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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

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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.

Acknowledgements:

The author would like to thank Mr. Henrik Garsdal for advice and valuable comments about hydrological data; Mr. Jorma Koponen and Dr. Juha Sarkkula for in-depth information, modelling and advice about water quality data; Mr. Christoph Feldkötter, Mr. Ulf Hedlund and Mr. Ith Sotha for information about Geographical Information Systems (GIS) databases; Mr. Huon Rath for assistance with land use data; Dr. Eric Baran for constructive comments and corrections on the report; and Mr. Chris Myschowoda for help with the report language.

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.

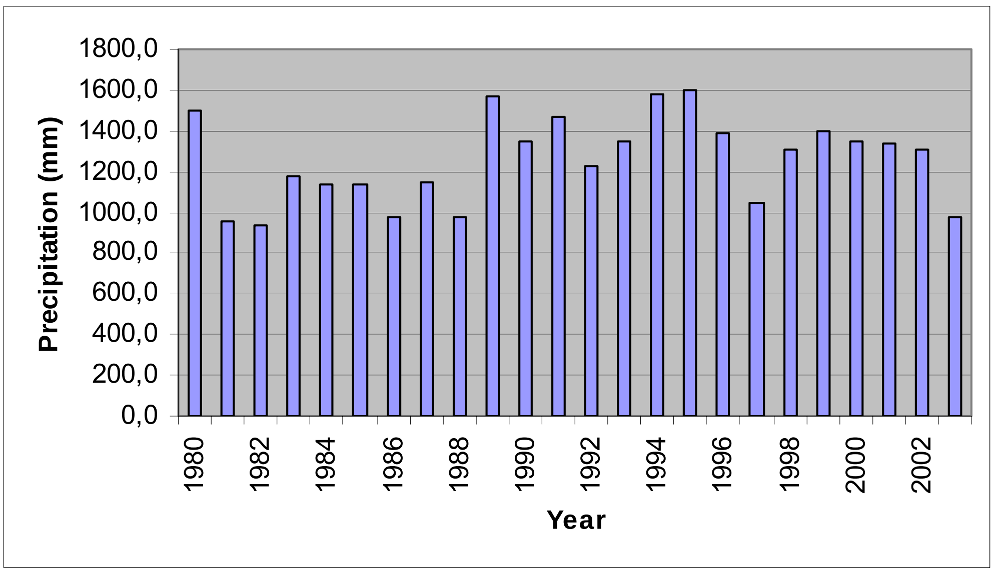

Figure 1 Average rainfall for the Tonle Sap catchment from 1980 to 2003 (millimetres).

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.

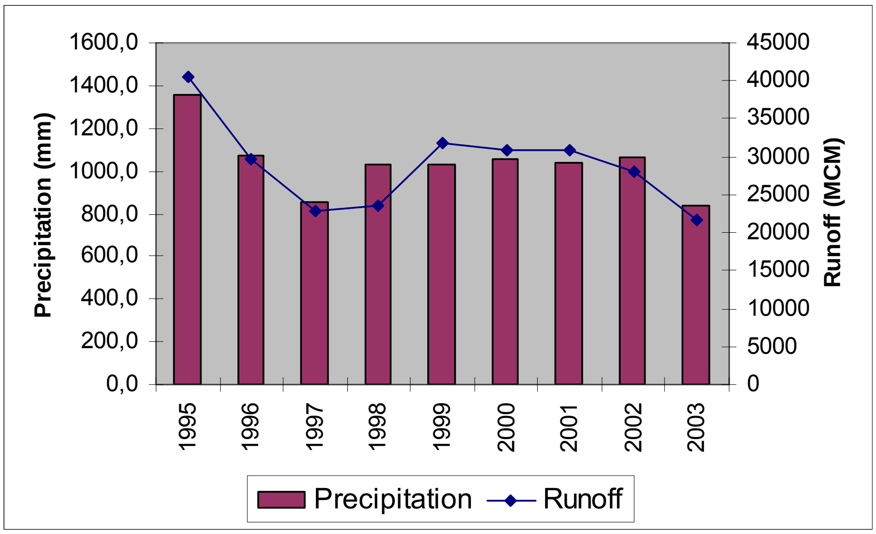

Figure 2 Comparison of Tonle Sap rainfall and runoff during rainy months (June to December).

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.

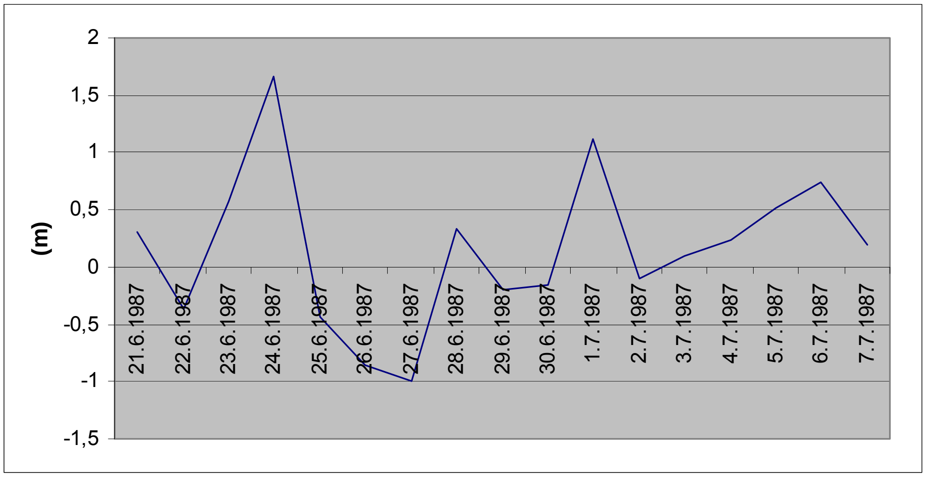

Figure 3 Kampong Chhnang daily water level difference from the 21st of June to the 7th of July, 1987.

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.

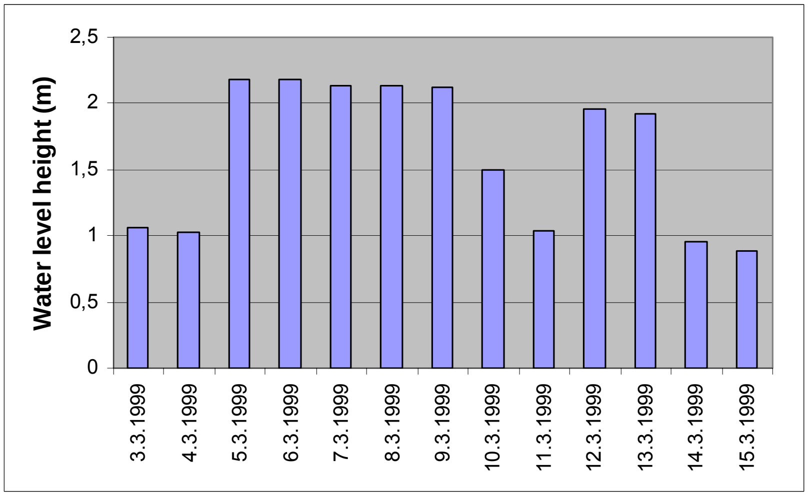

Figure 4 Daily water level shifts in Kampong Loung original measured data from the 3rd to the 15th of March, 1999.

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.

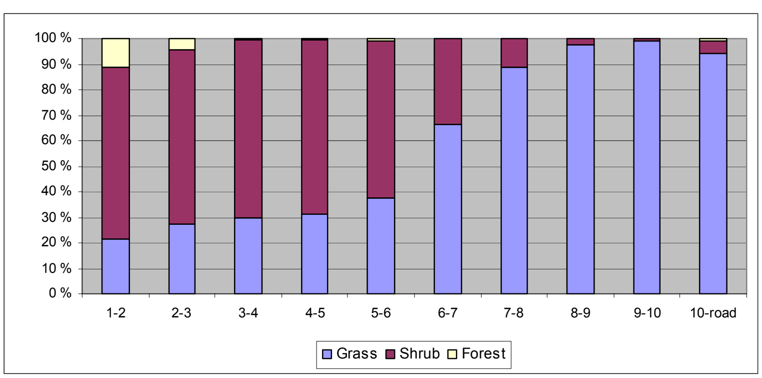

Figure 5 Percentages of Tonle Sap floodplain land use classes depending on elevation (in meters).

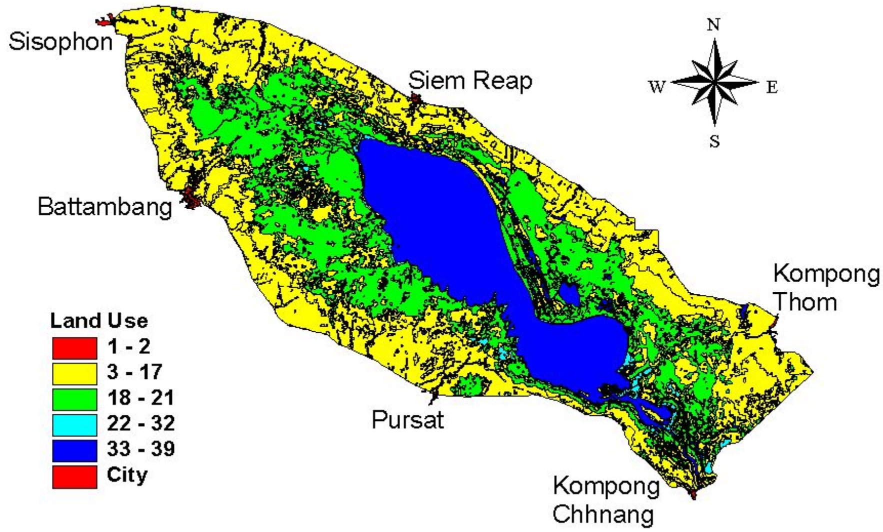

Figure 6 Distribution of selected land use classes in the Tonle Sap floodplain. JICA Land use classes 1-2 refer to *Urban*, 3-17 *Grass*, 18-21 *Shrub*, 22-32 *Forest* and 33-39 *Water feature, soil and rock*.

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).

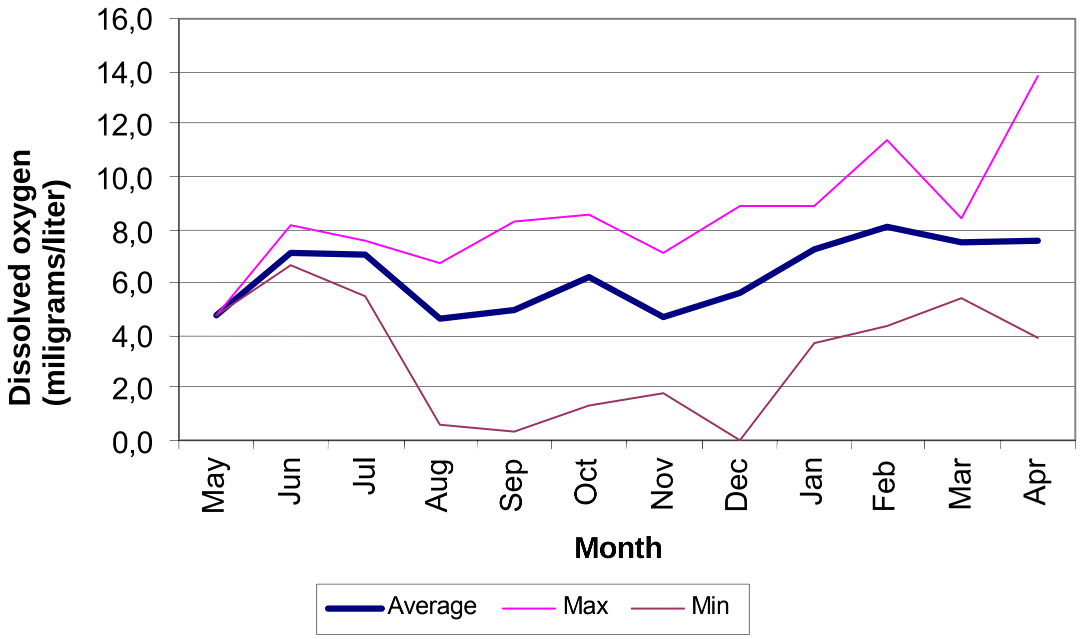

Figure 7 Dissolved oxygen levels for the 2000 and 2001 hydrological years (in milligrams per liter).

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).

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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*
2000	Grass	60	25	15	100
	Shrub	69	24	7	100
	Forest	32	53	15	100
1997	Grass	51	28	21	100
	Shrub	65	20	15	100
	Forest	27	37	36	100
1998	Grass	54	21	25	100
	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.

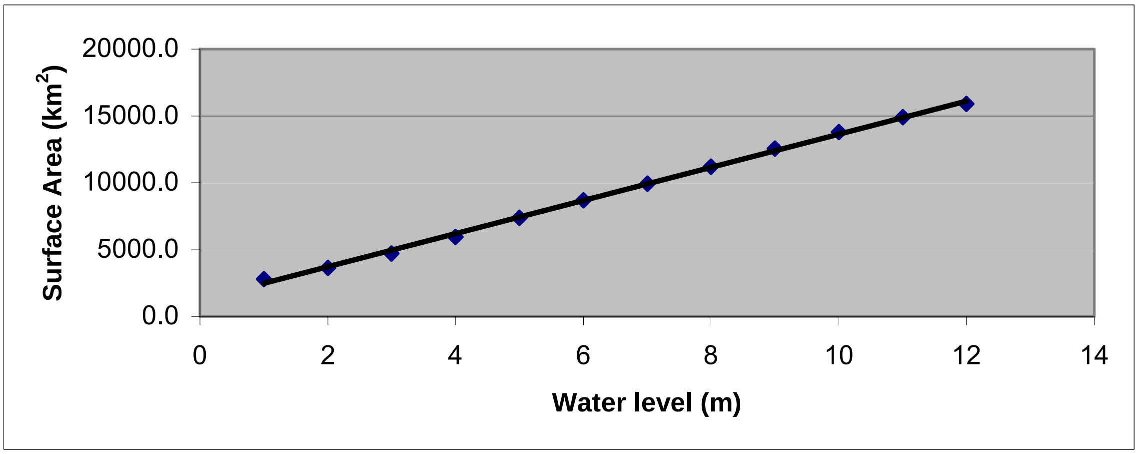

Figure 8 Certeza Survey based Triangulated Irregular Network (TIN) water levels plotted against lake surface areas with an added trendline (S_{lake}) y = 1880.4x + 1859.8 with R^2 = 0.9856 (Jantunen, 2001).

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.

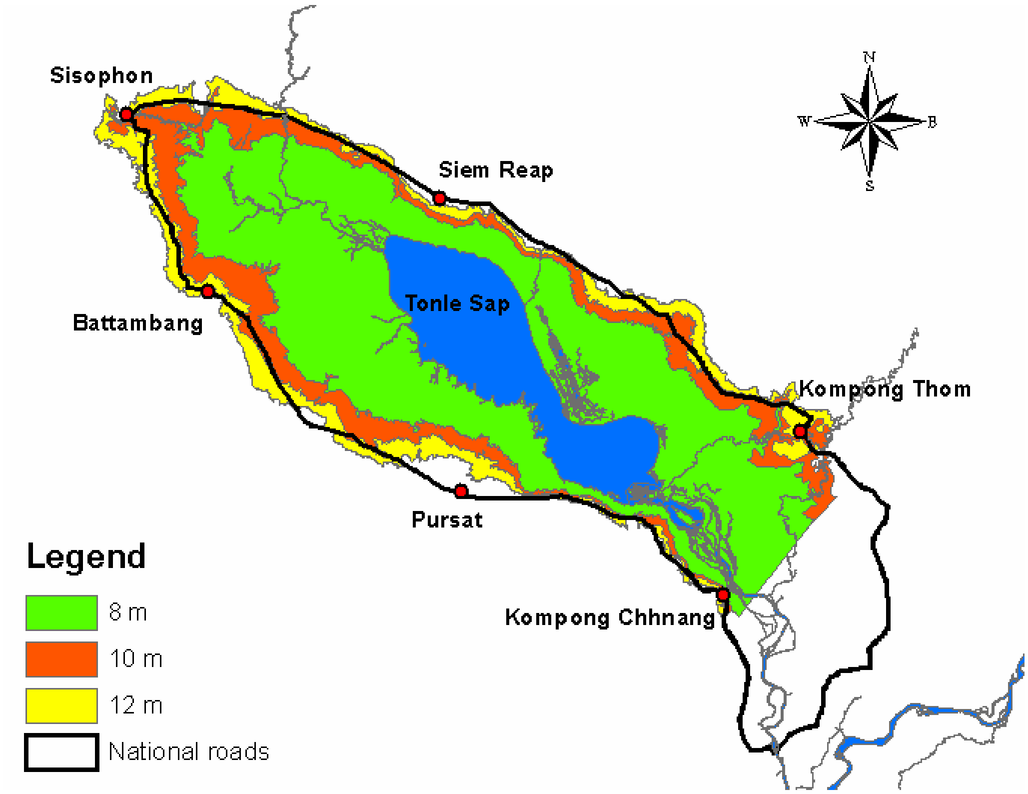

Figure 9: Elevation categories and the national roads 5 and 6

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.

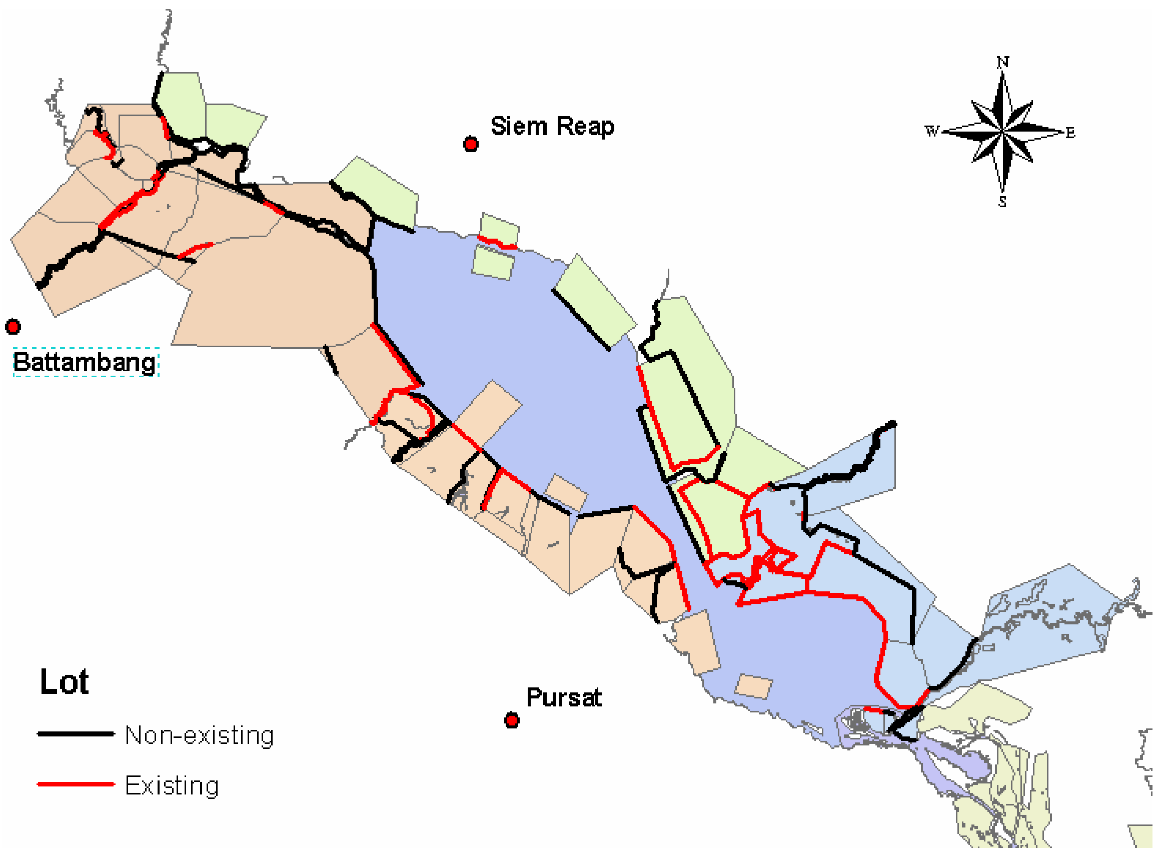

Figure 10: Digitized boundaries of the existing and dismantled lots

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.

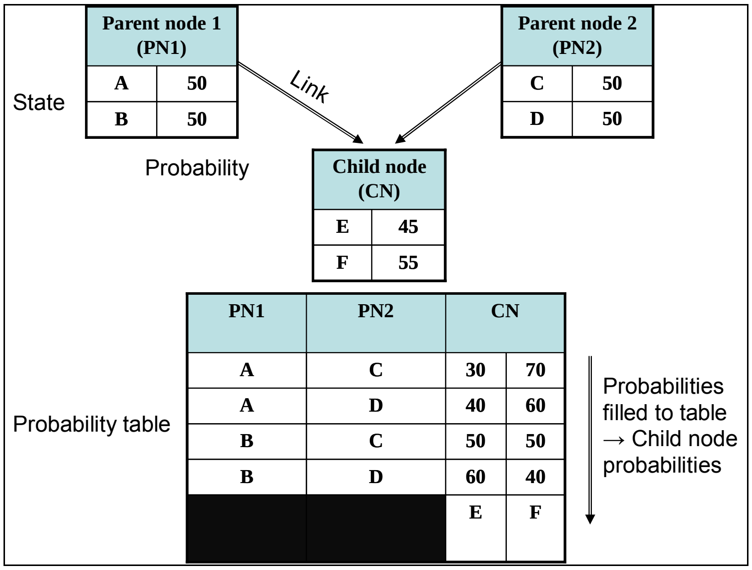

Figure 11 Example Diagram of a Netica Bayesian Belief Network model, terms used and structure of the probability table.

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).

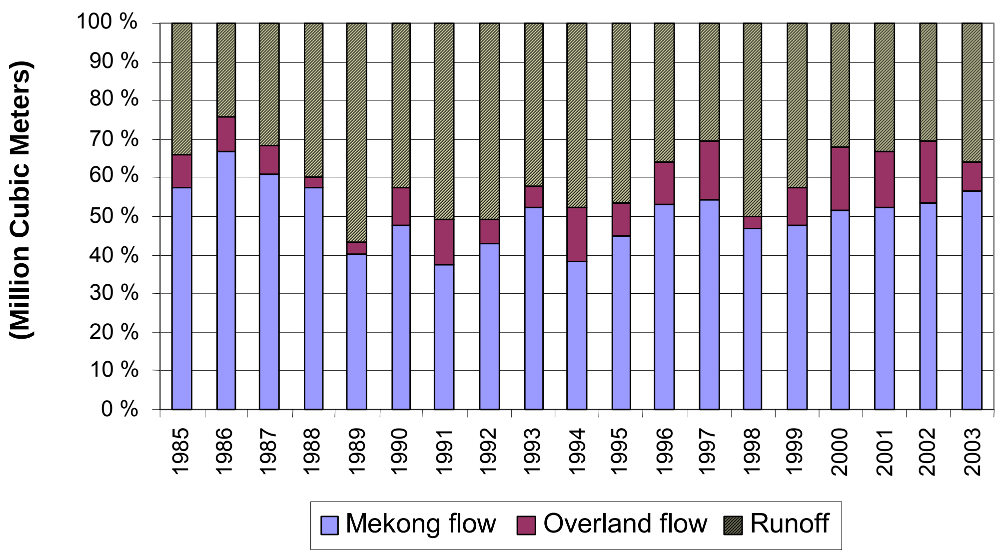

Figure 12 Comparison between total rainy season discharge shares of Mekong flow, Overland flow and Runoff (Tonle Sap).

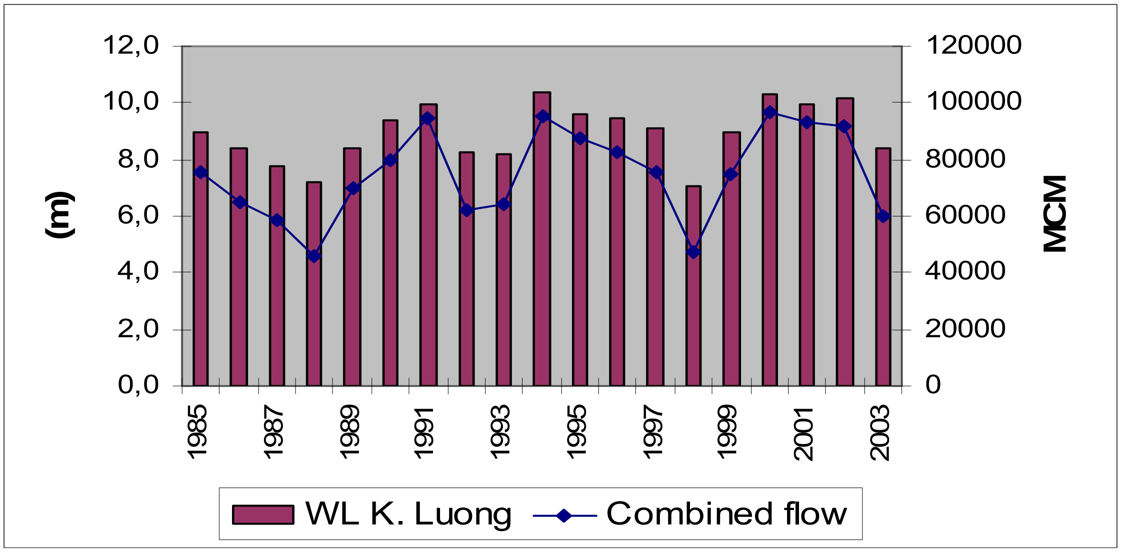

Figure 13 Comparison between combined discharge into the Tonle Sap Lake from River inflow, Overland flow and Runoff, and Tonle Sap water level at K. Loung.

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.

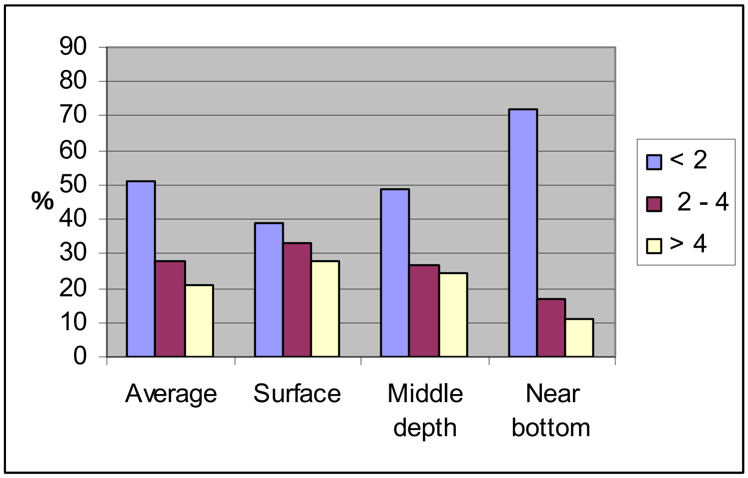

Figure 12 Comparison between 1997 *Grass* area dissolved oxygen levels at different depths for Below 2mg/l, From 2 to 4 mg/l and Above 4mg/l dissolved oxygen level categories.

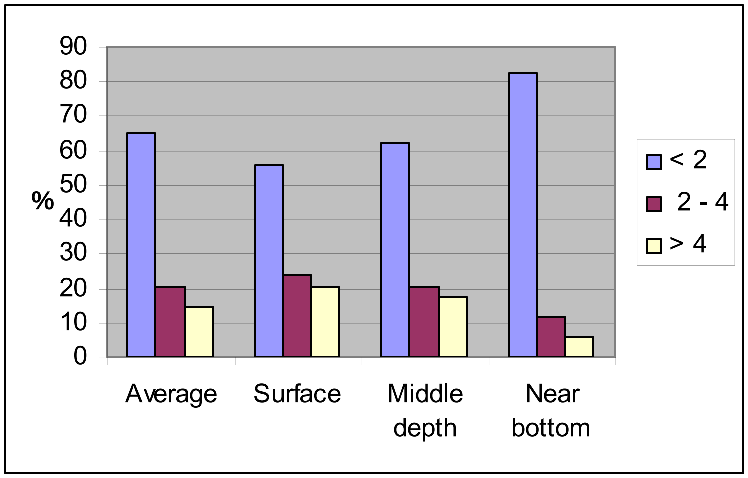

Figure 13 Comparison between 1997 *Shrub* area dissolved oxygen levels at different depths for Below 2mg/l, From 2 to 4 mg/l and Above 4mg/l dissolved oxygen level categories.

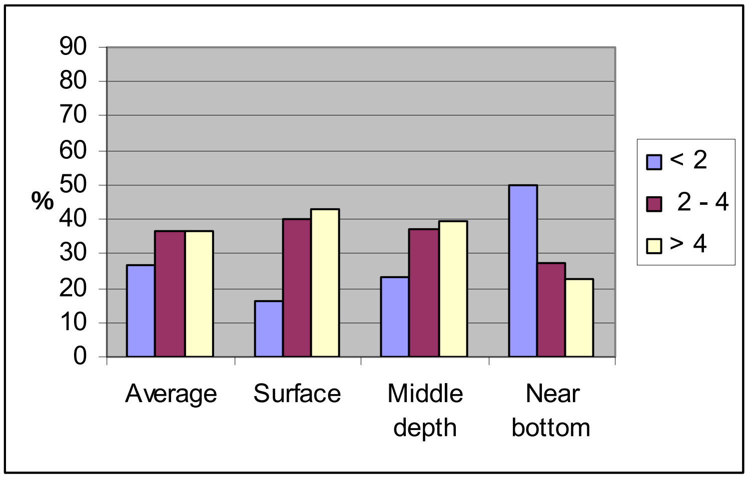

Figure 14 Comparison between 1997 *Forest* area dissolved oxygen levels at different depths for Below 2mg/l, From 2 to 4 mg/l and Above 4mg/l dissolved oxygen level categories.

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

List of data requested from the MRCS for the Bayesian Belief Network fisheries modelling activities:

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

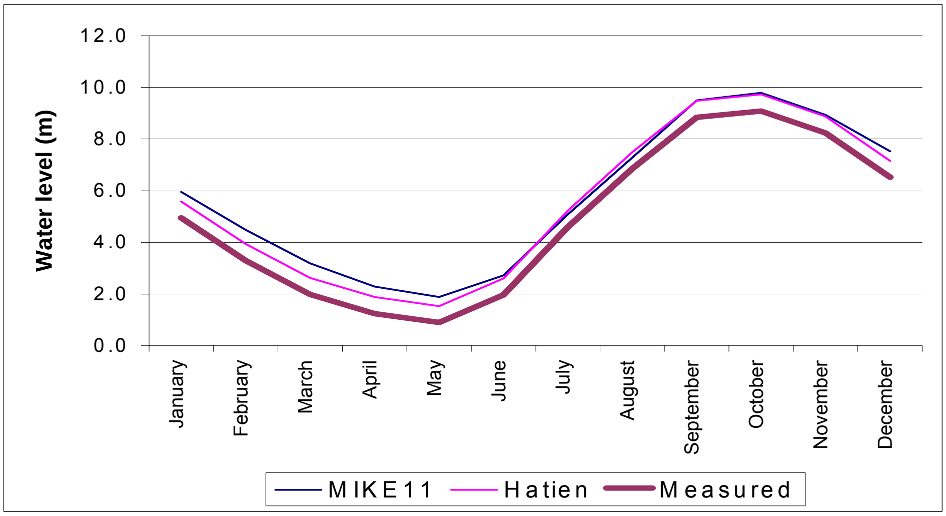

Figure 14 Comparison of average monthly water levels between MIKE11 model output, Ha Tien datum corrected and original measured data for the year 2001.

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

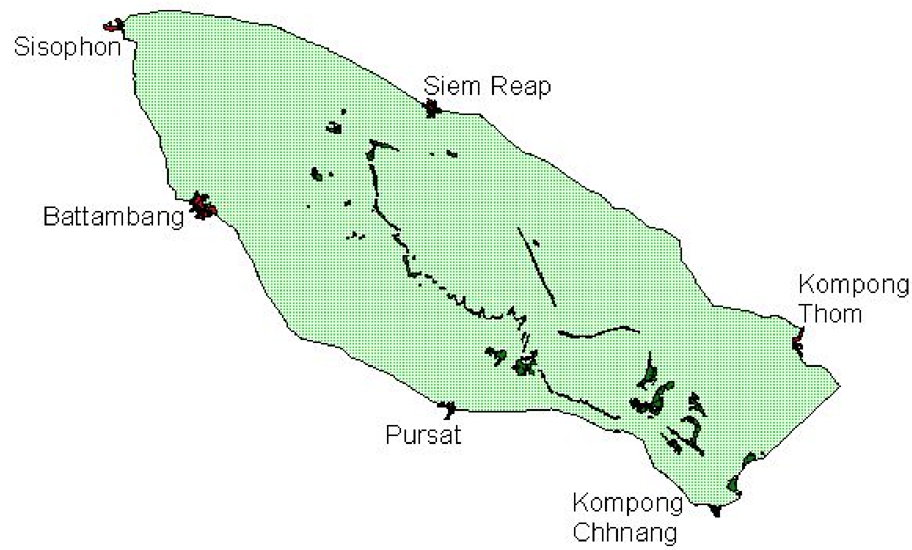

Figure 15 Spatial distribution of Bayesian Belief Network model floodplain vegetation, *Forest* parameter for the landuse node.

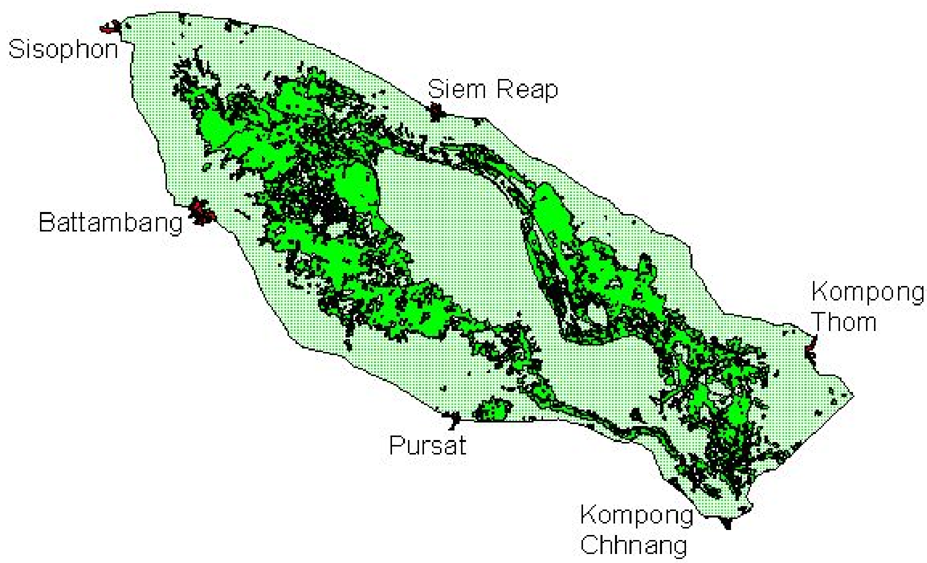

Figure 16 Spatial distribution of BBN model floodplain vegetation, *Shrub* parameter for the landuse node.

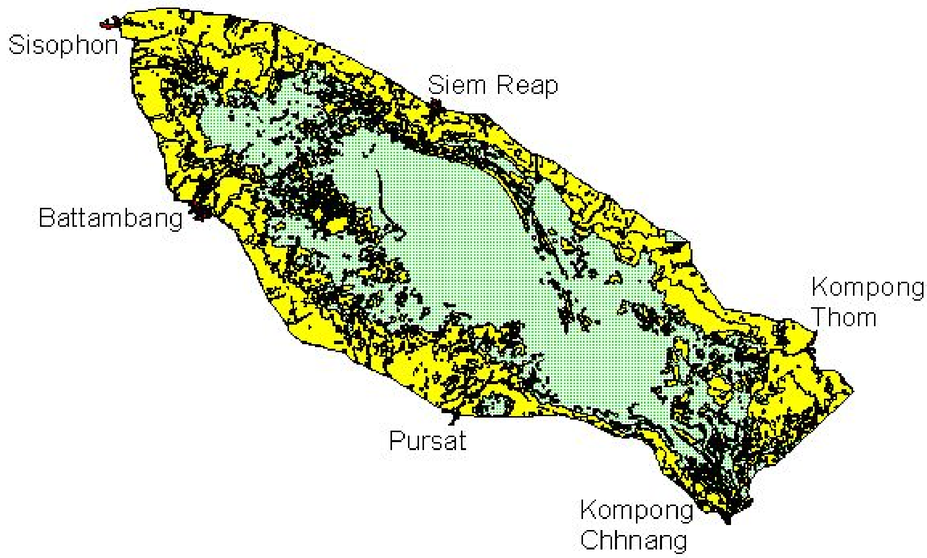

Figure 17 Spatial distribution of BBN model floodplain vegetation, *Grass* parameter for the landuse node.

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

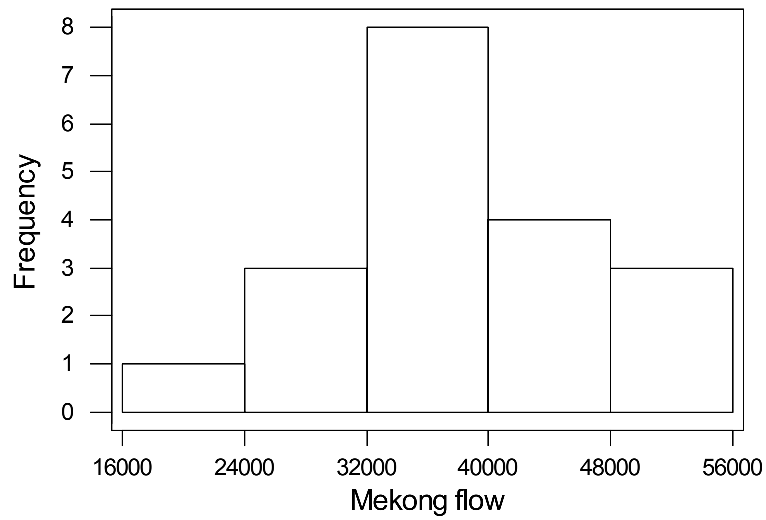

Figure 18 Frequency distribution of Mekong flow (MCM) towards the Tonle Sap Lake from 1985 to 2003.

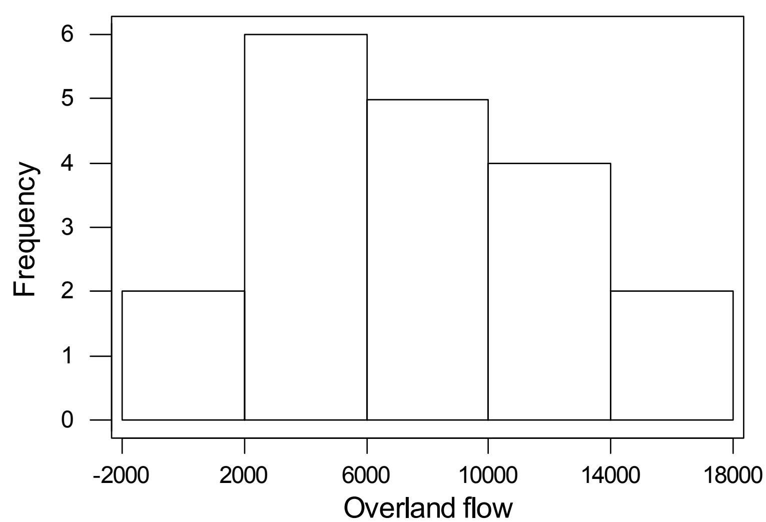

Figure 19 Frequency distribution of overland flow (MCM) towards the Tonle Sap Lake from 1985 to 2003.

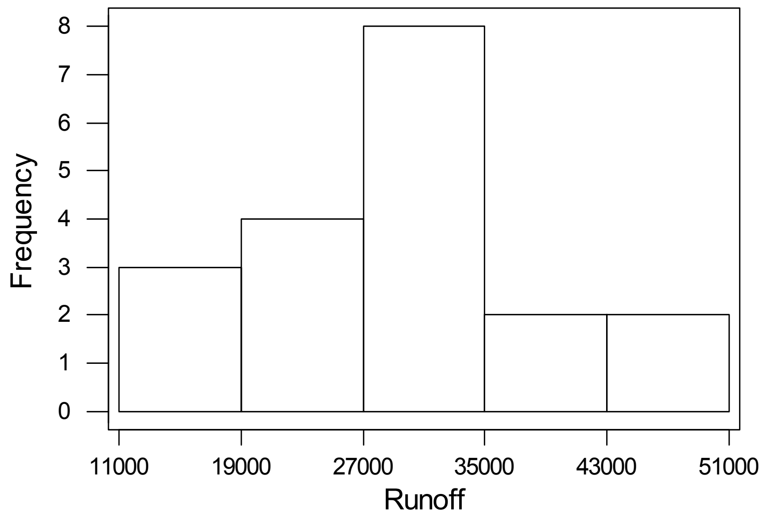

Figure 20 Frequency distribution of rainy season Tonle Sap tributaries runoff (MCM) from 1985 to 2003.

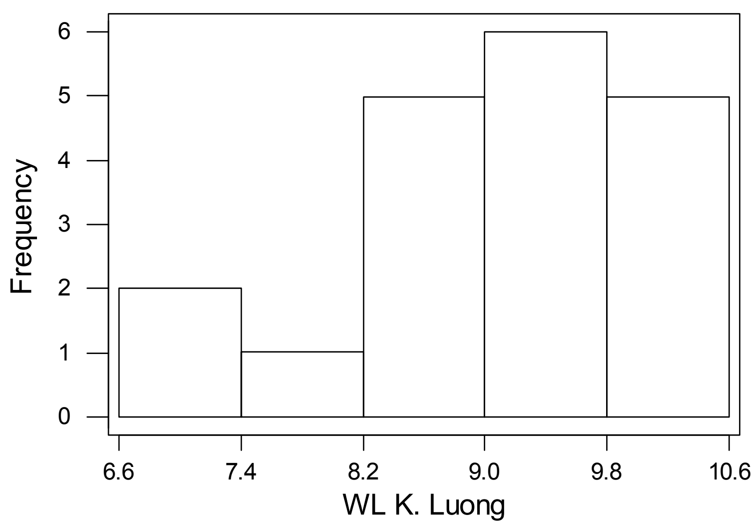

Figure 21 Frequency distribution of Kampong Loung maximum water level (m) from 1985 to 2003.

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	