networks of relationships among persons, firms, and institutions in a society, together with associated norms of behavior, trust, cooperation, etc., that enable a society to function effectively. It is measured by the degree to which a community collaborates and cooperates to achieve mutual benefits.

Transition zone. An area in which stakeholders work together in a variety of economic and other activities to manage and sustainably develop a biosphere reserve's natural resources. In the Tonle Sap Biosphere Reserve, a transition area of about 9,000 km^2 lies between the outer boundary of the buffer zone and Highways No. 5 and No. 6.

VILLAGE NAMES AND DESCRIPTIVE NAMES USED IN THIS REPORT

1. Road development case study, Pursat province:

Chong Khlong	Cham village near the road
Ou Ta Prok Main	Khmer village near the road
Ou Ta Prok Up	Khmer village far from the road

2. Irrigation case study, Kampong Thom province:

Snao	Head-user village
Sa'ang	End-user village

3. Fishing lot case study, Battambang province:

Thvang	Village far from Tonle Sap Lake
Prek Toal	Village near Tonle Sap Lake

ACRONYMS USED IN THIS REPORT

ADB	Asian Development Bank
CF	Community fishery
CFA	Community fishery area(s)
NGO	Non-governmental organization
TSL	Tonle Sap Lake
SLF	Sustainable Livelihoods Framework

EXECUTIVE SUMMARY

1. This report documents the results from an assessment of the influence of built structures on the livelihoods of Tonle Sap communities, as part of the livelihoods component of the "Study of the Influence of Built Structures on the Fisheries of the Tonle Sap". The livelihoods component aims to identify the links between built structures and socioeconomic change with a specific emphasis on fisheries, and aims to ensure that the analysis and recommendations regarding the influence of built structures incorporate the knowledge, perspectives and insights of people living in the immediate surroundings of the built structures.

2. This study examines cases involving three different types of built structures: road development in Pursat province, irrigation development in Kampong Thom province, and fishing structures along with associated management systems, in Battambang province.

3. Two field research approaches were employed simultaneously, namely quantitative analysis using household surveys (using semi-structured questionnaires with open-ended questions as well as ranking and rating questions) and qualitative analysis using a combination of key-informant interviews and group discussions and exercises (participatory village survey methods). These two approaches were selected to enable direct assessment of key observable and perceived influences of the built structures as well as to gauge communities' understanding of the interconnectivity between their livelihoods, environment, aquatic ecosystems and built structures.

4. The type of built structure clearly influences how direct benefits are distributed. The case studies illustrate that different types of built structures (roads, irrigation schemes, fishing gears) have different degrees of openness or exclusion in terms of the ability of poor households to access the livelihood opportunities enabled by the structures. Overall, roads are most open as they provide public access with no direct exclusion. Irrigation is meant to bring livelihood benefits by increasing the seasonal availability of water, but still to a limited group, i.e. for landholders within the irrigation scheme and possibly for laborers and marketers nearby. In addition, the irrigation reservoir creates a new open access resource for fishing, although the access to the reservoir may be limited by different kinds of regulation and management practices. Fishing structures of the lots are clearly most exclusive as they funnel benefits to a small group and exclude the majority from the fishing area.

5. Yet there is also much we can say that applies across different types of built structures in different social and ecological settings. Institutions matter quite significantly, in ways that enable positive livelihood strategies (for example, through effective participation and consultation in project planning), and that disenable opportunities for the poor (for example, through mechanisms that reinforce inequitable access to aquatic resources and their livelihood benefits). Scale also matters, as many of the factors that either threaten local livelihoods or open new opportunities are not within the direct influence of local communities. The cross-scale factors that emerged as significant in the case studies include such issues as seasonal migrants making use of community fishing grounds, markets that develop to provide for a demand for local products (e.g. pig rearing), and, of course, environmental factors, including the relationship between hydrological change, habitat, and fisheries productivity.

6. Built structures – by definition, purposeful modifications to the physical environment – clearly do affect livelihood outcomes, but they are by no means a "magic bullet." This study examined the influence of changes in both directions, namely interventions to introduce new (or improved) structures as with roads and irrigation, and interventions to remove structures (large fishing gears associated with the fishing lot). In all cases, the changes were justified on the grounds of poverty reduction.

7. Progress in poverty reduction has been modest, and inequality remains high. While it will be some years before the outcomes in these particular cases can be measured conclusively, the results already raise a justifiable concern. The ability of individual households to take advantage of changes depends very clearly on other assets, especially education. In certain contexts, other assets such as livestock holding may be key, and smaller family size may be an advantage. These observations signal the need to pay close attention to the livelihood context in which changes are being introduced, and the ways in which different households may or may not be able to benefit. In essence, it means considering infrastructure as one element in a broad array of useful investments to encourage pro-poor rural development.

Recommendations

8. **Link planning of new structures to decentralised natural resources management.** Planning, construction, and operation of built structures cannot operate in a vacuum, but must have strong connections both to long-term management of the Tonle Sap's natural resources and to local development planning. The case studies indicate that the best way to ensure community involvement and ownership is to link planning of built structures to on-going processes of decentralised rural development and natural resources management. In advance of the physical infrastructure, it is often necessary to strengthen local institutional capacity to address the new challenges for collective decision-making.

9. **Strengthen institutional mechanisms to integrate decision-making across sectors and geographic scales.** Social, economic, and ecological trade-offs stemming from alternative scenarios of infrastructure and water resources development need to be explicitly evaluated and publicly debated. Government policies and strategies should clearly prioritize the relative importance of different social and economic benefits derived from the fisheries of the Tonle Sap Lake. Efforts are also needed to overcome the communication gaps between different sectoral ministries.

10. **Adopt processes of consultation and participation in project planning that recognise the differences among local households.** More attention must be paid to participation and ownership from the very initial stages of project planning. At the planning stage, it is important to analyze sensitively how the anticipated benefits and costs of a project are likely to be distributed among different social groups, taking into account the role of local institutions and differences in household assets. Special provisions also need to be made so that the poorest groups can indeed participate effectively.

11. **Target built structure investments with an understanding of how the poorest groups can benefit.** Even when the net benefits of infrastructure

developments in terms of average household income appear to be positive, the poorest groups can be left behind. Addressing these distributional issues requires reconsidering priorities in terms of the links between infrastructure development and changes in livelihood opportunities, as well as types of infrastructure and their scale and complexity of operations. It means favoring investments in structures with high degrees of openness in terms of social groups that can access the benefits. And it means, where feasible, favoring smaller-scale projects that are more easily adapted to local needs, more easily managed locally, and less attractive for elite capture.

12. **Plan complementary investments to address the asset gaps of poorer groups.** Many households fail to take advantage of the livelihood opportunities offered by built structures because they lack other essential assets. Alongside infrastructure improvements, investments in basic education, training and technical support services, and credit may be needed, as well as support to community organizing capacity.

I INTRODUCTION

13. This report documents the results from an assessment of the influence of built structures on the livelihoods of Tonle Sap communities, as part of the livelihoods component of the "Study of the Influence of Built Structures on the Fisheries of the Tonle Sap"[1]. The livelihoods component aims to identify the links between built structures and socioeconomic change with a specific emphasis on fisheries, and aims to ensure that the analysis and recommendations regarding the influence of built structures incorporate the knowledge, perspectives and insights of people living in the immediate surroundings of the built structures.

14. The present study assesses possible changes in people's livelihood strategies and outputs, including those derived from fisheries, particularly in terms of changes in livelihood portfolios, vulnerability, resource access and income. It also summarises local people's perceptions of the connections between their livelihoods, environment, aquatic ecosystems and built structures, as well as their viewpoints on best practices for built structures with a specific focus on institutional arrangements.

15. A variety of other research studies in Cambodia have highlighted the importance of natural resources for people's livelihoods and people's strong dependence on them. These studies also emphasise the diversity and seasonal change in livelihood sources of rural households. Of particular note is the TA supported by the ADB as part of the preparation of the Tonle Sap Sustainable Livelihoods project – Phase 1 (ADB 2004a). An extensive participatory rural appraisal (PRA) documented the importance of fishing not only to the livelihoods of those living in the core zone of the biosphere reserve, but also to those in the transition zone. It also showed that food insecurity (essentially rice deficit) is perennial for landless and land-poor households in the lowland areas, and that a key consequence of this is increased harvesting of fish, animals, reptiles, fuelwood, building materials, and non-timber products from the flooded forests. Finally, it documented an interest in livelihood diversification among residents of the core zone and buffer zone based on a perceived decline in the fisheries resource, and a high demand among villagers in the transition zone for irrigation improvements to reduce livelihood vulnerability. Such findings help explain why there is a strong push for infrastructure development around the lake, and why the potential influence of these built structures on fisheries resources and livelihoods merit attention.

16. Yet few studies in the country have looked specifically at livelihoods in the context of built structures, or the influence of built structures on livelihoods. The analysis presented in this report seeks therefore to complement existing studies by evaluating both quantitatively and qualitatively the role of built structures in sustaining the livelihoods of the people living close to the built structures. The study considers both enabling and disenabling aspects of built structures, and consequently both positive and negative livelihood outcomes associated with them, with analysis based on the Sustainable Livelihoods Framework (SLF).

17. The study looks at the local influences of the selected built structures in their immediate surroundings. Consequently, the analysis of the livelihood outcomes, benefit and cost allocation and changes in vulnerability is done among the direct intended beneficiaries of different built structure projects. The study illustrates the complexities of the benefit allocation from the built structures, pointing out issues that should be taken into account when planning new structures and assessing their viability and contribution to poverty

[1] Asian Development Bank TA 4669-CAM "The Study of the Influence of Built Structures on the Fisheries of the Tonle Sap". Hereafter referred to as the Built Structures study.

reduction[2]. The focus on the local influences is, however, also a limitation, as the study does not address the issue of built structures' influence on fisheries (or other livelihood implications) outside the project areas. Thus, for example the downstream impacts on fisheries or the cumulative impacts on the livelihoods dependent on the natural resources of the Tonle Sap are not assessed within this study. Such influences at broader geographic scales are, however, addressed partly by the other project components. For example, the hydrology component looks at cumulative impacts of built structures on the Tonle Sap's flow regime, while the fisheries component includes a preliminary assessment of the influence on downstream and upstream fisheries. An upcoming synthesis report will employ findings from each of the component studies to characterise trade-offs associated with built structures in the Tonle Sap more comprehensively. This should also offer at least an indication of the livelihood implications in other areas not included in the present report.

II METHODOLOGY

18. Two key field research approaches were employed simultaneously, namely quantitative analysis using household surveys (using semi-structured questionnaires with open-ended questions as well as ranking and rating questions) and qualitative analysis using a combination of key-informant interviews and group discussions and exercises (participatory village survey methods). These two approaches were selected to enable direct assessment of the key observable and perceived influences of the built structures as well as to gauge communities' understanding of the interconnectivity between their livelihoods, environment, aquatic ecosystems and built structures.

19. As the two approaches build on different kinds of research methods, they provide different types of information that complement each other. For both household and participatory village surveys, two or three villages were selected in each study area to cover villages with varying characteristics, in terms of livelihood assets and seasonal vulnerabilities, and in terms of the possible direct influences of the built structures, their locations, and the prominence of fishing as a livelihood strategy in the communities. The information was analysed to assess the possible influence of built structures on the livelihoods of the communities in the study areas, particularly in terms of activity patterns, resource access, and income. Qualitative analysis was focused on capturing local people's perceptions of the interconnectivity between livelihoods, environment, aquatic ecosystems and built structures, as well as their viewpoints on best practices for built structures. The findings were synthesised using the Sustainable Livelihoods Framework as an organizing tool to describe the often complex relationships between built structures and livelihood outcomes. Each of these elements of the research approach is summarised below.

II.1 QUANTITATIVE ANALYSIS USING HOUSEHOLD SURVEYS

20. The quantitative analysis focused on the impact of built structures on livelihood activities, income, income sources and income portfolios, vulnerability and food security and the role of asset endowments. Existing studies provide a rich basis of comparative information on the general socioeconomic characteristics of communities in the Tonle Sap Basin, including diversity of their livelihood portfolios and the range of assets that they have at hand (see for example, Rab *et al.* 2005). However, none of these measure the specific impact of built structures, which is the rationale for undertaking additional, focused

[2] The results of the livelihoods component will thus be useful also to other projects designed to improve livelihoods opportunities for vulnerable communities in the Tonle Sap area, particularly the ADB-supported Tonle Sap Sustainable Livelihoods and Tonle Sap Lowland Stabilization projects.

surveys and analysis. Quantitative analysis focused on drawing inferences about the cause and effect relationship between built structures and livelihoods, food security and vulnerability. As such, it provides an important complement to the qualitative methods (described below), which focus on people's perceptions of past and potential future changes.

21. In brief, the quantitative analysis used household survey data to:

- assess changes in affected communities in terms of:
  - activity/occupation patterns
  - income, income portfolio and distribution
  - number and distribution of vulnerable households
  - consumption patterns and food security
  - access to resources, infrastructure and markets
- analyze the role of asset endowments on changes in income, income portfolio, vulnerability and activity patterns.

22. Sound quantitative analysis requires good information on rural livelihoods from a representative sample of households in the seven selected villages around the three built structure types. In order to generate information, the research team used a combination of data collection methods in a two-step approach:

- Step 1: key-informant interviews to gather overview information on livelihood activities, population, infrastructure, problems, etc.
- Step 2: household surveys to gather information on demographics and education, activities/occupation, access to resources, income, assets, housing and sanitation, access to credit and infrastructure, and perceptions about the influence of built structures on livelihood outcomes

23. To ensure that the information gathered was representative of the communities concerned, a *purposive stratified random sampling* approach was used. Households in the study villages were stratified, using information from Step 1, into four stratums on the basis of their main income generating activity: 1) fishing, 2) farming, 3) fishing plus farming, 4) other (non-farm & non-fishing activities). These households were further stratified by wealth status into rich and middle, poor and very poor. From each stratum 5-15 households were selected. This resulted in a total sample of 80 households in Pursat (road development) and 90 each in Kampong Thom (irrigation project) and Battambang (fishing lot), thus comprising 260 households in total.

24. In analyzing the survey data, income was estimated based on all livelihood activities as a sum of both cash and in-kind income sources, including those sold and retained for household consumption. Comparative analysis examined the contribution to total income by activities and the percentage of households engaged in each activity by study site, by village, and by income group, and assessed the change between two time periods – before the change in built structure versus the present time. The period of comparison varied between 2 and 5 years, according to the case. Additional analysis examined changes in the number of households below the poverty line, the depth of the poverty gap, income distribution and changes in income and assets, and the strength of statistical correlation between various measures of household assets and chronic poverty.

II.2 QUALITITATIVE ANALYSIS BASED ON LOCAL PERCEPTIONS

25. The aim of the qualitative case studies was to study local perceptions and local knowledge about the built structures and their influence on livelihoods. The analysis also looked at institutional arrangements in connection with built structures and local

viewpoints on best practices related to them. The qualitative approach of the livelihoods component was based on different Rapid Rural Assessment (RRA) methods, but the approach also made use of methods commonly applied in Participatory Rural Appraisals (PRA).

26. The qualitative case studies focused on the village level, but also included key-informant interviews at the provincial and district levels, with key-informants from case study projects, line agencies and NGOs. Main methods used in the qualitative case studies consisted of key-informant interviews, group discussions and exercises, and in-depth individual interviews (Figure 1). The number of interviewees differed between the case studies, but on average the group of villagers included around 10 people, while the number of key-informants (both during pre-survey and the actual survey) was between 5 and 10 people.

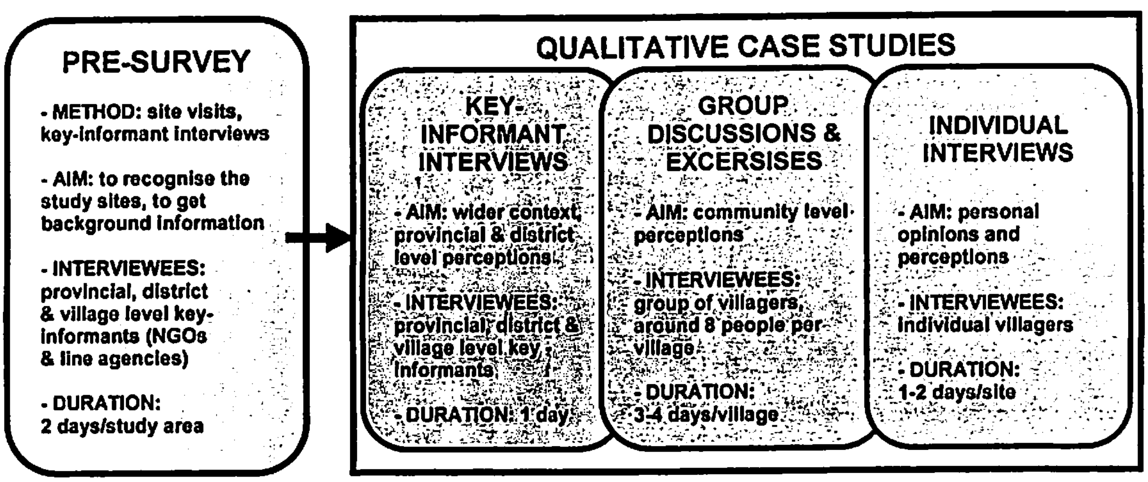

Figure 1. Details of the qualitative approach and case studies

27. The qualitative analysis focused on:

- identification of different classes of stakeholders in relation to built structures, and
- information regarding perceptions of the interconnectivity between built structures, environment, aquatic resources and livelihoods; ideas on possible alternative livelihoods, and viewpoints on best practices for (a) planning, (b) building, and (c) operating built structures.

28. The analysis of qualitative information was based on thematic analysis of detailed field notes from the surveys. The discussions[3] and interviews in different case study areas and with different stakeholders were written down into field notes and translated into English. In addition, part of the discussions and interviews were also recorded, allowing use of direct quotes of local perceptions. The information available from surveys—complemented by available literature—was then analysed according to themes building on the Sustainable Livelihoods Framework.

[3] As the focus was on the discussions that emerged during the surveys, different kinds of group exercises (e.g. rankings) were also aimed at facilitating discussions, rather than producing an end product in the form of a matrix or table.

II.3 SYNTHESIS OF FINDINGS USING THE SUSTAINABLE LIVELIHOODS FRAMEWORK

29. The Sustainable Livelihoods Framework (SLF) builds on the following overall idea: "A livelihood comprises the capabilities, assets and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base" (DFID, 2001). The SLF looks at livelihoods and their development with the help of different kinds of livelihood assets, livelihood strategies, vulnerability contexts, transforming processes and access to resources and institutions (ADB, 2004). As highlighted by ADB (2004), the SLF "brings attention to the inherent potential of people in terms of their skills, social networks, access to physical and financial resources, and ability to influence core institutions". The SLF is based on "evolving thinking about poverty reduction, the way the poor and vulnerable live their lives and the importance of structural and institutional issues" (ADB, 2004).

30. Within the Built Structures study, the SLF has been used in analysing how specific built structures undermine and/or enhance different livelihood opportunities. The framework provides a way of considering the dynamic linkages between built structures and livelihoods, including the role of institutional structures and processes. It also helps in applying findings to other projects that have employed a similar framework.

31. Because the objective of the Built Structures study differs from the occasions where the SLF is normally applied, a slightly modified framework was employed based on the framework developed by Carloni & Crowley (2005) for the FAO. The main difference is that instead of focusing on the actual development of livelihoods, the aim of the Built Structures study was to look at the interconnections between livelihoods, environment, natural resources and physical capital (built structures), and analyse how physical capital impacts –either positively or negatively – the natural capital (particularly fish resources) as well as livelihoods of different social groups. Figure 2 captures how the SLF was applied within this study.

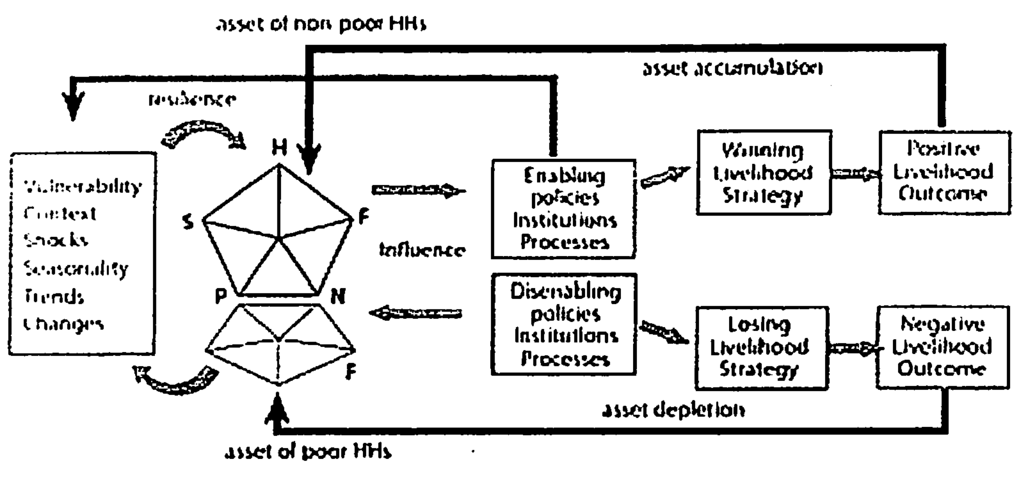

Figure 2. The modified Sustainable Livelihoods Framework with enabling and disenabling processes for livelihood development (Carloni & Crowley 2005)

32. In the context of this livelihoods study, the objectives of the Built Structures study have been addressed within the Sustainable Livelihoods Framework by:

1. Considering both enabling and disenabling aspects of built structures or associated institutions, and consequently both positive and negative livelihood outcomes
2. Analysing how different social groups are affected by built structures by identifying different stakeholders and analysing reasons behind (possible) differential allocation of benefits and losses linked to built structures
3. Analysing quantitatively in more detail how the households' ability to take advantage of opportunities provided by the studied built structures depends on households' assets
4. Looking at the wider institutional context, management practices and different ways of implementing existing rules in enabling and disenabling the livelihoods of different social groups, and considering institutional and management processes in different levels of planning, building and operating the built structures.

III RESULTS

33. The overall TA, "Study of the Influence of Built Structures on the Fisheries of the Tonle Sap," considers the influence of built structures at three geographic scales – Mekong Basin, Tonle Sap Lake, and local study sites. All findings from this present study on livelihoods are at the local scale. Results are presented in this section first by individual case study, then comparative results across the three cases are presented.

III.1 CASE STUDY 1. ROAD DEVELOPMENT IN KRAKOR DISTRICT, PURSAT PROVINCE

III.1.1 Context: Linking road development to livelihood outcomes

34. Roads are often assumed to be central in triggering growth in rural areas (see e.g. ADB 2006b; ADB 2004c; Cambodia New Vision 2001; Gannon and Liu 1997; IFRTD 2005). Rural roads have potentially several benefits: they connect people to markets, and farmers get better prices for their products; they provide incentives to produce crops for sale, and they enable better information sharing which facilitates livelihood development. Roads enhance access to health, education and other amenities. Rural roads also open villages for development interventions as both state actors and NGOs have better access to them. Without roads or other types of transportation networks (e.g. canals), rural areas face economic isolation and stagnation (see e.g. ADB 2006b; ADB 2004c; Gannon and Liu 1997; UN Millennium Project 2005).

35. Different studies indicate that impacts of roads on livelihoods depend on several factors and are not straightforward (see e.g. Howe and Richards. 1984). The assumption that roads generate positive development has been questioned by findings of negative economic and social effects (Simon 1996). Poverty is not always reduced as planned or expected, but just redistributed or even increased. It is often the case that roads provide new opportunities for those who already have a good asset base, while the poorest groups may not be able to take full advantage of the enhanced infrastructure (Taylor 2004). With the increased price of land, poor people are either forced or tempted to sell their land and move elsewhere, thus risking being even further away from markets and services (ibid.).

36. There are also environmental risks related to road construction. In wetlands or floodplains, building roads may alter flood patterns, fragment the habitat for fish and other aquatic animals, and create barriers for fish migration. When a road forms a barrier to the flood, it can worsen flooding in other areas and can reduce benefits derived from floods. In the Tonle Sap area, the roads in floodplains may, on one hand, enhance access to the flooded forests and increase income, but they may, on the other hand, result in unsustainable exploitation of these resources. On the whole, the impacts of roads in floodplains are not well studied, and even less so in Cambodia. There is, however, an on-going WWF-MRC project on roads' impact on floods in Cambodian floodplains and deltas, which aims to set standards for environmentally friendly design and engineering practices for roads[4].

III.1.2 Road development at the study site

37. The case study site is located in Krakor district of Pursat province. Stung Pursat (Pursat River) is the main tributary in the province, with a large number of new construction works

[4] The project 'Roads and Floods: Developing Economically Sound and Environmentally Friendly Guidelines' is due to finish in 2008.

within its basin. These include five proposed dams and at least ten irrigation and water management projects, such as river diversions, reservoir upgrading and flood control dykes. Most of the projects are still at the planning or construction stage, and their impact is therefore not well known yet. Pursat province is also part of the ADB-funded Northwest Irrigation Project and it has been wisely selected – given the high number of planned projects – as an ADB pilot site for integrated river basin management.

38. Although planned irrigation structures are likely to have a remarkable impact in the Pursat sub-basin, it was decided that the case study in Pursat would be focused on roads. There are three main reasons for this decision: firstly, the (re)construction of the roads in the study area had already been completed, and the roads-dyke system therefore offered a good opportunity to study its impacts on floodplain fragmentation and loss of fish habitat as well as more broadly its social implications. Secondly, the decision to focus on roads enabled the project to cover a variety of different types of built structures around the Tonle Sap. Thirdly, the case study on irrigation schemes was already carried out in Kampong Thom, and it was assumed that at least some of the findings and recommendations from there could be applied to planned irrigation projects in Pursat.

39. The road in the case study area is a seven kilometre long secondary/tertiary road and it is built on a natural levee. It was selected for study in part because it runs parallel to the lake bank, thus raising the possibility that it might interrupt water flows and fisheries. The road passes through three communes, namely Ou Sandan, Boeng Kantout and Kampong Pou (Figure 3). There has been a very low quality oxcart road in the area since 1970s, while a better clay road was built with support from CONCERN (an international NGO) in 1995. In 2003 the road was rehabilitated into a gravel road under the Seila Program. At the same time the embankment was elevated and communal road committees were established with two representatives from each village (village chief + one member) and three members from the commune council.

40. As there are the same kinds of areas in the province without proper road connections, it is likely that similar roads will also be built in the area in the future. When compared with some of the other provinces around the Tonle Sap, the road development in Pursat's floodplains has been moderate. The densest network of roads in the Tonle Sap floodplains currently exists in Siem Reap province, where the negative environmental impacts of the roads are most probably more severe than in Pursat.

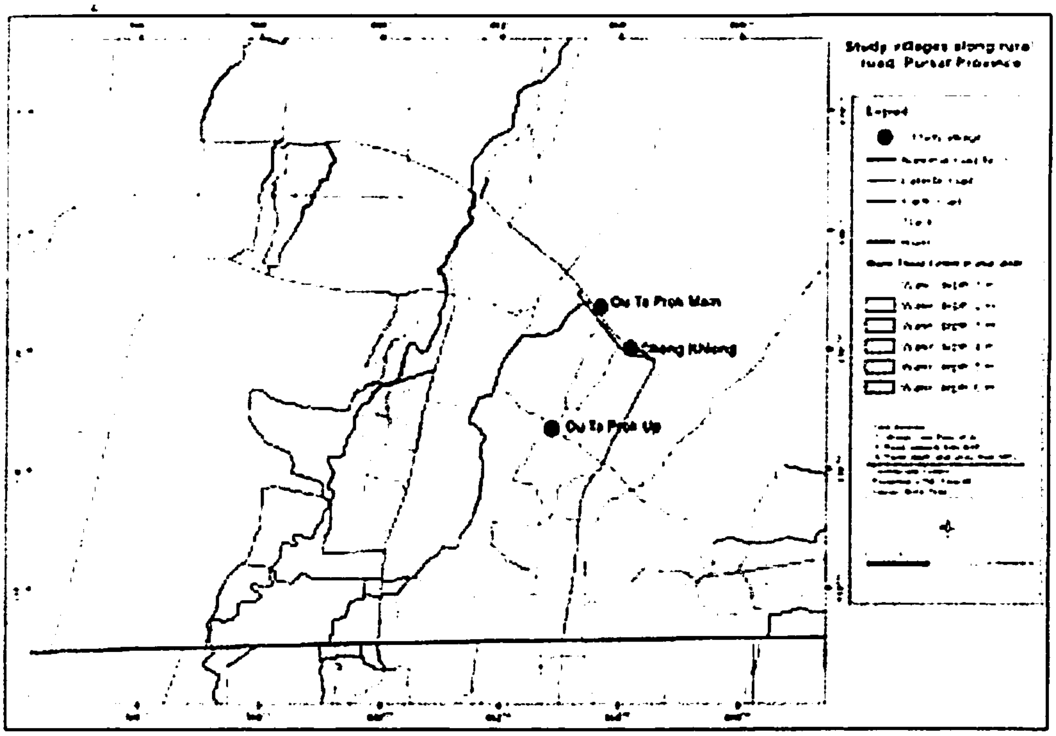

Figure 3. Map of study villages at the road development study site, Pursat province

41. At the same time, the rehabilitation of the national road — the major road running through the province -- has led to enhanced access to the Tonle Sap's natural resources. Some key-informants have observed that the price of the land around the national road has increased, and outsiders from urban centres have started to move in and buy land areas for cash crop cultivation. Although these trajectories are outside the scope of this case study, they do influence the development of the case study area and the whole Tonle Sap Basin.

III.1.3 Characteristics of the study villages and livelihood assets

42. The case study in Pursat has two different levels of analysis, involving three villages. Firstly, the case study compares Chong Khlong and Ou Ta Prok Main, which are both located along the new road but yet have distinct differences in terms of ethnicity and financial and social capital. While all the inhabitants in Chong Khlong consist of the Chvea minority group (a subgroup of Cham Muslims), Ou Ta Prok Main is a Khmer village. Secondly, the case study compares these two villages with Ou Ta Prok Up which is another Khmer village located 2 km upland from the road. The aim of this comparison is to examine the role of differences in terms of villages' proximity to the road. Thus, Chong Khlong is also referred to as the 'Cham village near the road,' Ou Ta Prok Main as the 'Khmer village near the road,' and Ou Ta Prok Up as the 'Khmer village far from the road.'

43. The survey indicates that Chong Khlong is better endowed than Ou Ta Prok, which is also validated by prior village survey data from 2002 to 2004 (SEILA Commune Database 2006; see Annex A, Table 1). Over 90 percent of the households in the three villages are engaged in rice farming and almost 80 percent in fishing (Table 1, see also Annex A, Table 2). On average, fishing is the most important source of income (in cash and in kind). However, other livelihood sources are also important. In Chong Khlong, fishing, followed by rice farming, farm labour and petty trade are the main livelihood sources, whereas in Out Ta Prok Main and Out Ta Prok Up, fishing, rice farming and livestock

(particularly pig rearing) are the main sources of livelihoods. Being a Muslim community, Chong Khlong does not have a piggery.

44. The main sources of income in the survey villages are fishing and rice farming. The estimated average household income of Chong Khlong is highest at around US$ 653, followed by Ou Ta Prok Up at US$ 569 and lowest for Ou Ta Prok Main at US$ 459 (Table 1; details in Annex A, Table 3). The major differences in financial assets seem to result partly from remittances from overseas, particularly in Chong Khlong. It may also be linked to the differences in social capital. While Ou Ta Prok has more localised social contacts, Chong Khlong has more connections to outside the village, including even some global networks, resulting therefore in better information. It seems also that Chong Khlong has better connections to those holding positions of power, such as their Cham patron in the National Assembly. Further, while both villages have some indigenous associations, they seem to be more active and better organised in Chong Khlong, possibly associated with religion. Based on the key-informant interviews and the field observations, there is an impressive internal re-distribution mechanism of wealth to the village's poorest groups and students in Chong Khlong.

	Chong Khlong	Ou Ta Prok Main	Ou Ta Prok Up	Pursat case (combined)
Village location and proximity to the road	Along the road	Along the road	2 km upland from the road	
Ethnic group	Cham	Khmer	Khmer	
Main livelihood activities (% households participating)	Rice farming 91%	Rice farming 90%	Rice farming 100%	Rice farming 93%
	Fishing 82%	Other 76%	Livestock 93%	Fishing 79%
	Other 75%	Livestock 70%	Fishing 87%	Other 79%
	Other crops 58%	Fishing 60%	Other 78%	Livestock 66%
	Livestock 56%	Farm Labour 45%	Other crops 47%	Other crops 51%
Main sources of income (% total income)	Fishing 32%	Rice farming 27%	Fishing 33%	Fishing 29%
	Rice farming 17%	Livestock 21%	Rice farming 19%	Rice farming 19%
	Fish related 13%	Fishing 16%	Others 19%	Other 13%
	Other 12%	Petty trade 16%	Livestock 13%	Petty trade 9%
	Petty trade 8%	Other 12%	Nonfarm labour 7%	Livestock 9%
Average household income (in US$ per year)	653	459	569	589
Average livestock index	12.05	6.55	12.00	10.63
Average landholding (ha)	0.95	0.84	0.76	0.89
Average yrs of schooling	2.13	2.35	1.86	2.14
Average household size	5.02	4.85	6.00	5.15

Note: Livestock index was estimated using the conversion index by Taylor and Turner (1998)

Table 1. Key characteristics and household assets by village, road development case study, Pursat province

45. All three villages have small landholdings with an average of less than one hectare per household (see Table 1). Inequality in landholdings is high in Chong Khlong and Ou Ta Prok Main (gini coefficient of 0.46), and relatively lower in Out Ta Prok Up (gini coefficient 0.38). The livestock assets index in Chong Khlong and Ou Ta Prok Up is 12 while in Ou Ta Prok Main it is 6.5. Similar to landholding, the inequality in livestock assets is high in Chong Khlong and Ou Ta Prok Main and lower in Ou Ta Prok Up (gini coefficients of 0.62, 0.53 and 0.38, respectively). In Chong Khlong, the main livestock assets are cattle and poultry, while in Ou Ta Prok Main it is pigs and in Ou Ta Prok Up it is both cattle and pigs (Annex A, Table 4).

III.1.4 Influence of the road development on livelihood outcomes

46. On the whole, some of the potential benefits and risks described above (section II.1.2) have been experienced in the case study area, while some have not. Contrary to the hypothesis which led to the selection of the case study area, the environmental impacts of

the roads seem not to be so relevant in the case study area, according to local perceptions. The summary of the influence of the road development on livelihood outcomes is as follows.

47. **Overall improvement in livelihood outcomes is seen through improved market access and new livelihood opportunities.** The most frequently highlighted improvement brought by the road was better access to public services, most importantly to the health centre, followed by improved access to markets. In the past, reaching the market took a long time, making it difficult for villagers to take their products there themselves. This resulted in high dependence on middlemen that were very few due to the difficult access to the villages. The situation in the Khmer village far from the road (Ou Ta Prok Up) reflects this situation, as stated by one villager:

> *"It is difficult for us to bring vegetables to market and there are not so many middlemen come to buy our products such as palm sugar and vegetables and animals. They offer us low prices so we are not encouraged to grow vegetables and raise animals."*

48. Now when the road connection is better, the villagers can go to market themselves. There are also more middlemen coming to the villages. As a consequence of these two changes, the villagers are less dependent on the middlemen and are able to negotiate fair prices. Better market access has also increased the incentives to produce products for sale and encouraged new activities like pig raising in Ou Ta Prok. In Chong Khlong, many villagers have themselves started to act as middlemen, buying and selling products such as fruits, chicken, fish and medicine between villages. Chong Khlong has also become a kind of a local centre for cattle trade, where Chong Khlong middlemen trade cattle from near-by areas to middlemen from other districts and towns. In terms of increased benefits for different products, the villagers pointed out that better market access is especially significant for fish, which is not easy to preserve for a long period.

49. **The household livelihood activities and income portfolios have become more diversified since the construction of the road.** The percentage of households participating in different livelihood activities has generally increased (see Annex A, Table 2). For example, more households in the Cham village near the road (Chong Khlong) are engaged in rice farming and livestock raising while in the Khmer village near the road (Ou Ta Prok Main), the increase is seen in fishing, livestock raising and farm labour, Such increases may not all be attributed to the road, however, as seen in Oa Ta Prok Up where the highest increase in the livelihood activities portfolio is observed, particularly in fishing, fishing-related activities, rice farming and farm labour.

50. Livelihood diversification implies changes in income portfolio. For instance, the contribution from fishing to the average household income has declined in all the villages. Nevertheless, fishing is still the main source of income except in the Khmer village near the road (Out Ta Prok Main), where income from rice farming has replaced fishing as the main source of income and livelihoods by contributing about 27 percent of the household income (Annex A, Table 3).

51. The contribution of income from livestock rearing to the average household income has increased most significantly in the Khmer village near the road (Ou Ta Prok Main) from 18 percent before the road to 21 percent after the road, while in the Khmer village far from the road (Ou Ta Prok Up) it has declined from 22 percent to 13 percent. Livestock does not contribute much to the income portfolio in the Cham village as they do not engage in pig rearing, which seems to be a quite lucrative source of income for other rural households in the area. The contribution from petty trade to the total income has increased significantly except for the Khmer village far from the road, which suggests that improved roads have helped foster developments in trade and business. While the importance of petty trade to livelihoods has increased, high remunerative trade requires

some investments, which places the asset-poor households in a disadvantaged position. A similar case was observed in relation to investment in livestock encouraged by the new road, where asset-poor households had a weaker capacity to invest. As for the contribution of non-farm labour income, it remained unchanged except in the Khmer village far from the road where a significant increase was shown.

52. **Richer households have benefited more than poorer households from the road development.** Quantitative analysis of the survey data shows a strong correlation between changes in the household income and household assets like education, livestock and financial capital (Annex A, Table 5). While the average household income may have increased, further analysis reveals that the richer households experienced a significantly higher increase in their average household income compared to the poorer households (Annex A, Table 6).

53. **Locals perceive no significant impacts on fisheries.** The impacts of the road on fish abundance and flooding pattern were perceived to be minimal by the informants. According to the villagers of Ou Ta Prok and Chong Khlong, the road neither blocked nor protected their villages from flooding as the culverts built under the road let the water flow to the other side of the road. For the same reason the road does not block fish migration, either.

54. The fact that the culverts provide new, easier opportunities for catching fish was not mentioned by the villagers, but commented on only when asked. Although fishing activities that block fish in the mouths of culverts may disturb fish migration, the villagers did not see this as very relevant. There are also regulations related to fishing that should be enforced jointly by the Road Committee and Community Fisheries Committee, but according to the field observations these seemed to be widely ignored.

55. **Households' ability to take advantage of opportunities provided by the road depends significantly on other assets.** The Cham village near the road seemed to have benefited more and also more equally from the road than the Khmer villages. This may be due to the differences in social capital and attitudinal orientation in life. The Cham community has more connections to extra-village networks. They also have better organised social institutions, including a Muslim-influenced and locally managed income re-distribution system. These and other differences in the social asset base and in livelihood strategies that are influenced by a culturally different 'ethos', result in different interests and abilities to take advantage of a changed situation. While this does not mean that Cham communities are always more capable of enhancing their living standard, the differences do indicate that cultural and social issues play a significant role in how the roads and other infrastructure – and the changes they bring – influence livelihood outcomes.

56. **Management structures and institutions are key in mitigating environmental impacts and ensuring long-term maintenance.** At present the national government is focused on the core network of primary roads, while the lower levels of government, including communal road maintenance committees, are given responsibility for local roads (IFRTD 2006). Decentralised authority can potentially result in more efficient maintenance work, but this is challenged by scarce sources of revenue. Villagers in the study pointed out that the local road committee is able to undertake only small repairs, while bigger ruptures still require assistance from the commune or higher levels. This highlights the challenge of finding a balance between decentralisation and the need for an integrated approach at broader geographic scales in road planning and maintenance.

57. Poor road maintenance has been a common problem in Cambodia (IFRTD 2006). Roads located in flood-prone areas – like the one in study area – need special emphasis on maintenance. Successful maintenance requires a stable source of revenue, responsible and controlled use of the road, and mobilisation of special funds and labour to work in

case of road ruptures. Good communication and collaboration between the villages sharing the road is important as well, which implies capacity of commune officials to network, communicate, and share information.

58. Even though the road-related institutional structures do not require the same level of mobilization as irrigation (as in the Stung Chinit case, for example), participation is still crucial. The key-informants from the road committee stated that after the CONCERN project was finished in 1995, there was no program for maintenance. The villagers felt that as the NGO was responsible for the construction of the road, it should also be responsible for its maintenance. This resulted in poor maintenance which together with high floods in 2000-03 led to major damage to the road. With the rehabilitation of the road initiated by the Seila Program, a road committee was established and road fees were introduced. According to the informants this resulted in an increased sense of ownership, and consequently more attention has been paid to the maintenance of the road. The challenge is that while the road is used in a more responsible way at the beginning — when the road is new and its benefits more apparent — less attention is paid to its maintenance later on when the existence of the road is taken for granted.

59. While there were some challenges in finding enough funds for the road maintenance, some innovative solutions came up. For example, the middlemen coming from outside have been convinced to pay fees for road maintenance. Cooperation with the local *wat* (temple), initiated by the commune council members, has also been established. When a rupture occurs in the road, funds for repairing it are raised at the temple, and not only the village where the rupture occurred but also the entire commune contributes to the repairs. People generally entrust their money more easily to the monks than to the commune authorities. These examples highlight the importance of innovative solutions based on indigenous institutional networks.

III.2 CASE STUDY 2. STUNG CHINIT IRRIGATION AND RURAL INFRASTRUCTURE PROJECT, KAMPONG THOM PROVINCE

III.2.1 Context: Linking irrigation infrastructure development to livelihood outcomes

60. The Stung Chinit Irrigation and Rural Infrastructure Project (SCIRIP) is currently the largest irrigation scheme in Cambodia. The project also reflects the Cambodian government's strategy to reduce poverty through improvements in agricultural production, especially through irrigation, as emphasised in the Second Socio-Economic Plan of Cambodia. The irrigation sector is therefore expected to gain substantial investments in future, and this trend is already evident also in the Tonle Sap area. The SCIRIP can also be seen to serve as a pilot project for the ADB's Northwest Irrigation Sector Project (NWISP), where several irrigation schemes will be rehabilitated in Siem Reap, Battambang, Beantey Meanchey and Pursat. In addition, the ADB Lowland Stabilization Project addresses agricultural issues in the Tonle Sap area, including needs for irrigation.

61. The objective of the Stung Chinit case study is to record the most important lessons learnt from the project to inform implementation of future irrigation projects in the area and in other areas around the lake. As the project is still on-going and long-term impacts are therefore not yet evident, the emphasis is on the planning and construction process, particularly that of large-scale irrigation projects. Consequently, the case study does not focus only on physical built structures, but also looks at the interaction between the different project components and livelihood outcomes.

III.2.2 Irrigation and other infrastructure development at the study site

62. The project is located in Santuk district of Kampong Thom province, and there are two Tonle Sap tributaries in the area: Stung Chinit and Tang Krasang. The project is intended to benefit 2,400 households within 3 communes and 25 villages, mainly in Kampong Thmor commune. The irrigated area is projected to be 3,000 ha in the wet season (supplemental irrigation) and 1,800 ha in the dry season (full irrigation). The project was designed to deliver economic benefits primarily through increased agricultural income and productivity. The overall cost of project maintenance has been estimated to be US$80/ha/year, and water use fees are planned to offset these costs.

63. The physical built structures in the project consist of irrigation and drainage canals, the dam and spillway, and the related reservoir. However, the project design acknowledges that physical infrastructure alone does not have positive livelihood outcomes. Consequently, the project components also include the establishment of irrigation management groups, agricultural extension activities, and the enhancement of roads and market access. As it is not sensible or even possible to isolate the built structures as physical structures from other project activities, the case study also looks at these other project components.

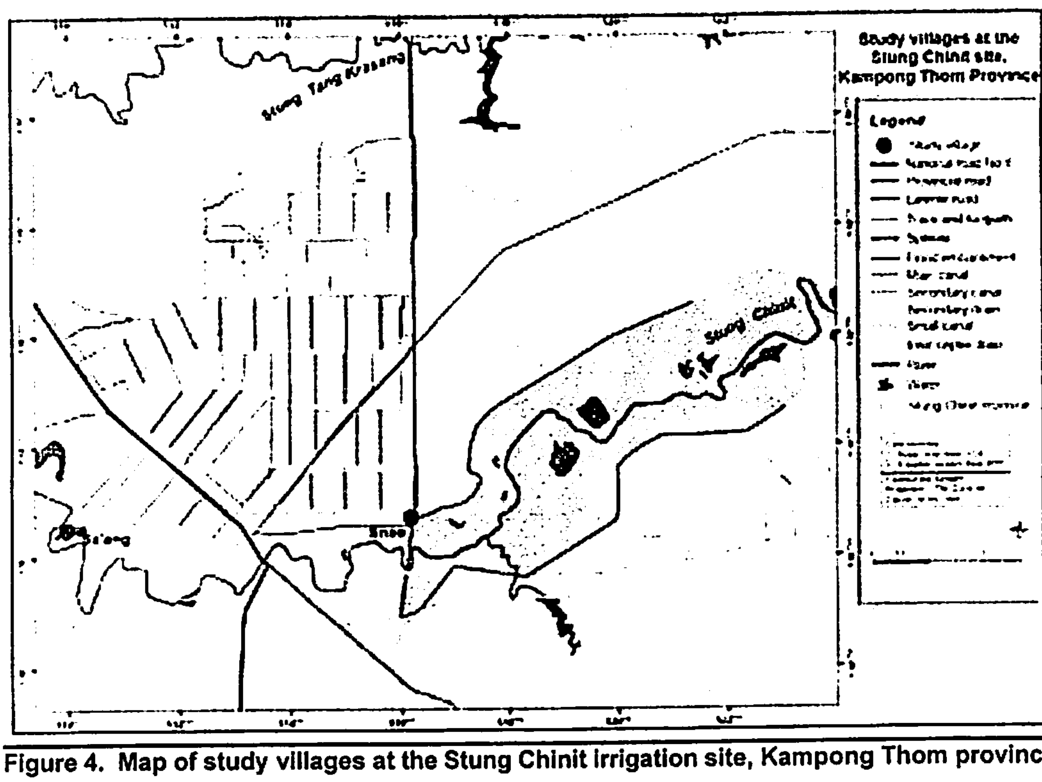

Figure 4. Map of study villages at the Stung Chinit irrigation site, Kampong Thom province

III.2.3 Characteristics of the study villages and livelihood assets

64. The case study compares two villages within the Stung Chinit irrigation scheme, Snao and Sa'ang. Snao represents a head-user village which is very close to the reservoir, to the spillway and to the project offices. Villagers in Snao have experienced some losses related to the project due to the construction and relocation of households.[5] Sa'ang, on

[5] One of the main points for criticism of the project's planning and construction phase has concerned land losses and the compensation for these. The number of households relocated has also been higher than originally estimated. Not only villagers, but key-informants from the governmental line agencies also

the other hand, is an end-user village at the southern edge of the scheme. Given the high reliance of the villagers in Sa'ang on fish in the Stung River, fishing might be impacted negatively by the irrigation scheme and particularly by (re)construction of the dam and spillway. This case study does not, however, address impacts outside the project area (downstream or upstream).

65. Both of the study villages embody occupational pluralism with a strong seasonal character. As shown in Table 2, the main livelihood activities in both head-user and end-user villages are rice farming, livestock and fishing. The income sources of the people include rice farming, water melon and vegetable crops, fishing, forestry (firewood and timber cutting and non-timber forest products), sugar palm, livestock raising, trade and labour work. The main difference in asset base is that financial capital is much lower in the end-user village (Sa'ang), which is linked to the lower average household income (US$ 589, compared to an average of US$ 785 in the head-user village (Snao). In addition, the villagers in the end-user village are more dependent on fishing. In the head-user village, a significant income source consists of forestry activities (firewood, timber cutting and non-timber forest products) in an area 40 km upland from the village. In the end-user village, forestry is less important and limited only to non-timber forest product collection in the vicinity of the village. Vegetables or other upland crops are not very significant in the villages, but the project aims to augment their importance. A common characteristic in both villages is that the households with less landholding are more dependent on fish and other aquatic resources (see Table 2). In other words, fishing and other aquatic resources provide a higher proportion of income for the poorer households, even if wealthier households earn more from these activities.

Livelihood assets	Snao		Sa'ang		Kampong Thom case (combined)	
Village location and proximity to the irrigation scheme	Head-user, closer to the scheme		End-user, farther from the scheme			
Main livelihood activities (% households participating)	Rice farming	89%	Rice farming	91%	Rice farming	91%
	Livestock	73%	Livestock	67%	Livestock	73%
	Fishing	67%	Fishing	64%	Fishing	67%
	Other	65%	Other	60%	Other	66%
	Other crops	63%	Other crops	49%	Other crops	63%
Main sources of income (% total income)	Fishing	27%	Fishing	30%	Fishing	28%
	Rice farming	19%	Rice farming	20%	Rice farming	19%
	Livestock	16%	Other	14%	Livestock	15%
	Petty trade	12%	Livestock	13%	Other	13%
	Other	12%	Farm labour	13%	Petty trade	9%
Average household income (US$ per year)		786		589		688
Average livestock index		18.9		19.8		19.4
Average landholding (ha)		1.0		1.0		1.0
Average yrs of schooling		1.3		0.7		1.0
Average household size		5.1		10.0		7.5

Livestock index measures estimated using the conversion index by Taylor and Turner (1998)

Table 2. Key characteristics and household assets by village, irrigation development case study, Kampong Thom province

66. According to the household survey, the head-user village is richer in its asset base and has a higher average income than the end-user village. This finding is also consistent with prior village survey data (SEILA 2006; see Annex A, Table 7). Some of the income differences can already be related to the irrigation scheme as the location of Snao, the head-user village, with regard to the scheme is more favourable, and thus even prior to the operation some indirect benefits had been accruing there. For example, Snao

highlighted the problematic nature of the compensations and resettlements. Many villagers expressed concern about the village chiefs not representing the different stakeholders in the village fairly in this process. The land losses due to the scheme have occurred in both Santuk and Baray districts (see also FACT 2004).

villagers worked as labourers during the construction phase, and the vicinity of the reservoir has brought an increasing number of tourists to the area.

67. There were no marked differences observed between the villages in terms of social capital. In both villages, several self-help and indigenous associational initiatives exist. However, the level of institutional capital in terms of links to higher level and/or state institutions seems to be rather low in both villages. This represents a common situation in the rural areas of Cambodia (cf. Pellini and Ayers 2005). Related to this, there seems to be a lack of confidence in the initiatives of higher level officials and some suspicion related to the projects coming from outside.

III.2.4 Influence of the irrigation and rural infrastructure development on livelihood outcomes

68. **It is still too soon to assess the direct impacts of improved irrigation, but the influences of other aspects of the infrastructure project are noted.** The Stung Chinit Irrigation and Rural Infrastructure Project (SCIRIP) has been delayed, and as a result the actual irrigation structures of the project only became operational in 2006, three years later than originally planned.[6] The long construction period meant additional hardship for the villagers, as some of the canals were closed for long periods during the construction work and farmers were not able to get water to their fields. The water gates letting the reservoir water into the rice fields were opened on 20 July 2006.

69. Consequently, the surveys under this study were carried out too early to assess the actual impacts of the irrigation project as the first crop cultivated under the irrigation system had not even been harvested (harvest took place in December-February) when the surveys took place (in September). Instead, the case study can address only the impacts that had already emerged– mainly due to construction of the irrigation structures – and illustrate some of the possible future impacts that were addressed during the surveys.

70. **Livelihood portfolios have diversified in all wealth groups, but for different reasons.** In both villages, the households have become slightly more diversified in terms of their livelihood activities (see Annex A, Table 8). However, it is important to distinguish whether this change is due to a "push" (increased threats to the traditional livelihoods) or a "pull" (promising new opportunities).[7] The poor household may diversify out of the need to make their living, while richer households may diversify in order to maximise their outcomes. In the case of the head-user village, it seems that households have been pulled to diversify because of new opportunities offered by being close to the built structures (Annex A, Table 9), while in the end-user village, diversification has resulted from a decline in income (Annex A, Table 10). This conclusion is supported by the survey result showing that in the end-user village, more households are currently engaged in farm and non-farm labour compared to before the irrigation project was built (Annex A, Table 8).

71. In the head-user village (Snao), the percentage of households participating in fishing activities has increased from 51 percent before the irrigation project to 67 percent at

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[6] The delay of the project is related in part to changes in project design, including a reduction of the project area from around 7,000 ha to less than 3,000 ha. The original TA documents underestimated the costs of the project and included estimates of the internal economic rate of return which have since been revised downward.

[7] Livelihood adaptation is defined as the continuous process of change to livelihoods, often geared towards enhancing security and wealth, reducing vulnerability and poverty (Ellis 2000). Adaptation can be positive or negative; it is positive if it is by choice, reversible and increases security; negative if it is out of necessity, irreversible and fails to increase security. Negative adaptation leads to the adoption of a successively more vulnerable livelihood system over time (Davis 1999).

present (Annex A, Table 8). In both villages, the percentage of households engaged in rice farming has increased marginally. The percentage of households engaged in livestock rearing has shown a significant increase from 58 percent to 73 percent in the head-user village, while it has registered a marginal decline from 69 percent to 67 percent during the same period in the end-user village. Significant increase in diversification into livestock (particularly pig rearing) in the head-user village could have resulted from increased market access (a "pull" towards livelihood diversification).

72. **The distribution of income from fishing has been affected by the reservoir.** The contribution of fishing to household income in the head-user village has increased significantly from 21 percent before the project to 27 percent at present, while in the end-user village (Sa'ang), the contribution from fishing to total income has declined from 47 percent to 30 percent. The increase in the contribution from fishing in the head-user village may be credited to the reservoir, while the villages in the end-user village reported that the decline in contribution of the fishery is due to increased competition from other fishers downstream. As shown by the quantitative study, livelihood options, particularly in the head-user village, have increased and household income portfolios have become diversified, thereby spreading risk and reducing vulnerability to food insecurity, poverty and income fluctuations. Despite a decrease in the contribution of fishing to total household income for those in the end-user village, it continues to be the highest contributor to household income on average (Annex A, Table 9).

73. **Overall, villagers in the two case study villages were not particularly concerned about the irrigation project's possible impacts on fisheries.** For example, in the end-user village, where the involvement in fishing was clearly higher, the villagers were actually more concerned about the impacts of downstream fishing activities than on the impacts of the irrigation scheme *per se*. In general, the villagers in both cases have noticed an overall decline in the availability of fish, and this trend is feared to continue. Illegal fishing is seen as the main reason for the decline, and better control of illegal fishing activities is considered to be the key to stop the decline. At the same time, the project has brought benefits particularly to members of the head-user village as they have easy access to the reservoir as well as to the areas just downstream of the spillway. Both of these areas have seen increased availability of fish (at least temporarily) after the construction of the spillway. Finally, it is important to remember that both study villages are located within the scheme, and the project's impacts further away downstream and upstream from the dam and spillway were therefore not assessed by the surveys.[8]

74. When discussing specifically the impacts caused by the irrigation structures, the main impact locals perceived was that the structures –essentially the dam and the spillway – block fish migration between the Tonle Sap and areas upstream from the reservoir. According to villagers, the reason for this is that the water flow in the spillway is too strong. In addition, there is only one way for fish to pass through the water gate (i.e. fish pass), and it still seemed unclear for villagers at this point whether the fish pass was actually functioning. In addition, during the construction phase of the dam and spillway, the partial destruction of the Stung Chinit dam in 2005 killed many fish, and villagers in the end-user village also lost their boats and fishing equipment.

75. **Households' ability to take advantage of opportunities provided by the irrigation and infrastructure scheme depends significantly on other assets.** Households with more education and livestock holdings are better positioned to take advantage of more profitable opportunities (Annex A, Table 10). Though the direct impact of the built structure through the irrigation scheme is yet to be realised, some of the indirect impact have been felt by the households, particularly those in the head-user village. Similar to the situation in Pursat, households belonging to the richer group registered a much higher

[8] For a more thorough assessment of the impacts of the dam and irrigation system on fisheries, see the companion fisheries component report within this technical assistance study.

increase in their income (Annex A, Table 11) suggesting that the richer households have more capacity to take advantage of the opportunities. Qualitative findings also support these conclusions. The households' possibility to make use of the emerging opportunities from the development of the irrigation structures depends very much on the larger context where the development happens. The wealthier households usually have better capacity to adapt to changes.

76. In the case of the irrigation project in Stung Chinit, it is yet too early to clearly say which groups are set to benefit most and if the project will really bring equal benefits to the villagers living in the project area. It is, however, relatively evident that – similar to many other infrastructure projects with participatory institutional arrangements – the farmers' water-user groups in Stung Chinit, which have been set up as part of the scheme, face the possible risk of being dominated by the local elite and thus failing to include the poorest and weakest groups. In addition, the sheer scale of the Stung Chinit scheme adds to the challenge, as experiences from other irrigation projects demonstrate that equitable water distribution is more commonly achieved in smaller-scale systems than in large ones (Hussain *et al.* 2006).

77. **The quality of local participation in infrastructure planning is key in villagers' perception of the scheme's suitability and their willingness to invest in long-term maintenance.** The findings from the Stung Chinit irrigation project illustrate the challenges related to participation of local villagers in the planning and construction phases of the project. Based on the interviews, most villagers in both case study villages feel that they did not have possibility for real participation during the planning of the project, but were just briefed about up-coming project activities. At the same time, villagers consistently expressed a desire to have more input into technical decisions, so that the hoped-for benefits of improved irrigation would be realized. One of the reasons for the communication difficulties was related to language. As one respondent described, "*They [project staff] used too technical language and we were afraid to say anything*".

78. Feedback from villagers included in the study suggests inadequate local ownership. In the case of Stung Chinit, the farmers' participation is wanted for the maintenance of the structures, but the villagers seem to be bit hesitant about this, as they feel their participation was not encouraged during the planning and construction phases. The results from the Stung Chinit case indicate that it will be difficult to create ownership of local farmers only at the later stages of the project.

79. **Comparison with other irrigation and water management projects suggests that many of the planning and management challenges of the Stung Chinit scheme may be related to its large scale.** Other studies have suggested that the risks of large-scale infrastructure projects are generally greater than those of smaller-scale projects. The scale of the impacts of a possible failure is greater in a larger project while in a smaller project, there are more chances for correction during implementation and running of the scheme (Öjendal 2000). Also, participation and mobilization of local farmers is more challenging the larger the scale of the project is. There are also studies demonstrating that equitable water distribution in a smaller-scale system is more likely than in a large one (see e.g. Hussain *et al.* 2006). In the specific case of Cambodia, there have been concerns about large-scale projects because of the lack of sufficient capacity for their planning, construction and maintenance (Molle 2005, Öjendal 2000).

80. Examples around the world indicate that in large-scale solutions the costs of construction and running are often higher than anticipated and that the cost recovery in terms of water fees is difficult (Öjendal 2000). In the Stung Chinit scheme, some interviewed for this study are beginning to question the local economic benefits of the investment, a concern raised by other observers as well (cf. FACT 2004). In Cambodia, a special challenge is related to intersectoral coordination (cf. e.g. Ovesen *et. al.* 1996, Öjendal 2000, Molle 2005). Due to its scale and integrative approach, the Stung Chinit project has different

components under the responsibility of different government sector agencies. The communication and cooperation between the agencies seems, however, not to have worked as well as planned[9].

III.3 CASE STUDY 3. FISHING LOTS IN AND AROUND PREK TOAL CORE AREA, BATTAMBANG PROVINCE

III.3.1 Context: Linking large fishing structures and fishing lot management systems to livelihood outcomes

81. The built structure studied in the Battambang case consists of large-scale bamboo fences used in the fishing lot. The fences form a barrier across the floodplain for fish leaving the inundated floodplain on their way back to the lake when the flood recedes. The physical closure of the lot by bamboo fences starts when the water begins to recede in January and February. It is thus the lot management system, with its privileges granted to leesees, rules for restricted access and relatively effective enforcement of access, that has the main influence on local livelihoods, and not the physical structures themselves.

82. Thus, **in assessing livelihood outcomes, the influence of the physical built structures (large bamboo fence gear) is inseparable from the management system of the fishing lots.** The qualitative study looks broadly at how the restricted access and the management practices of the private concessions are perceived to influence the local communities. It also focuses on the successes and shortcomings of community fisheries management practices. In addition to fishing Lot #2, the study also examines the experiences of community fisheries in the area formerly covered by Lot #3. The experiences related to the release of Lot #3 are relevant in order to understand some of the opportunities, challenges and constraints that the cessation of commercial fishing lots could bring. The quantitative analysis, on the other hand, concentrates mainly on comparing the livelihood outcomes before and after the release of Lot #3.

III.3.2 Characteristics of the study villages and livelihood assets

83. The case study in Battambang includes two main villages, Prek Toal and Thvang. The villages differ in their location, with Prek Toal being closer to the Tonle Sap Lake (TSL), closer to Lot #2 and closer to the commune centre, while Thvang is situated 8 km upstream along Stung Sangkae without any areas connected directly to Lot #2. Villagers of these two sites have different access to fishing grounds and Community Fisheries Areas (CFA) as shown in Table 3. Additionally, Peak Kantiel, situated between Lots #1 and #2, was included in the qualitative study to represent a village[10] under more direct influence of the lot system and with no direct access to the Community Fisheries Area.

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[9] For example, agro-ecosystem analysis of the project – a prerequisite for any irrigation scheme – was carried out only after the design of the structures had already been completed. In addition, one key-informant from the project indicated that the construction of new roads and markets is not well connected with the actual scheme.

[10] Officially, Peak Kantiel is a settlement rather than a recognized village.

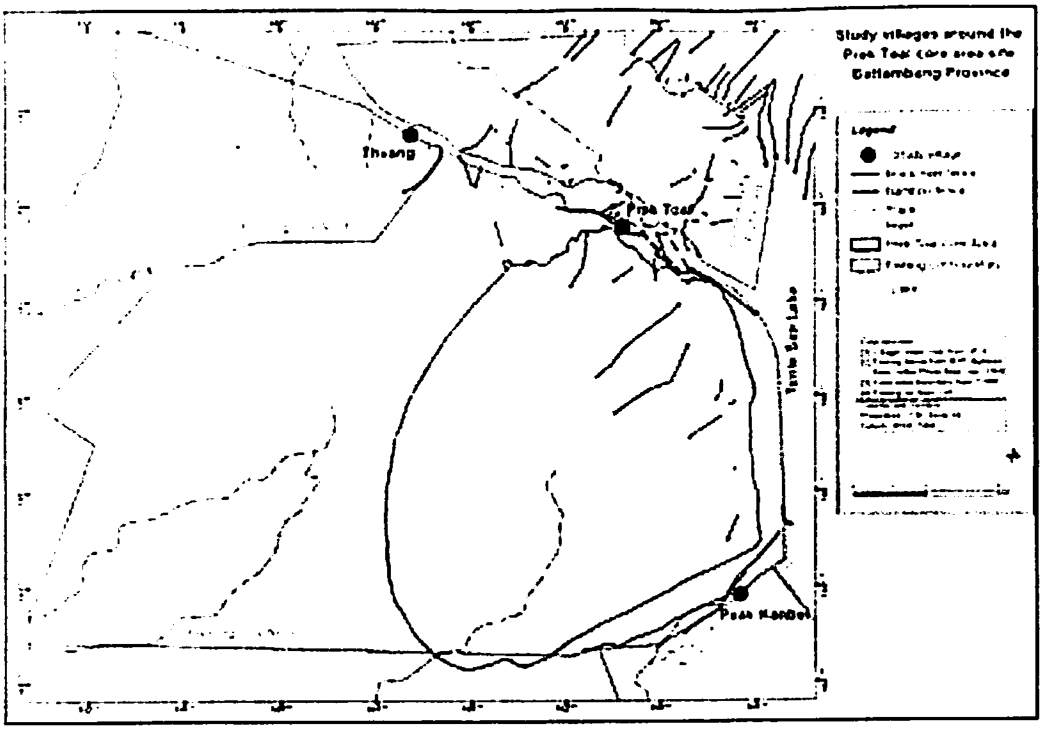

Figure 5. Map of study villages around the Prek Toal core area site, Battambang province

84. According to the village survey data from the previous study (Annex A, Table 12), the village far from the TSL (Thvang) seems to be slightly better endowed than the village close to the TSL (Prek Toal). The quantitative analysis shows, however, no major differences between the livelihood portfolios of the two main case study villages, as both are predominantly fishing communities (Annex A, Table 13). The main source of livelihoods in both villages is fishing and most of the other significant activities are also fishing-related, such as processing (including fish paste, salted, and fermented fish) and marketing. The better-off families also engage in cage culture of fish and/or crocodile rearing. The possibilities for livestock raising are understandably very limited, but some chickens and pigs are raised on the floating platforms for household consumption and sale. Farming is not feasible in the area as the riverbanks are inundated for most of the year (June-January) and the flooded forests in the nearby area are protected and theoretically cannot be cleared for agricultural purposes.

85. The distance from the commune and less frequent connections to centres such as Chong Kneas harbour in Siem Reap make Thvang more isolated than Prek Toal. There are currently no NGOs working in Thvang, and there have been far fewer development projects than in Prek Toal where, for example, the environmental NGO "oSmoSe" has been active. The distance from the communal offices also makes Thvang less frequently patrolled by the local authorities. The internal differences and divisions are actually notable in both villages. One categorising factor for the fishers is their financial resources which distinguishes those who fish primarily for subsistence from those who market more of their catch. Ethnicity (ethnic Vietnamese and Khmer) is also an important distinguishing characteristic, as is the distinction between the villagers and the seasonal fishers from outside the area.

86. In terms of social capital, the villages in the Battambang case study seem to be worse off than in the two other other case study sites. At the village level, the relations between the different social groups are often characterised by competition over fish resources, and solidarity between the different social groups seems to be quite low. There are also

internal patron-client relations, and the poorest groups seem to be highly indebted to their wealthier neighbors. There are, however, also more horizontal networks in the form of indigenous associations e.g. related to schools, funeral arrangements, and communal platform management that seem to work rather well. Villagers spoke of being much more comfortable in dealing with local village leaders as compared to other officials from outside the immediate area.

Livelihood assets	Prek Toal		Thvang		Battambang case (combined)	
Village location and proximity to Tonle Sap Lake and the fishing lot	Close to Lot #2 and Tonle Sap Lake		Far from Lot #2 and Tonle Sap Lake			
Fishing locations and access to Community Fisheries Areas (CFA, former Lot #3)	Fishing in Tonle Sap Lake, Lot #2 and CFA		Fishing in CFA (and also in Lot #4)			
Main livelihood activities (% households participating)	Fishing	100%	Fishing	96%	Fishing	98%
	Other	80%	Other	96%	Other	88%
	Fishing labour	38%	Fishing labour	20%	Fishing labour	29%
	Fish culture	20%	Fish culture	27%	Fish culture	23%
Main sources of income (% of total)	Fishing	65%	Fishing	69%	Fishing	67%
	Other	16%	Crocodile	11%	Other	10%
	Fish culture	6%	Petty trade	9%	Fish culture	8%
	Crocodile	5%	Other	5%	Petty Trade	6%
	Fishing labour	5%	Fish culture	3%	Fish culture	4%
Average household income ($US per year)		984		1083		1033
Average livestock index		2.0		4.3		3.7
Average yrs of schooling		3.0		2.3		2.7
Average household size		5.6		6.2		5.8

Livestock index measures estimated using the conversion index by Taylor and Turner (1998)

Table 3. Key characteristics and household assets by village, fishing lot case study, Battambang province

III.3.3 Influence of the fishing lots on livelihood outcomes

87. **Fishing remains the main source of income in both villages; the overall decline in fish catch per household highlights a significant vulnerability.** Survey results show a decline in the fish catch per household in both villages during the recent season (2005/2006) as compared to before the release of Lot # 3 (2000/2001). That decline is most significant in the village near the TSL (Prek Toal). Such a decline in the fish catch per household may be influenced by increasing pressure from migrants coming from other provinces like Kampong Thom, Siem Reap, Kampong Cham and Banteay Meanchey. However, the sales/catch ratio remains the same in both periods. This has resulted in a drop in the contribution of fishing to the total income, but fishing remains the dominant source of income.

88. **Livelihood portfolios have diversified because of other opportunities becoming available, but also in response to the decline in income from fishing.** In both villages the livelihood portfolio has become slightly more diversified, particularly in response to the loss of income per household from fishing sources (Annex A, Table 13). But fishing is still the main livelihood source for the majority of the households, signifying the higher dependence on fishing activity.

89. The contribution of fishing to average household income has declined from 75 percent before the release of Lot #3 to 65 percent after the release in the village near the TSL (Prek Toal), and from 85 percent to 69 percent in the village far from the TSL (Thvang). (See Annex A, Table 14). The contribution from fish culture has declined in the former village but it has remained at the same level in the latter. The contribution from crocodile culture has shown a significant increase in both villages. In the village far from the TSL,

the contribution from petty trade has increased significantly from 2 percent to 9 percent. The contribution from other activities has also registered an increase in both villages.

90. **The release of fishing Lot #3 has opened access to local villages but also increased competition with outside groups; livelihood benefits for local villages are less than anticipated.** The main change in both villages due to the release of the Lot #3 was the increased access to the fishing grounds that were previously restricted during the open season from October to May. This provided new fishing grounds for those households that previously could not afford the licenses and were thus solely dependent on fishing outside the restricted area (the river, near-by flooded forest or the lake). The increased access provided better chances to secure yearround subsistence and income. For the previous sub-leasees, the change did not offer entirely new fishing grounds, but less expensive and less controlled access. The downside was, however, that the fishing domain became more crowded than before.

91. The release opened the restricted area not only for the locals, but also for fishers from outside. After the release the number of seasonal migrants, mostly from upland areas[11], has been growing and new social tensions have emerged between these newcomers and the locals. Many local fishers pointed to the seasonal migrants when asked to explain the decline in catch per household, but there is little direct evidence. The actual role of the seasonal migrants and their indirect influence on local livelihoods requires further research, also to gain a better understanding of their motivations and possible methods to ease the pressure on Tonle Sap Lake fisheries by upland farmers.

92. **The continued operation of Lot #2 entails significant trade-offs in terms of conservation, economic returns, and equity.** Although fishing inside the lot is intensive, the exclusive management system does provide a controlled habitat for fish and other fauna, which may provide a conservation benefit as compared to more open access. The lot system with armed patrols and guards and heavy penalties and fines effectively keeps unwanted fishers out of the area, while the subleasing system provides the possibility to identify and regulate the fishers within the lot. The management system in effect channels economic benefits to the lot concessionaire, while restricting local villagers' access to the most productive fishing areas of the Tonle Sap Lake. There are also regular complaints about restricted transportation routes that leave the fishers without access to the flooded forests on the other side of the lot.[12]

93. On the other hand, negotiations and commercial partnerships take place (cf. Goes 2005). The lot provides rich fishing grounds for those who can afford to sublease fishing grounds (streams or lakes) or other sections of the lake from the operator. For the poorest groups, the lot provides working opportunities in patrolling and fish processing, particularly to households in the lower income group. However, outside labour increasingly appears to be substituted for this local employment, and the use of processing machines is reducing the overall labour demand.

94. Lot operations also appear to undermine the legitimacy of official management interventions and law enforcement in the eyes of local villagers. Villagers reported receiving conflicting information about the boundaries and regulations of the lot and obligations of the lot concessionaire, with the result that they frequently feel decisions are arbitrary. Interviewees regularly expressed frustration about the reluctance of fisheries officials to take action on lot practices which they suspected to be illegal or destructive. In

[11] Villagers reported seasonal migrants from Siem Reap, Kampong Thom, Pursat, and Banteay Meanchey provinces, as well as upland areas of Battambang, coming to access the community fishing area (formerly Lot #3) during the period February – May before returning to their home villages for the rice harvest.

[12] Villagers reported that the concessionaire of Lot #2 does not allow villagers to travel through the lot to the common fishing area located on the other (upland) side of the lot, although this was allowed before and the villagers' right to cross the lot seems also to be stated in the lot's burden book.

addition, many villagers found the community fishery regulations that restrict fishing to small-scale gears hard to justify, as compared to the entitlements given to the lot operator.

95. **Households' ability to take advantage of opportunities provided by the release of the lot depends significantly on other assets.** Wealthier and more educated households are significantly more represented in community fisheries, and are realizing a significantly higher catch per household as compared to poorer households. The study finds that there is a direct correlation between household assets and the capacity to benefit from the opportunities offered by the reforms (Annex A, Tables 15 and 16). Survey results show that chronically poor households have lower levels of education, financial capital and livestock assets. This finding is supported by the qualitative analysis that shows inequality in benefits derived by households from the community fishery areas.

96. One might anticipate that the group most benefiting from increased access to fishing areas would be the poorer fishers who, prior to the release, were unable to pay for access. Many villagers interviewed reported, however, that richer fisher groups have maintained their higher income level, and intensive large-scale fishing activities have continued despite the community fishery regulations that allow only family-scale fishing. Several interviewees claimed that local power imbalances have enabled wealthier households to capture the community fishery area's best locations, and to restrict the access of poorer groups. These imbalances are not merely about wealth, but also reflect differences in peoples' access to decision-making. As stated by a poor fisherman: "*If we have conflict over fishing activities with rich people who are involved in large-scale fishing activities, we can't win...*"

III.4 COMPARATIVE FINDINGS

97. In this section, we analyze both qualitative and quantitative findings from the three case studies from a comparative perspective, incorporating additional analyses to draw conclusions regarding trends in income inequality, poverty, and the role of household assets in influencing people's ability to capture benefits from the changes in built structures.

III.4.1 The institutions and processes of planning and managing built structures are highly influential in determining livelihood outcomes

98. All case studies demonstrate that livelihood outcomes (e.g. access to natural resources, income benefits, and equity) cannot be predicted based on physical structures *per se*. The allocation of benefits and costs from built structures depends strongly on processes of planning and management. With poor planning and management, the built structure's benefits threaten to be short-term and unequal (with better-off households benefiting more), and costs unbearably high for some stakeholders (e.g. downstream fishers). Well-functioning management is thus crucial for equal distribution of benefits, and consequently for poverty reduction. The success of planning and management is related to the institutional and socio-political structures at different levels of society (see also Kibler and Perroud 2006).

99. For all types of built structures, the planning phase with prompt environmental and social impact assessments is crucially important. With regard to fishing structures, the questions about planning and management primarily refer to rules about access, gear restrictions, and the enforcement of these. In terms of roads, the most important aspect of management is maintenance, which is also very important with the irrigation structures, and more complex. A common management issue for both community fisheries committees and farmers' water user groups is conflict settlement between the users.

100. The case studies demonstrate that informal institutional structures and arrangements are often not well incorporated into the implementation of built structure projects. Yet, against the commonly held idea of the lack of social capital in Cambodia (e.g. Ovesen *et al.* 1996), many of the studied communities illustrated strong capacity and will to act collectively. In all case studies, the project interventions had acknowledged at the planning stage the need to set up appropriate community user groups. However, in each case, community members also reported unfulfilled expectations related to participation. A common challenge related to irrigation structures and roads was the difficulty in changing the role of recipients to active and responsible partners in maintenance.

101. While the new institutional and participatory arrangements (user groups, community fishery committees, etc.) are set up to secure more long-term and equal benefit allocation, they can also have exactly the opposite consequences. The case study on community fisheries, for example, demonstrated how community user groups can fail to include the poorest groups. This partially explains why progress in poverty reduction is slow in some areas (see section III.4.5).

III.4.2 On average, household income is rising and livelihood portfolios are diversifying, though the influence of built structures on these trends varies significantly by case.

102. Survey data shows that overall average income increased for all villages included in the study (Figure 6). In all cases, survey respondents overwhelmingly judged the changes in built structures as positive, in reference to the construction of the road in Pursat (100 percent), the irrigation scheme in Kampong Thom (96 percent), and the *removal* of Lot #3 in Battambang (93 percent).

103. In the case of the road development, there is strong evidence that the road is significantly contributing to improvements in income and other positive livelihood changes. The comparison between the Khmer village and the Cham village, both of which are near the road, shows that the increases in overall income are higher in the Cham village, which may be attributed to high social and financial capital among villagers that enable them to take advantage of the new livelihood opportunities emerging with the road development. For the irrigation project, it is still too soon to determine the net effects of the irrigation and infrastructure scheme, but expectations about the future point to a strong anticipated benefit in terms of an increase in average income for the villages studied. Of the two villages near the irrigation project, the income increase is higher in the head-user village, where there are both higher asset endowments and a favorable location within the core of the project area. Finally, in the case of fishing structures, both villages experienced an increase in income, but for different reasons. For the village far from the TSL, such an increase may be largely explained by gains among the wealthier households from crocodile farming and improvements in fish catch. In the village near the TSL, though some households are benefiting from the increased access offered by the removal of Lot #3, many, and particularly poorer, households are not (discussed further below in section III.4.4).

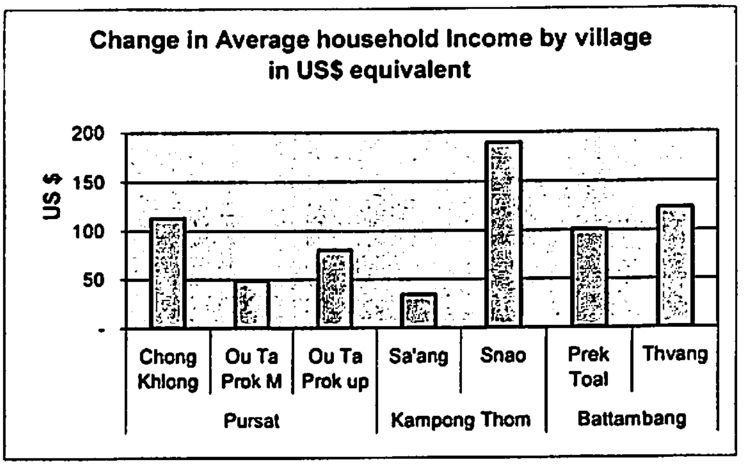

Figure 6. Change in average annual household income by village, in US$ equivalent

104. Most households are diversifying their livelihood portfolios, which appears linked variously to new opportunities from changes in built structures and to new risks. Across the three study sites, the survey results show a modest decline in the degree of reliance on wild fisheries as a source of income, but fishing and fishing-related activities remain the leading sources of income. (Figure 7). For many households, this appears to reflect a reduction in vulnerability as they shift their livelihood strategies to spread risk. For other households, particularly those who are diversifying with no gains (or only minor gains) in income, it seems to be better explained as a necessary reaction to declining opportunities from traditional livelihood sources. Note, however, that, in the case of the fishing structure, the dependence of the villages on fisheries resources is relatively high, despite increased livelihood diversification.

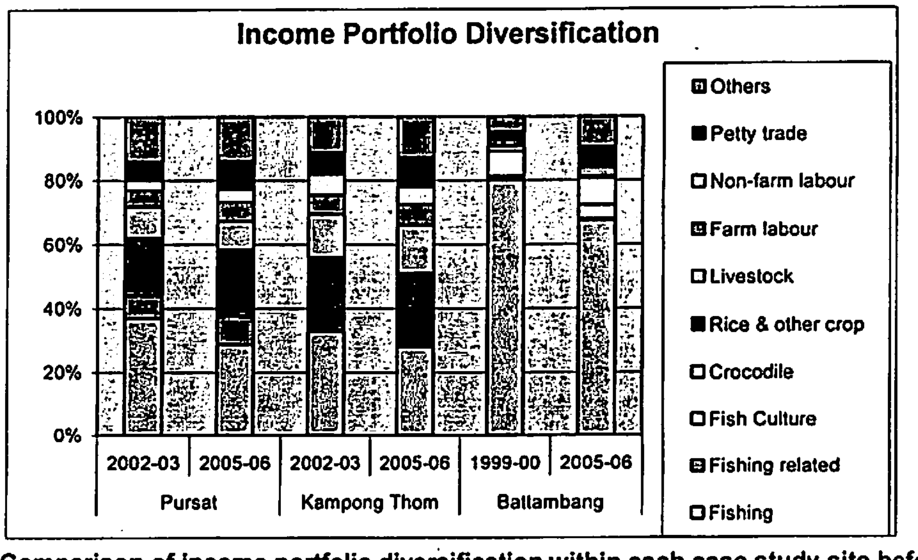

Figure 7. Comparison of income portfolio diversification within each case study site before and after the change in built structure, shown as percentage contribution of various livelihood activities to average household income

III.4.3 **In the villages studied, the built structure changes are generally benefiting wealthier households more; many poor households are also benefiting, but at a slower rate.**

105. In addition to assessing the influences of built structures on livelihoods at the aggregate level (comparisons among communities), it is important to examine the relative benefits for different social groups (comparisons among households). Who is gaining most? Who is falling behind? Answers to these questions are essential in designing future infrastructure investments and complementary policy interventions. Note, however, that evaluating such trade-offs requires a broader perspective – assessing the potential gains and losses for all communities affected, including those farther upstream and downstream. The results in this report address only the villages studied, which were all intended beneficiaries of the interventions.

106. The rural households are placed differently in terms of their capacity to benefit from the opportunities provided by the road, the irrigation scheme and related infrastructure, and by the release of the fishing lot. This survey analysis confirms that households with higher asset endowments generally have been able to capture higher return (more profitable) activities, while poorer households are left with low return activities. Poorer households lack capital to makes investments in more remunerative activities, and other assets to take advantage of the changing opportunities (see section III.4.5 below).

107. Income inequality generally remains high in the study sites. According to the survey results, it has generally been slightly reduced in most of the villages studied, except in two villages, the Khmer village far from the road (Ou Ta Prok Up) and the fishing village near the TSL (Prek Toal), where it increased (Figure 8).

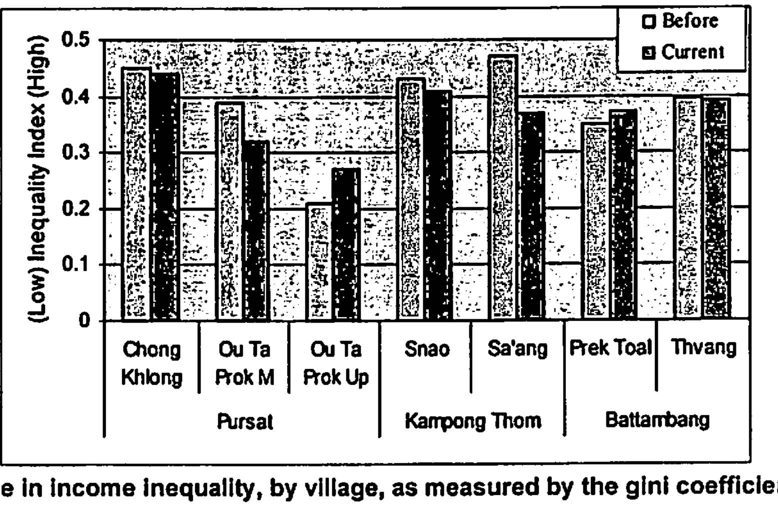

Figure 8. Change in income inequality, by village, as measured by the gini coefficient of inequality

III.4.4 With few exceptions, chronically poor households are not yet benefiting enough to step out of poverty.

108. The two previous subsections focused on trends comparing changes among different economic groups within the study villages. In this section, we conduct the analysis with reference to the nationally-defined poverty line[13]. This provides a means of assessing progress in poverty reduction, and the dynamics of households' movements in and out of poverty. It is important to note the distinct differences among the study villages in reference to this national norm. The study villages in the road development and irrigation cases are poor compared to the average for rural Cambodia, while those in the fishing lot case are relatively well off in relation to the floating villages of the Tonle Sap.

109. In terms of absolute measures of poverty, survey results from most of the study villages indicate either no change or a slight decline (Figure 9). Despite having the lowest incidence of poverty at the initial time period (before the fishery reforms), the village near the TSL (Prek Toal) is the only village in the study where survey data shows an increase in both incidence of poverty (the percentage of households categorised as falling below the poverty line) and depth of poverty (how far below the poverty line these households are on average).

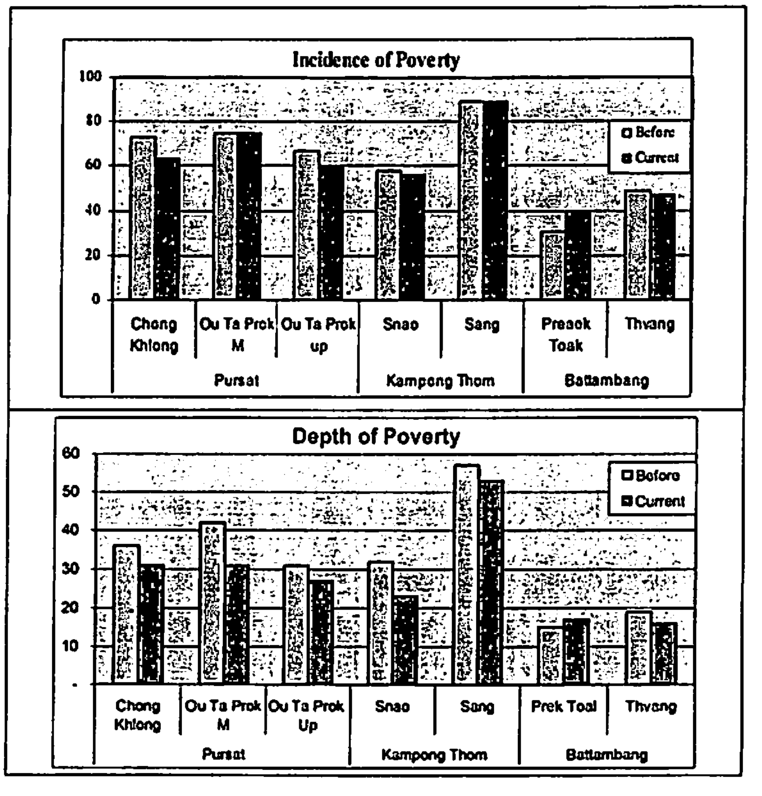

Figure 9. Change in incidence and depth of poverty, by village

110. The ability of villagers to rise above poverty is assessed to provide some inference about the influence of built structures. In this analysis, households are categorised as chronic poor and 'non-chronic' poor. The "chronic poor" are defined as households that remained

[13] The poverty line is defined as the minimum requirement for subsistence living in monetary terms. Poverty line information is taken from World Bank (2005) and JICA (2001). Poverty measures were estimated using Foster, Greer, and Thorbecke's index (Foster *et al.* 1984).

poor between the period prior to the built structure development (or, in the fishing lot case, prior to the removal of the fishing lot) and the current period. The "non-chronic poor" are households above poverty line during both time periods. The latter group also includes those who are "vulnerable to chronic poverty" (previously in the non-poor group but then fell below the poverty line), and those who were previously in the poor group but then managed to move above the poverty line.

111. Based on the current study, there is no indication that the chronically poor households (normally those with the lowest asset endowments) are benefiting enough to step out of poverty. The increase in the average absolute income of the chronically poor households is much lower than the non-chronic poor, highlighting again that the most disadvantaged have gained less than other households from the changes in livelihood opportunities, including those related to built structures. (See Figure 10.) The analysis shows that on average the non-chronic poor in each study village increased their incomes between 2 and 10 times more than the chronic poor, with an overall average of 3.2 times more.

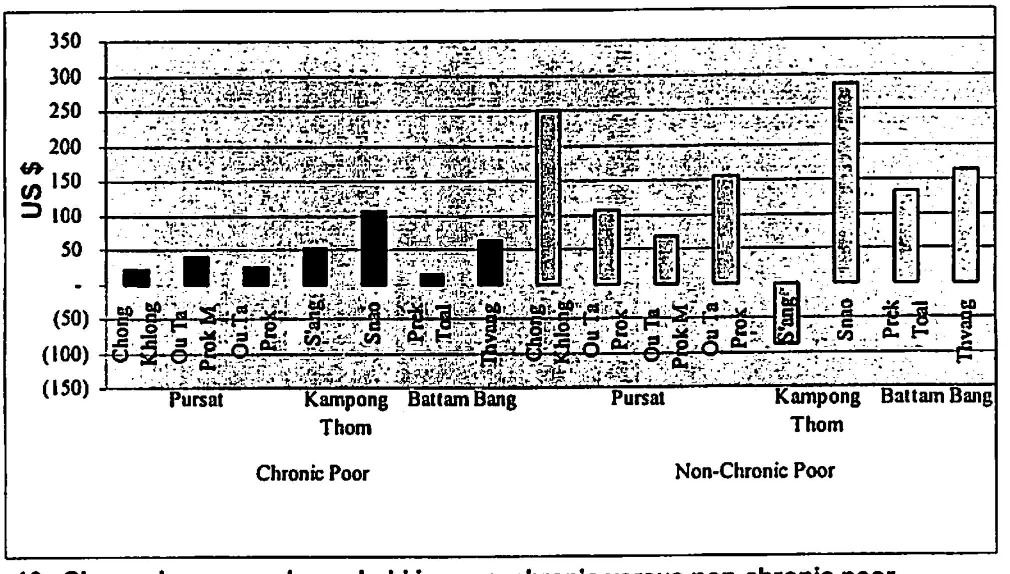

Figure 10. Change in average household income, chronic versus non-chronic poor

112. Chronic poverty is severe in the road development and irrigation sites, and still significant in the fishing lot site. On average, over the period studied, there have not been large numbers of households stepping out of poverty. But the trends vary significantly by village. For the road development case study in Pursat, a significant positive trend of people moving out of poverty has been observed: 13 percent in the Cham village near the road (Chong Khlong), 10 percent in the Khmer village near the road (Ou Ta Prok Main) and 7 percent in the Khmer village far from the road (Ou Ta Prok Up). In the case of the irrigation project, chronic poverty remains high, most notably in the end-user village (Sa'ang). In the fishing lot case study, a significant percentage of households have moved out of poverty – 21 percent in the village near the TSL (Prek Toal) and 23 percent in the village far from the TSL (Thvang), but an almost equal number have slipped below the poverty line, demonstrating a relatively dynamic situation. (See Figure 11.) However, keep in mind that the time period in consideration for the fishing lot case study in Battambang is also longer – five years as opposed to three for the other cases – so more change is to be expected.

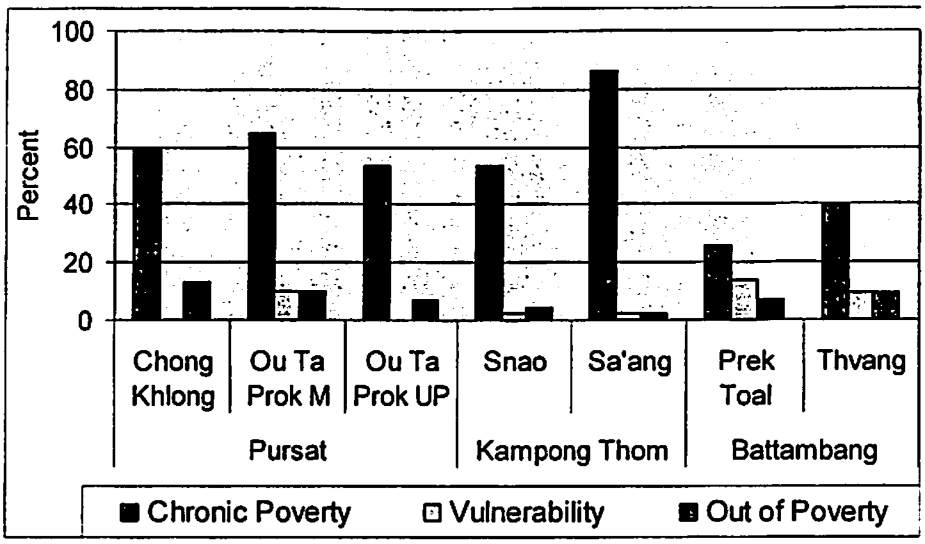

Figure 11. Dynamics of poverty, by village

III.4.5 The capacity to take advantage of new livelihood opportunities offered by changes in built structures depends on other household assets, particularly education.

113. The study also shows a strong relationship between household asset endowments and the capacity to take advantage of opportunities offered by changes in the physical environment (built structures) and related institutions. The asset endowment of households plays a major role in determining the influence of built structures and related institutional reforms on livelihoods. This finding is consistent with other research in development economics showing that household asset endowments are critical determinants of acute and chronic poverty, vulnerability and income (Gaiha 1992, Gaiha 1989, Gunawardena 1982, Jalan and Ravallion 1998, Makhanya and Ngidi 1999).

114. Quantitative analysis of the survey data shows education is the most significant variable in explaining the ability of households to get out of poverty; next is livestock, a form of savings (see Annex A, Table 23).[14] Landholding was not shown to be a statistically significant contributing factor to the ability of households to move out of poverty (Annex A, Table 24). Indeed, counterintuitively, in two case study villages (Sa'ang and Ou Ta Prok Main) the chronic poor actually have slightly more landholdings than the non-chronic poor[15] (Annex A, Table 23). However, these villages also have the highest rates of chronic poverty and their landholdings are relatively small. Financial capital also seems to play a crucial role in determining the influence of built structures on chronic poverty. Physical proximity to the structure is a less important factor in making comparisons among the households studied (though location would be very important in the case of clear upstream-downstream impacts).

115. In the qualitative analysis, social capital emerged as a key factor in explaining the degree to which the benefits of changes in built structures were broadly shared or captured by more privileged households alone. In the fishing lot case, particularly in the village near the TSL (Prek Toal) the relations between the different social groups are characterised by

[14] These findings are indicated both by a simple correlation analysis (Annex A, Table 23), and by a regression analysis that measures the statistical significance of correlation independent of other variables (see Annex A, Table 24, with accompanying note.)

[15] Non-chronic poor consist of three groups, namely: those who were above the poverty line in both periods, those who were previously above but then dropped below the poverty line ("vulnerable to poverty"), and those who moved above the poverty line ("out of poverty").

competition over the fish resources, and the solidarity between the different social groups seems to be quite low. In addition, the management of community fisheries seems to be in the hands of local elites, which has resulted in an unequal distribution of benefits with poorer and weaker groups suffering more. In the road development case, on the other hand, the differences in social organisation within the villages explains in part why the Cham village (Chong Klong) – with more active and effective community organizations – has benefited somewhat more than the Khmer village (Ou Ta Prok) from opportunities brought by the new road.

IV CONCLUSIONS

116. This study has examined cases involving three different types of built structures in an effort to draw broader conclusions concerning the influence of built structures on local livelihoods around the Tonle Sap Lake and beyond. Building on the case studies, what more general conclusions can we draw?

117. First, the type of built structure clearly influences how direct benefits are distributed. The case studies illustrate that different types of built structures (roads, irrigation schemes, fishing gears) have different degrees of openness or exclusion in terms of the ability of poor households to access the livelihood opportunities enabled by the structures (see Figure 12). Overall, roads are most open as they provide public access with no direct exclusion. Irrigation is meant to bring livelihood benefits by increasing the seasonal availability of water, but still to a limited group, i.e. for landholders within the irrigation scheme and possibly to laborers and marketers nearby. In addition, the irrigation reservoir creates a new open access resource for fishing, although access to the reservoir may be limited by different kinds of regulation and management practices. Fishing structures in the lots are clearly most exclusive as they in effect funnel benefits to a small group and exclude the majority from the fishing area. Other institutional implications concern demands for conflict resolution, maintenance, and decision-making related to the distribution of direct costs and benefits from the intervention.

	Pursat case: Roads	Kampong Thom case: Irrigation structures	Battambang case: Fishing structures
Level of exclusion	Low	Medium	High
Need to settle conflicting interests	Medium	High	Very high
Maintenance / local ownership	High	Very high	Not relevant (private)
Importance of equal distribution	Relevant only in additional interventions (larger context)	High	High

Figure 12. Institutional implications of different built structures in the case studies

118. Yet there is also much we can say that applies across different types of built structures in different social and ecological settings. Institutions matter quite significantly, in ways that enable positive livelihood strategies (for example, through effective participation and consultation in project planning), and that disenable opportunities for the poor (for example, through mechanisms that reinforce inequitable access to aquatic resources and their livelihood benefits). (Refer to Figure 2.) This finding is also strongly supported by other studies (see, for example, Kibler and Perroud 2006). Scale also matters, as many of the factors that either threaten local livelihoods or open new opportunities are not within the direct influence of local communities. The cross-scale factors that emerged as significant in the case studies include such issues as seasonal migrants making use of community fishing grounds, markets that develop to provide for a demand for local products (e.g. pig rearing), and, of course, environmental factors, including the relationship between hydrological change, habitat, and fisheries productivity.

119. Built structures – by definition, purposeful modifications to the physical environment – clearly do affect livelihood outcomes, but they are by no means a "magic bullet." This study examined the influence of changes in both directions, namely interventions to introduce new (or improved) structures as with roads and irrigation schemes, and interventions to remove structures (large fishing gears associated with the fishing lot). In all cases, the changes were justified on the grounds of poverty reduction. Yet, as the study shows, progress in poverty reduction has been modest, and inequality remains high. While it will be some years before the outcomes of these particular cases can be measured conclusively, the results already raise a justifiable concern. The ability of individual households to take advantage of changes depends very clearly on other assets, especially education. In certain contexts, other assets such as livestock holdings may be key, and smaller family size may be an advantage. These observations signal the need to pay close attention to the livelihood context in which changes are being introduced, and the ways in which different households may or may not be able to benefit. In essence, it means considering infrastructure as one element in a broad array of useful investments to encourage pro-poor rural development.

V RECOMMENDATIONS

V.1 LINK PLANNING OF NEW STRUCTURES TO DECENTRALISED NATURAL RESOURCE MANAGEMENT

120. **Planning, construction, and operation of built structures cannot operate in a vacuum and must have strong connections both to long-term management of the Tonle Sap's natural resources and to local development planning.** Many infrastructure projects seem to be considered short-term and localised interventions without appropriate consideration of the larger context in which they operate. In other instances, complex project management units and systems have been set up that isolate decision-making too much from local stakeholders and authorities.

121. The case studies indicate that **the best way to ensure community involvement and ownership is to link planning of built structures to on-going processes of decentralised rural development and natural resources management.** In terms of roads and irrigation canals, this would mean the planning processes led by commune councils and the forthcoming provincial and district councils in particular. In planning road developments, for example, this coordination is essential so as to identify and mitigate potential environmental impacts, particularly on fish habitat and migration routes, and to ensure that more remote local communities will indeed be able to access the main road. At the maintenance stage, too, intersectoral coordination remains critical, as responsibility for the maintenance of roads falls under the Ministry of Rural Development, culverts under the MOWRAM, and regulation of fishing effort under the Fisheries Administration. In both planning and maintenance, commune councils have a natural coordinating role to play, including where appropriate local organizations such as community fishery committees, road maintenance committees, as well as informal networks such as the Buddhist *sangha* or Muslim networks that have local legitimacy and can mobilize collective action.

122. **In advance of the physical infrastructure, it is often necessary to strengthen local institutional capacity to address the new challenges to collective decision-making.** Irrigation projects, for example, tend to be technically complex, so training is likely needed to help build effective communication between engineers, local officials, and community members. Support to establish and facilitate the work of water user committees is also helpful in promoting equitable water distribution and avoiding conflicts over operation and maintenance of the system. Similarly, future analysis and decision-making regarding the possible release of additional fishing lots should carefully consider the advance preparation of new local institutions to assume management and enforcement responsibility, as well as rules and conflict resolution mechanisms to address the increased competition from fishers within and outside the local area.

V.2 STRENGTHEN INSTITUTIONAL MECHANISMS TO INTEGRATE DECISION-MAKING ACROSS SECTORS AND GEOGRAPHIC SCALES

123. The Tonle Sap Lake's ecosystem productivity is highly sensitive to changes in the flood regime. Even relatively small changes to the quantity and timing of flood patterns, and to the connectivity of aquatic environments may have significant consequences for the productivity of the lake, with direct and indirect implications for the livelihoods of millions of people. This demands an integrated approach to the area's water resource management, connecting existing actors and information from different sectors and levels.

124. **Social, economic, and ecological trade-offs stemming from alternative scenarios of infrastructure and water resource development need to be explicitly evaluated and publicly debated.** Planned developments expected to have an effect on the flood regime need to be clearly summarised together, and their possible cumulative impacts assessed.

This requires a comprehensive database including information on projected developments at different geographic scales.

125. **Government policies and strategies should clearly prioritize the relative importance of different social and economic benefits derived from the fisheries of the Tonle Sap Lake.** In the case of fishing lots and community fisheries, this should address the trade-offs regarding the role of fisheries as a source of government revenue (a benefit of the lot system), a "safety net" for vulnerable groups from around the basin (a benefit of unrestricted access for small-scale fishing), or a source of wealth generation for lakeshore communities (a potential benefit of community fisheries organizations with appropriate implementation).

126. **An integrated approach should start by overcoming the communication gaps and improving cooperation between different sectoral ministries.** Priorities here include, for example, cooperation between the Ministry of Water Resources (MOWRAM) and the Ministry of Agriculture (MAFF) in irrigation planning, and between the Fisheries Administration and Ministry of Public Works in assessing the potential influence of road development on fisheries.

V.3 ADOPT PROCESSES OF CONSULTATION AND PARTICIPATION IN PROJECT PLANNING THAT RECOGNISE THE DIFFERENCES AMONG LOCAL HOUSEHOLDS

127. Stakeholder consultation and participation are key factors influencing the success of infrastructure projects. The fundamental question is how to further improve actual participation and consultation so that projects can result in more equitable resource allocation and a stronger sense of ownership. When this expectation comes too late, as when locals are asked to contribute their efforts primarily for maintenance once the structure has already been built, it is extremely difficult to build a genuine partnership.

128. Therefore, **more attention must be paid to participation and ownership from the very initial stages of project planning.** Active involvement of commune councils from the project area is required in reviewing potential infrastructure developments. At the village level, identification of existing networks (both formal and informal) and cooperation with locally respected leaders in all stages of the project is crucial. Regular information sharing is important so that the division of responsibilities is clear and the expectations not unrealistic.

129. **At the planning stage, it is important to analyze sensitively how the anticipated benefits and costs of a project are likely to be distributed among different social groups, taking into account the role of local institutions and differences in household assets.** The case studies demonstrate the importance of recognizing the heterogeneity of communities as well as the social groups within communities, considering not only wealth and income, but also education, ethnicity, the strength of social networks, and local power relations.

130. **Special provisions need to be made so that the poorest groups can indeed participate effectively.** A variety of approaches have been shown to be effective. NGOs that have legitimacy in the area, good local knowledge, and experience working with the more vulnerable households can sometimes be good intermediaries in bringing local insights and helping organise consultations with the poorest groups. Consultations conducted separately with more vulnerable groups, with women, or with ethnic minorities that protect individuals' confidentiality can help ensure a more frank sharing of views. And, quite practically, it is important to provide appropriate compensation (such as meals and transportation) so that participation does not become an economic burden for the people involved. Even with such efforts, however, successful participation is not a uniquely local process. It is also contingent on the broader context of governance,

particularly the degree of accountability of public officials, which either encourages or discourages people from making the effort (and sometimes assuming the risk) of seeking a voice in public decision-making.

V.4 TARGET BUILT STRUCTURE INVESTMENTS WITH AN UNDERSTANDING OF HOW THE POOREST GROUPS CAN BENEFIT

131. This research has shown that even when the net benefits of infrastructure developments in terms of average household income appear to be positive, the poorest groups can be left behind. Addressing these distributional issues requires reconsidering priorities in terms of the links between infrastructure development and changes in livelihood opportunities, as well as types of infrastructure and their scale and complexity of operations.

132. **Be clear about the livelihood opportunities that structures are meant to help facilitate.** Because the influence of built structures on livelihoods varies significantly based on the institutional context, assets and vulnerabilities of households affected by the change, project planning should explicitly identify what groups are expected to benefit and how. Making these expectations clear helps facilitate informed public debate about whether the investment is worthwhile, or how it might be adapted to reach the groups intended. Such adaptations may include technical design modifications, as well as changes to the planned operation and management of the structures. With road development, for example, this may entail including smaller, feeder roads in the construction plan, or choosing labor-intensive building approaches that can help build financial capital among poorer households in the area while simultaneously developing a local skill base to support maintenance in subsequent years.

133. **Favor investments in structures with high degrees of openness in terms of social groups that can access the benefits.** Public roads are by design available to all users without a fee (apart from toll roads and possible maintenance fees), and access can be increased as the network of feeder roads expands. Irrigation systems deliver water to a defined area, so the number of people who can directly benefit is limited, though there are significant indirect benefits from associated labor opportunities, trade, etc. Large fishing structures are designed specifically to exclude the majority of fishers and channel the fish catch to a few; it would be very difficult to shift the institutional arrangements so that the benefits of such structures would be equitably distributed.

134. **Where feasible, favor smaller-scale projects that are more easily adapted to local needs, more easily managed locally, and less attractive for elite capture.** Many of the common risks encountered with large infrastructure projects are associated with their scale and complexity of operation.

V.5 PLAN COMPLEMENTARY INVESTMENTS TO ADDRESS THE ASSET GAPS OF POORER GROUPS

135. Many households fail to take advantage of the livelihood opportunities offered by built structures because they lack other essential assets. Ensuring that the poorest households have a chance to access these new opportunities is essential if infrastructure investments are to make a measurable contribution to reducing poverty.

136. **Alongside infrastructure improvements, investments in basic education, training and technical support services, and credit may be needed, as well as support to community organizing capacity.** Setting priorities for such complementary investments should be part of the local livelihood assessment associated with infrastructure planning.

In many areas, securing land rights is an essential step, as the value of agricultural land typically rises along with irrigation or road improvements, and villagers may face pressure to vacate or sell if they feel their tenure is insecure. Special attention should be given to the phasing of investments as well – in many instances it may be wise to begin support to develop these other household assets long before construction of the physical infrastructure begins.

137. **Invest in building household assets to take advantage of alternative livelihood opportunities, not to increase fishing effort.** Unlike the case with irrigated agriculture or road development, the potential advantages from the release of fishing lots and support to community fisheries stem from a more equitable distribution of economic benefits, not from an intensification of production. For communities that have depended overwhelmingly on fishing (such as most floating villages), efforts to regulate fishing and make it more sustainable need to be complemented with support for alternatives such as ecotourism, post-harvest processing, and (for those who wish) training for jobs on shore.

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ANNEX A: DATA TABLES

Road development case study, Pursat province (Tables corresponding to section III.1)

Table 1: Village level socioeconomic indicators for the case study villages, Pursat province

	2002		2003		2004	
	Chong Khlong	Ou Ta Prok	Chong Khlong	Ou Ta Prok	Chong Khlong	Ou Ta Prok
Number of households	148	182	152	182	158	195
Number of females	341	514	356	514	365	522
Number of males	305	422	322	422	339	430
Percent of houses with thatched roofs	38.5	74.7	23.7	74.7	20.3	76.9
Percent of houses with tiled roofs	25.7	12.1	25.7	12.1	25.9	10.3
Percent of houses with fibro roofs	2.7	0.0	2.6	0.0	2.5	0.0
Percent of houses with zinc roofs	33.1	9.9	42.8	9.9	47.5	12.8
Percent of houses with concrete roofs	0.0	0.0	0.0	0.0	0.0	0.0
Percent of households with cattle	71.6	95.1	57.9	95.1	63.9	93.8
Percent of households with pigs	0.0	93.4	0.0	93.4	0.0	97.4
Number of motorcycles per 100 people	6.5	0.0	7.4	1.1	7.5	1.6
Number of cars per 100 people	0.0	0.1	0.0	0.1	0.0	0.1
Number of ox carts per 100 people	15.6	6.4	10.0	6.4	9.7	6.8
Number of bicycles per 100 people	10.2	0.0	12.4	16.0	12.4	16.1
Number of row boats per 100 people	8.5	3.7	9.4	3.7	9.7	5.5
Number of motor boats per 100 people	0.3	0.9	0.0	0.9	0.0	1.4
Percent of households with TV	24.3	8.2	27.0	9.3	30.4	24.6

Source: Estimated using SEILA Commune Database 2006

Table 2: Changes in livelihood activities in Pursat (shown as percentage of households participating in each activity)

Activities	Pursat		Chong Khlong		Ou Ta Prok Main		Ou Ta Prok Up	
	Before	Current	Before	Current	Before	Current	Before	Current
Fishing	76.3	78.8	82.2	82.2	60.0	65.0	80.0	86.7
Fishing related activities	22.5	23.8	33.3	33.3	10.0	10.0	6.7	13.3
Rice farming	90.0	92.5	88.9	91.1	90.0	90.0	93.3	100.0
Other crops	52.5	51.3	60.0	57.8	40.0	40.0	46.7	46.7
Livestock	62.5	66.3	53.3	55.6	60.0	70.0	93.3	93.3
Farm labour	26.3	31.3	20.0	22.2	40.0	45.0	26.7	40.0
Non-farm labour	10.0	12.5	4.4	6.7	20.0	20.0	13.3	20.0
Petty trade	28.3	29.8	15.6	15.6	11.7	13.8	13.3	14.2
Other	79.2	79.4	74.6	75.6	76.0	75.5	78.3	78.0

Table 3: Changes in livelihood portfolio diversification in Pursat (shown as percent contribution to the total household income)

Activities	Pursat		Chong Khlong		Ou Ta Prok Main		Ou Ta Prok Up	
	Before	Current	Before	Current	Before	Current	Before	Current
Fishing	37.5	28.9	42.8	31.8	24.9	16.2	33.9	32.5
Fishing related activities	7.1	8.8	8.6	12.9	5.3	1.0	3.9	2.7
Rice farming	16.2	19.4	14.8	17.2	20.0	27.0	16.8	18.9
Other crops	2.0	1.9	2.5	2.2	1.6	1.9	0.7	0.6
Livestock	9.5	8.9	2.9	3.8	18.4	21.4	22.1	13.2
Farm labour	5.0	5.6	7.4	8.1	1.5	1.8	0.7	1.2
Non-farm labour	2.8	3.8	3.5	3.4	2.2	2.5	1.1	6.8
Petty trade	6.5	9.4	4.6	8.4	13.7	16.2	4.5	5.2
Other	13.5	13.4	13.1	12.3	12.2	12.1	16.3	18.9

Table 4: Percentage of household by assets (Pursat)

Livestock assets	Percentage of household			
	Pursat	Chong Khlong	Ou Ta Prok (Main)	Ou Ta Prok (Up)
Livestock	87.5	86.7	90.0	86.7
Cows/oxen	27.5	40.0	10.0	13.3
Buffalo	45.0	46.7	45.0	40.0
Pigs	32.5	0.0	70.0	80.0
Chickens	66.3	66.7	55.0	80.0
Ducks	25.0	33.3	20.0	6.7

Table 5: Correlation between assets and changes in income (Pursat)

	Correlation coefficient of the household asset with changes in income			
	Landholding	Livestock Index	Education	Household size
Pursat	0.49	0.32	0.04	0.03
Chong Khlong	0.59	0.35	0.06	0.06
Ou Ta Prok Main	(0.15)	0.01	0.05	(0.11)
Ou Ta Prok Up	0.41	0.18	0.26	(0.30)

Table 6: Income change by chronic poor vs. non-chronic poor (Pursat)

Groups	Village	Change in average household income (US$)	Average household income (US$)
Overall Average	Pursat	91.2	589.2
Chronic Poor	Chong Khlong	22.3	312.3
	Ou Ta Prok Main	38.9	327.3
	Ou Ta Prok Up	25.6	443.4
Non-Chronic Poor	Chong Khlong	249.7	1,164.9
	Ou Ta Prok Main	67.0	702.6
	Ou Ta Prok Up	154.0	737.1

Irrigation case study, Kampong Thom province (Tables corresponding to section III.2)

Table 7: Village level socioeconomic indicators for case study villages, Kampong Thom province

	2002		2003		2004	
	Snao	Sa'ang	Snao	Sa'ang	Snao	Sa'ang
Number of households	172	71	172	69	195	69
Number of females	423	186	448	186	450	187
Number of males	396	163	409	171	434	173
Percent of houses with thatch roofs	66.9	22.5	66.9	23.2	67.7	23.2
Percentage of houses with tiled roofs	23.3	42.3	23.3	43.5	21.5	43.5
Percent of houses with fibro roofs	0.0	5.6	1.2	5.8	1.0	5.8
Percent of houses with zinc roofs	5.8	18.3	4.7	18.8	4.1	18.8
Percent of houses with concrete roofs	0.0	0.0	0.0	0.0	0.0	0.0
Percent of households with cattle	88.4	93.0	88.4	95.7	92.8	100.0
Percent of households with pigs	62.8	91.5	59.9	94.2	76.9	91.3
Number of motorcycles per 100 people	1.3	1.1	1.6	1.4	3.1	1.7
Number of cars per 100 people	0.0	0.0	0.0	0.0	0.3	0.0
Number of ox carts per 100 people	15.8	18.1	15.1	17.6	14.7	17.5
Number of bicycles per 100 people	12.2	19.8	11.7	19.3	12.4	18.9
Number of row boats per 100 people	3.1	1.4	2.3	1.4	2.3	1.4
Number of motor boats per 100 people	0.0	0.0	0.0	0.0	0.0	0.0
Percent of households with TV	12.8	8.5	13.4	15.9	14.9	34.8

Source: Estimated using SEILA Commune Database 2006

Table 8: Livelihood activities diversification in Kampong Thom (shown as percentage of households participating in each activity)

Activities	Kampong Thom		Snao		Sa'ang	
	Before	Current	BBefore	Current	Before	Current
Fishing	58.9	66.7	51.1	66.7	66.7	64.4
Fishing related activities	10.0	10.0	6.7	10.0	13.3	6.7
Rice farming	86.7	91.1	88.9	91.1	84.4	91.1
Other crops	66.7	63.3	53.3	63.3	80.0	48.9
Livestock	63.3	73.3	57.8	73.3	68.9	66.7
Farm labour	32.2	42.2	33.3	42.2	31.1	42.2
Non-farm labour	18.9	18.9	31.1	18.9	6.7	31.1
Petty trade	11.1	12.2	11.1	12.2	11.1	13.3
Other	62.1	66.3	61.6	65.2	58.7	60.2

Table 9: Income portfolio diversification in Kampong Thom (shown as percent contribution to the total household income)

Activities	Kampong Thom		Snao		Sa'ang	
	Before	Current	Before	Current	Before	Current
Fishing	33.6	28.0	20.7	26.7	47.4	29.6
Fishing related activities	0.3	0.3	0.3	0.2	0.3	0.5
Rice farming	19.6	19.3	25.7	18.6	13.0	20.3
Other crops	3.7	3.5	4.9	3.6	2.4	3.4
Livestock	13.9	15.0	17.4	16.2	10.1	13.3
Farm labour	6.2	6.5	1.8	1.9	11.0	12.8
Non-farm labour	6.4	5.4	11.6	8.8	0.9	0.8
Petty trade	7.1	9.2	8.8	12.2	5.3	5.1
Other	11.5	12.8	12.4	11.8	10.5	14.0

Table 10: Correlation between assets and changes in income (Kampong Thom)

	Landholding	Livestock asset	Education	Household size
Kampong Thom	(0.07)	0.05	0.17	(0.18)
Snao	(0.09)	0.03	0.20	0.17
Sa'ang	(0.08)	0.04	0.13	(0.15)

Table 11: Income change by chronic poor vs. non-chronic poor (Kampong Thom)

Groups	Village/province	Change in average household income (US$)	Average household income (US$)
Combined average change	Kampong Thom	91.2	687.6
Chronic Poor	Snao	105.3	482.8
	Sa'ang	53.4	401.6
Non-Chronic Poor	Snao	285.3	1,281.5
	Sa'ang	(88.6)	1,224.9

Fishing lot case study, Battambang province (Tables corresponding to section III.3)

Table 12: Village level socio-economic indicators in case study villages, Battambang

	2002		2003		2004	
	Thvang	Prek Toal	Thvang	Prek Toal	Thvang	Prek Toal
Number of households	180	467	200	497	244	497
Number of females	545	1308	576	1346	650	1351
Number of males	516	1270	505	1242	656	1247
Percentage of houses with thatch roofs	38.3	58.9	35.5	60.4	17.6	60.4
Percentage of houses with tiled roofs	0.6	0.0	0.5	0.0	0.4	0.0
Percent of houses with fibro roofs	0.0	0.0	0.0	0.0	0.0	0.0
Percent of houses with zinc roofs	60.6	39.6	64.0	37.2	82.0	39.6
Percent of houses with concrete roofs	0.0	0.0	0.0	0.0	0.0	0.0
Percent of households with cattle	0.0	0.0	0.0	0.0	0.0	0.0
Percent of households with pigs	2.8	2.4	3.5	3.0	2.1	0.6
Number of motorcycles per 100 people	0.0	0.0	0.0	0.0	0.0	0.0
Number of cars per 100 people	0.0	0.0	0.0	0.0	0.0	0.0
Number of ox carts per 100 people	0.0	0.0	0.0	0.0	0.0	0.0
Number of bicycles per 100 people	0.0	0.0	0.0	0.0	0.0	0.0
Number of row boats per 100 people	38.8	27.9	39.1	29.0	22.1	32.7
Number of motor boats per 100 people	6.1	6.6	6.9	7.3	16.1	7.7
Percentage of households with TV	48.3	36.4	51.5	36.2	49.2	50.1

Source: Estimated using SEILA Commune Database 2006

Table 13: Livelihood activities diversification in Battambang (shown as percentage of households participating in each activity)

	Battambang		Prek Toal		Thvang	
Activities	Before	Current	Before	Current	Before	Current
Fishing	97.8	97.8	100.0	100.0	95.6	95.6
Fishing related activities	10.0	6.7	11.1	8.9	8.9	4.4
Fish culture	12.2	23.3	17.8	20.0	6.7	26.7
Crocodile	2.2	6.7	0.0	4.4	4.4	8.9
Rice farming	1.1	1.1	0.0	0.0	2.2	2.2
Other crops	3.3	4.4	2.2	4.4	4.4	4.4
Livestock	3.3	8.9	0.0	4.4	6.7	13.3
Fishing labour	18.9	28.9	22.2	37.8	15.6	20.0
Non-farm labour	4.4	4.4	0.0	0.0	8.9	8.9
Petty trade	7.8	8.9	11.1	11.1	4.4	6.7
Other	88	88	82.2	80.0	93.3	95.6

Table 14: Income portfolio diversification in Battambang (shown as percent contribution to the total household income)

Activities	Battambang Before	Battambang Current	Prek Toal Before	Prek Toal Current	Thvang Before	Thvang Current
Fishing	80.1	67.4	75.2	64.8	85.1	69.4
Fishing related activities	1.3	0.6	1.6	0.7	0.9	0.5
Fish culture	7.7	4.3	13.2	6.3	2.0	2.9
Crocodile	1.6	8.2	0.0	4.6	3.2	11.0
Rice farming	0.1	0.0	0.0	0.0	0.2	0.1
Other crops	0.1	0.2	0.1	0.3	0.1	0.2
Livestock	0.2	0.4	0.0	0.0	0.5	0.6
Fishing labour	1.1	2.7	1.2	5.4	1.0	0.7
Non-farm labour	0.8	0.8	0.0	0.0	1.6	1.5
Petty trade	2.2	5.6	2.8	1.9	1.6	8.5
Other	4.8	9.9	5.8	16.0	3.8	4.6

Table 15: Correlation between assets and changes in income (Battambang)

	Livestock assets	Education	Household size
Battambang	0.293	0.107	0.066
Prek Toal	-	0.031	0.123
Thvang	0.874	0.219	(0.004)

Table 16: Income change by chronic poor vs. non-chronic poor (Battambang)

Groups (Chronic poor and non-chronic poor)	Village/province	Change in average household income (US$)	Average household income (US$)
Overall average change	Battambang	112.2	1033.8
Chronic Poor	Prek Toal	13.3	505.5
	Thvang	62.0	540.1
Non-Chronic Poor	Prek Toal	131.4	1148.9
	Thvang	163.3	1438.4

Comparative findings (Tables corresponding to section III.4)

Table 17: Change in average household income by village

Province	Village	Income Change (US$)
Pursat	Chong Khlong	113.26
	Ou Ta Prok Main	48.74
	Ou Ta Prok Up	80.66
Kampong Thom	Sa'ang	34.44
	Snao	189.30
Battambang	Prek Toal	101.16
	Thvang	123.24

Table 18: Change in income inequality, by village, as measured by the gini coefficient of inequality

Province	Village	Gini Index	
		Before	Current
Pursat	Chong Khlong	0.45	0.44
	Ou Ta Prok Main	0.39	0.32
	Ou Ta Prok Up	0.21	0.27
Kampong Thom	Snao	0.43	0.41
	Sa'ang	0.47	0.37
Battambang	Prek Toal	0.35	0.37
	Thvang	0.40	0.39

Table 19: Incidence of poverty (Head Count Index) by village

Province	Village	Incidence of Poverty (%)	
		Before	Current
Pursat	Chong Khlong	73	63
	Ou Ta Prok Main	75	75
	Ou Ta Prok Up	67	60
Kampong Thom	Snao	58	56
	Sa'ang	89	89
Battambang	Prek Toal	33	40
	Thvang	49	49

Table 20: Depth of poverty (Poverty Gap Index) by village

Province	Village	Depth of Poverty (%)	
		Before	Current
Pursat	Chong Khlong	36	31
	Ou Ta Prok Main	42	31
	Ou Ta Prok Up	31	27
Kampong Thom	Snao	32	23
	Sa'ang	57	53
Battambang	Prek Toal	15	17
	Thvang	17	20

Table 21: Changes in average income, chronic vs. non-chronic poor

Province	Village	Average Income Change (US$)	
		Chronic Poor	Non-Chronic Poor
Pursat	Chong Khlong	22.30	249.70
	Ou Ta Prok Main	38.92	66.97
	Ou Ta Prok Up	25.63	154.00
Kampong Thom	Snao	105.26	285.34
	Sa'ang	53.40	(88.64)
Battambang	Prek Toal	13.30	131.36
	Thvang	62.00	163.30

Table 22: Dynamics of poverty

Province	Village	Percentage		
		Chronic Poverty	Vulnerability	Out of Poverty
Pursat	Chong Khlong	60	0	13
	Ou Ta Prok Main	65	10	10
	Ou Ta Prok Up	53	0	7
Kampong Thom	Snao	53	2	4
	Sa'ang	85	2	2
Battambang	Prek Toal	26	14	7
	Thvang	40	9	9

Table 23. Household assets and chronic poverty

Province	Village		Assets: Land (ha)	Assets: Livestock Index	Assets: Education (years schooling of household head)
Pursat	Chong Khlong	Chronic poor	0.85	10.34	1.81
		Non-chronic poor	1.11	14.52	2.61
	Ou Ta Prok Main	Chronic poor	0.86	6.39	2.29
		Non-chronic poor	0.79	6.61	2.38
	Ou Ta Prok Up	Chronic poor	0.64	11.03	1.00
		Non-chronic poor	0.70	13.14	3.00
Kampong Thom	Snao	Chronic poor	2.04	15.23	1.25
		Non-chronic poor	2.05	22.55	1.33
	Sa'ang	Chronic poor	2.00	19.00	0.64
		Non-chronic poor	1.50	19.91	1.33
Battambang	Prek Toal	Chronic poor		-	2.59
		Non-chronic poor		-	3.73
	Thvang	Chronic poor		-	2.24
		Non-chronic poor		-	2.29

Table 24. Determinants of poverty (Probit estimation)

Variables	Pursat (Road development) Coefficient	Kampong Thom (Irrigation development) Coefficient	Battambang (Release of Fishing Lot) Coefficient
If male headed	-0.59	0.21	-0.71
	(0.49)	(0.38)	(0.45)
Age of household head	0.02	0.00	0.01
	(0.01)	(0.01)	(0.01)
Household size	**0.23****	0.06	**0.31*****
	(0.10)	(0.06)	(0.08)
Education of household head	**-0.02***	**-0.11***	**-0.08***
	(0.07)	(0.08)	(0.06)
Livestock assets	**-0.01***	**-0.02***	
	(0.01)	(0.01)	
Landholding	-0.16	0.11	
	(0.26)	(0.22)	
Number of observations	70	82	86
LR chi2(8)	17.25	20.82	19.05
Prob > chi2	0.03	0.00	0.00
Pseudo R2	0.19	0.21	0.16

*Note: This table shows the results of a regression analysis (probit estimation) to estimate which factors are significant in explaining the ability of households in the case study villages to move out of poverty. Only the bold figures are statistically significant, noted as follows: *** significant at 1%; ** significant at 5%; * significant at 10%. A positive value indicates a positive correlation with poverty, whereas a negative value indicates that the variable is significant in explaining the ability of households to move out of poverty. "If male headed" is a dummy variable (binary). Standard error is shown in parenthesis. All regression estimates include constant.. The estimation controlled for location using village dummies.*

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Livelihoods Component

ENABLING ALTERNATIVE LIVELIHOODS FOR AQUATIC RESOURCE DEPENDENT COMMUNITIES OF THE TONLE SAP

SUMMARY RESEARCH NOTE

Prepared by

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I INTRODUCTION

1. This research note is provided as a supplement to the technical report, "Influence of Built Structures on Livelihoods: Case Studies of Road Development, Irrigation, and Fishing Lots,"[1] as part of the livelihoods component of the "Study of the Influence of Built Structures on the Fisheries of the Tonle Sap"[2]. The technical report assesses possible changes in people's livelihood strategies and outputs, including those derived from fisheries, particularly in terms of changes in livelihood portfolios, vulnerability, resource access and income. It also summarises local people's perception of the connections between their livelihoods, environment, aquatic ecosystems and built structures, as well as their viewpoints on best practices for built structures with a specific focus on institutional arrangements.

2. As described in the main technical report, all three study sites show an overall decline in fishing as a proportion of household income, a trend that is consistent with reports of a declining catch per household from other areas around the Tonle Sap. In such a context, the ability of poorer households in particular to diversify their livelihood portfolios, reducing their dependence on the natural resource base, is a key factor in reducing vulnerability.

3. In developing recommendations to improve the ability of rural households to diversify their livelihoods, it is important to understand what the livelihood priorities are for local communities, what alternatives are available, and what constraints prevent some households from taking advantage of these alternatives. This research note is meant to answer these questions.

4. In preparing this research note, data collected through the household surveys[3] was analyzed with specific reference to these questions, and to identify issues for focus group discussions among selected survey participants. Focus group discussions were organized in two villages in each of the three study sites[4], with participants selected to have a balance in gender and wealth groups (poorer, medium, and richer). The village chief and vice-chief were also included in each focus group, for a total of 10-12 people per group. Existing and alternative livelihood scenarios were discussed and evaluated by the focus group participants. Constraints to livelihood diversification were identified and ranked, as well as suggestions about addressing these constraints.

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[1] Ratner, B. D., D. B. Rahut *et al.* 2007. "Influence of Built Structures on Livelihoods: Case Studies of Road Development, Irrigation, and Fishing Lots." Technical Report. Asian Development Bank TA 4669-CAM.

[2] Asian Development Bank TA 4669-CAM. Financed by the Government of Finland, with the Cambodian National Mekong Committee as executing agency and the WorldFish Center as implementing agency.

[3] For a description of the methodology used in the household surveys, please see the main technical report.

[4] The villages are Chong Khlong and Ou Ta Prok in Ou Sandan commune, Krakor District, Pursat province (road development case study), Snao and Sa'ang villages in Kampong Thma Commune in Santuk District, Kampong Thom province (irrigation development case study), and the floating villages of Prek Toal and Thvang in Kaoh Chiveang commune, Aek Phnum district, Batambang province (fishing lot case study). For a description of the study sites and their socioeconomic characteristics.

5. The results of these discussions have been integrated into the recommendations of the main report addressing investment in household assets to better enable poorer households to take advantage of alternative livelihood opportunities.

6. The research note is organized according to the three questions addressed: (i) What are the current livelihood activities in the study sites? (ii) What are the preferred livelihood activities? (iii) What are the constraints associated with livelihood diversification, and what do locals see as priorities for overcoming these constraints? In addressing each question, we note differences by income group, and where relevant, by gender.

II CURRENT LIVELIHOOD ACTIVITIES

7. **Fishing is the most important source of household income in all three study sites.** The contribution is of course highest in the floating villages of Battambang, where fishing accounts for about 67 percent of total household income. But even in the road development (Pursat) and the irrigation (Kampong Thom) cases, where almost all households (90 percent) are rice farmers, fishing still accounts for a higher percentage of household income than rice farming (28-29 percent from fishing versus 19 percent from rice farming in both cases). (See Figure 1.)

8. In terms of the percentage of households participating, the most prevalent livelihood activities in the road development (Pursat) and irrigation (Kampong Thom) cases are rice farming, fishing, and livestock rearing, in that order. In the fishing lot case (Battambang), fishing is the most prevalent, with virtually all households participating, and fish labour is the second most common livelihood activity (with 29 percent of households participating).

9. **Besides fishing, rice farming and livestock rearing, households in the study sites are engaged in a wide variety of other livelihood activities.** These can be categorized as fishing-related activities (such as fish processing, making and repairing fishing gear), other crops (such as corn and vegetables), farm labour (wage labour in agriculture), fishing labour (including wage labour with the fishing lots), non-farm labour (wage labour outside the fishing and agriculture sectors), and petty trade (including marketing and selling of groceries, fish, agricultural products, and other goods).

10. **There are consistent gender differences in many livelihood activities.** The following activities are predominately male: fishing, fishing labour, carpentry, poultry and livestock rearing, buying and selling livestock, and serving as porters. Women are engaged in selling fishery and agricultural products in the public markets and operating neighborhood convenience stalls, tending to gardens and various vegetable crops, and collecting rattan and various other natural resources. Many other livelihood activities commonly have participation of both men and women.

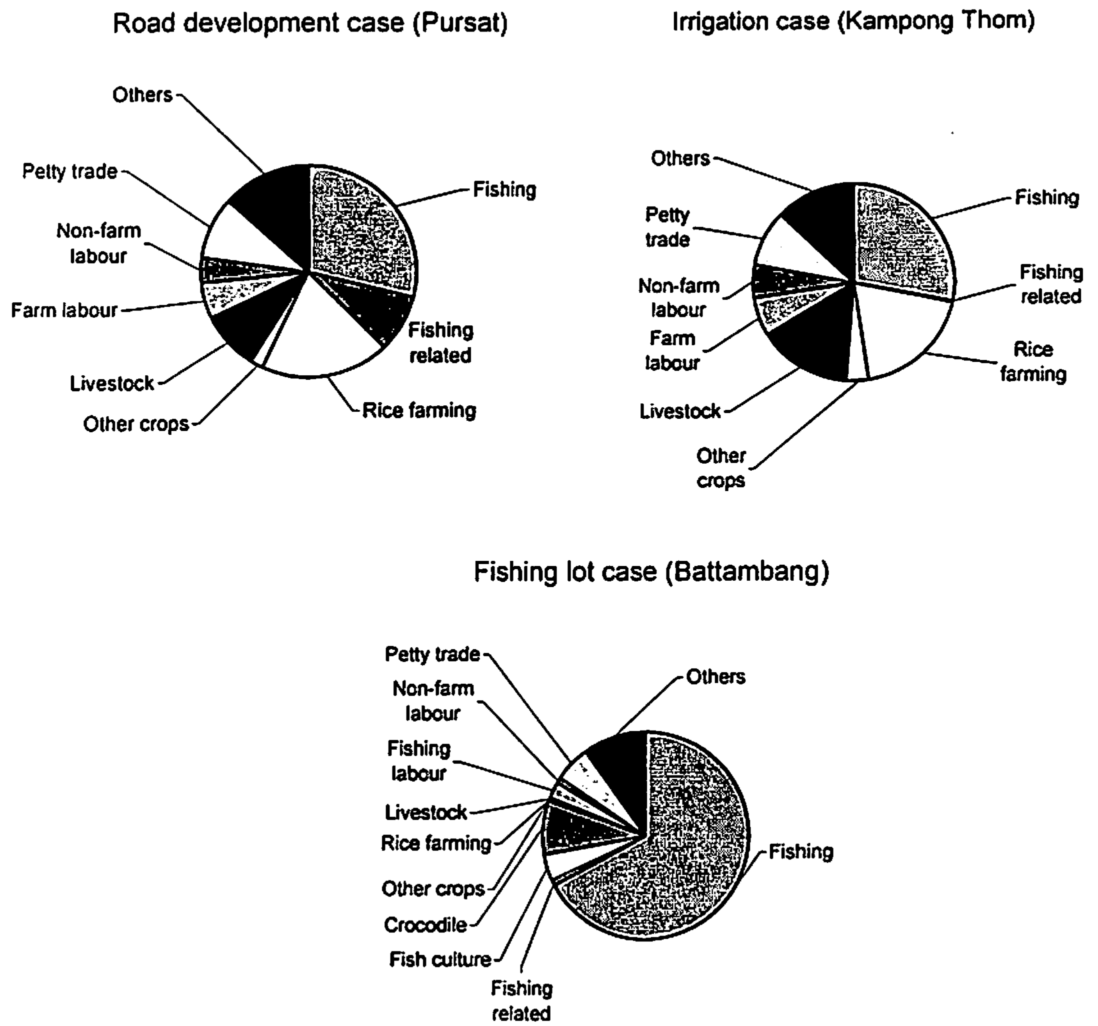

Figure 1. Household income portfolios in the three study sites. Shows the percentage of average household income contributed by each category of livelihood activity.

11. **Even in nearby villages, the pattern of livelihood activities among richer or poorer households varies significantly.** The following analysis examines the percentage contribution to total household income by dividing households into three income groups (terciles) and comparing these groups.[5] While one might expect, for example, that the higher income households consistently rely more on petty trade and less on fishing as a source of income, the analysis

[5] It is important to note that these income groups (terciles) are formed by dividing surveyed households *within each village* according to current annual income. This is useful in making comparisons to assess the relative importance of different livelihood activities to each income group. But keep in mind that the groupings are relative to other households in the same village, such that in a village with overall lower income (Chong Khlong, for example), households in the "higher income" group in fact earn less on average than households in the "medium income" group in Prek Toal, where overall incomes are higher. For analysis based on an absolute measure of poverty (the national poverty line), see the main technical report.

shows that the pattern is inconsistent from one village to the next. This implies that even nearby villages have a significantly different local context influencing livelihood choices.

12. **In the road development case study (Pursat), fishing is a more significant income source for poorer villagers in one village near the road, while in a nearby village the opposite is true.** Poorer households in the Cham village near the road (Chong Khlong) derive slightly more income from fishing while in the Khmer village (Ou Ta Prok) richer households derive significantly more of their income from fishing activities. In Chong Khlong the poorer households derive significantly more of their income from rice farming, but in Ou Ta Prok each of the income groups derives about the same proportion of their income from rice farming. In Chong Khlong petty trade seems to be dominated by the higher income households but in Ou Ta Prok, it is the poorer households who depend more on petty trade. (See Table 1.)

	Chong Khlong			Ou Ta Prok		
Activities	Lower	Middle	Upper	Lower	Middle	Upper
Fishing	36.7	33.6	30.5	17.3	20.9	27.8
Fishing related activities	10.7	18.9	11.0	0.0	1.3	2.7
Rice farming	33.1	25.0	12.3	25.3	22.4	23.1
Other crops	1.8	3.3	2.0	1.7	1.3	1.1
Livestock	7.9	8.7	1.5	19.2	17.9	16.9
Farm labour	1.3	1.9	11.2	4.0	1.7	0.8
Non-farm labour	2.6	0.0	4.7	3.0	1.4	7.1
Petty trade	0.0	1.2	12.2	20.2	10.6	8.8
Other	6.1	7.4	14.9	9.3	22.5	12.0

Table 1. Household income portfolios by income group (tercile) for villages studied in the road development case study, Pursat

13. **In the irrigation case study site (Kampong Thom), rice farming represents a significantly higher proportion of income for poorer households.** In the end-user village (Sa'ang), fishing is significantly more important to the richer households, while in the head-user village (Snao) no such distinction is evident. (See Table 2.)

	Snao			Sa'ang		
Activities	Lower	Middle	Upper	Lower	Middle	Upper
Fishing	26.0	30.4	25.6	12.1	22.8	36.7
Fishing related activities	0.1	0.0	0.3	0.3	0.9	0.3
Rice farming	34.3	21.3	14.6	30	25.2	15.8
Other crops	2.5	3.7	3.8	7.1	5.1	1.7
Livestock	9.0	14.2	18.4	13.7	9.7	14.9
Farm labour	7.0	3.4	0.3	18.1	5.3	15
Non-farm labour	7.5	18.4	5.7	1.6	2	0.1
Petty trade	0.0	4.8	17.2	4.9	1.2	7
Other	13.5	3.7	14.2	12.1	27.7	8.4

Table 2. Household income portfolios by income group (tercile) for villages studied in the irrigation case study, Kampong Thom

14. **In the floating villages in Battambang, fishing is the dominant source of income for richer and poorer groups alike.** Crocodile culture is important to

richer households only, and fishing labour is an important income source primarily for poorer households. (See Table 3.)

	Prek Toal			Thvang		
Activities	Lower	Middle	Upper	Lower	Middle	Upper
Fishing	66.8	71.1	61.4	58	85.9	65.9
Fishing related activities	5.1	0	0	1.5	0	0.5
Fish culture	7.3	5.5	6.4	10	1.2	2.3
Crocodile	0	0	7.8	1.5	0	16.3
Rice farming	0	0	0	0.5	0	0
Other crops	0	0.7	0.2	1.9	0	0
Livestock	0	0	0	0.6	0.2	0.8
Fishing labour	11.6	0.8	6.2	2.6	0.9	0.4
Non-farm labour	0	0	0	11	1.1	0
Petty trade	0.4	6.1	0.2	0	0	12.8
Other	8.8	15.8	17.8	12.4	10.8	1.4

Table 3. Household income portfolios by income group (tercile) for villages studied in the fishing lot case study, Battambang

III PREFERRED LIVELIHOOD ACTIVITIES

15. **When asked about diversifying their livelihoods, people in the study villages typically look to activities that are already established in the area,** meaning that someone has already demonstrated the option to be economically viable. The following results summarize the focus group discussions. The results from the two villages in each site did not differ significantly, so the results are presented here by study site rather than by village. We also note distinctions in terms of the preferences between the relatively poorer households and the relatively richer households.[6] (See Table 4.)

16. **In the road development study site (Pursat), where the road has increased market access, poorer households are seeking to increase production of a range of agricultural products.** They hope to improve and diversify their livestock rearing activities, expand production of vegetable crops such as water melon, cucumber, long bean, cabbage, morning glory, and also hope to extend rice farming to two times per year. In Ou Ta Prok village, the poorer households also wish to diversify into fish culture, in particular *Pangasius djambal* (trey pra), *Channa striata* (trey ros), and Clarias batrachus (trey andeng). The richer households are also seeking to intensify rice farming, vegetable growing and livestock raising, as well as to improve non-farm livelihood activities such as grocery selling and livestock trade.

17. **In the irrigation study site (Kampong Thom) the poorer households are seeking to benefit from the anticipated irrigation by intensifying rice farming to two crops per year, and diversifying vegetable production.** Vegetable crops identified by the villagers include morning glory, water melon, cucumber, mung bean, tomato, cabbage, bitter gourd, wax gourd, and mushroom. In the livestock sector, the poorer households are looking to raise

[6] For the focus group discussions, participants where divided into wealth groups based on judgment by the village leader and common agreement among the participants.

more chicken, ducks, pigs and cattle. The richer households too are looking to intensify rice farming, vegetable growing (water melon, cucumber, long bean, black cabbage, chinese cabbage, head cabbage, kinky cabbage and mushroom) and livestock raising (chicken, ducks and pigs). In addition, richer households are seeking to diversify into some non-farm livelihood activities such as motor repairs and grocery selling.

18. **In the fishing lot study site (Battambang), the poorer households are primarily seeking to improve their livelihoods through additional fishing-related activities and fish culture.** For fish culture, they cited in particular *Pangasius djambal* (trey bra), *Channa striata* (trey ros), and *Clarias batrachus* (trey andeng). In addition, they are seeking additional income through working as fishing labour, collecting wood for sale and expanding poultry raising. The richer households want to maintain their existing activities, including fishing, grocery selling, motorized boat taxi, fish and crocodile culture, fish processing and fish trade.

	Road development case (Pursat)	Irrigation case (Kampong Thom)	Fishing lot case (Battambang)
Very poor & poor households	• Intensify and diversify livestock raising (cows/oxen, buffalo, chickens, ducks -- and pigs in Ou Ta Prok only) • Intensify fishing activities • Intensify rice farming • Vegetable growing • Fish culture	• Intensify fishing • Sugar palm making • Vegetable growing • Livestock raising (chickens, ducks and pigs) • Intensify rice farming	• Intensify fishing • Fish culture • Fishing labour • Collecting firewood for sale • Livestock raising (chickens, ducks and pigs in the dry season)
Medium & richer households	• Intensify rice farming • Vegetable growing • Intensify and diversify livestock raising (cows/oxen, buffalo, chickens and ducks) • Improve existing non-farm activities like grocery selling and cow/oxen and buffalo trade	• Intensify fishing • Livestock raising (chickens, ducks and pigs) • Vegetable growing • Intensify rice farming • Intensify and diversify non-farm activities like motor repairs, grocery selling, and trading	• Intensify fishing • Intensify and diversify non-farm activities like grocery selling at home, motorized boat taxi, fish trade • Fish and crocodile culture. • Fish processing

Table 4. Livelihood activities that households seek to pursue, distinguished by wealth group

19. **Notably, in almost all cases, villagers hope to increase their income by intensifying fishing.** The one exception is the richer group in the Pursat case, which did not identify this as a preference. People's preferences as expressed in the focus groups are closely linked to observations about what activities others in the village or nearby villages are successfully engaged in now. This implies that there remains a very significant gap between what people now say they prefer and what may indeed be viable, i.e. the future mix of livelihood activities that the local ecosystems and/or economies may be able to sustain at higher levels.

IV CONSTRAINTS TO LIVELIHOOD DIVERSIFICATION AND LOCAL PERCEPTIONS ABOUT ADDRESSING THESE

20. **The constraints to livelihood diversification identified by villagers are remarkably consistent across the three cases studied. The two most important obstacles are lack of capital / access to credit facilities, and inadequate extension services.** Villagers say that limited financial assets prevents them from diversifying into economically attractive livelihood activities, particularly as alternatives to fishing and collection of wild natural resources. Also very important in their view is the limited knowledge about methods of production and marketing strategies for alternative products, which they seek extension services to address, along with support for inputs such as improved rice seed varieties, fish seed and feed. In the irrigation (Kampong Thom) and fishing lot (Battambang) cases, access to markets ranked as the third major obstacle, while in Pursat it ranked fourth. (This is not surprising as market access was identified as the major benefit of road improvement in the Pursat case.) The remaining obstacles identified were lack of skills and technical knowledge (for example, about livestock raising), poor or inadequate infrastructure, and lack of awareness about the opportunities available for livelihood diversification. (See Table 5.)

Constraints	Road dvpt. case (Pursat)	Irrigation case (Kampong Thom)	Fishing lot case (Battambang)
• Access to credit facilities	1	1	1
• Inadequate extension services and agricultural inputs	2	2	2
• Markets	4	3	3
• Skills and technical knowledge	3	4	4
• Infrastructure	5	5	5
• Lack of awareness/information about alternative livelihood opportunities	6	6	6

Table 5. Constraints to livelihood diversification, as ranked by village focus groups

21. **Low-interest microcredit lending was identified – by poorer and richer villagers alike – as the most important way to assist households to overcome the constraints to livelihood diversification.** Because most households do not have appropriate collateral to seek loans from the formal banking system, and because their loan requirements are very small, they typically now rely on informal lending at very high rates of interest.

22. **Other priorities include technical assistance and inputs, information about livelihood alternatives and market opportunities.** In the road development (Pursat) and irrigation (Kampong Thom) cases, technical assistance and training is sought in such areas as sewing, fish culture,

livestock raising, vegetable cultivation, and intensive rice farming. In the case of the floating villages in Battambang, technical assistance and training is sought in such areas as poultry and pig raising, crocodile and fish culture, and sewing, in addition to government support to community fisheries with effective enforcement.

	Road development case (Pursat)	Irrigation case (Kampong Thom)	Fishing lot case (Battambang)
Very poor & poor house-holds	• Credit service with low interest rate (1-2% per month) • High yield rice seed, fertilizer and low-lift-pumps • Technical assistance for farming, livestock raising and fish culture	• Credit service with low interest rate (1-2% per month) • High yield rice seed, fertilizer and enough water • Technical assistance for vegetable farming • Marketing channels for palm sugar • Equipment for farming • Assistance from Fisheries Administration to create a community fishery	• Credit service with low interest rate (1-2% per month) • Technical assistance for fish culture
Medium & richer house-holds	• Credit service with low interest rate (1-2% per month) • High yield rice seed, fertilizer and low-lift-pump • Technical assistance for farming, livestock raising and fish culture	• Credit service with low interest rate (1-2% per month) • High yield rice seed, fertilizer and enough water • Technical assistance for vegetable farming • Marketing channels for palm sugar • Assistance from Fisheries Administration to create a community fishery	• Credit service with low interest rate (1-2% per month) • Technical assistance for fish and crocodile culture

Table 6. Summary of solutions sought by villagers to address the constraints to livelihood diversification

V CONCLUSION AND RECOMMENDATIONS

23. **Promoting rural development that enables new livelihood alternatives or expands the number of participants that can viably take part in existing alternatives is an indirect means of reducing competition and pressure on the natural resource base, fisheries included.** This is especially important in areas where fishing is the leading source of income, as it is currently in the road development (Pursat) and irrigation (Kampong Thom) cases included in this study, or where it is the dominant source of income, as is the case with the floating villages of Battambang.

24. **Efforts at promoting livelihood diversification should include a mix of reducing constraints to enable poorer households to enter into existing alternatives, and cautiously experimenting with newer options.** Outside interventions often focus on new and original, or "boutique" options which may be appealing to project designers but are unproven in the area. Because villagers typically look to activities that are already established in the area (a reasonable way of managing risk for the household), it is likely to be much easier to facilitate livelihood diversification by enabling people to access the livelihood options they are already seeking. Other alternatives will need a longer time to establish as viable. Many will prove inappropriate even if they are technically feasible, for example, because they entail unacceptably high risk or require social organization that may not exist.

25. **Yet, some local expectations about intensifying existing livelihood activities – fishing in particular – are unrealistic.** For communities that have depended overwhelmingly on fishing (such as most floating villages), efforts to regulate fishing and make it more sustainable need to be complemented with support to alternatives such as ecotourism, post-harvest processing, improvements to equity and efficiency in fish trade, and (for those who wish) training for jobs on shore.

26. **Microfinance is in high demand and is perhaps the simplest measure to help families overcome barriers to livelihood diversification.** In terms of the sustainable livelihoods framework, microcredit is a means of increasing household financial assets to permit very modest investments in other livelihood activities. Successful microcredit initiatives require investment in social capital at the same time, to build the patterns of trust among borrowers so that they can monitor and support one another in implementing their business plans and repaying the loans.

27. **In responding to the high demand for technical support services and training, a variety of public-private partnerships should be assessed to provide cost-effective and locally appropriate solutions.** Enabling commune councils select among alternative service providers and allocate local budgets accordingly is one approach. Competitive bidding for service provision contracts at the provincial level is another approach, as has been tried with the health sector in Cambodia. Similarly, the demand for information about livelihood alternatives and about access to markets suggests room for exploring public-private partnerships in incubating business models, for example with aquaculture or small fish processing enterprises.

28. **Complementary investments in basic education and public health are likewise critical for the longer term.** As the analysis in the main technical report demonstrated, many households fail to take advantage of the livelihood opportunities offered by improvements in infrastructure because they lack other essential assets, education in particular. In terms of the sustainable livelihoods framework, investments in education and health are a means of raising human capital assets particularly for poorer households, increasing their chances of moving and staying out of poverty.