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"BAYFISH-TONLE SAP", A MODEL OF THE TONLE SAP FISH RESOURCE

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Acknowledgements

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1 INTRODUCTION

As demand for freshwater steadily increases, decision makers at a national as well at basin level require information on the role of river flow in sustaining environmental benefits and tools to assess the necessary trade-offs between different water uses. River and floodplain fisheries are one of these benefits, and in the case of Cambodia are assets of remarkably high importance for the country.

Inland fisheries amounted to 360,000 tons in 2002 according to the Department of Fisheries, contributing up to 16% of the GDP (Van Zalinge *et al.* 2004). Depending upon years, this catch is equal or superior to that of the inland fisheries in the whole Northern America. However, detailed scientific monitoring shows that this annual catch varies a lot from year to year, depending among others on the flood characteristics (Ngor Peng Bun 2000, Baran *et al.* 2001a and b). Recent studies have also shown that the fish production in the Mekong Basin is dependant upon a number of hydrological, environmental and ecological factors (Baran 2001c). A modelling approach is the only possible way to integrate all these states (Baran and Cain 2001; Baran and Baird 2003), as the global trend resulting from intricacy of factors is beyond the reach of individual experts and the number of interacting variables would require decades of data for a standard statistical approach. For example, 60 annual cycles would be required to test all the interactions of four environmental variables on the annual fish production with a non parametric method, the least data-hungry approach (Sokal and Rohlf, 1981).

Reviews of modelling approaches and tools for tropical floodplain rivers management have also demonstrated the interest of Bayesian networks (Baran 2002; Arthington *et al.* 2004) as they allow the integration of quantitative as well of qualitative information (databases or expert knowledge), and they are intuitive, flexible and powerful.

In 2001-2002 a decision support tool based on Bayesian networks was developed to integrate the 25 variables that drive the Mekong fish production (Baran *et al.* 2003a). The paucity of data available at this time at the scale of the whole basin led to a rather crude model, whose parameterization was based on expert knowledge only. Lessons learnt from this undertaking were that:

a) the usefulness of Bayesian networks as a management tool would be better demonstrated if undertaken at a smaller scale, at which sufficient data would be available and variables could be more precisely described;
b) the expert consultation process was a crucial step in building a model that would be recognized as relevant by stakeholders, balancing simplification and accuracy, sophistication and uptake.

Learning from these lessons, in 2003 the WorldFish Center, in collaboration with IFReDI, undertook the development of a model of the Tonle Sap fish production. The objectives of this study were to identify relationships between river hydrology, floodplain habitats and fish production; to raise awareness among stakeholders and decision-makers about the dependency of fish production upon environmental factors; and to predict the relative abundance of the fish groups dominant in the Great Lake fisheries. An additional objective was also to train IFReDI counterparts in modelling approaches.

This report describes the progressive building of this model named BayFish – Tonle Sap (Bay- stands for Bayesian, and Fish- for fisheries). After having introduced the principles of Bayesian networks (section 2) and the process of stakeholders consultation for model building (section 3), we detail the creation of the model framework by selection of relevant variables (section 4), and the characterization of these variables (section 5). Then the parametrization of the variables is described in sections 6 and 7; the integration of data sets in the model, briefly addressed here, is extensively detailed in a companion report by Jantunen (2006). The model obtained is tested and validated, before scenario analyses are run (section 8). The conclusion of this study are presented in the final section.

2 BAYESIAN NETWORKS AS INFORMATION INTEGRATORS

A Bayesian network consists in defining the system studied as a network of variables linked by probabilistic interactions (Jensen 1996). Bayesian networks are also called Bayes nets or Bayesian belief networks (BBN). These methods based on the calculation of dependant probabilities (Bayes theorem) were originally developed in the mid-90s as Decision Support Systems (DSS) for medical diagnostic. Their principles and application to environmental management have been detailed in Charniak (1991), Ellison (1996), Cain (2001) and Reckhow (2002).

Variables representing the modelled environment can be quantitative (e.g. “Number of fishers”) or qualitative (e.g. “Fishing strategy”). For each variable a small number of classes are defined. One of the challenges, when building a network, consists in defining enough but not too many variables.

Probabilities are attached to connected variables, based on what is known about the system represented (Figure 1).

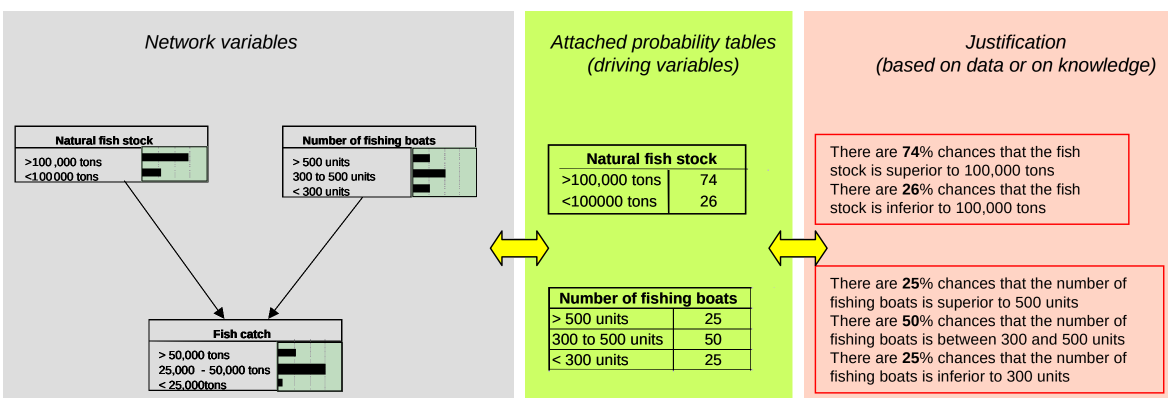

Figure 1: Mini-network of 3 connected variables representing a hypothetical fishery (left). The probabilities of the first two driving variables are detailed in the central section, and the justification is detailed in the right part of the figure.

In a driven variable all the possible combinations of driving variables are integrated (Figure 2).

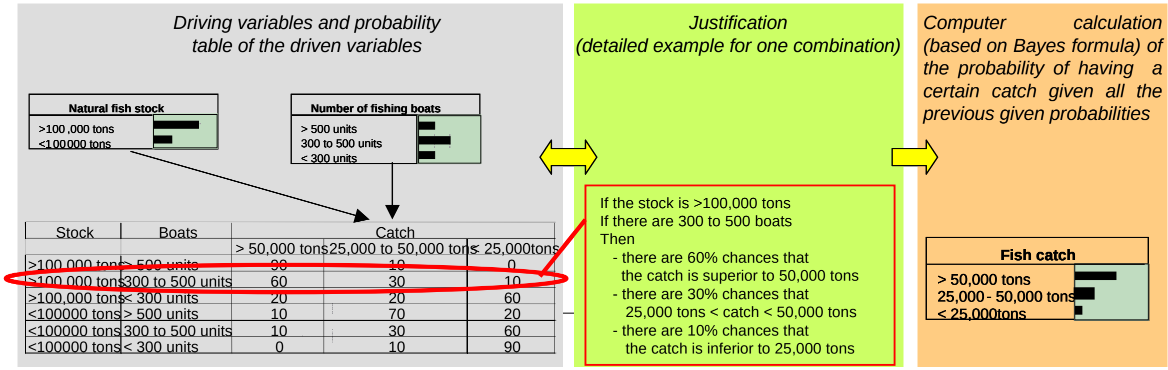

Figure 2: Mini-network of 3 connected variables representing a hypothetical fishery (continued). The probability table of the driven variable is detailed and in the middle of the figure, and the resulting probabilistic computation is given in the right part of the figure.

Thus the major tasks in building the model are:

a) *Network development:*

- ➢ To identify the major variables of the system studied;
- ➢ To arrange them into a meaningful network.

b) *Variables definition:*

- ➢ To define a few relevant states for each variable.

c) *Parameterization:*

- ➢ To define the probability of each state of each driving variable (action named "elicitation of prior probabilities");
- ➢ To define for each driven variable the probabilities of each combination of driving variables.

If data is available, then the quantified relationship between two variables can be automatically converted into probabilities. If data is not available, then expert knowledge can be used to express in terms of probabilities the known relationship between two variables.

Ultimately the computer calculates, based on the Bayes formula of combined probabilities, the probability of having a certain state in a driven variable given all the states defined in all driving variables.

<u>Bayes formula</u>

$$P(a|b) = \frac{P(b|a) \times P(a)}{P(b)} \quad \text{i.e.} \quad \text{Probability of a knowing b} = \frac{(\text{Probability of b knowing a}) \times (\text{Probability of a})}{\text{Probability of b}}$$

In other words

$$\text{Posterior} = \frac{\text{Conditional likelihood} \times \text{Prior}}{\text{Likelihood}}$$

The possible integration of expert knowledge (an expert being any person having a first hand experience of the system studied) into a modelling framework contributed significantly to the success of the Bayesian approach; such consultations are nowadays being more and more broadly used (e.g. McKendrick *et al*. 2000, Soncini-Sessa *et al.* 2002, Hahn *et al.* 2002, Bertorelle *et al.* 2004). In the field of fisheries, Bayesian networks have been used since the mid-nineties (e.g. Lee and Rieman 1997, Kuikka *et al.*1999, Borsuk *et al.* 2002) and are being increasing used, for instance for stock assessment (Hoggarth *et al.* 2006).

Different software applications are available to build and run Bayesian networks (review in Arthington *et al.* 2004) although some teams prefer to develop their own (Varis 2003). We chose for the development of this model the Netica software developed by Norsys (www.norsys.com) as it is intuitive, user friendly (it does not require to master a computer language) and is easily accessible on Internet, where a freeware version allows the development of small models and the running of any big model such as BayFish – Tonle Sap.

3 THE STAKEHOLDERS CONSULTATION PROCESS

In using Bayesian networks for environmental management, the consultation of experts and stakeholders is acknowledged as being of critical importance (Borsuk *et al.* 2001; Cain *et al.* 2003; Ravnborg and Westermann 2002). The experts or stakeholders consultation has been described with more or less details in almost all studies using Bayesian networks. However for modelling approaches touching up on societal issues such as natural resources management, studies focusing on consultation processes and methodologies are very few (Reckhow 2002). Some authors have addressed specific aspects of consultations, in particular on the formal side (Beierle 2002, Gregory *et al.* 2003, Wilkins *et al.* 2002, Seidel *et al.* 2003), whereas others have highlighted the psychological pitfalls inherent to consultation of individuals or stakeholders (Anderson 1998, De Bruin *et al.* 2002, Fenton 2004). On the practical side, the recommendations provided by Cain (2001) and Ravnborg and Westermann (2002) for stakeholders consultations are among the most detailed; however the lack of concise and pragmatic methodological framework led Baran and Jantunen (2004) to propose guidelines for stakeholders consultation for Bayesian modelling in environmental management.

The Tonle Sap model has been built from scratch following the recommendations of 38 stakeholders overall, met during four one-day workshops, (Hort *et al.* 2004). The meetings were attended by a majority of stakeholders pertaining to the fisheries sector, from national agencies (IFReDI, DoF) but also from local organizations (community fisheries, farmers-fishers organizations). Environmental and socio-economic disciplines were also represented, in particular hydrology, water quality and environmental valuation. Among other disciplines, managers (MRC Basin Development Plan) and policy-makers (Cambodian National Mekong Committee) were also present. In term of origin of the stakeholders, governmental agents were a majority, which is coherent with the target of the tool developed. The presence of independent scientists and representatives from fisher organizations balanced the number of specialists from the governmental agencies.

Several consultations were necessary so that the modellers could progressively convert the information provided by stakeholders into a computer model. This back-and-forth process also permitted to identify missing notions, incoherencies and mistakes. The model presented below is the final accepted one, and the intermediate steps have not been detailed.

The three main steps of the consultation consisted in:

a) building the model framework;
b) defining the model variables, and;
c) parameterizing the variables.

A report following each major step has been produced and served as a basis of the following consultation.

4 BUILDING THE MODEL FRAMEWORK

The model framework is based on contributions from stakeholders, as detailed in Hort *et al.* (2004).
By convention the variables of the network are represented in a box and the states of each variable are in *"Italics"*. In this section, description starts from the driven variables, moving up towards their driving variables.

4.1 Fish production variables

• Tonle Sap fish production is expressed as Total fish catch (Figure 3):

- Fish stock depends on hydrology, habitat available, and amount of fish migrations;
- Fish catch depends on fish stock and on the efficiency of the fishing sector.

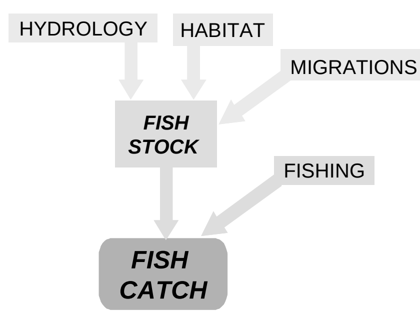

Figure 3: Main variables contributing to Tonle Sap fish production.

4.1.1 <u>Components of the fish catch</u>

• Total fish catch results from Catch of Mekong migrants, Catch of Tonle Sap migrants and Catch of residents.

• "Resident fish" is a term considered here as synonym of "Black fish"; this ecological category is that of species with limited lateral migrations and no longitudinal migrations, able to survive in swamps and ponds all year round. These fish are mostly carnivorous and detritus feeders. The group of "resident fish" includes: *Channidae* (Snakeheads), *Clariidae*, *Bagridae* (*Mystus* sp.) and *Anabantidae* (Van Zalinge *et al. 2004)*.

• "Mekong migrants" is synonym here of "White fish"; i.e. the ecological group of species showing long distance migrations, in particular back to the Mekong mainstream. This group includes many cyprinids (e.g. "Trey riel" *Henicorhynchus spp.* and *Cirrhinus sp*.) but also most *Pangasidae*.

• “Tonle Sap migrants” is synonym of Grey fish, as defined by Welcomme (2001). This ecological category corresponds to fishes that do not spend the dry season in floodplain ponds, but do not undertake long distance migrations either. They tend to spend the dry season in Tonle Sap tributaries and their ecological and physiological characteristics are intermediate between those of black and white fish. This guild includes species such as *Belodontichthys dinema* (trey khlang hay in Khmer), *Mystus albolineatus* (trey kanhchos bai) or *Kryptopterus cheveyi* (Trey kamphleav stung).

The terms “resident” and “migrant” have been preferred to the classical terms “black fish”, “white fish” or “grey fish” as the latter are not familiar to stakeholders who do not see the point of a classification based on colour, although it is actually based on ecology and behaviour. It is also acknowledged that “resident” fishes also move laterally between different habitats in the floodplain and thus qualify as migrants, but this feature is considered minor by stakeholders when compared to the migrations undertaken over much longer distances by white or grey fishes. Stakeholders also decided not to detail fish groups further, as classifying into more detailed and significant ecological groups the 296 species or so that constitute the Tonle Sap fish community seemed to be impossible at this point of time.

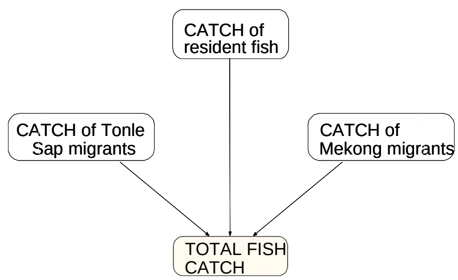

Figure 4: Variables contributing to Tonle Sap fish catch.

• As catch results from a fishing pressure on a fish stock, Catch of Mekong migrants is dependant on Stock of Mekong migrants and of Pressure on Mekong migrants. The same applies to Tonle Sap migrants and resident fish.

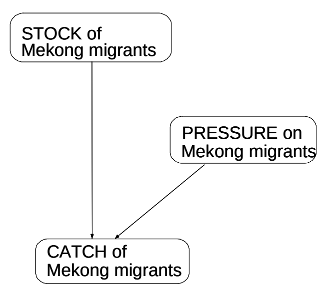

Figure 5: Variables contributing to catch of resident fish .

4.1.2 Components of the fish stock

• Stock of Mekong migrants depends on the annual flooding pattern (Flooding for fish), on the available options for migrations (Migrations of Mekong migrants), and on the quality of the environment used (Habitat for Mekong migrants). The same applies to Tonle Sap migrants and Resident fish (figure 6).

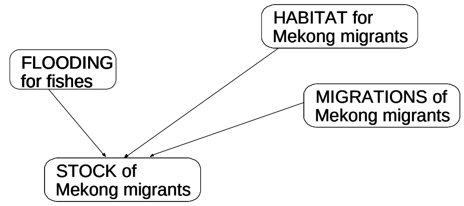

Figure 6: Variables contributing to the fish stock.

Thus these fish stock nodes serve as the combination point for hydrological, environmental and fishing sections of the model.

4.2 Hydrology variables

4.2.1 Quality of flooding

• Flooding for fish is understood as a combination of the Flood beginning (date of beginning of the flood in the floodplain), of the Flood duration and of the Flood level. At the same time Flood duration is affected by Flood beginning and Flood level, i.e. earlier and higher flood causes duration to extend.

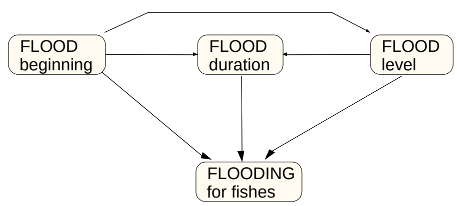

Figure 7: Variables contributing to Flooding for fish.

4.2.2 Details of hydrological variables

• Flood level results from Tonle Sap water level as measured in a reference site. Flood level is also affected by Flood beginning as earlier floods have a higher possibility to cause higher floods.

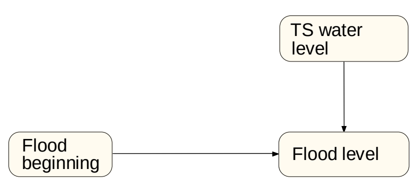

Figure 8: Variables contributing to Floodplain flood level.

• Tonle Sap water level results from Tonle Sap runoff (water originating from rainfall over the Tonle Sap Basin), from the Mekong inflow (water coming from the Mekong River via the Tonle Sap River) and from the Overland flow (Mekong River water spilling over the land, in particular between Kompong Cham and Phnom Penh, hence not contributing to discharge measurements at Prek Kdam). Justifications can be found in Jantunen (2006).

• Tonle Sap runoff results directly from Tonle Sap rainfall over the basin, as seen in figure 9.

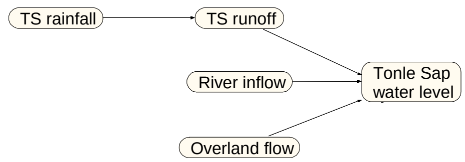

Figure 9: Variables contributing to Tonle Sap water level.

4.3 Habitat variables

• Habitat for Mekong migrants, Habitat for residents and Habitat for Tonle Sap migrants are understood as the quality of the environment used by these fishes. Stakeholders and recent studies show that the states of critical importance to all fish groups are the oxygen level in the floodplain (O2 for resident fish, O2 for Mekong migrants and O2 for Tonle Sap migrants) and the nature of the vegetation in the floodplain (Flooded vegetation). Incidentally dissolved oxygen (DO) is the only indicator of scientifically proven importance to fish production as that of other chemical variables could not be ascertained. In general the lake is well oxygenated due to wind and wave induced aeration, but parts of the floodplain are largely anoxic due to the decaying of vegetation and lack of wind induced mixing (Sarkkula and Koponen 2003).

• O2 for residents is the concentration of Floodplain oxygen biologically acceptable for black fishes used to living in the floodplain. The same applies to O2 for Mekong migrants and O2 for Tonle Sap migrants (a distinction was made as the three groups do not have the same requirements, black fishes being the least demanding, white fish the most demanding in oxygen and grey fish having intermediate requirements).

• Floodplain dissolved oxygen depends upon Tonle Sap water level and upon the nature of Flooded vegetation. Usually the higher the water level the higher the dissolved oxygen levels.
Vegetation type affects DO through the amount of organic matter produced (leaves and branches absorb oxygen when they decompose in the water) as well as vegetation height (high vegetation such as flooded forest reduces wave formation, water stirring and the subsequent mixing of oxygen in the water column).
• Flooded vegetation is a function of the Tonle Sap water level, the amount of vegetation flooded being directly dependant on the surface area covered by the flood.

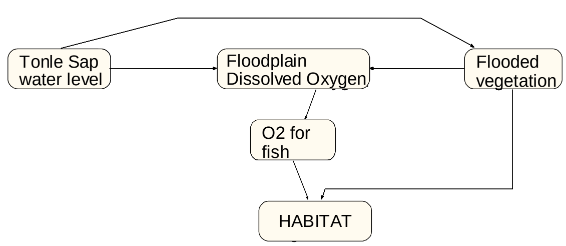

Figure 10: Variables contributing to Habitat for migrant and resident fish.

4.4 Fish migration variables

• Migrations of resident fish is understood as the possibility for fish to migrate within the floodplain and to have access to refuges in the dry season. This variable is thus driven by two factors: the availability of Floodplain refuges and the presence Built structures that reduce access to floodplain habitats and increase fish catchability and mortality. Migrations of Mekong migrants and Migrations of TS migrants depends upon the same factors, although there is more emphasis on longitudinal migrations and larval drift between the Mekong or Tonle Sap tributaries and the Lake.

• Floodplain refuges describe temporary and perennial ponds in the Tonle Sap floodplain that have the potential to offer dry season refuges for fish (mainly for residents and Tonle Sap migrants). Any pond (temporal) that completely dries up at some point of the year is not considered as a refuge. For this reason irrigation channels, most of which dry up, are not considered as refuges (Cambodian irrigated rice fields produce only two crops per year, hence they dry up at some point).

• Built Structures depends upon Tonle Sap water level. The higher the water level the more the built structures affect the flow and especially extent of the flood. Larger area of flood provides wider habitat for fish, therefore built structures have a negative impact on fisheries. The only built structures considered here were National Roads 5 and 6 due to lack and quality of data.

4.5 Fishery variables

4.5.1 Components of the fishing pressure

• Pressure on residents, Pressure on Tonle Sap migrants as well as Pressure on Mekong migrants all depend on the fishing pressure of three major components of the overall fishery: the small scale (SS), middle scale (MS) and large scale (LS) fisheries (DoF 2001; figure 11)

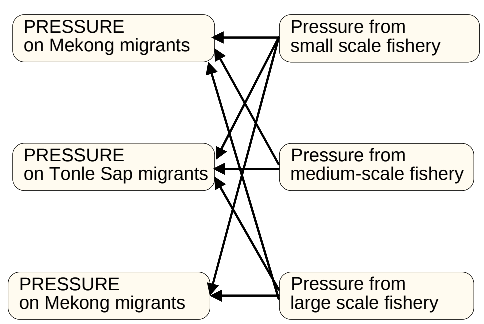

Figure 11: Variables contributing to fishing pressure.

4.5.2 Components of each fishery

• In absence of significant and quantified alternative information, it is considered that the Pressure from large-scale fishery is primarily a reflection of the length of fences constituting the large scale fishing lots.

• The Fishing pressure from small-scale fishery depends on the Gear size of small-scale fishers, on the Activity of small-scale fishers (i.e. their intensity of fishing), and on the Number of small-scale fishers. The Number of small-scale fishers is a combination of the Number of Khmer small-scale fishers and of the Number of Vietnamese/Cham small-scale fishers. As a matter of fact that it is believed by stakeholders that the expertise and impact of Vietnamese and Cham specialised fishers are superior than that of Khmer fishers, who considers themselves mainly as rice farmers (Nettleton and Baran 2004).

The “gear size” variable illustrates the fact that the dominant gear of the small scale fishery is the nylon gill net, whose size has been increasing over years from the 10 meters allowed by law to an average of 300m (Nettleton and Baran 2004).

The Activity of small-scale fishers depends on the Tonle Sap water level since subsistence farmers-fishers spend their time either fishing or farming, depending upon the flooding conditions.

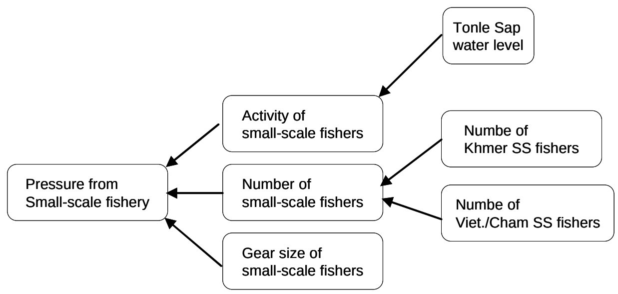

Figure 12: Variables contributing to fishing pressure from the small-scale fishery.

• The Pressure from middle-scale fishery depends on the Number of middle-scale fishers and on the Middle-scale gear efficiency. The number of fishers is the variable easiest to assess (relatively speaking), and can be a proxy of the total fishing effort; however the gear efficiency has also has been evolving, in particular since the fishery reform in 2000, with for instance the spreading of electric fishing, the introduction of the “Boh” gear and the electrification of certain dragnets. These technical evolutions towards more efficiency are well known from fisheries specialists but it remains difficult to quantify them and their impact, and there is currently no monitoring system allowing a quantification of these changes.

• The Number of middle-scale fishers is a combination of the Number of Vietnamese/Cham middle-scale fishers, of the Number of Khmer middle-scale fishers and of the Number of migrant middle-scale fishers, as detailed in Nettleton and Baran (2004). The difference between Vietnamese/Cham or Khmer fishers reflect the fact that the former are considered to operate intensely, whereas the pressure exerted by the latter is believed to be of lesser intensity. Migrant fishers also play a role considered important as they are said to harvest exhaustively and indiscriminately a few months a year.

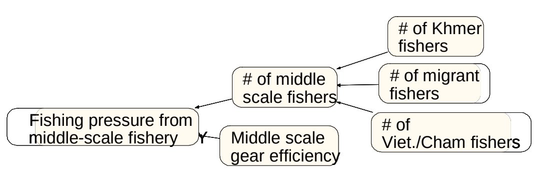

Figure 13: Variables contributing to fishing pressure from middle-scale fishers.

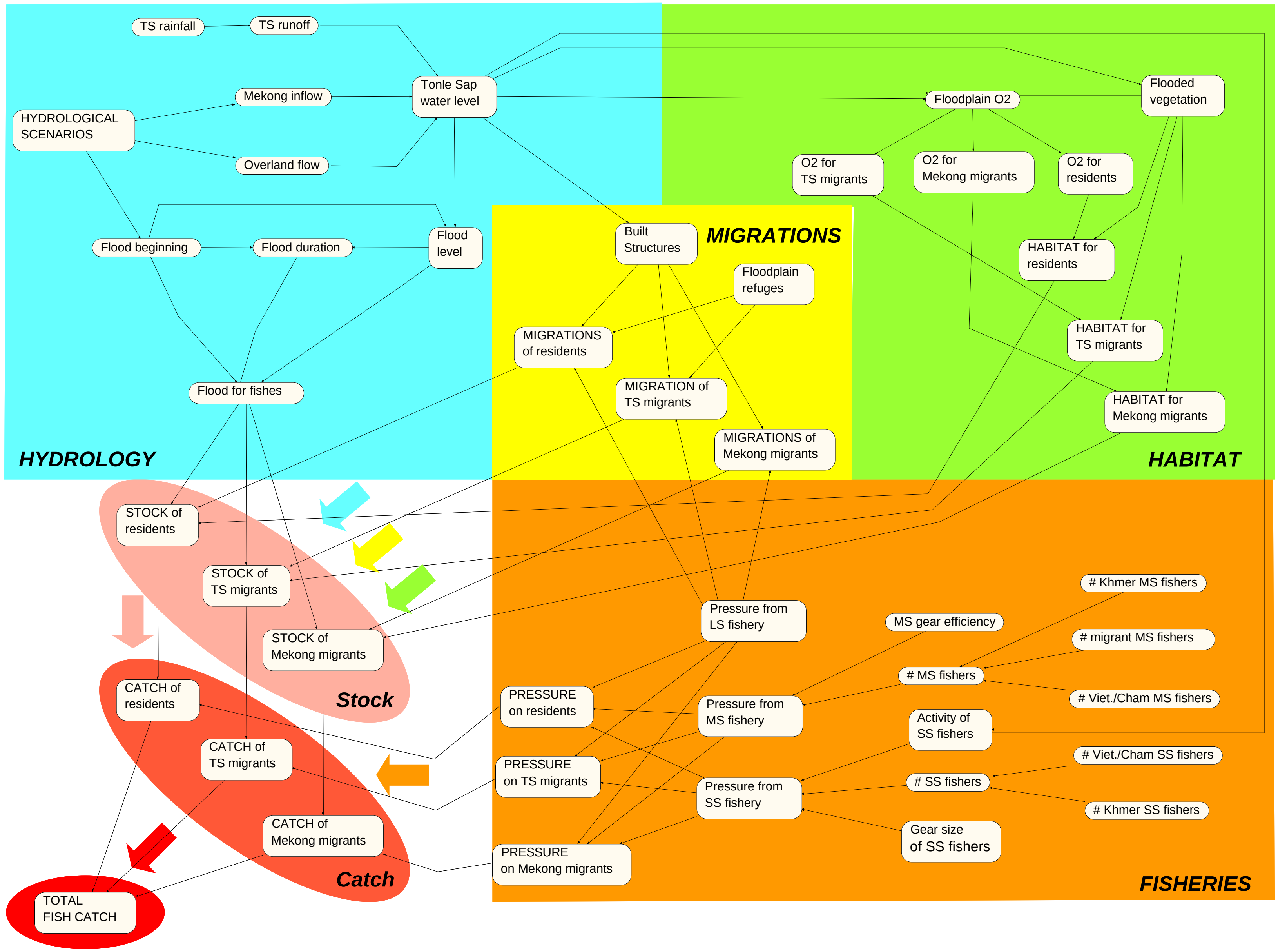

Figure 14: Overview of the model variables

5 DEFINING THE MODEL VARIABLES

Once the model framework built, a second stakeholders consultation led to the definition of the relevant states for each variable (Hort and Baran 2004). Several of these variables had to be qualified in vague terms, such as *“Abundant”* or *“Scarce”*, which illustrates the absence of reliable quantified data for these variables. From this perspective, this modelling study is useful in highlighting the areas that require more research, and shows in particular how little quantitative knowledge exists about the fish resource. The states defined for some other variables can also seem vague (e.g. Flooding for fish, *“Good”* or *“Bad”*) but in that case this is normal and inherent to the integrative nature of these variables, that represent a status indicator (this is reflected in sayings such as “this year the fish production was good”).

5.1 Fish production variables

• Total fish catch is defined as *"High"* or *"Low"*. Quantitative estimates would be possible *IF* reliable fishery statistics were available to feed the model, but at the moment such data do not exist (Coates 2002).

• Catch of Mekong migrants, Catch of Tonle Sap migrants as well as Catch of residents are defined as *"High"* or *"Low"* as no detailed catch statistics are available; therefore more precise states were impossible to define.

• Stock of resident fish, Stock of Tonle Sap migrants and Stock of Mekong migrants are simply defined as *"Abundant"* and *"Scarce"*, in absence of any quantitative stock assessment.

5.2 Hydrology variables

• Flooding for fishes is purposely qualified as *"Good"* or *"Bad"*, which synthetically describes the quality of a hydrological year from a fishery perspective. All variables seen as essential by stakeholders for fish are taken into account, i.e. flood maximum level, duration and date of beginning.

• The Flood beginning has been defined as “the date of spill-over from the river to the floodplain”; stakeholders have considered, after extensive debates opposing memorized experience to recorded data and people from different locations, that a flood can be considered as “early” when it starts *"Before mid-July"*, “normal” when it starts from *"Mid-July to mid-August"*, and “late” when it begins *"After mid-August"*. In data analysis this ‘spill-over’ was defined as occurring when the water level at Kompong Loung exceeded 4 metres (due to highly fluctuating nature of the water level two reference dates were used: 15^{th} July and 15^{th} August).

• Variable Flood duration has been defined as the time span between Flood beginning and date of end of the flooding; the ”end of flooding” being defined by the flow reversal towards Mekong in Tonle Sap River at Prek Kdam. In the second stakeholders consultation, flood duration was expressed in terms of dates; this was later converted into a number of weeks. This consultation also identified states as “Long” (over 13 weeks), “Medium” (5-13 weeks) and “Short” (less than 5 weeks) but data analysed showed that no flood was longer than 13 weeks or shorter than 5 weeks in records. Ultimately states were defined as "*Less than 6 weeks"* (short flood), "*Around 8 weeks"* (6 to 11 weeks, normal flood) and "*More than 11 weeks"* (long flood).

• Flood level was characterized as being *"Low"* or *"High"*, and these values are closely associated to the Tonle Sap water level. This simplicity is also required to allow easier elicitation in the probability table of the Flooding for fish child variable that has three parent variables.

• The definition of the Tonle Sap water level in a reference place has been subject to several revisions, due to the complexity of this notion. Kompong Chhnang was initially proposed by stakeholders as a reference site but the analysis of datasets revealed that Kompong Chhnang had 34 gaps (2526 days in total) over 37 years of data whereas Kompong Loung had only 8 gaps (819 days in total) in 20 years of data; subsequently Kompong Loung was chosen as reference site for Tonle Sap Lake water level.
Thresholds set for water level in 2nd stakeholders consultation were "Above 11m", "10-11m" and "Below 10m" for Kompong Chhnang; however these thresholds were invalid for Kompong Loung (where water level never reach 11m and rarely 10m). Thus in the 4th stakeholders consultation the thresholds were set at "*Below 8m"*, "*From 8 to 10m"* and "*Above 10m"* (Hort *et al*. 2004). This correlates with the natural system, i.e. "*Below 8m"* being considered bad for fish production (dry year), "*From 8 to 10m"* good and "*Above 10m"* as moderately good for fish production (a high water level favouring the abundance of fish in water but reducing the catchability of these fish by fishers) and bad for agriculture. Jantunen (2006) gives detailed justifications for the final choice, i.e. Kompong Loung as a reference site for gauging and *"Below 8m"*, *"Between 8 and 10m"* and *"Above 10m"* as reference marks of low, normal or high water levels.

• Tonle Sap rainfall, Tonle Sap runoff, Mekong inflow and Overland flow were calculated based on existing databases (Jantunen 2006) and are simply expressed in terms of a state *"Above"* or *"Below"* of their respective average after several rainy seasons. Given existing knowledge it was impossible to define the states more meaningfully, and defining more states would have generated a non-manageable complexity in probability tables, with impossible combinations and unrealistic data requirements (e.g. 3 driving variables with 3 states each = 27 combination of states; when related to 3 states in the driven variables, this would correspond to 27 x 3 = 81 probabilities to be set or calculated into the probability table).

5.3 Habitat variables

• Habitat for residents, Habitat for TS migrants as well as Habitat for Mekong migrants have been described as *"Good"* or *"Bad"*, as this describes the quality of the habitat from a fish perspective. Only two variables define the habitat quality: dissolved oxygen concentration and vegetation type. A lot of other variables were mentioned and discussed during the stakeholder consultations, but these two variables are the only ones whose role vis-à-vis fish production could be substantiated and states defined. Vegetation in particular provides feed and protection from predators for juvenile fishes, but also plays a negative role by reducing dissolved oxygen concentrations through decomposition of organic material at the beginning of the flood.

• O2 for residents has been simply expressed in terms of *"Acceptable"* or *"Impossible"*; this variable is linked to Floodplain Dissolved Oxygen. The same applies to O2 for Mekong migrants. See Floodplain Dissolved Oxygen below for more detailed description.

• The essential states of Floodplain Dissolved Oxygen has been defined, after a review of literature using FishBase (2004), as *"Above 4 mg/l"* (value acceptable to almost all fishes), *"Between 2 and 4 mg/l"* (values acceptable by resident black fishes and most grey fish but too low for migrant white fishes) and *"Below 2 mg/l"* (values too low for any fish species). This rough classification was confirmed by a consultation of local aquaculturists.

• Flooded vegetation is defined in terms of surface of *"Grass"*, *"Shrub"* and of *"Forest"* as these variables has been acknowledged to be the ecologically significant ones by stakeholders, as well as in scientific studies (Baran *et al.* 2001c).

• Floodplain refuges are defined from JICA (1999) data as *"Perennial"* (an actual dry season refuge for fish) or *"Temporal"* (non-refuge because dry in the dry season). Refuges play an important role for resident and Tonle Sap migrant fishes during the dry season providing habitat, shelter and food on the driest months of the year.

• Built Structures are defined for now as structures that prohibit the extent (area) of the flood. Therefore the structures can be either *"Blocking"* or *"Open"*.

5.4 Fish migration variables

• Migrations of resident fish : it is likely that the hydrological and environmental requirements of larvae and juveniles (feeding migrations) are different from those of the adults (breeding migrations), but the paucity of knowledge in that field did not allow the stakeholders to be more specific. In absence of any other information, Migrations of resident fish is qualified as *"Free"* or *"Blocked"* (by unfavourable hydrological conditions or built structures).

• Having to define the Migrations of migrant fish highlighted the knowledge gaps about most of these species (the migration status being known for only one fourth of Mekong fish species; Baran *et al.* 2005), and the difficulty of quantifying migrations on a large scale. As a consequence the status defined were simply "*Free*" or "*Blocked*", the elicitation of probabilities allowing a full range of situations between these two extremes.

• The (mainly lateral) Migration of resident fish was defined with the same states.

5.5 Fishery variables

In view of developing a model that matches the approach of the Department of Fisheries, the description of the Cambodian fishery sector has been based on the official classification of the Ministry of Agriculture, Forestry and Fisheries (DoF 2001): large scale fishing (fishing lot operations, barrages fishing and bag net fishing), medium-scale fishing (gill nets longer than 10 m, seine net, fishing traps not longer than 500m of bamboo fence, hook lining, etc); and small-scale or subsistence fishing (simple small gears). From the data we gathered on the field, it appeared that small-scale fishers categories harvest around 3,000 kg/fisher/year, as compared to middle scale fishers yielding more than 20,000 kg/year/fisher. It was also felt necessary to disaggregate fishers according to their ethnicity, as the fishing activity (methods, efficiency and pressure on the resource) is quite different depending upon the ethnic group. As put by Luco (1997): "traditionally, important fishermen on the lake are of Cham or Vietnamese descent. The Khmer are farmers first, becoming fishermen in the dry season" The Vietnamese, like the Muslim Chams, are reported to be excellent fishers, and are always consulted by fishing lot operators (Degen & Thuok 1998). As noted by Keskinen (2003), "ethnic minorities are significantly concentrated in the areas close to the lake and particularly in the floating villages where they are involved in fishing and fishing-related activities. One of the main reasons for this is that often ethnic minorities do not own any agricultural land".

• As all stakeholders agreed that the fishing pressure was unlikely to decrease in the coming years because of population growth, Pressure on resident fish, Pressure on Mekong migrant fish and Pressure on Tonle Sap migrant fish were defined as *"Increasing"* or *"Stable"*, even though no quantitative assessment of this fishing pressure is available nor in progress. The on-going reforms of the fisheries sector also justified the need to differentiate between fishing pressure on resident black fish (valuable species targeted in particular by the lot fisheries) and fishing pressure on migrant white fish (mainly small cyprinids, caught in particular with gill nets and by the *dai* fishery).

• The large-scale fishery was the one that could be best quantified; Pressure from large-scale fishery has been described as varying between *"Blockage"* and *"Nil"*. This describes the effect of fences at the end of the flooding period (blockage of the migration routes) or during the rainy season (lots are not in operation, fences have been removed, pressure is nil).

• Considering the Fisheries Reform that opened access to more small-scale fishers than in the past and the recent suppression of licence fees in the middle-scale fishery sector, the Pressure from small-scale fishery has been described as *"Increasing"* or *"Stable"*. The lack of assessments does not allow a quantification of this fishing pressure, but a reduction is not expected in a near future.

• The Activity of small-scale fishers, who are also part-time farmers when they are ethnic Khmers, varies depending on the benefits perceived: they may shift to *“More fishing”* or *“More farming”* depending upon environmental conditions. It is considered that when the water level is high (above 10m), farmer-fishers shift towards more fishing because of relative fish abundance and high value of the catch relatively to rice. When the water level is low (below 8m), fish stock is relative scarce and farmer-fishers tend to shift toward more farming.

• According to Keskinen’s study (2003), with 12,000 persons the Vietnamese represent 3% of the population of the Lake’s basin, and Chams 2.2%. However the Vietnamese concentrate around the borders of the permanent water body, where they fish and make up to 14% population. The Number of Vietnamese/Cham small-scale fishers is considered to increase moderately. In absence of studies on the demography and migrations of ethnic minorities, field interviews have led to the conclusion that natural population growth in these minorities is largely offset by a push away from the lake and emigration towards booming cities. The state of this variable was thus defined as *"Decreasing"* or *"Stable".*

• With about 1.2 million persons living around the lake and 94.8% of them being Khmer (Keskinen 2003), the Number of Khmer small-scale fishers was considered significant by stakeholders. At the scale of the country, the population growth rate amounts to 1.8%; however Haapala (2003) has shown that the difficult conditions of living and insufficient natural resources around the lake result in emigration towards cities and borders, and that four out of five of the lake provinces actually lose inhabitants. Subsequently the states of the above variable were defined as *"Decreasing"* or *"Stable".* It should be noted however that this does not integrate temporary migrants from the upper parts of the Tonle Sap basin that seasonally come to the lake to exploit it, and whose dynamics and impact have never been quantified.

• The Gear size of small-scale fishers was defined as *"Increasing"* or *"Stable"*, because the size of the small scale fishing gears of subsistence family fishers has increased over time, but it is said to have stabilized to a maximum manageable size in recent years. Small-scale gear efficiency is a complementary variable that should be present in the model but that is simply impossible to quantify; therefore it has not been taken into account.

• Considering the Fisheries Reform that opened access to more small-scale fishers than in the past and the recent suppression of licence fees in the middle-scale fishery sector, the Pressure from middle-scale fishery have been described as *"Increasing"* or *"Stable"*. The lack of assessments does not allow a quantification of this fishing pressure, but a reduction is not expected in a near future.

• Depending upon technological improvements, Middle-scale gear efficiency may increase. A common trend is increased motorization and use of smaller mesh sizes that make nets more efficient. Although it is almost impossible to quantify the efficiency of a multi-gear fishery, we consider it is either “*Stable*” or “*Increasing*”.

• The Number of middle-scale fishers is the sum of Number of Vietnamese/Cham, Khmer and migrant fishers. States for this node are defined as “*Stable*” or *“Increasing”*.

• Middle scale fishers consist of Vietnamese, Cham, Khmer commercial fishers, and migrant fishers who come from the surroundings of the basin and exert a temporary but intense pressure on the resources Nettleton& Baran 2004). For the same reasons as those detailed for the number of subsistence fishers, it was considered that the states of the variables Number of Vietnamese/Cham middle-scale fishers, Number of Khmer middle-scale fishers and Number of migrant middle-scale fishers should be "*Stable*" or *"Increasing"*.

• Overall the extreme and unrealistic simplicity of the states of the fishery variables sadly reflects the absence of scientific knowledge about the status of the Cambodian inland fishery, and the subsequent weakness of the Fishery module in the overall model. Because of this fact, the BayFish Tonle Sap model can be considered strongly underpinned by best available information down to the Stock level, but not down to the Catch level.

Figure 15 summarizes all the states defined for each variable of the network.

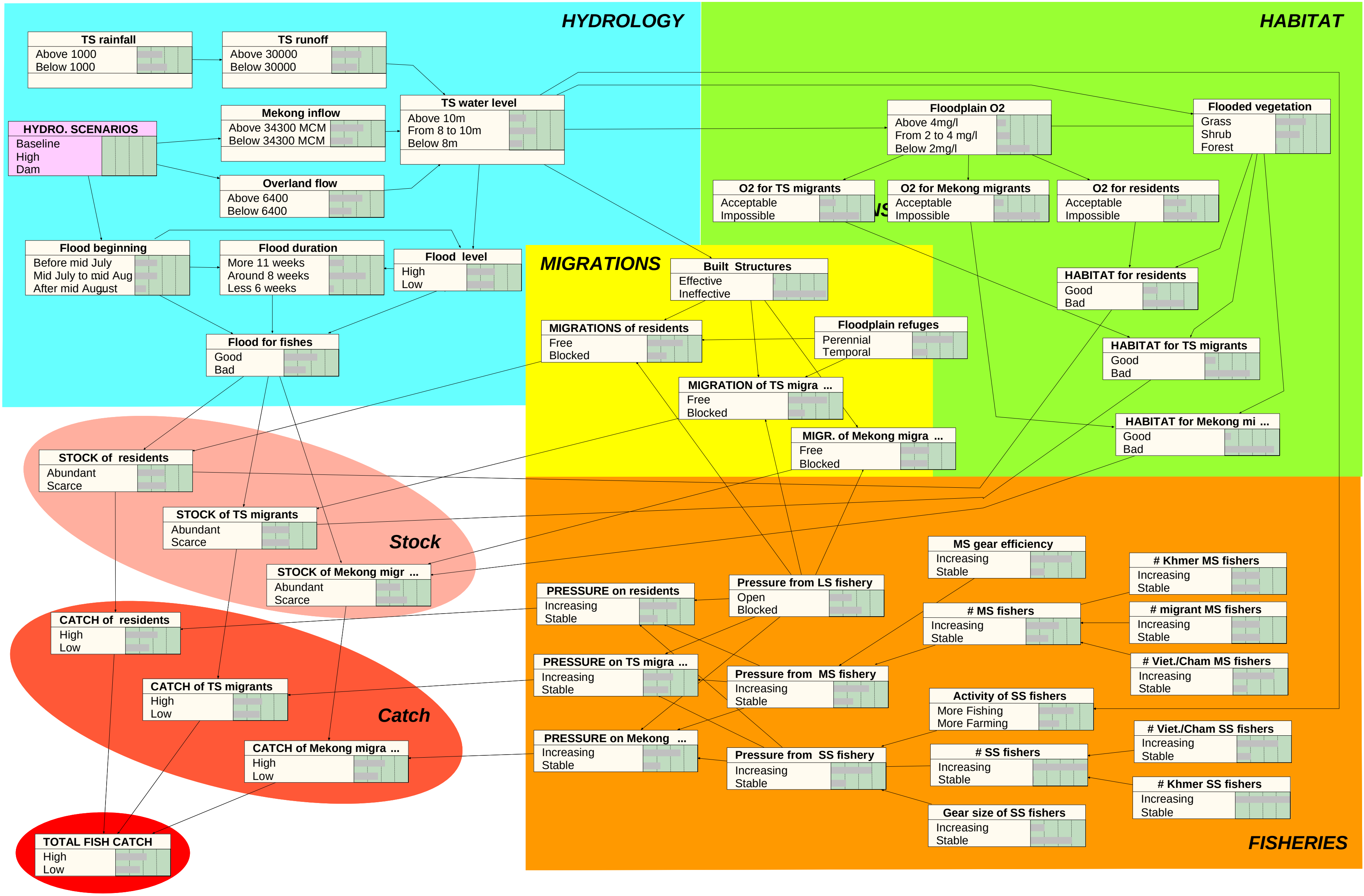

Figure 15: States defined for each variable of the network.

6 INTEGRATING DATABASES

A significant effort was put in the integration of databases to the model. These data consist in hydrological (rainfall, runoff, Mekong inflow, overland flow, flood beginning, and flood duration), water quality (dissolved oxygen), land use for the Tonle Sap Lake and floodplain and built structures (opposing flow, refuges and fishing lots). In addition scenarios of the model are based on output data of MRCS/WUP_FIN hydrological model. Special attention in analysis was given to data accuracy, reliability and suitability for the model. A specific report has been dedicated to this study (Jantunen 2006), and the reader might want to refer to this companion report.

The databases gathered and used in the model are summarized in table 1.

Table 1: Summary of all data sources integrated to the Bayesian model of the Tonle Sap fish resource.

Dataset	Source	Area and period	Description	Format	Obtained from
Water level data	JICA & TSLV Flow Reversal Project	Kratie 1934-2002, Prek Kdam 1960-2002, Kompong Loung 1924-2002, Phnom Penh Port 1960-2002	DSF model input data, corrected for same datum from MRCS Hymos dataset.	Numerical	MRCS/JICA & TSLV Flow Reversal Project
Water level data	MRCS	Kompong Loung 1924-2002, Kompong Chhnang 1924-2002	Datasets with uncorrected datum (measured)	Numerical	MRCS/WUP_FIN
MIKE11 model output data	JICA & TSLV Flow Reversal Project	Discharge Prek Kdam and Kratie, Water level Kompong Loung, Overland flow. 1984-2003	Flow reversal model output data taking into account backwater effect and overland flow. Fills gaps in data.	Numerical	MRCS/JICA & TSLV Flow Reversal Project
Rainfall data	MRCS JICA & TSLV Flow Reversal Project	Tonle Sap catchment 1980-2003	Average rainfall data over each of the sub-cathcments	Numerical	MRCS/JICA & TSLV Flow Reversal Project
Land use, road network, ponds and administrative data	JICA	Tonle Sap catchment	1999 JICA Land use map simplified for Tonle Sap floodplain	GIS layer 1:100 000	MRCS/WUP_FIN
Land use data	WUP_FIN	Tonle Sap floodplain	Calculated percentages of land use types depending on elevation	Numerical	MRCS/WUP_FIN
Dissolved oxygen data	WUP_FIN and MRCS	Tonle Sap Lake and floodplain	Measurements by MOWRAM and MRCS/WUP_FIN	Numerical	MRCS/WUP_FIN
MRCS/WUP_FIN model output data	WUP_FIN	Tonle Sap Lake and floodplain	Average dissolved oxygen levels and anoxic conditions prevalent in the lake and floodplain	Numerical and bitmap	MRCS/WUP_FIN
Certeza survey contour data	MRCS	Tonle Sap floodplain	Digital contour lines based on 1964 levelling survey	GIS layer 1m contour lines	MRCS/WUP_FIN
Water balance data	JICA & TSLV Flow Reversal Project and MRCS/WUP_FIN	Tonle Sap catchment	Calculated water balance to Tonle Sap catchment	Numerical	MRCS/JICA & TSLV Flow Reversal Project and MRCS/WUP_FIN
Fishing lots	MRC	Tonle Sap catchment	Location, extent and state of fishing lots	GIS layer	MRCS/WUP_FIN

7 PARAMETERIZING THE VARIABLES

Parameterizing the variables in the model consists in attributing probabilities to variables; more specifically attributing probabilities to each state of a driving variable and, to each combination of states of a driven variable. This process is the one described in section 2 and illustrated in Figures 1 and 2. Parameterization is detailed in the reports of the third and fourth stakeholders consultations (Hort *et al.* 2004; Baran 2004). In this section, description starts from the driving variables, that combine into driven variables. In the BayFish model all probability tables are open to viewing and to modification by the user if this is felt necessary. For a detailed explanation of the computations in case of variables based on databases it is recommended to refer to the Netica manual (available online at http://www.norsys.com/download.html).

7.1 Fish production variables

- Total fish catch

The Tonle Sap total fish catch results from the yielding of white, grey and black fish. However the creation of a grey fish category is new, and has never been reflected in catch statistics so far. It is therefore impossible to date to quantify the contribution of grey fish to the Tonle Sap total catch. Since grey fish used to be previously considered as white fish (they leave the floodplain when the flood recedes, and do not spend the dry season in ponds), grey fish have been assimilated below by default to white fish. This approximation allows using available statistics regarding white fish and black fish to parametrize the last node of the model.

According to Van Zalinge *et al.* (2000), Black fish harvest represents only 17.5% in biomass while the rest is represented by White fish harvest (See Table 2).

Table 2: Parameterization of Total fish catch variable.

			Total fish catch		
CATCH of residents	ATCH of Mekong migrants	CATCH of TS migrants	High	Low	Justifications
High	High	High	100	0	If the harvest of all guilds is high, the chance that the TS fish harvest is high is 100%
High	High	(Low)	100	0	If the harvest of White and Black fish are both high, the chance that the TS fish harvest is high is 100%. Here Catch of TS migrants is assimilated to that of Mekong migrants (i.e. High)
High	Low	(High)	17.5	82.5	If the harvest of Black fish is high but the harvest of White fish is low, the chance that the TS fish harvest is high is 17.5%. Here Catch of TS migrants is assimilated to that of Mekong migrants (i.e. Low)
High	Low	Low	17.5	82.5	If the harvest of Black fish is high but the harvest of White fish is low, the chance that the TS fish harvest is high is 17.5%. Here Catch of TS migrants is assimilated to that of Mekong migrants (i.e. Low)
Low	High	High	82.5	17.5	If the harvest of Black fish is low but the harvest of White fish is high, the chance that the TS fish harvest is high is 82.5%. Here Catch of TS migrants is assimilated to that of Mekong migrants (i.e. High)
Low	High	(Low)	82.5	17.5	If the harvest of Black fish is low but the harvest of White fish is high, the chance that the TS fish harvest is high is 82.5%. Here Catch of TS migrants is assimilated to that of Mekong migrants (i.e. High)
Low	Low	(High)	0	100	If the harvest of White and Black fish are both low, the chance that the TS fish harvest is high is 0%. Here Catch of TS migrants is assimilated to that of Mekong migrants (i.e. Low)
Low	Low	Low	0	100	If the harvest of all guilds is low, the chance that the TS fish harvest is low is 100%

• Catch of residents

The Catch of residents results from the combination of a stock of resident fish and a fishing pressure on these black fish. In absence of quantitative information we assumed that both variables contributed 50% each to the total Catch of residents.

• Catch of Tonle Sap migrants

The Catch of Tonle Sap migrants results from the combination of a stock of resident fish and a fishing pressure on these grey fish. In absence of quantitative information we assumed that both variables contributed 50% each to the total Catch of residents.

• Catch of Mekong migrants

The Catch of Mekong migrants results from the combination of a Stock of Mekong migrants and a fishing pressure on these white fish. In absence of quantitative information we assumed that both variables contributed 50% each to the total Catch of Mekong migrants.

• In absence of specific information, the Stock of Mekong migrants is considered to result equally from a proper habitat, recruitment from migrations and adequate hydrology; hence 33%-33%-34% chances attributed to each variable.

• In absence of specific information, the Stock of Tonle Sap migrants is also considered to result equally from a proper habitat, possible migrations to local tributaries and adequate hydrology; hence 33%-33%-34% chances attributed to each variable.

• For the Stock of resident fish, less importance is given to migrations (20% only) because of the short homerange of this guild; the size of the stock is considered to also result from a proper habitat (50%, in particular since dry season refuges are required) and adequate hydrology (30%).

7.2 Hydrology variables

• The parameterization of variables Tonle Sap rainfall, Tonle Sap runoff, Mekong inflow and Overland flow is described in detail in Jantunen (2006). Basically the databases provided several years long time series (1985-2003) from which average values for each variable were calculated. Then the modelling software used the data table generated (average per variable per period of time) to fill in the probability table of having an annual value above or below the average. Parameterization was changed for Mekong inflow and Overland flow when hydrological scenarios were made available through ADB Built Structures Project (WUP_FIN) as upstream development only affects inflow originating from Mekong. However, the WUP_FIN model could only process years 1996-2000, thus severely reducing the amount of data available for producing probabilities for the nodes. Changes are described shortly below, and data analysis is detailed in Jantunen (2006).

For Tonle Sap rainfall, data used was the data checked and edited by MRCS/WUP-JICA & TSLV project. For this data no sophisticated spatial weighting were used for rain gauge network due to its non-uniform distribution. In addition, rainfall on the open lake was not accounted for, as it is equal to evaporation. Also, only post-1996 data were used due to inconsistencies before this date. Standard deviation of rainfall data showed that most variation in rainfall amounts takes place between August and November, and thus only half a year of data (from June to December) was used for each hydrological year.

For Tonle Sap runoff, MIKE11 model output data from the MRCS/WUP-JICA & TSLV project was used, whereas Mekong inflow and Overland flow are derived from WUP_FIN model output data. The water balance of the Tonle Sap Lake depends on these three components and deriving them from one and the same dataset ensures compatibility of data in their common child node Tonle Sap water level at Kompong Loung. Even though two parent nodes for Tonle Sap water level were changed with new data, the parameterization of Tonle Sap water level was not changed. The MRCS/WUP-JICA & TSLV project data provides much more comprehensive range of combinations for generating probabilities.

- The reference average value for Tonle Sap rainfall is 1000 mm of rain during the June-December period (45% above average and 55% below average).
- The reference average value for Tonle Sap runoff is 30,000 million cubic meters (MCM) of water during the June-December period (43% above average and 57% below average when TS rainfall is below 1000mm and 67% above average and 33% below average when TS rainfall is above 1000mm).
- The reference average value for Mekong inflow was 37,000 MCM of water during the June-December period (48% above average and 52% below average). This was changed into 34,000 MCM with WUP_FIN data. The resulting probabilities for baseline are 60% above average and 40% below average. This shows a general increase in likelihood of above average floods, but the change is due to lowered threshold level from 37388 to 34363 (average of total time series), shorter time series and generally lower flows of WUP_FIN output data.
- The reference average value for Overland flow is 7,600 MCM of water during the June-December period (43% above average and 57% below average). This was changed into 6,400 MCM with WUP_FIN data. The resulting probabilities for baseline are 60% above average and 40% below average. See scenarios (section 8) for full explanation. Similarly there is a general increase in likelihood of above average floods, but the change is due to lowered threshold level from 7800 to 6400 (average of total time series), shorter time series and generally lower flows of WUP_FIN output data.

• For Tonle Sap water level, the reference is the annual maximum water level at Kompong Loung; Parameterization is derived from the simulation outputs of the MRCS/WUP-JICA & TSLV MIKE11 model for the 1985-2003 period. Measured data were not used because of unexplained daily shifts (+/- 1m per day) and because of approximately 2.5m difference between pre-1965 and post-1996 datasets. Furthermore using the MIKE11 model output data provided a longer dataset (1985-2003). It has an excellent correlation with MRCS/Hymos corrected data (restricted to 1996-2003). In addition MIKE11 model output data was also used for parameterization of some of Tonle Sap water level parent nodes, therefore using the same dataset increases compatibility. Baseline of the node changed a little due to incorporation of hydrological scenarios from WUP_FIN from 25.4/49.8/24.8 to 29.6/47.8/22.6 (*Above 10m/Between 8m and 10m/Below 8m* respectively).

Table 3: Parameterization of Tonle Sap water level variable.

Flow from Mekong	Overland Flow	TS runoff	Water level at Kompong Loung: Above 10m	Between 8 and 10m	Below 8m
Above 37000	Above 7600	Above 30000	42.857	42.857	14.286
Above 37000	Above 7600	Below 30000	40	40	20
Above 37000	Below 7600	Above 30000	25	50	25
Above 37000	Below 7600	Below 30000	20	60	20
Below 37000	Above 7600	Above 30000	40	40	20
Below 37000	Above 7600	Below 30000	15	55	30
Below 37000	Below 7600	Above 30000	16.667	66.667	16.667
Below 37000	Below 7600	Below 30000	12.5	37.5	50

• Flood level takes into account flood beginning and Tonle Sap water level. The probability of having a "*High*" Flood level with Tonle Sap water level (at Kompong Loung) being "*Between 8 and 10m*" and Flood beginning from "*Mid Jul to mid Aug*" is based on actual data (4/9 out of example years). In general early floods are correlated with higher floodplain flood levels. Shaded probabilities showing *Low* Flood level even though Tonle Sap Water level is *Above 10m* are dismissed from calculations through declaring them as impossible combinations in Flooding for Fish variable. Baseline of the node changed a little due to incorporation of hydrological scenarios from WUP_FIN from 49/51 to 51.3/48.7 (*High/Low* respectively). This seems to confirm that minor changes to probabilities caused by WUP_FIN data does not significantly alter the hydrological module of the model.

Table 4: Parameterization of Flood level variable.

Tonle Sap water level	Flood beginning	*Flood level*: High	Low
Above 10m	Before Mid-July	100	0
Above 10m	Mid July to Mid Aug	100	0
Above 10m	After Mid Aug	0	100
Between 8 and 10m	Before Mid-July	100	0
Between 8 and 10m	Mid July to Mid Aug	44.444	55.556
Between 8 and 10m	After Mid Aug	0	100
Below 8m	Before Mid-July	0	100
Below 8m	Mid July to Mid Aug	0	100
Below 8m	After Mid Aug	0	100

Note: as detailed above, Built structures do not intervene in the calculation of Flood level

• The fourth stakeholders consultation identified the spilling of water to the floodplains (i.e. when water breaches natural levee around the open lake and rivers) as the threshold for Flood beginning. However it is impossible to identify these levees from the 1964 Certeza survey contour lines, as well as from the Hydrographic Atlas (produced in 1998) that only covers the open lake. It should be possible to identify this threshold precisely from the MRCS/WUP-FIN depth measurements, but for a number of reasons these were unavailable during the study. Alternatively we used generic thresholds already agreed by stakeholders (early flood = "*Before mid-July*", normal = "*Between mid-July and mid-August*" and late = "*After mid-August*"). Corresponding water levels for each date from each year were checked, and

4m water level was chosen as the threshold that fits best with floods regarded as early (2000-2002) and late (1998). Probabilities were calculated by the software from the occurrences recorded between 1985 and 2003 ("*Before mid-July*" = 36%, "*Mid-July to mid-August*" = 46% and "*After mid-August*" = 18%). This was then slightly changed due to incorporation of WUP_FIN output data ("*Before mid-July*" = 40%, "*Mid-July to mid-August*" = 40% and "*After mid-August*" = 20%), which shows minor increase in earlier and late floods. This change is due to length of WUP_FIN data available, but even so the simplified version still represents strength of each state well. Detailed justifications and data can be found in Jantunen (2006).

• In order to parametrize Flood duration, the outputs of the MIKE11 hydrological model were used to define the exact moment of flow reversal in the Tonle Sap River at Prek Kdam towards the Mekong. Duration was calculated by combining the date of floodplain flooding, and probabilities were calculated from the recorded occurrences from years 1985 to 2003 ("*More than 11 weeks*" = 15.79%, "*Around 8 weeks*" = 78.95% and "*Less than 6 weeks*" = 5.26%). Flood duration is also influenced by Flood beginning and Flood level, but the 19 years screened did not cover every combination of states theoretically possible. For instance all cases of flood beginning between "*Mid-July* and *Mid-August*" had a duration of "*Around 8 weeks*" whereas in theory longer and shorter durations are possible; therefore these probabilities had to be estimated based on the data available. Furthermore, incompatible hydrological combinations had to be eliminated from the model (they were given 0% probability; see Table 5).

Table 5: Parameterization of Flood duration variable.

		Flood duration			
Flood beginning	Flood level	More than 11 weeks	Around 8 weeks	Less than 6 weeks	Justifications
Before mid-July	High	42.857	57.143	0	3/7 of Before mid-July floods were *"more than 11 weeks*" long and 4/7 lasted "around 8 weeks"
Before mid-July	Low	33.333	66.667	0	Estimated because no examples in data.
Mid-July to mid-August	High	33.333	66.667	0	Estimated because no examples in data.
Mid-July to mid-August	Low	15.79	78.95	5.26	Based on average possibilities calculated from 19 example years
After mid-August	High	0	0	100	Not possible to have more than 6 weeks flood After Mid-July
After mid-August	Low	0	66.667	33.333	2/3 of After Mid-July floods were around 8 weeks, 1/3 Less than 6 weeks

With these changes the baseline of Flood duration ended up being ("*Before mid-July*" = 25.7%, "*Mid-July to mid-August*" = 67% and "*After mid-August*" = 7.3%. This was then slightly changed due to incorporation of WUP_FIN output data which effected Flood duration node through Flood beginning and Flood level nodes ("*Before mid-July*" = 26.2%, "*Mid-July to mid-August*" = 66.1% and "*After mid-August*" = 7.7%). Detailed justifications and setting of thresholds can be found in Jantunen (2006).

• The variable Flooding for fish was parameterized with the values and justifications shown in the table below. Incompatible hydrological combinations such as late *and* long flood are marked with an X and are not taken into account by the model in any of the calculations or respective probabilities.

Table 6: Parameterization of Flooding for fish variable.

Flood Level	Flood Beginning	Flood Duration	Good - Bad	Justifications
High	Before mid-July	More than 11 weeks	80% - 20%	Big and long flood => considered very good for fish (but not 100% positive since longest floods do not correspond to higist catches)
High	Before mid-July	Around 8 weeks	100% - 0%	Big flood and appropriate timing still long enough => considered very good
High	Before mid-July	Less than 6 weeks	X X	Historicaly incompatible
High	Between mid-July and mid-August	More than 11 weeks	90% - 10%	High and timely flood => considered very good for fish
High	Between mid-July and mid-August	Around 8 weeks	100% - 0%	High flood of average duration, coming on time=> considered ideal
High	Between mid-July and mid-August	Less than 6 weeks	60% - 40%	High and timely flood but too short, not so good
High	After mid-August	More than 11 weeks	X X	Incompatible
High	After mid-August	Around 8 weeks	X X	Incompatible
High	After mid-August	Less than 6 weeks	40% - 60%	High, but late and too short flood => not so good for fish
Low	Before mid-July	More than 11 weeks	55% - 45%	Low flood, but timely and long => medium quality
Low	Before mid-July	Around 8 weeks	45% - 55%	Low flood, timely and long => medium quality
Low	Before mid-July	Less than 6 weeks	X X	Incompatible
Low	Between mid-July and mid-August	More than 11 weeks	50% - 50%	Low flood, timely and long duration => medium quality
Low	Between mid-July and mid-August	Around 8 weeks	20% - 80%	Low flood, timely and normal duration=> rather bad for fish[1]
Low	Between mid-July and mid-August	Less than 6 weeks	25% - 75%	Low flood, timely but too short=> rather bad for fish
Low	After mid-August	More than 11 weeks	X X	Incompatible
Low	After mid-August	Around 8 weeks	20% - 80%	Low and late flood of medium duration => bad for fish
Low	After mid-August	Less than 6 weeks	10% - 90%	Short, small and late flood => very bad for fish

Based on experience and model runs, that Flooding for fish variable and associated table seem to have most influence on the outcome of the catch node of the model.

7.3 Habitat variables

- For variable Floodplain dissolved oxygen data was derived from the MRCS/WUP-FIN water quality model due to temporal and spatial limitations in measured point water quality data. As part of collaborative activities with WorldFish, the WUP-FIN team produced directly compatible output data that could be directly inputted into the BayFish model. Data table for this can be seen below and detailed justifications in Jantunen (2006).

[1] This combination was tweaked to better fit the curve of Dai catches

Table 7: Parameterization of Floodplain dissolved oxygen variable.

Water level	Land use	< 2 mg/l	2 – 4 mg/l	> 4 mg/l
Below 8m flood (1998)	grass	54	21	25
	shrub	72	17	12
	forest	37	29	34
From 8 to 10m flood (1997)	grass	51	28	21
	shrub	65	20	15
	forest	27	37	37
Above 10m flood (2000)	grass	60	25	15
	shrub	69	24	7
	forest	32	53	15

- A literature review and discussion with fish biologists and aquaculturists led to the conclusion that Dissolved oxygen for residents is not bearable (0% acceptable) if DO level is below 2mg/l; it is considered acceptable for these tolerant black fish between 2 and 4 mg/l, and above 4 mg/l.

- White long-distance migrant fish are less tolerant than black fish; as a consequence in variable Dissolved oxygen for Mekong migrants above 4mg/l only is considered as "*Acceptable*" (100%) for White fish. Therefore the state "*From 2 to 4*" and "*Below 2*" mg/l was elicited as impossible (0% "*Acceptable*").

- Grey short-distance migrant fish are less tolerant to environmental conditions than resident fish, but also more tolerant than Mekong migrants. As a consequence in variable Dissolved oxygen for TS migrants the state *"Above 4mg/l"* is considered as "*Acceptable*" (100%) while state "*From 2 to 4*" was given 50% and "*Below 2*" mg/l was elicited as impossible (0% "*Acceptable*").

- Parameterization of Flooded vegetation was based on the JICA land use GIS map produced in 1999 and edited by the MRCS/WUP-FIN project. When this modelling study started this map was the latest and had the best accuracy available. The original 40 land use classes were reduced to three: Grass (JICA classes 3-17), Shrub (JICA classes 18-21), and Forest (JICA classes 22-32). Other classes such as water or soil and rock left out. The corresponding map is given in Figure 16.

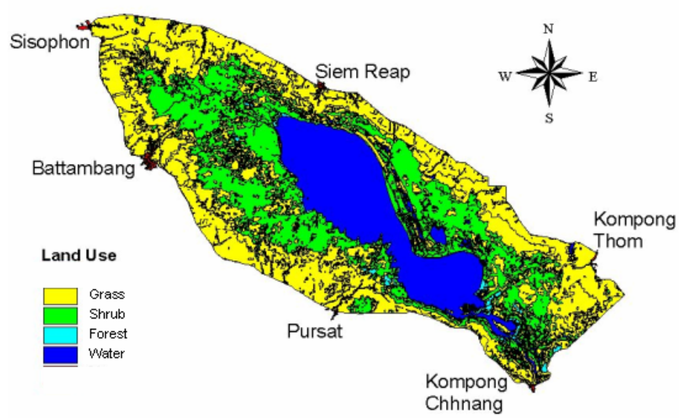

Figure 16: Map of the Tonle Sap vegetation cover (1999, JICA data reclassified; Jantunen 2006).

Percentages for each of the three classes were calculated from surface area to elevation table, and were manually imported into the model probability table (see below).

Table 8: Parameterization of Flooded vegetation variable.

Land use by elevation	Grass	Shrub	Forest
1-8	43.9	53.7	2.4
1-10	55.8	42.3	1.9
1-road	60.8	37.4	1.8

• Habitat for residents, Habitat for TS migrants and Habitat for Mekong migrants were elicited by fishery experts by default. In fact the lack of information about the detailed ecological requirements of each the 3 different guilds did not allow making a difference in the response of each guild to environmental conditions; therefore the parameters are the same for all guild. "*Impossible*" (i.e. unbearable) dissolved oxygen level is 100% bad for fish and acts as a threshold, that defines a given habitat as bad whatever the other environmental conditions. Forest is traditionally seen as the best habitat for fish (100%), but because fish catch has not decreased dramatically even though the forests has been largely cut down shrub is also regarded as a good habitat (90%). Grass does not provide shelter and food in the way that shrub and forest do, therefore it is only 50% "*Good*". The resulting table is detailed below:

Table 9: Parameterization of Habitat for fish nodes.

		Habitat for residents, TS migrants, Mekong migrants	
Flooded vegetation	Dissolved oxygen	Good	Bad
Grass	Acceptable	50	50
Grass	Impossible	0	100
Shrub	Acceptable	90	10
Shrub	Impossible	0	100
Forest	Acceptable	100	0
Forest	impossible	0	100

• Floodplain refuges were parameterized using JICA (1999) data on area of Perennial and Temporal ponds in the floodplain. The total surface area of ponds identified by JICA amounts to 323.7 km^2, and perennial ponds represents 237 km2, or 73.23% of the total (see Jantunen 2006 for details). Hence among floodplain refuges, Perennial refuges = 73.23% and Temporary refuges = 26.77%

• Parametrization of Built structures is based on JICA (1999) road data and Certeza Survey (1964) 1m contour data and the JICA 1999 GIS road layer and 10m contour line data. Probabilities were derived by comparing the total area of the each elevation category (0-8m, 0-10m and 0-12m) to the area limited by the road. Details can be found in Jantunen (2006).

Table 10: Parameterization of the Built Structures node.

	Built structures	
TS water level	Blocking	Open
Above 10 m	8.25	91.75
From 8 to 10	2.51	97.49
Below 8 m	0	100

7.4 Fish migration variables

Overall, information on fish migrations, on the impact of built structures or of fishing practices on fish migrations is very deficient. The parameters below are therefore largely “guesstimates” awaiting for new quantitative studies of fish migrations in the system studied. Overall this module on fish migration is very simplistic and can be largely be improved; at the moment it mainly highlights in a qualitative way the importance of migrations in the sustainability of the overall fishery production system.

• The Migration of Mekong migrants is assumed to be hampered by two main obvious factors: by the fences of the large scale fishing sector and by built structures. In absence of detailed quantitative information, the fishing lots are assumed to contribute 80% of the obstacle to migrations, while built structures contribute 20%. This limited number of factors probably overlooks the role of the two other fishing sectors (middle scale and small scale) whose gears also act against migrations, but the role of these two sectors has been deemed too fuzzy to be quantified.

Table 11: Parameterization of Migration of Mekong migrants node.

		Migration of Mekong migrants	
Built Structures	Pressure from large scale fisheries	Free	Blocked
Blocking	Nil	80	20
Blocking	Blockage	0	100
Open	Nil	100	0
Open	Blockage	20	80

• According to fishery experts consulted, the Migration of residents is hampered by fishing lots but also by the fishing pressure exerted on refuges during the dry season; therefore the 80% previously allocated to fishing lots only (in the case of white fish) were split between fishing lots proper (40%) and refuges (40%), the share of built structures remaining the same (20%).

Table 12: Parameterization of Migration of residents node.

			Migration of Mekong migrants	
Built Structures	Refuges	Pressure from large scale fisheries	Free	Blocked
Blocking	Perennial	Nil	80	20
Blocking	Perennial	Blockage	40	60
Blocking	Temporary	Nil	40	60
Blocking	Temporary	Blockage	0	100
Open	Perennial	Nil	100	0
Open	Perennial	Blockage	60	40
Open	Temporary	Nil	60	40
Open	Temporary	Blockage	20	80

• The migration of Tonle Sap migrants is poorly known. Since these fish have ecological requirements intermediate between white and black fish, it was assumed that the constraint they face is somehow intermediate between those experienced by black and white fish. Hence three parent variables (Pressure from large scale fisheries, refuges and built structures) and a similar weight given to each parent node (33%). The resulting table of probabilities is detailed below:

Table 12: Parameterization of Migration of Tonle Sap migrants node.

Built Structures	Refuges	Pressure from large scale fisheries	Migration of Mekong migrants: Free	Migration of Mekong migrants: Blocked
Blocking	Perennial	Nil	66.7	33.3
Blocking	Perennial	Blockage	33.3	66.7
Blocking	Temporary	Nil	33.3	66.7
Blocking	Temporary	Blockage	0	100
Open	Perennial	Nil	100	0
Open	Perennial	Blockage	66.7	33.4
Open	Temporary	Nil	66.7	33.4
Open	Temporary	Blockage	33.3	66.7

7.5 Fishery variables

The fishing component of the model is based on background studies by Nettleton and Baran (2004) and additional field surveys by Kum (2004), supplemented by unpublished stakeholders consultations. The fishing pressure actually results from a combination of four components:

Fishing pressure = fishing intensity = number of fishers + time spent fishing + size of fishing gears + gear efficiency.

In practice, the only factor that could be approached by a degree of monitoring is the number of fishers, hence the focus on this variable in the model. This fact illustrates the fact that significant additional research remains necessary to properly understand the various components of the fisheries and its main driving forces. As a consequence, the fisheries module of the BayFish model, based "only" on the very limited quantitative knowledge available, remains the least strong component of this model.

7.5.1 Small-scale fishery

The fishing Pressure from small-scale fishery results from four driving variables: Activity of subsistence fishers; Gear size of subsistence fishers; Number of Khmer subsistence fishers and Number of Vietnamese/Cham subsistence fishers; the parametrization of these variables is detailed below.

• The Activity of subsistence fishers is directly linked to water level in the Tonle Sap Lake. If there is more water, then there is more fish and thus subsistence fishers' shift to more fishing as fish is more valuable than crops per kilogram. In absence of quantified information the proportions were estimated as follows:

Table 13: Parameterization of the Activity of subsistence fishers variable.

Water_level	More fishing	More farming	
Above_10m	80	20	When water level is above 10m, there is a 80% chances that fishers-farmers switch towards more fishing
From_8_to_10m	50	50	When water level is between 8 and 10m, there is a 50-50% chances that fishers-farmers go fishing or farming
Below_8m	70	30	When water level is below 8m, there is a 70% chances that fishers-farmers switch towards more farming (but fishing still important, as fish catchability is higher)

• According to the World Bank, Cambodia's population growth rate of over 2.5 percent per annum provides almost 200,000 new entrants to the labour force each year, a fraction of these entrants becoming small-scale fishers. This trend is increased by the Fisheries Reform that gives more access to small scale fishers over fishing lots. Despite emigration towards cities mentioned above, we consider that at least in the coming years the Number of Khmer subsistence fishers has 100% chances of *"Increasing"*.

• The Number of Vietnamese/Cham subsistence fishers looks moderately increasing, except in Kompong Chnnang province where they migrate to become workers. According to anecdotal evidence, the growth of Vietnamese/Cham communities is less important than that of Khmer people; subsequently it was decided that this variable would qualify as 75% *"Increasing*" and 25% "*Stable"*.

• According to Keskinen (2003), there are 94.8% of Khmer, 3% of Vietnamese and 2.2% of Cham in the Lake's basin (see section 5.5.1). The combinations of these variables are detailed in Table 14.

Table 14: Parameterization of the Number of subsistence fishers variable.

Number of Khmer subsistence fishers	Number of Vietnamese/Cham subsistence fishers	# of subsistence fishers	
		Increasing	Stable
Increasing	Increasing	100	0
Increasing	Stable	5.2	94.8
Stable	Increasing	94.8	5.2
Stable	Stable	0	100

• The Gear size of subsistence fishers is changing over time. During field interviews all villagers admitted that the length of their gillnets had increased two to four times in the past years, up to 200m to 400m per gill net (Kum, 2004). However, the gear size cannot increase forever: the longer the gillnets, the more time required to process the catch. Moreover, longer gillnets require more capital investment, which is not always possible for the subsistence fishers whose investment power is limited. Given this context the chances of fishing gear size increasing were estimated to 25% and those of staying stable to 75%.

• The overall fishing Pressure from small-scale fishery is determined by 3 variables, whose combination is detailed in Table 15 (after Kum, 2004):

Table 15: Parameterization of Pressure from small-scale fishery variable.

Subsistence fisher activities	Size of gear	Number of subsistence fishers	Pressure from small-scale fishery		Justification
			Increasing	Stable	
More fishing	Increasing	Increasing	100	0	If the number of subsistence fishers increases, their activity involves more fishing and the size of gear increases, there is a 100% chance that this will result in an increase of the small scale fishing pressure
More fishing	Increasing	Stable	50	50	If the number of subsistence fishers is table, but their activity involves more fishing and the gear size increases, there is a 50% chance that this will result in an increased fishing pressure
More fishing	Stable	Increasing	80	20	If the number of subsistence fishers increases, their activity involves more fishing, but the size of gear is stable, there is a 80% chance that this will result in an increased fishing pressure
More fishing	Stable	Stable	30	70	If the number of subsistence fishers is stable, their activity involves more fishing, and the gear size is stable, there is a 30% chance only that this will result in an increased fishing pressure
More farming	Increasing	Increasing	70	30	If the number of subsistence fishers increases, the size of their gears increases but their activity involves more farming, there is a 70% chance that this will result in an increased fishing pressure
More farming	Increasing	Stable	20	80	If the number of subsistence fishers is stable, the size of their gears increases but their activity involves more farming, there is a 20% chance only that this will result in an increased fishing pressure
More farming	Stable	Increasing	50	50	If the number of subsistence fishers increases and their activity involves more farming, but the size of gears is stable, there is a 50% chance that this will result in an increased fishing pressure
More farming	Stable	Stable	0	100	If the number of subsistence fishers is stable, their activity involves more farming and the size of their gears is stable, there is a 100% chance that this will result in a stable small scale fishing pressure.

7.5.2 Middle-scale fisheries

- Number of Khmer middle-scale fishers

Nettleton *et al.* (2004) reported that for Khmer fishers who can own land, fishing is becoming less and less profitable, in particular considering the significant capital investment needed in this fishery. In the other hand the recent abolishment of the licence fees on middle-scale fisheries created an incentive to invest in this sector. In absence of additional information, we define the Number of Khmer commercial fishers as 50% "*Increasing*" and 50% "*Stable*".

- Number of Viet./Cham middle-scale fishers

The Vietnamese families around the Lake do not usually own any land and depend on fishing for their livelihood, and the fishing seems more attractive to them because of their well-known expertise in the job (e.g. only 15 out of the total 1,072 Vietnamese families in Psar Chnnang commune are running sale business). Therefore, although the growth trend of the Vietnamese population is not clearly known (Kum, 2004), it is expected that the chance that the number of Vietnamese fishers in the floodplain increases is more likely at least by the natural growth. Based on this, we define the Number of Viet./Cham middle-scale fishers as 75% "*Increasing*" and 25% "*Stable*".

- Number of migrant middle-scale fishers

There is no recorded data about the migrant families who come seasonally to fish in some areas in the Tonle Sap Great Lake. Interviews of local fishers (Kum 2004) led to the conclusions that despite a significant social problem with migrant fishers who tend to over-harvest fish, there is no significant increase in the number of families of migrant fishers. Because of the lack of data, we define the state of Number of migrant middle-scale fishers as 50% "*Increasing*" and 50% "*Stable*".

• Total Number of middle-scale fishers

After discussion and vote among the stakeholders, the share of each community in the fishing pressure has been amounted to 40% to Vietnamese and Cham fishers, 40% to Khmer fishers and 20% to migrant fishers respectively (Kum, 2004).

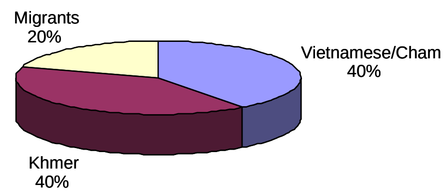

Figure 17: Share of each ethnic group in middle scale fisheries

Table 16: Parameterization of the variable Number of middle-scale fishers.

Number of migrant fishers	Number of Vietnamese/ Cham fishers	Number of Khmer fishers	Pressure from middle-scale fishers		Justification
			Increasing	Stable	
Increasing	Increasing	Increasing	100	0	If the number of migrant, Vietnamese/Cham and Khmer middle-scale fishers increases, the chance that the fishing pressure from middle scale fishers increases is 100 %.
Increasing	Increasing	Stable	60	40	If the number of migrant and Vietnamese/Cham fishers increases but the number of Khmer fishers is stable, the chance that the pressure from middle scale fishers increases is 60%
Increasing	Stable	Increasing	60	40	If the number of migrant and Khmer fishers increases but the number of Vietnamese/Cham fishers is stable, the chance that the pressure from middle scale fishers increases is 60%.
Increasing	Stable	Stable	20	80	If the number of migrant fishers increases but the number of Vietnamese/Cham and Khmer fishers is stable, the chance that the pressure from middle scale fishers increases is 20%
Stable	Increasing	Increasing	80	20	If the number of migrant fishers is stable but the number of Vietnamese/Cham and Khmer fishers increases, the chance that the pressure from middle scale fishers increases is 80%
Stable	Increasing	Stable	40	60	If the number of migrant and Khmer fishers is stable but the number of Vietnamese/Cham fishers increases, the chance that the pressure from middle scale fishers increases is 40%
Stable	Stable	Increasing	40	60	If the number of Khmer fishers increases while the number of Vietnamese/Cham and migrant fishers remains stable, the chance that the pressure from middle scale fishers increases is 40%
Stable	Stable	Stable	0	100	If the number of migrant, Vietnamese/Cham as well as Khmer fishers remain stable, the chance that the fishing pressure from middle scale fishers increases is nil.

• Middle-scale gear efficiency

In the past few years new ways of operating middle-scale fishing gears have spread, such as electrification of drag-nets, and overall the mesh size has been reduced. In the other hand the cost of operation (engine, petrol) has also increased, which slows down the tendency to increase the overall size and reduce the mesh size of the gears actively dragged.. Based on this anecdotal evidence and in absence of additional information, we define the state of Middle-scale gear efficiency as 75% "*Increasing*" and 25% "*Stable*".

• Pressure from middle-scale fishery was roughly estimated to be 30% determined by the efficiency of middle-scale gears, and 70% by the number of fishers. The subsequent table of probabilities is:

Table 17: Parameterization of Pressure from middle-scale fishery variable.

Number of middle-scale fishers	Fishing efficiency	Pressure from middle-scale fishery		Justification
		Increasing	Stable	
Increasing	Increasing	100	0	If the number of fishers and the gear efficiency both increase, the chance that the fishing pressure from middle scale fishery increases is 100 %.
Increasing	Stable	70	30	If only the number of fishers increases, the chance that the pressure from middle scale fishery increases is 70%.
Stable	Increasing	30	70	If only the gear efficiency increases, the chance that the pressure from middle scale fishery increases is 30%
Stable	Stable	0	100	If both the number of commercial fishers and the gear efficiency remain stable, there is a 100% chance that the pressure from the middle-scale fishery remains stable.

7.5.3 Large-scale fisheries

- Pressure from large-scale fishery

Basically, the fishing pressure from large scale fishery results from the number of lots and from the extent of fishing fences associated to lots. In order to reflect the actual fishing conditions, we encompassed as part of lots the fishing pressure from community fisheries in former lots decommissioned in 2000. The extent of fences was calculated from a digitization of GIS maps, and operating fishing lots currently total 409 km of fences (see Jantunen 2006 for details). The extent of fishing lots decommissioned amounts to 596 km, and it was considered that in these former lots the fencing is less systematic, and only blocks 50% of the waterways[2], hence an assumed length of fences of 298 km in decommissioned fishing lots. The total length of fences thus amounts to 409+298 = 707 km, which represents 59% of the periphery of the lake. Hence the elicitation of the Pressure from large scale fishery node: 59% *blockage*, 41% *nil*.

[2] The team attempted to calculate the actual ratio [length of fences / area considered] in the Prek Toal study site (current fishing lot nº2 and former lot nº3 not under community fishery regime). However this calculation was impossible because:
- the resolution of orthophotomaps does not allow formally identifying lines as fences without extensive field verification;
- a lot of gears and fences are located among the vegetation and under trees, and are not visible from the sky;
- extensive nets are set underwater over hundreds of meters, but cannot be seen by remote sensing.

7.5.4 Fishing pressure on each fish guild

The fishing pressure on the TS fish harvest results from small-scale fishery, medium scale fishery and large-scale fishery as officially defined (Gum, 2000). An assessment of the pressure of each type of fishery on each guild of fish requires 1) a quantification of the share of each fishery to the total catch, and 2) an assessment of the proportion of each guild of fish in each type of fishery.

Share of each fishery to the total catch

According to Van Zalinge *et al.* (2000):

- Large scale fishing ranks between 39,000 and 91,000 tons (average 65,000 tons);
- Middle scale fishing operation ranks between 85,000 and 100,000 tons (average 92,500 tons);
- Small scale fishing operation rank between 165,000 and 240,000 tons (average 202,500 tons).

The above data reflects the situation before the 56% reduction in surface of the lots in 2000. To better reflect the present situation, we assume that the reduction in the fishing lots surface results in a 56% decrease in total catch of the large scale fishing operation (although it is said that the decommissioned lots were much less productive than the remaining ones). We also assume that the catch lost by fishing lots, i.e. around 36,400 tonnes, is shared between the two other fisheries according to their respective importance (31% for the middle scale fishery, and 69% for the large scale fisheries). Based on this**,** the average catch from the Lake fisheries is:

- Large scale fishing operation: 65,000 - 56% = 28,600 tonnes = 7.9%
- Middle scale operation is 92,500 + 11,300 = 103,800 tonnes = 28.8%
- Small scale operation is 202,500 + 25,100 = 227,600 tonnes = 63.2%
- Average total catch: 360,000 tons.

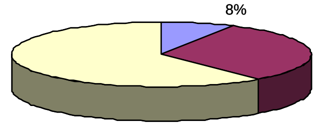

Figure 18: Estimated proportion of the total catch by type of fishery.

Share of each guild to each fishery

Table 18, based on bibliographic references applying to the whole of Cambodia, shows the proportion of resident black and migrant white fish in the catch of small scale, middle scale and large scale fisheries.

Table 18: Proportion of resident and migrant fish in the catch of Cambodian fisheries.

	Black fish (%)	White fish (%)
Small scale fishing*	25.5	74.5
Middle scale fishing**	17	83
Large scale fishing**	39	61
* Source: Ahmed *et al.* (1998) **Source: Baran *et al.* (2003)		

This gives the estimated proportion of resident black fish and migrant white fish in the total catch of the Tonle Sap system:

Table 19: Proportion of resident and migrant fish in the catch of Tonle Sap fisheries.

	Black fish (%)	White fish (%)
Small scale fishing	25.5*63 =16%	74.5*63 =47%
Middle scale fishing	17*29 =5%	83*29 =24%
Large scale fishing	39*8 =3%	61*8 =5%
Total	*24%*	*76%*

Pressure of each fishery on each guild

Pressure on residents

- small-scale fishing contributes 16/24 of the Catch of residents (cf. Table 19); i.e. 66.7%
- middle-scale fishing contributes 5/24 of the Catch of residents; i.e. 20.8%
- large-scale fishing contributes 16/24 of the Catch of residents; i.e. 12.5%

Thus when these fisheries are integrated, the probability table of their combinations is next:

Table 20: Parameterization of Pressure on resident fish variable.

Small scale fishing	Middle scale fishing	Large scale fishing	Fishing pressure on resident fish	
			Increasing	Stable
Increasing	Increasing	Nil	100	0
Increasing	Increasing	Blockage	87.5	12.5
Increasing	Stable	Nil	79.2	20.8
Increasing	Stable	Blockage	66.7	33.3
Stable	Increasing	Nil	33.3	66.7
Stable	Increasing	Blockage	20.8	79.2
Stable	Stable	Nil	12.5	87.5
Stable	Stable	Blockage	0	100

Pressure on Mekong migrants

- small-scale fishing contributes 47/76 of the Catch of residents (cf. Table 21); i.e. 61.8%
- middle-scale fishing contributes 24/76 of the Catch of residents (cf. Table 21); i.e. 31.6%
- large-scale fishing contributes 5/76 of the Catch of residents (cf. Table 21); i.e. 6.6%

Thus when these fisheries are integrated, the probability table of their combinations is next:

Table 21: Parameterization of Pressure on Mekong migrants variable.

Small scale fishing	Middle scale fishing	Large scale fishing	Fishing pressure on White fish	
			Increasing	Stable
Increasing	Increasing	Nil	93.4	6.6
Increasing	Increasing	Blockage	100	0
Increasing	Stable	Nil	61.8	38.2
Increasing	Stable	Blockage	68.4	31.6
Stable	Increasing	Nil	31.6	68.4
Stable	Increasing	Blockage	38.2	61.8
Stable	Stable	Nil	0	100
Stable	Stable	Blockage	6.6	93.4

Pressure on Tonle Sap migrants

The absence of catch statistics for grey fish forced us to assimilate again grey fish to white fish (see section 7.1), and to parametrize the table of Pressure on Tonle Sap migrants just like in Table 21.

The overall BayFish – Tonle Sap model is depicted in Figure 19.

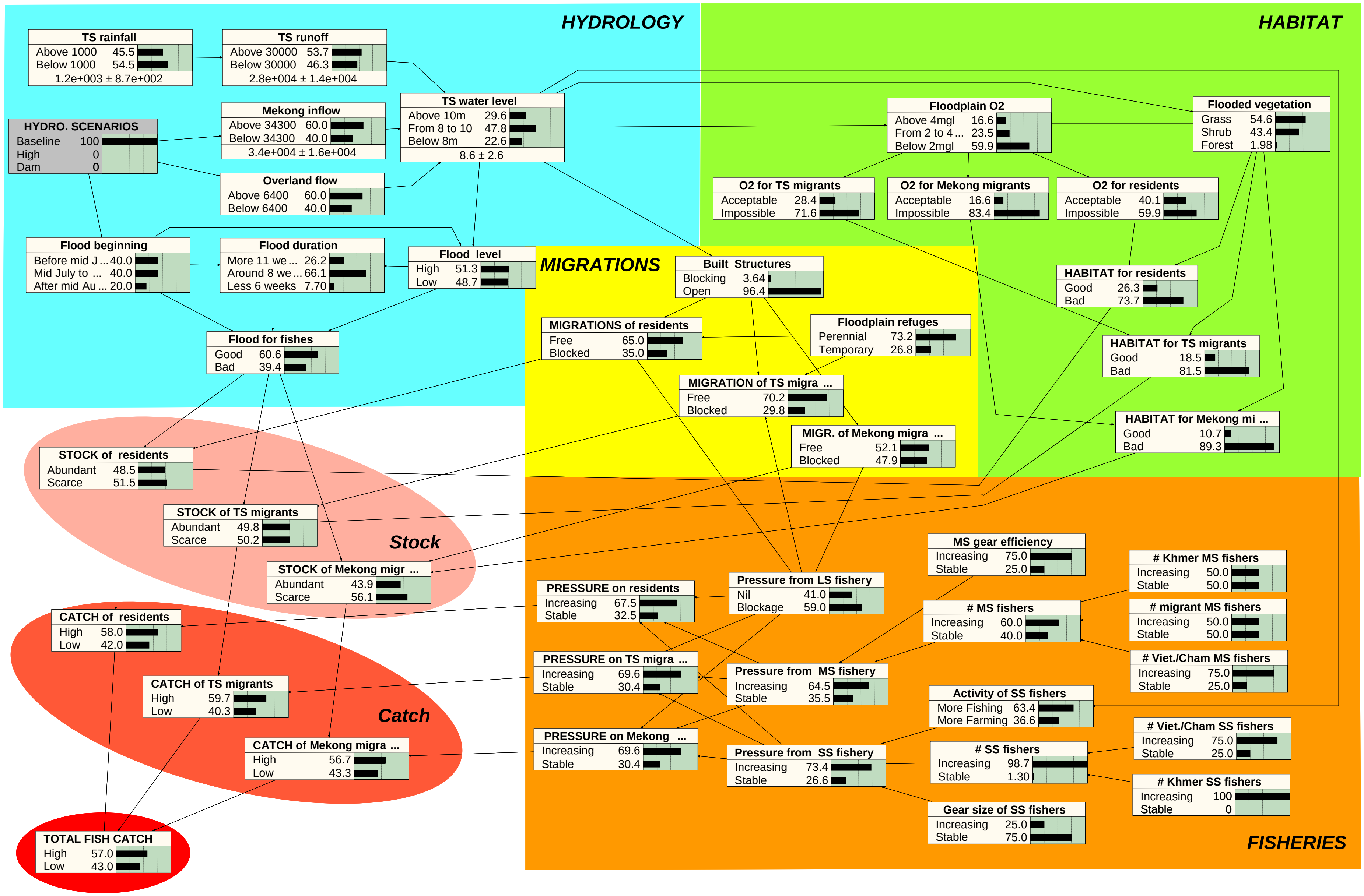

Figure 19: Overview of the Bay-Fish – Tonle Sap model

8 RESULTS

Model testing was carried out in order to verify the models logical workability. Testing consisted in choosing 100% probability for a given state of each variable and analysing the changes in the probabilities of other variables, especially the most relevant ones. A number of scenarios, based on MRC/WorldBank scenarios (2004) and computed at MRCS/WUP_FIN were tested with the model, concentrating on hydrological changes. In addition to development scenarios a baseline scenario production figures for several years was compared with the Dai fisheries fish catch data in order to obtain estimates of the model accuracy.

8.1 Model testing and verification

The model testing concentrated more on hydrology and habitat sections of the model as these are largely supported by data, with all nodes checked and approved by extensive stakeholders consultations (less consultations contributed to the building and elicitation of the fisheries module). In addition, in the hydrological section of the model there are several nodes with state combinations that are incompatible in the natural system, and therefore careful testing, modification and validation was required to address this issue. These testing results were achieved with MRCS/TSLV_JICA data.

8.1.1 Bugs identification

One problem in the model workability was found during testing with Overland flow probabilities. In the natural system when Overland flow state "*Above 7600*" has 100% probability it should increase the Water level at Kompong Loung probabilities linearly from "*Below 8m*" to "*Above 10m*". However, as can be seen in Table 21 the probabilities actually decrease from "*Below 8m*" to "*From 8 to 10m*" before increasing again.

Table 22: Initial results for Water level at Kompong Loung node testing of problematic probabilities.

	TS Runoff		Flow from Mekong		Overland flow	
Water level K. Loung	Above 30000	Below 30000	Above 37000	Below 37000	Above 7600	Below 7600
Baseline	53.7	46.3	47.6	52.4	42.9	57.1
Below 8m	41	59	38.3	61.7	37.2	62.8
From 8 to 10m	57.9	42.1	49.1	50.9	35.3	64.7
Above 10m	57.9	42.1	53.6	46.4	61.3	38.7

The problem was located in Water level at Kompong Loung node, where one set of probabilities was just averaged between the three states due to lack of examples in the data. The problem was solved by giving weights to the averaged probabilities based on probabilities derived from the data.

The combinations of states causing the lower water levels were chosen for comparison. From Table 23 it can be seen from the probabilities (selected node state = "*Above*") that the most effect on water level in the Lake is inflicted by TS Runoff (row 2) and Flow from Mekong (row 1) respectively. Therefore, Overland flow probabilities for high water levels (and vice verse for low water levels) should be below that of rows 1 and 2, but above the lowest possible probabilities (row 3). So Water level at Kompong Loung state "*Above 10m*" probability was set at 15% which is between otherwise lowest probabilities in rows 2 and 3 (Table 22). "*From 8 to 10m*" was set at 55% (lower than both rows 1 and 2, but higher than 3) and "*Below 8m*" at 30% (higher than rows 1 and 2, but lower than 3). By changing the probabilities in above manner based on existing weights between the probabilities derived from the data the workability problem was solved (Table 24).

Table 23: Changes made to Water level at Kompong Loung probability table. Row 4a (bolded) represents averaged probabilities and 4b (italics) weighted probabilities.

Row	Flow from Mekong	Overland flow	TS Runoff	Water level at K. Loung: Above 10m	From 8 to 10m	Below 8m	Notes
1	Above 37000	Below 7600	Below 30000	20	60	20	Flow from Mekong has second highest influence on water level
2	Below 37000	Below 7600	Above 30000	16.667	66.667	16.667	TS Runoff has highest influence on water level
3	Below 37000	Below 7600	Below 30000	12.5	37.5	50	All "*below*" average
4a	Below 37000	Above 7600	Below 30000	**33.333**	**33.333**	**33.333**	Original probabilities averaged between all states
4b	Below 37000	Above 7600	Below 30000	*15*	*55*	*30*	New weighted probabilities

Table 24: Final results for Water level at Kompong Loung node testing of problematic probabilities.

	TS Runoff		Flow from Mekong		Overland flow	
Water level K. Loung	Above 30000	Below 30000	Above 37000	Below 37000	Above 7600	Below 7600
Baseline	53.7	46.3	47.6	52.4	42.9	57.1
Below 8m	41.6	58.4	38.9	61.1	*36.3*	*63.7*
From 8 to 10m	55.3	44.7	46.9	53.1	*38.2*	*61.8*
Above 10m	62.3	37.7	57.6	42.4	58.4	41.6

8.1.2 Hydrology section analysis

Hydrological analysis of the model workability included testing sensitivity of hydrological variables to changes in selected nodes (Table 24). Sensitivity of Tonle Sap water flow input variables to water level changes in the Lake revealed that **Overland flow has the highest impact on the "*Above 10m*" water level**. This is because the variable is closely linked to inflow from the Mekong River as overland flow only takes place when water levels are high enough in the Mekong, especially characteristic of extreme floods such as years 2000 and 2001. The water level in the Lake is extremely low in years not experiencing any overland flow, such as 1998. Therefore "*Below 6400*" overland flow also causes "*Above 10m*" water level to decrease to 19.5% compared to the baseline value of 29.6% while increasing "*From 8 to 10m*" water level from 47.8% to 54%.

On the other hand overland flow has slightly less impact on probabilities of Water level at Kompong Loung state "*Below 8m*" compared to Tonle Sap Runoff and Mekong Inflow. In conclusion flood cycles with average or high overland flow are likely to have high water levels in the Tonle Sap Lake. Also, approximately 50% of all floods are between 8 and 10m, with roughly 30% extremely high (>10m) and 20% very low (<8m) as shown by the baseline values. Both extremes are considered bad for fish production.

Table 25: Results for testing Water level at Kompong Loung node.

		Water level at Kompong Loung		
		Above 10m	From 8 to 10m	Below 8m
Baseline		29.6	47.8	22.6
Mekong Inflow	Above 34400	34.0	46.8	19.2
	Below 34400	22.9	49.4	27.6
Overland flow	Above 6400	36.3	43.7	20.0
	Below 6400	19.5	54.0	26.5
Tonle Sap runoff	Above 30000	33.7	47.7	18.6
	Below 30000	24.8	48.0	27.2

Analysis of flood beginning, duration and flood level revealed that **high, long and early floods provide the best flooding conditions for fish stocks whereas low, short, and late floods are detrimental to them** (see Table 26). This has also been shown in literature, e.g. van Zalinge *et al.* (2000). It seems that late flood has more negative gross effect than early flood has positive. Similarly short flood is more detrimental than a long flood is beneficial. Perhaps this is a sign that **the natural system is more effective and productive with earlier and longer floods; manmade changes to this pattern might severely affects its balance**. Therefore serious consideration should be given to dam building upstream which could cause the floods to become shorter and to arrive later. **The single most influential variable for flooding conditions in terms of fisheries is Flood level, followed by Flood beginning and Flood duration.** However, flood beginning has an effect on flood level and duration, whereas flood level only affects flood duration (section 4.2). Mekong migrant fish seem to be most susceptible to hydrological changes, whereas residents are less susceptible. All probabilities reflect the natural system and its fluctuations as they are understood by experts at the moment.

Table 26: Tests on the effect of hydrological variables on flooding conditions in the floodplain.

	Node	Flood for fishes		STOCK TS resident		STOCK TS migrants		STOCK Mek migrants	
	State	Good	Bad	Abundant	Scarce	Abundant	Scarce	Abundant	Scarce
	Baseline	60.6	39.4	48.5	51.5	49.8	50.2	43.9	56.1
Flood beginning	Before mid July	81.7	18.3	56.5	43.5	56.8	43.2	49.1	50.9
	Mid July to mid Aug	61.4	38.6	48.8	51.2	50	50	44.1	55.9
	After mid Aug	16.7	83.3	31.7	68.3	35.1	64.9	32.9	67.1
Flood duration	More than 11 weeks	76.2	23.8	54.4	45.6	54.9	45.1	47.7	52.3
	Around 8 weeks	60.1	39.9	48.3	51.7	49.6	50.4	43.8	56.2
	Less than 6 weeks	12	88	30	70	33.7	66.3	31.8	68.2
Flood level	High	93.5	6.5	61	39	60.4	39.6	51.7	48.3
	Low	25.9	74.1	35.3	64.7	38.5	61.5	35.6	64.4

8.1.3 Habitat section analysis

Habitat analysis concentrated on flooded vegetation, floodplain dissolved oxygen levels and water level changes (Table 26). Flooded vegetation "*Forest"* state is by far the best vegetation type for both dissolved oxygen and habitats. "*Grass*" is better than "*Shrub*" for dissolved oxygen, but worse as overall habitat, because "*Shrub*" provides more food and shelter for fish than "*Grass*". Water level directly affects the surface area of vegetation flooded as well as dissolved oxygen levels. With a high flood (>10m) dissolved oxygen levels are lower than normal (8-10m) because more floodplain periphery with more or less anoxic condition water are included in the calculation. Also, resident fish depend more on water level than migrant fish due to accessibility of their dry season refuges to open water.

Table 27: Tests on habitat variables

		O2 for Mekong migrants		O2 for residents		Habitat for Mekong migrants		Habitat for residents	
		Acceptable	Impossible	Acceptable	Impossible	Good	Bad	Good	Bad
Baseline		16.1	83.9	39.5	60.5	10.3	89.7	25.9	74.1
Flooded vegetation	Grass	19.3	80.7	44.7	55.3	9.66	90.3	22.3	77.7
	Shrub	11.5	88.5	31.5	68.5	10.3	89.7	28.4	71.6
	Forest	28.3	71.7	68.3	31.7	28.3	71.7	683	31.7
Floodplain oxygen	Above 4mg/l	100	0	100	0	64.1	35.9	64.1	35.9
	From 2 to 4mg/l	0	100	100	0	0	100	66.6	33.4
	Below 2mg/l	0	100	0	100	0	100	0	100
Water level	Above 10m	12	88	37.1	62.9	7.2	92.8	23.8	76.2
	From 8 to 10m	18.7	81.3	43.5	56.5	12.3	87.7	28.4	71.6
	Below 8m	18.2	81.8	36.7	63.3	12.1	87.9	25.1	74.9

8.1.4 Fishery section analysis

Both subsistence fisher activity and small scale gear size have more impact on fishing pressures than nodes affecting middle scale fisheries because small scale fishing contributes most to the annual fish catch. From the number of middle scale fisherman the Khmer fishers have the most impact, while Vietnamese and migrant fishers have equal importance.

Table 28: Results for testing fisheries variables.

			Pressure from small scale fishery		Pressure from middle scale fishery		PRESSURE on residents		PRESSURE on Mekong migrants	
			Increasing	Stable	Increasing	Stable	Increasing	Stable	Increasing	Stable
Baseline			73.4	26.6	64.5	35.5	67.5	32.5	69.6	30.4
Small scale fishery	Activity of SS fishers	More fishing	84.3	15.7			74.8	25.2	76.4	23.6
		More farming	54.4	45.6			54.8	45.2	57.9	42.1
	Gear size of SS fishers	Increasing	88.4	11.6			77.5	22.5	78.9	21.1
		Stable	68.4	31.6			64.1	35.9	66.5	33.5
	No. of Khmer SS fishers	Increasing	73.4	26.6			67.5	32.5	69.6	30.4
		Stable	-	-			-	-	-	-
	No. of Viet./Cham SS fishers	Increasing	74	26			67.9	32.1	70	30
		Stable	71.4	28.6			66.2	33.8	68.4	31.6
Middle scale fishery	No. of Khmer MS fishers	Increasing			78.5	21.5	70.4	29.6	74	26
		Stable			50.5	49.5	64.6	35.4	65.2	34.8
	No. of migrant MS fishers	Increasing			71.5	28.5	68.9	31.1	71.8	28.2
		Stable			57.5	42.5	66	34	67.4	32.6
	No. of Viet./Cham MS fishers	Increasing			71.5	28.5	68.9	31.1	71.8	28.2
		Stable			43.5	56.5	63.1	36.9	63	37
	MS gear efficiency	Increasing			72	28	69	31	72	28
		Stable			42	58	62.8	37.2	62.5	37.5

In terms of actual fish production, migrant fish contribute more than resident fish (see section 7.5). However it was decided not to analyze in detail the catch of each guild nor the total Tonle Sap catch. This is justified by two main reasons:

1) **there are excessive knowledge gaps regarding grey fish and the nature and functioning of the overall fishery sector** (absence of disaggregated catch statistics for Tonle Sap migrants, lack of quantitative factors describing precisely each type of fishery, and overly simplistic descriptors of the each type of fishery);

2) the nature of the fishery module of the model is different from that of the other modules: while the Hydrology, Habitat and Migration variables are based on the current or past situation as documented by data and expert experience, the fishery module uses variables that refer to the future (e.g. number of fishers increasing). This fact is due to the quasi-total absence of information and data about the fishery sector and its history (how many fishermen, what fishing effort, etc). This situation introduces a twist in the model and an excessive reliance, for that module, on assumptions and guesses; it also highlights the **urgent need for researchers and managers to start documenting and monitoring the fishery sector for its role in the sustainability of the fish production can be better appraised**.

For these reasons, we focused on the relationship between environmental factors (hydrology, habitat, migrations) and the fish stocks. Fish stock variables were also used for scenario analysis and for comparison with Dai fishery fish catch data. The model shows that **the main influence on resident fish stocks is due to Flood for fishes and Habitat for residents, whereas Mekong migrants are mainly influenced by Migrations of Mekong migrants**. For Tonle Sap migrants no single driving variable is more influential than another.

8.2 Model validation

This model validation is based on the Baseline scenario fish production. The baseline scenario based on probabilities elicited by the stakeholders was compared with the Dai fisheries annual fish catch data. This dataset is regarded as the best fish catch data available in Cambodia, and reflects the Tonle Sap Lake fish production quite well.

Years 1995 to 2003 were used for the comparison, even though WUP-FIN model has output data for years 1996-2000 only. During the testing it was assumed that same consistency shown in Tables 32-34 in WUP_FIN and WUP_JICA baselines would apply for 1995 and 2001-2003. Model input states for Mekong flow, Overland flow and Flood beginning were used for each year at a time to set up the model (Table 29). Years 1996-1997 and 2000-2001 have the same flooding states, and therefore flood for fish probabilities as well.

Table 29: Input states for Baseline scenarios 1996-2000 based on hydrological data.

Year	Date of floodplain flooding	Flow from Mekong	Overland flow
1996	Mid July to mid Aug	Above 34300	Above 6400
1997	Mid July to mid Aug	Above 34300	Above 6400
1998	After Mid Aug	Below 34300	Below 6400
1999	Before mid Jul	Below 34300	Below 6400
2000	Before mid Jul	Above 34300	Above 6400

Comparison of actual data vs. predicted outputs

We ran BayFish for each year between 1995 and 2004, and calculated for each year the probability of a high fish stock, knowing all actual environmental parameters for these years. The model outputs were then compared to the data of the Dai fishery, that is the only fishery for which catches have been scientifically monitored over a long period of time. The modelled curves of Mekong migrant and Tonle Sap resident fish stocks fits well with published catch data for the Dai fishery (Figure 20).

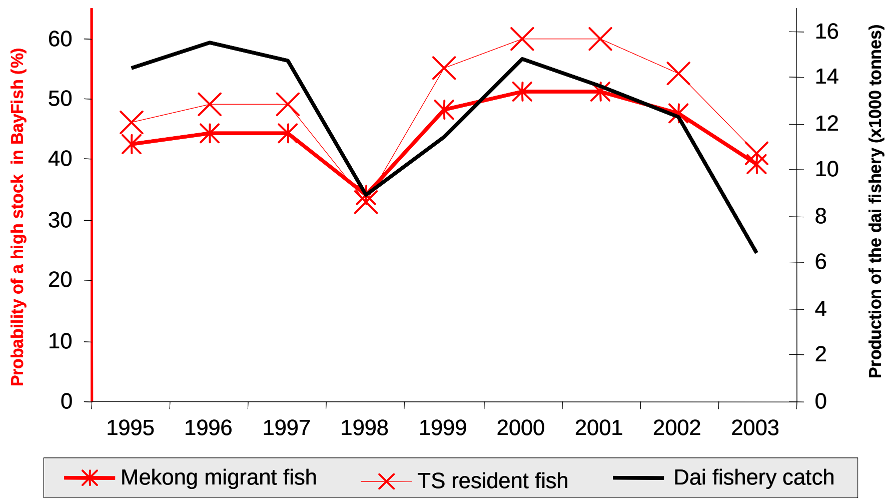

Figure 20: Comparison of actual Dai fishery catches (data from Starr, 2004) with model predictions (residents and Mekong migrants disaggregated)

These results have been produced by the BayFish model on the sole basis of variables and parameters proposed *a priori* by stakeholders and extracted from databases; no adjustment nor recalibration has been done at this stage.

Table 30: Results for Baseline scenario analysis for fish harvest and fish stocks.

Node	Flood for fishes		STOCK of resident		STOCK of TS fishers		STOCK of Mekong	
State	Good	Bad	Abundant	Scarce	Abundant	Scarce	Abundant	Scarce
Baseline	60.6	39.4	48.5	51.5	49.8	50.2	43.9	56.1
1995	54.4	45.6	46.2	53.8	47.9	52.1	42.5	57.5
%	-10.2	15.7	-4.7	4.5	-3.8	3.8	-3.2	2.5
1996	62.9	37.1	49.2	50.8	50.4	49.6	44.3	55.7
%	3.8	-5.8	1.4	-1.4	1.2	-1.2	0.9	-0.7
1997	62.9	37.1	49.2	50.8	50.4	49.6	44.3	55.7
%	3.8	-5.8	1.4	-1.4	1.2	-1.2	0.9	-0.7
1998	20	80	33	67	36.5	63.5	34.1	65.9
%	-67.0	103.0	-32.0	30.1	-26.7	26.5	-22.3	17.5
1999	76.6	23.4	55	45	55.4	44.6	48.1	51.9
%	26.4	-40.6	13.4	-12.6	11.2	-11.2	9.6	-7.5
2000	91	9	59.9	40.1	59.7	40.3	51.2	48.8
%	50.2	-77.2	23.5	-22.1	19.9	-19.7	16.6	-13.0
2001	91	9	59.9	40.1	59.7	40.3	51.2	48.8
%	50.2	-77.2	23.5	-22.1	19.9	-19.7	16.6	-13.0
2002	75.9	24.1	54.1	45.9	54.6	45.4	47.5	52.5
%	25.2	-38.8	11.5	-10.9	9.6	-9.6	8.2	-6.4
2003	40.6	59.4	40.9	59.1	43.4	56.6	39.3	60.7
%	-33.0	50.8	-15.7	14.8	-12.9	12.7	-10.5	8.2

8.3 Scenario analysis

8.3.1 Development scenarios

Development scenarios for Lower Mekong Basin and Tonle Sap Lake have been designed by Mekong River Commission Basin Development Programme, WorldBank (2004) and Cambodian National Mekong Commission (2004). However, very little has been published in actual numeric data on the scenarios required as an input for this model. Therefore, WUP-FIN hydrological model was used to obtain the data for the scenario input states (nodes: Mekong Inflow, Overland flow and Flood beginning). Due to differences between the MRCS/TSLV_JICA and WUP_FIN models the output data is somewhat different. Two hydrological development scenarios were created for testing purposes, both based on MRC scenarios:

1) High development (HD) scenario. The High Development Scenario has been defined by the MRCS according to the table below (Koponen *et al.* 2007):

Table 31: High Development scenario assumptions (Koponen, 2007)

Scenario Summary	Baseline	High Development
Upper Mekong Basin Dams	None	Xiowan and Nuozhadu
Diversions	None	• Inter-basin diversion from Chiang Rai tributary • Intra-basin diversion from Mun Chi tributary • Intra-basin diversion from Mun Chi mainstream
Domestic Water Consumption (litres per capita per day)	• Based on MRC (2004) data on per capita water demands: Laos – 64, Thailand – 115, Cambodia – 32, Viet Nam – 66	• Laos – 150 , Thailand – 200, Cambodia – 100, Viet Nam – 150
Irrigated Areas	• Total irrigated area of 74,655 km^2 allocated among sub-areas on the basis of the data contained in the DSF	• Total irrigated area of 104,287 km^2 allocated among sub-areas on the basis of the projections used in the DSF
Hydropower	• 4 dams modelled: Nam Ngum, Theun Hinboun, Houay Ho, Yali •	• 8 dams modelled: Nam Ngum, Theun Hinboun, Nam Theun 2, Nam Theun 3, Yali, Xe Kaman 1, • Se Kong 5, Lower Se San & Lower Sre Pok

2) Main stream dam (MSD) development scenario. The Mainstream Dams scenario includes mainstream dam development to the High Development Scenario. The net storage of the reservoirs is assumed to be 85 billion m3 (Mekong Committee, 1970) based on the most feasible hydropower and irrigation development plan.

Results from the scenario testing can be seen in tables 32-35. The results are also compared to the baseline of TSLV/WUP_JICA results that were used previously in the model to ensure data integrity. It is clear from the tables that the baselines from two different models fit well (bold figures representing years with *Above* average flows, or beginning of the flood). For the development scenarios average of WUP_FIN baseline was used. This produced clear differences especially with Mainstream dams development scenario. For Mekong inflow above average flow probabilities drop from 60% to 40% (HD) and 20% (MSD), similar trend being seen in Overland flow. MSD scenario for overland flow was not received from WUP_FIN, but by analysing the data it can be seen that the trend follows closely Mekong inflow trends, hence only year 2000 is going to be above average flow (giving 20% above average probability). For overland flow baseline year 1997 flow of 6400 was counted as above average (average being 6408) in order to follow old baseline based on WUP_JICA model data.

Table 32: Mekong inflow results from WUP_FIN model

Year	1996	1997	1998	1999	2000	Average
Baseline	**37523**	**35910**	20624	29865	**47895**	34363
High Development	**34775**	33083	15704	26012	**46568**	31228
Mainstream Dam dev	25256	24206	8461	20301	**38494**	23344
Baseline from WUP_JICA	**43910**	**40897**	22110	35718	**49772**	38481

Table 33: Overland flow results from WUP_FIN model

Year	1996	1997	1998	1999	2000	Average
Baseline	**8400**	**6400**	240	4500	**12500**	6408
High Devevelopment	**6500**	4800	20	3100	**10700**	5024
Mainstream Dam dev						
Baseline from WUP_JICA	**9118**	**11621**	1309	7036	**16366**	9090

Flood beginning remained the same for both of the baselines and HD scenario, but MSD scenario showed a change towards later floods. Also the analysis showed that another stakeholders consultation would be required to be able to determine flood beginning in a more precise way to increase the sensitivity of the model.

Table 34: Flood beginning results from WUP_FIN model

Year	Date	1996	1997	1998	1999	2000
Baseline	15.7	2.48	2.58	2.55	**4.05**	**5.03**
	1.8	**3.69**	**4.56**	3.56	4.82	6.72
	15.8	5.18	6.31	**3.95**	6.25	7.22
High Development	15.7	2.51	2.64	2.54	**3.85**	**4.85**
	1.8	**3.55**	**4.44**	3.27	4.46	6.44
	15.8	4.86	6.05	**3.51**	5.80	6.79
Mainstream Dam dev	15-Jul	2.48	2.57	2.43	**4.05**	**4.74**
	01-Aug	3.43	**4.00**	2.94	4.67	6.07
	15-Aug	**4.48**	5.16	**3.23**	5.65	6.42
WUP_JICA baseline	15.7	2.9	2.9	2.9	**5**	**5.7**
	1.8	**4.2**	**4.9**	3.8	5.8	7.1
	15.8	5.6	6.7	**4.3**	7.1	8.3

After analyzing results from WUP_FIN output data it was noted that Flood duration did not change at all with HD scenario and very little even with MSD scenario, except for one year in the time series (1996). In addition, the data showed that with MSD scenario all but one year actually had an increase in flood duration, whereas one had 2 weeks shorter duration, hence no clear trend was seen. It also appears that development scenarios mainly cause flood beginning to change, but not flood duration. This is partly due to the definition of flood duration in the model in weeks, which blends in the minor changes in duration occurring often in days. The phenomenon is well illustrated by figure 10 below.

Table 35: Flood duration results from WUP_FIN model

Year	Date	1996	1997	1998	1999	2000
WUP_FIN Baseline	Length (d)	67	48	45	80	67
	Weeks	9.6	6.9	6.4	11.4	9.6
	Flow reversal	07-Oct	18-Sep	29-Sep	03-Oct	23-Sep
High Development	Length (d)	68	48	45	81	68
	Weeks	9.7	6.9	6.4	11.6	9.7
	Flow reversal	08-Oct	18-Sep	29-Sep	04-Oct	24-Sep
Main stream Dams Development	Length (d)	52	50	48	83	73
	Weeks	7.4	7.1	6.9	11.9	10.4
	Flow reversal	05-Oct	19-Sep	01-Oct	05-Oct	25-Sep
WUP_JICA baseline	Length (d)	69	51	49	81	69
	Weeks	9.9	7.3	7.0	11.6	9.9
	Flow reversal	09-Oct	21-Sep	03-Oct	04-Oct	22-Sep

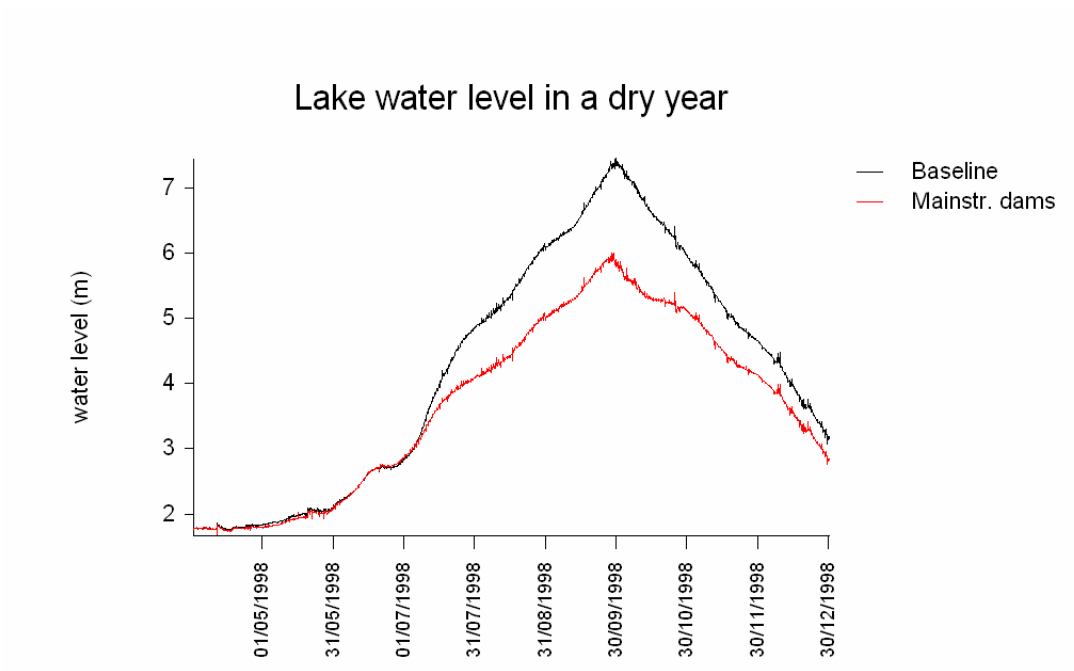

Figure 10: Simulated Tonle Sap Lake water levels for the WUP_FIN baseline and Mainstream Dams scenario (Koponen *et al.* 2007).

8.3.2 Results of scenarios

When comparing WUP_FIN (baseline) and High Development scenario it can be seen that there is tendency for lower flood levels at the Lake, as well as some shortening of the floods. However, the difference in stock is minute. On the other hand, MSD scenario shows alarming rate of lowering of flood levels and increasing of shorter floods, also reflected in fish stocks. Resident fish stocks seem to be more sensitive to mainstream dam development with 8.6% reduction in stock probability units in model (4.3 units), while similar reduction is 6% for Mekong migrants. Tonle Sap migrants stock are reduced by 7.1% in the model. Scenario comparison can be seen in table below:

Table 36: Scenario comparison

	Flood for fishes		Tonle Sap water level			Flood duration			Abundant STOCK for fishes		
	Good	Bad	Above 10	8-10	Below 8	>11	7-10	<7	TS residents	TS migrants	Mekong migrants
WUP_JICA	63.2	36.8	25.4	49.8	24.8	25.7	67	7.3	38.2	-	51.7
WUP_FIN	60.6	39.4	29.6	47.8	22.6	26.2	66.1	7.7	48.5	49.8	43.9
difference	-2.6		4.2	-2	-2.2	0.5	-0.9	0.4	10.3	-	-7.8
%	-4.1		16.5	-4.0	-8.9	1.9	-1.3	5.5	27.0	-	-15.1
High dev	58.8	41.2	24.2	50.2	25.6	25.7	66.5	7.8	47.9	49.3	43.5
difference	1.8		5.4	-2.4	-3	0.5	-0.4	-0.1	0.6	0.5	0.4
%	-3.0		-18.2	5.0	13.3	-1.9	0.6	1.3	-1.2	-1.0	-0.9
Dam dev	49.3	50.7	19.3	51.9	28.8	20.7	65.4	13.9	44.3	46.2	41.3
difference	11.3		10.3	-4.1	-6.2	5.5	0.7	-6.2	4.2	3.6	2.6
%	-18.6		-34.8	8.6	27.4	-21.0	-1.1	80.5	-8.7	-7.2	-5.9

9 CONCLUSIONS

The Bayesian approach is a good modelling option for situations where the structure of the system is not well known or data are nonexistent. Including years of expert knowledge, often untapped in scientific studies and model building, can substantially improve and develop a model to represent the modelled system more accurately and reliably. Moreover, a Bayesian model can be used as a teaching and training tool for decision makers, civil servants and other stakeholders to improve their understanding of the linkages and trade-offs of a given system. However, the model output is in probabilities which can only be used indicatively for management decisions and scientific predictions.

BayFish – Tonle Sap model has proven in scenario analysis the accuracy obtainable with the combination of data integration and extensive stakeholders consultations into a Bayesian Belief Network. Even though the model is simplified it can be used as an efficient management and planning tool for the Tonle Sap fisheries and environment.

The next steps of the model development are:

1) training of decision makers in using and modifying the model;
2) fine tuning the model according to feedback from decision makers and stakeholders;
3) studying the importance and linkages of overland flow to fish and larvae migration (replenishment of fish stocks);
4) dissemination of model results as well as the model itself to wider audience.

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ANNEX: Abbreviations used in the Netica model framework and corresponding model section for each of the variables

Abbreviation	Corresponding variable	Model section
BFMigrations	MIGRATIONS of residents	Fish migrations
BS	Built Structures	Fish migrations
GFMigrations	MIGRATION of TS migrants	Fish migrations
Refuges	Floodplain refuges	Fish migrations
WFMigrations	MIGRATION of Mekong migrants	Fish migrations
BFCatch	CATCH of residents	Fish production
BFStock	STOCK of residents	Fish production
GFCatch	CATCH of TS migrants	Fish production
GFStock	STOCK of TS migrants	Fish production
TotalCatch	TOTAL FISH CATCH	Fish production
WFCatch	CATCH of Mekong migrants	Fish production
WFStock	STOCK of Mekong migrants	Fish production
BFPressure	PRESSURE on residents	Fishing
GFPressure	PRESSURE on TS migrants	Fishing
LSPressure	Pressure from LS fishery	Fishing
MSFishers	# MS fishers	Fishing
MSGear	MS gear efficiency	Fishing
MSKhmer	# Khmer MS fishers	Fishing
MSMigrant	# migrant MS fishers	Fishing
MSPressure	Pressure from MS fishery	Fishing
MSVietCham	# Viet./Cham MS fishers	Fishing
SSActivity	Activity of SS fishers	Fishing
SSFishers	# SS fishers	Fishing
SSGear	Gear size of SS fishers	Fishing
SSKhmer	# Khmer SS fishers	Fishing
SSPressure	Pressure from SS fishery	Fishing
SSVietCham	# Viet./Cham SS fishers	Fishing
WFPressure	PRESSURE on Mekong migrants	Fishing
BF_DO	O2 for residents	Habitat
BFHabitat	HABITAT for residents	Habitat
DO_Floodplain	Floodplain O2	Habitat
FVegetation	Flooded vegetation	Habitat
GF_DO	O2 for TS migrants	Habitat
GFHabitat	HABITAT for TS migrants	Habitat
WF_DO	O2 for Mekong migrants	Habitat
WFHabitat	HABITAT for Mekong migrants	Habitat
FBeginning	Flood beginning	Hydrology
FDuration	Flood duration	Hydrology
FFish	Flood for fishes	Hydrology
FLevel	Flood level	Hydrology
MInflow	Mekong inflow	Hydrology
OverlandFlow	Overland flow	Hydrology
Scenarios	Hydrological scenarios	Hydrology
TSRainfall	TS rainfall	Hydrology
TSRunoff	TS runoff	Hydrology
TSWLevel	TS water level	Hydrology