Mekong River Commission
Basin Development Plan Programme, Phase 2

Assessment of basin-wide development scenarios

Technical Note 10

Impacts on the Tonle Sap Ecosystem

(***For discussion***)

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Mekong River Commission
Basin Development Plan Programme, Phase 2

Assessment of Basin-wide Development Scenarios

Supporting Technical Notes

This technical note is one of a series of technical notes prepared by the BDP assessment team to support and guide the assessment process and to facilitate informed discussion amongst stakeholders.

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1. Introduction

1.1. Basin Development Plan

The second phase of MRC's Basin Development Plan Programme (BDP2) is designed to provide an integrated basin perspective through the participatory development of a rolling Integrated Water Resources Management (IWRM) based Basin Development Plan. The plan will comprise the following elements:

- ***Basin-wide Development Scenarios***, which will provide the information that Governments and other stakeholders need to develop a common understanding of the most acceptable balance between resource development and resource protection in the Lower Mekong Basin, taking into account developments in the upper Mekong Basin. The results will guide the formulation of the IWRM-based Basin Development Strategy.

- ***An IWRM-based Basin Development Strategy***, which provides a shared vision and strategy of how the water and related resources in the LMB could be developed in a sustainable manner for economic growth and poverty reduction, and an IWRM planning framework that brings this strategy into the various transboundary and national planning, decision-making and governance processes.

- ***A Project Portfolio*** of significant water resources development projects and supporting non-structural projects that would require either promotion or strengthened governance, as envisioned in the 1995 Mekong Agreement.

The preparation of the Plan will bring all existing, planned and potential water and related resources development projects in a joint basin planning process, through a combination of sub-basin and sector activities, and a basin-wide integrated assessment framework.

1.2. Formulation and assessment of scenarios

The formulated basin-wide development scenarios represent different levels and combinations of sectoral development and consider the many development synergies and trade-offs among the different water-related sectors, such as irrigation and hydropower synergies and hydropower and fisheries tradeoffs. The table below summarizes the scenarios agreed by the countries.

Considered scenarios

No.	Short Title	Full Title	Development Period	Interventions/Projects
Baseline situation				
1	BS	Baseline scenario		Year 2000 infrastructure including existing HEP dams
Definite future situation				
2	2015-UMD	Upper Mekong dam scenario	2000 - 2015	Baseline extended to include the full HEP cascade on the Lancang
3	2015-DF	Definite future scenario	2000 - 2015	2015-UMD plus 25 additional HEP dams in LMB and 2008 irrigation and flood measures

Foreseeable future situation				
4	2030-20Y	LMB 20-year plan scenario	2010 - 2030	2015 DF plus 11 LMB mainstream dams and planned tributary dams, irrigation, and water supply
5	2030-20Y-w/o MD	LMB 20-year plan scenario without mainstream dams	2010 - 2030	As above, excluding 11 LMB mainstream dams
6.1	2030-20Y-w/o LMD	LMB 20-year plan with 6 mainstream dams in Northern Lao PDR	2010 - 2030	As above plus 6 LMB mainstream dams in upper LMB
6.2	2030-20Y-w/o TMD	LMB 20-year plan with 9 mainstream dams	2010 - 2030	2030-20Y, excluding the two Thai mainstream dams
6.3	2030-20Y-w/o CMD	LMB 20-year plan with 9 mainstream dams	2010-2030	2030-20Y, excluding the two Cambodian mainstream dams
7	2030 – 20Y Flood	Mekong delta flood management scenario	2010 - 2030	Baseline plus 3 options for flood control in Cambodia and Vietnam Delta
Long term future situation				
8	2060-LTD	LMB long-term development scenario	2030-2060	2030-20Y plus all feasible infrastructure developments in LMB
9	2060–VHD	LMB very high development scenario	2030-2060	As above, extended to full potential infrastructure developments

First the development scenarios are assessed on a range of hydrological indicators to evaluate future water availability and use, and the flow changes caused by different levels of water use, taking into account the existing and planned developments in the Upper Mekong Basin. The scenarios for the foreseeable and the long term future will be assessed with and without consideration of climate change impacts. The results are then fed into the 'assessment of the transboundary economic, social and environmental impacts and IWRM requirements'.

In these assessments, the development scenarios are evaluated against 13 main indicators that can measure how well each scenario achieves the countries' objectives of economic development, social development and environmental protection. As well, a basin wide 'equity' indicator is included that measures the degree of 'equitable development' between each country that each scenario produces, taking into account benefits from existing water use and further planned investments in each country.

After basin-wide consultations on the assessment results, the countries will determine which development scenario would provide the most acceptable balance between economic, environmental, and social outcomes in the LMB, and would bring mutual benefits to the LMB countries. It is noted that in choosing a development scenario, the LMB countries are not committing to a particular set of projects (which are in any case subject to feasibility studies, EIAs etc.), but are identifying a development space within which they can plan and work. Conflicts and trade-offs may occur, but within the agreed vision and outcome of the IWRM-based Basin Development Strategy.

1.3. Purpose and Scope of this Annex

In this Annex results of the assessment of the impacts of the hydrological changes brought about by the various basin development scenarios on the Tonle Sap ecosystem and the associated species diversity are presented.

Chapter 2 describes the Assessment methodology, in Chapter 3 the unique role of the Tonle Sap Great Lake ecosystem as a 'fish factory' for the Lower Mekong fisheries and a habitat for an variety of (rare and endangered) species is described. Emphasis is on migratory fish species and the key features of the Mekong River hydrological system and flood characteristics that are important for the maintenance of theses species and their habitats. The information presented in this chapter has been taken directly from a number of key publications on the Tonle Sap ecosystem, fish migration and spawning patterns and inland fish production. The most important publications used are listed in the Reference list.

Expected impacts of the above mentioned scenarios on the state and functioning of the Tonle Sap system are described in Chapter 4. The impacts mainly pertain to changes in flood conditions in the area: that is changes in total flooded area, changes in ecosystem types being flooded, changes in flood depth and duration and changes in the timing of the flooding.

In the impact assessment predicted changes in water quality of the rivers discharging into the lake are also taken into consideration. These changes result from expected changes in agricultural area and agro-chemical use, as well as in expected changes in waste water discharges in the basin under the various development scenarios. Changes in sediment supply to the system, due to sediment trapping by the Chinese dams, the tributary dams and the dams on the mainstream is also briefly discussed.

2. Assessment Methodology

2.1. General Approach

2.1.1 Main drivers of change

The basin development scenarios under consideration consist of a (combination of a) number of elements: further hydropower development by construction of storage reservoirs (a cascade of dams in the Upper Basin in China, dams on the tributaries), construction of run-of the river dams on the mainstream, implementation of flood protection measures in the Cambodian and Vietnamese floodplains, development of irrigated agriculture, and increase in domestic and industrial water use driven by population growth.

These developments (causes of impact) induce a number of changes in the physical and bio-chemical environment of the Tonle Sap area, that ultimately have an impact on the human use of the natural resources.

The hydropower development results in changes in river flow regimes. These changes on their turn result in changes in water levels in the downstream channels and ultimately in changes in flood volumes and flooding patterns in the Tonle Sap area. At the same time, construction of storage reservoirs may result in a sharp decrease in the rivers' sediment load since a large proportion of the inflowing sediment may become trapped in the reservoirs. As a result the sediment inflow into the Tonle Sap Lake may reduce.

Further development of the irrigated agriculture and the increased domestic and industrial water use have an effect on river flows (part of the extracted water will not return to rivers) and on the water quality. Return flows from agriculture may be polluted by pesticides and nutrients, whereas domestic and industrial waste water discharges may result in increased levels of BOD, nutrients and contaminants. This will be the case for both the mainstream as for the local rivers draining into the Tonle Sap Lake.

The main causes of impacts are thus changes in flood volume, changes in flooding pattern and changes in water quality, including changes in suspended sediment concentrations. In two of the scenarios climate change has been taken into account as well.

2.1.2 Indicators for assessment

Environmental impacts that may result from the changes in flood volume and flooding pattern are changes in area and distribution of valuable ecosystems/ habitats. These changes, on their turn have a number of secondary impacts:

- Changes in ecosystem productivity
    - Fish and other aquatic animals
    - Other products
- Changes in environmental services provided
    - Water supply in the dry season
    - Flow regulation
    - Water purification capacity
    - Cultural/religious values
    - Aesthetic/tourism/recreational values
- Changes in ecosystems/habitat existence and biodiversity, flora and fauna

Changes in water quality may have an impact on:

- The availability of good quality drinking water;
- Agricultural production in flooded areas (fertilizing effect of sediment);
- Wetland productivity (fertilizing effect of sediment);
- Fish production (nutrient status of flood water); and
- Biodiversity.

The environmental assessment concentrated on the environmental development objectives and the key environmental indicators as agreed upon in the development scenario assessment process that are relevant in the Tonle Sap area: maintenance of wetland productivity and ecosystem services and conservation of biodiversity. Another environmental objective of the BDP, maintenance of water quality is discussed in a separate Annex, Annex E, Impacts on Water Quality.

2.2. Quantification of impacts

The impacts of the basin development scenarios on the Tonle Sap system have been assessed as much as possible quantitatively. Area and distribution of valuable wetland ecosystems, and so ecosystem productivity and biodiversity, directly depend on the extent, depth and duration of the annual flooding. and have been assessed by overlaying GIS maps of the important ecosystems/habitats with maps displaying the changes in flooding conditions (extent, depth and duration). Not only average conditions were taken into consideration but also changes during a hydrologically wet and a hydrologically dry year. This resulted in maps displaying the change in total area of each of the ecosystems/habitats and an indication of areas in which flood conditions (depth, duration) change. The impacts of these calculated changes in wetland area, as well as in depth and duration of the flooding, on ecosystems and biodiversity have mainly been assessed by expert judgment, applying simple impact functions that describe the relationship between an external condition (e.g. flood duration) and an internal ecosystem condition (e.g. production).

Assessment of the impacts on biodiversity concentrated on the flagship species and a number of rare and endangered species that are known to be dependent on a certain ecosystem/habitat. Losses of these specific ecosystems can be directly translated to losses of these specific species.

Important data sources were the MRC Wetland map, level 5 (MRC, Environmental programme, 2005), the flood model results produced by MRC IKMP (Information and Knowledge Management Programme) and processed by de BDP hydrologist and GIS persons. The area mapped was the area that flooded during the largest historically known flood, the flood in the year 2000.

Information of ecosystems, habitats, rare and endangered species etc. was taken from a variety of sources, amongst other a number of publications of the MRC Environment programme, the WorldFish Center in Phnom Penh, BirdLife International Indochina, the World Wide Fund for nature (WWF), the International Union for the Conservation of nature (IUCN) and various government and non-government organizations in the LMB countries.

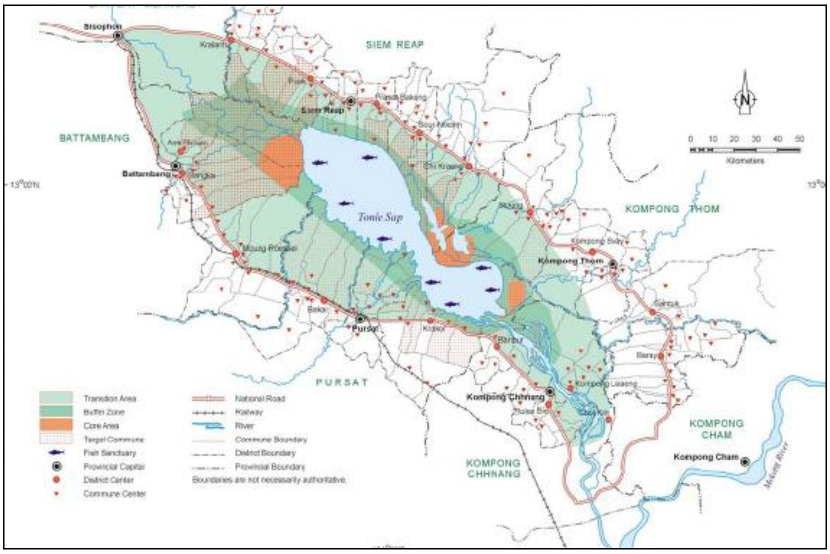
3. The Tonle Sap Great Lake ecosystem and it's importance for ecology and Lower Mekong fisheries

3.1. Introduction

The Tonle Sap Great Lake is one of the largest freshwater lakes in Southeast Asia. It appears that the lake originated about 5,000 years ago. The unique hydrological regime of Tonle Sap Lake is characterized by an annual inflow of Mekong waters into the lake basin during the wet season, when the water levels in the Mekong rise. At the end of the wet season, the flow reverses and the lake empties again. This hydrological cycle supports and maintains high biodiversity and productivity, particularly fish, plant communities, and wildlife, which are the resource base for the national economy of Cambodia. Nearly half of the Cambodian population depends on the Lake's resources, about one million of which is fish dependent community. Tonle Sap Lake furthermore plays a vital role in Khmer cultural identity, which is reflected in the traditions, livelihood, festivals, and taste. It is believed that the Khmer Angkor civilization and many temples could not prosper without the rich natural resources of Tonle Sap Lake as sources of wealth. Evidence of cultural influence of Tonle Sap Lake can be found in the bas-reliefs of the Bayon temple. Figure 1 shows the general lay-out of the area (After ADB, 2005).

Recognizing the ecological, economical, and socio-cultural value of the Lake, the Royal Government of Cambodia decided to designate the whole Tonle Sap Lake and adjacent floodplain, flooded forests and rivers as Biosphere Reserve under the Man and Biosphere Program of UNESCO in October 1997. Parts of its wetlands are included in the Angkor World Heritage Site under the World Heritage Convention (http://whc.unesco.org); in a Ramsar Site 'Boeng Chhmar and Associated River System and Floodplain' under the Ramsar Convention (http://ramsar.org); and in the Protected Area System as GMS Hotspot Area or Important Bird Area (IBA) (Chhnuk Tru, Stung/Chi Kreng/Kampong Svay, Veal Srongae).

Figure 1: General lay out of the Tonle Sap Great Lake (After ADB, 2005)



3.2. Physical resources

3.2.1 Climate

Cambodia's climate is dominated by the tropical wet and dry monsoons. The southwest monsoon brings the rainy season from mid-May to mid-September or early October, while the northeast monsoon's flow of drier and cooler air lasts from early November to March. Temperatures are fairly uniform at around 25°C throughout the Tonle Sap Basin area. Average annual rainfall is between 1,300 and 1,900 millimeters, with the largest amounts in the southeast.

3.2.2 Topography and soil

The Tonle Sap Lake is surrounded by a rather flat floodplain. The soils are mainly developed in unconsolidated alluvial deposits, comprising clay, silt, sand, and gravel.

3.2.3 Groundwater

Groundwater depth in the area varies considerably. The water table changes with rainfall, specific local geomorphologic conditions, and the distance to the permanent water of the Tonle Sap Lake. Manganese is reported to be found in the groundwater in concentrations that might cause some consumer inconvenience (e.g., staining of laundry and sanitary ware, taste), though it is not believed to have any negative health effects. Although arsenic concentrations are found in the groundwater throughout Cambodia, they commonly do not pose a problem.

3.2.4 Surface water

The Tonle Sap Lake is connected to the Mekong River through the 100 km long Tonle Sap River. Fifty seven percent of the water in the Tonle Sap Lake comes from the Mekong River. During an average wet season, about 52 percent comes in directly through the Tonle Sap River, and 5 percent flows overland through the floodplain from the Mekong. Another 30 percent comes from rivers that flow directly into the lake and about 13 percent comes from rainfall over the lake itself.

The annual 'flood pulse', the cyclical changes between high and low water levels, is crucial in maintaining this highly productive system that has adapted to the exceptionally high natural variability of the lake level. Between the dry and the wet season the volume of the lake ranges from about 1.3 km^3 up to 75 km^3, its surface area varies from 2,500 km^2 up to about 15,000 km^2, and its water level increases from 1.4 m to 10.3 m above sea level.

The quality of surface water shows extreme variations. In the dry season, pollution by human and household waste can be high near densely populated areas.

3.3. Ecological resources

3.3.1 Fisheries and aquatic biology

The flooding of the extensive plain covered with forest and other types of vegetation enables the transfer of terrestrial primary products into the aquatic phase and entry into lake-wide food webs. Sedimentation occurs almost exclusively in the floodplain. The floodplain vegetation plays a crucial role in ecosystem productivity by providing habitats, substrate area, and food for aquatic organisms. Many fish species have commercial value, and more than 100 species are caught regularly. However, about a dozen make up the bulk of the catches, by weight and value. A wide variety of active (seining, lifting, casting) and passive (traps, hooks and line, gillnets) fishing gear and methods are used. Fish behavior (migration, habitat preference, reaction to water quality changes, feeding strategies) is exploited in the fishery. The use of destructive gear and practices (poisoning, electrocution, brush parks, damming, and pumping of channels) are widespread. The importance of the area for fisheries in the entire Lower Mekong Basin is discussed in more detail in Section 6.

Other aquatic animals with direct livelihood significance include water snakes, mollusks, and invertebrates such as shrimp. Water snakes are common in the Tonle Sap ecosystem, and five species commonly are caught and traded. Around the lake, commercial rearing of captive crocodiles is practiced. Indicators suggest that the current use of the Tonle Sap's natural resources has exceeded optimum ecosystem productivity.

3.3.2 Timber and non-timber forest products

The natural floodplain vegetation is used for the collection of a variety of wood and non-wood forest products. Wood is collected for domestic use, including for (i) fuel wood or charcoal, (ii) construction material, (iii) use in brick kilns, (iv) fish processing (smoking and drying), and (v) the construction of fishing gear. The dominant species include *Barringtonia acutangula*, *Diospyros cambodiana*, *Terminalia cambodiana*, *Gmelina asiatica*, *Ficus heterophylla*, and *Vitex holoadenon*. Non-wood forest products include a wide range of plants used as food, and for medicinal purposes for humans and animals. Lianas (in particular *Combretum trifoliatum*, *Breynia rhamnoides*, *Tetracera sarmentosa*, and *Acacia thailandica*) are collected for furniture and fishing gear production. Other plant products include fruits, seeds, resins, tubers, bark, and mushrooms. Some forest animals and their products are collected, including bee wax and honey. Some larger animals are used as pets (macaques, iguanas, birds), traded, or consumed as food. Birds are hunted for food, pets, and trade. Eggs are collected for consumption. Aquatic plants are collected for human consumption, as feed for farm animals, or for further cultivation (e.g., lotus).

3.3.3 Biodiversity

The Tonle Sap ecosystems are exceptionally important for global biodiversity at the genetic, species, habitat, and ecosystem process levels.

At the ecosystem level, Tonle Sap Lake and its floodplain contain the largest continuous natural wetland areas/habitats remaining in the Mekong River system and have very high ecosystem diversity. Tonle Sap ecosystem comprises at least 8 major sub-ecosystems: the permanent water body or the Great Lake itself, rivers and streams, seasonally inundated forests, seasonally inundated shrublands, seasonally inundated grasslands, receding and floating ricefields, seasonally flooded crop fields, and marshes and swamps.

With the very high ecosystem diversity, the Tonle Sap ecosystem has an exceptionally high species biodiversity, is one of the most productive inland waters, and is one of the most fish-abundant lakes in the world. It has >197 species of phytoplankton, >46 species of zooplankton, >57 species of zoobenthos, >215 fish species, >225 bird species (>104 waterbird species), >46 mammal species, >42 reptile species, >370 plant species in the flooded forests and floodplains. Among these are at least 44 species having globally threatened status, i.e. 7 Critically Endangered (2 bird, 2 fish, 1 mammal, and 2 reptile species), 12 Globally Endangered (2 bird, 4 fish, 4 mammal, and 2 reptile species), 17 Globally Vulnerable (9 bird, 2 mammal, 5 reptile, and 1 plant species), and 8 Globally Near-threatened (6 bird, 1 mammal, and 1 reptile species). At least 6 important species are endemics to the Mekong River region (5 endemic fish and 1 endemic reptile species).

With the global loss of wetlands, the Tonle Sap Lake and its relatively intact ecosystem processes are exceptionally important for global biodiversity. The species richness of the Tonle Sap ecosystem is only partly known. In a recent inventory, 885 species of floodplain plants and animals were found in the Tonle Sap. However, this does not include, for instance, the 197 species of phytoplankton that have been identified separately. Over 170 species of plants have been identified from the shores around Lake Tonle Sap. Many species are deciduous, shedding leaves with the rising water. Over 140 species of fish have been recorded in the Lake. The lake's productivity is very high and makes a substantial contribution to the annual fish production in Cambodia.

(a) Open water bodies, including Tonle Sap Lake

Open water bodies, including the Tonle Sap Lake support at least 70 bird species (Davidson, 2006). Among these are 1 Globally Endangered Greater Adjutant *Leptoptilos dubius;* 3 Globally Vulnerable Spot-billed Pelican *Pelecanus philippensis*, Milky Stork *Mycteria cinerea*, Lesser Adjutant *Leptoptilos javanicus;* and 4 Globally Near-threatened Grey-headed Fish Eagle *Ichthyophaga ichthyaetus*, Oriental Darter *Anhinga melanogaster*, Painted Stork *Mycteria leucocephala* and Asian Golden Weaver *Ploceus hypoxanthus.* The open lake area of Tonle Sap is an important feeding area of Brown-headed Gulls

Larus brunnicephalus (2% of the global population) and Whiskered Tern *Chlidonias hybridus* (the highest known concentrations in Southeast Asia). Tonle Sap Lake is not only one of the most fish-abundant lakes of the world, it is also of global fish biodiversity conservation value as habitat for at least 2 Critically Endangered Mekong Giant Catfish *Pangasianodon gigas* (an Endemic species, using the flooded forests as nursery ground and the Tonle Sap River as a migratory corridor for mature fish moving to the Mekong River) and Giant Pangasius *Pangasius sanitwongsei* (an Endemic species); 4 Globally Endangered Mekong Freshwater Stingray *Dasyatis laosensis*, Jullien's Golden Carp or Seven-line Barb *Probarbus jullieni* (using Tonle Sap Lake, Tonle Sap River, and its flooded forests as spawning habitats), Laotian Shad *Tenualosa thibaudeaui* (using Tonle Sap Lake and Tonle Sap River as spawning habitats), and Tricolor Sharkminnow *Balantiocheilos melanopterus.* Many other additional fish species of conservation concern include at least 4 Endemic species: Eye-spot Barb *Hampala dispar*, Thicklip Barb *Probarbus labeamajor*, and Giant Barb *Catlocarpio siamensis* (one of the world's largest cyprinid fish).

(b) Inundated forests and shrublands

Seasonally inundated forests and shrublands surrounding the Tonle Sap Lake are unique in both structure and floristic composition. Over 200 species of plants have been found in the inundated forests. Most of the forests are distributed at the upper limit of open water around the lake, along river channels and major tributaries. Trees are usually 7 – 15 (or up to 20) m tall and are inundated by a maximum of 4 – 6 m of water, up to 8 months/year. Seasonally inundated shrublands, consisting of medium-sized trees not taller than 2 – 4 m with a closed canopy, are encountered in the areas between flooded forests and inundated grasslands. Most plants are 'flood-deciduous', their leaves fall under water when the flood submerges the branches. New leaves form when receding waters expose the trees and shrubs to the air again around November-December. Flowering and fruit production takes place during the late dry and early wet season. Fish play an important role in seed dispersal.

The forests and shrublands contain a number of Endemic plant species, e.g. *Samandura harmandii, Terminalia cambodiana, Coccoceras anisopodum, Diospyros bejaudii, Diospyros cambodiana, Garcinia loureiri, Acacia thailandica,* and *Hydnocarpus saigonensis*. Major communities include *Barringtonia acutangula*, *Elaeocarpus madopetalus* and *Diospyros cambodiana*; floating and emergent herbs including *Brachiaria mutica, Eichornia crassipes, Polygonium barbatum, P. tomentosum* and *Sesbania javanica*. Noteworthy are also a number of grass and sedge species i.e. Wild Rice *Oryza rufigpogon* which is very important in terms of gene pool and genetic biodiversity conservation and the Globally Vulnerable *Cynometra inaequifolia*, which is a species of legumes in the Fabaceae family

Over 200 species of fish use this habitat as a feeding, breeding, and nursery ground. The woody species of this forest are often laden with fruits and seeds at the time of inundation, providing food for the 34 species of fruit-eating fish of the Lower Mekong Basin.

Lake Tonle Sap's inundated forest is also one of the most important breeding sites for large waterbirds in Asia: the system supports at least 85 bird species (Davidson, 2006). These species are believed to migrate to other wetlands in the Lower Mekong Basin during periods of high water level on Lake Tonle Sap. Flooded forest and flooded shrubland habitats support at least 12 globally threatened bird species: 1 Critically Endangered White-shouldered Ibis *Pseudibis davisoni;* 1 Globally Endangered Greater Adjutant *Leptoptilos dubius;* 5 Globally Vulnerable Eastern Sarus Crane *Grus antogone sharpii*, Spot-billed Pelican *Pelecanus philippensis*, Milky Stork *Mycteria cinerea*, Lesser Adjutant *Leptoptilos javanicus*, and Manchurian Reed-warbler *Acrocephalus tangorum*; 5 Globally Near-threatened Grey-headed Fish Eagle *Ichthyophaga ichthyaetus*, Oriental Darter *Anhinga melanogaster*, Black-headed Ibis *Threskiornis melanocephalus*, Painted Stork *Mycteria leucocephala*, and Black-necked Stork *Ephippiorhynchus asiaticus.*

They also support at least 12 mammal species (Davidson, 2006), 8 of which are globally threatened: 1 Critically Endangered Irrawaddy Dolphin *Orcaella brevirostris;* 4 Globally Endangered Hairy-nosed Otter *Lutra sumatrana* (the area holds globally significant populations of this species and is the single most important priority area for otter surveys in Cambodia), Fishing Cat *Prionailurus viverrinus*, and just outside the flooded zone Eld's Deer *Rucervus eldii* and Hog Deer *Axis porcinus*; 2 Globally Vulnerable Smooth-coated Otter *Lutrogale perspicilata* and Greater Slow Loris *Nycticebus cougang*; and 1 Globally Near-threatened Silvered Leaf Monkey *Trachyoithecus cristatus* which is less well adapted to swimming long distances than Long-tailed Macaque.

Other mammal species of interest reported in flooded forests of the Tonle Sap system include the Long-tailed Macaque *Macaca fascicularis*, the Common Palm Civet *Paradoxurus hermaphroditus*, Flying Foxes *Pteropus sp.* and other bats, Loris *Nycticebus spp.*, Giant Flying Squirrel *Petaurista sp.* and many other squirrels, Leopard Cat *Prionailurus bengalensis*, Small Asian Mongoose *Herpestes javanicus*, and many rodents. There is a strong relationship between the presence of seasonally flooded shrubs and rice crop damage due to rodents (loss of flooded forests → decreased rice crop damage; short-tree shrublands are key shelter and nesting habitat of rodents especially during flooding period).

Seasonally flooded forests and shrublands of the Tonle Sap system or more specifically Tonle Sap Biosphere Reserve (TSBR) are the single most important wetland for reptile conservation in Southeast Asia. TSBR supports at least 10 globally threatened reptile species : 2 Critically Endangered Siamese Crocodile *Crocodylus siamensis* and River Terrapin *Batagur baska;* 2 Globally Endangered Yellow-headed Temple Turtle *Hieremys annandalii* (one of the large Asian swamp turtles, lives in slow-moving muddy rivers, feeds on aquatic plants and fruits falling down from trees) and Asian Giant Softshell Turtle *Pelochylys cantorii* (the Tonle Sap system supports a regionally important population and perhaps the most important in Southeast Asia)*;* 5 Globally Vulnerable Asian Box Turtle *Cuora amboinensis*, Black Marsh Turtle *Siebenrockiella crassicollis* (in floodplain ponds), Giant Asian Pond Turtle *Heosemys grandis* (in muddy substrates in ponds that dry out during the dry season), Malayan Snail-eating Turtle *Malayemys subtrijuga* (ricefield turtle – the most numerous turtle around Tonle Sap Lake, favored for its meat and used in traditional medicine), and Asiatic Softshell Turtle *Amyda cartilaginea*; and 1 Globally Near-threatened Burmese Python *Python molurus* (one of the biggest snakes of the world, lives in flooded forests, nests on the ground within dense shrubs during the dry season, is an excellent swimmer and can stay submerged for up to 30 minutes. The skin, meat and blood are traded on the domestic and international market.

Most turtle species breed in the dry season when human disturbances and the risk of fire are highest. Some species lay eggs in submerged substrates within ponds that later dry-out. Seasonally flooded forests and shrublands with numerous pools are the most important habitats for turtles especially during the dry season, particularly in areas with high numbers of fruiting trees. Change in flood levels in the dry season will thus impact these species.

At least 105 wild crocodiles were recorded in Tonle Sap between 1998-2002, now the total wild population may not exceed a few pairs. The existing large, unregulated crocodile farming industry and strong incentives for the harvesting the last remaining wild individuals are primary threats to wild crocodiles in the TSBR. Suitable but unoccupied crocodile habitat remains in the TSBR.

The forests and shrublands also support the Rainbow Watersnake *Enhydris enhydris* (most abundant species caught) and Tonle Sap Watersnake *Enhydris longicauda* (second abundant species caught), Cambodia's only known Endemic reptile (endemic to Tonle Sap Lake and River) which lives in flooded forests and is closely associated to shallow water edge habitats. It feeds on small fish, frogs and crustaceans, and plays an important role in the lake's ecosystem as food source for nesting colonies of large waterbirds, for crocodiles, and for human consumption. Another species of interest is the King Cobra.

(c) Seasonally inundated grasslands

Seasonally inundated grasslands are common on the floodplains of the Tonle Sap. Close to the water edge, floating or emergent vegetation forms dense mats or stands up to 3 meters tall. As water levels rise, dense mats may dislodge and float, propelled by currents or the wind. The main species include *Achyranthes aquatica, Brachiaria mutica, Eichornia crassipes, Polygonium barbatum* and *Sesbania javanica*. Other plant species found on the upper reaches of the inundated plain include several grasses, including *Echinochloa stagina*, sedges including *Cyperus pilosis, Rhynchospora* sp., and dicotyledons such as *Aeschynomene indica, Impatiens sp., Ludwigia hyssopifolia* and *Nelumbo nucifera* (lotus).

The seasonally inundated grasslands, together with herbaceous wetlands including sedge beds and agro-ecosystems of the Tonle Sap system support at least 135 bird species (Davidson, 2006, Campbell et al., 2006) of which at least 17 are globally threatened: 2 Critically Endangered Bengal Florican *Houbaropsis bengalensis* and White-shouldered Ibis *Pseudibis davisoni*; 1 Globally Endangered

Greater Adjutant *Leptoptilos dubius*; 9 Globally Vulnerable Eastern Sarus Crane *Grus antigone sharpii*, Eastern Imperial Eagle *Aquila heliaca*, Manchurian Reed Warbler *Acrocephalus tangorum*, Greater Spotted Eagle *Aquila clanga*, Lesser Adjutant *Leptoptilos javanicus*, Milky Stork *Mycteria cinerea*, Spot-billed Pelican *Pelecanus philippensis*, Masked Finfoot *Heliopais personata*, and Yellow-breasted Bunting *Emberiza aureola*; and 5 Globally Near-threatened Painted Stork *Mycteria leucocephala*, Asian Golden Weaver *Ploceus hypoxanthus*, Black-necked Stork *Ephippiorhynchus asiaticus*, Oriental Darter *Anhinga melanogaster*, and Black-headed Ibis *Threskiornis melanocephalus*. A mammal species of interest depending on the Tonle Sap flooded grasslands is the Asiatic Jackal *Canis aureus.*

(d) Marshes, small pools and seasonal wetlands

The marshes small pools and seasonal wetlands in the area are vital in maintaining breeding stocks of floodplain fish, including air-breathing species (e.g. gouramies, walking catfish), while in the wet season they function as breeding and nursery grounds for many fish species, the black fish. These wetlands are important for almost all water birds in the Lower Mekong Basin, particularly cormorants, Oriental Darter, Spot-billed Pelican, Greater and Lesser Adjutants, Milky Stork, Woolly-necked Stork *Ciconia episcopus,* Black-necked Stork *Ephippiorhynchus asiaticus*, Painted Stork, the Globally Endangered White-shouldered Ibis *Plegadis davisoni*, Glossy Ibis *P. falcinellus*, Black-headed Ibis *Threskiornis melanocephalus*, White-winged Duck, Pallas's Fish Eagle *Haliaeetus leucoryphus,* Grey-headed Fish Eagle, the Globally Vulnerable Masked Finfoot *Heliopais personata*, and the Globally Near-threatened Sarus Crane *Grus antigone*.

(e) Overall conservation status

The 2004 International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species mentions 197 species in Cambodia considered at risk of extinction, endangered, critically endangered, or vulnerable. Many of these are found in the Tonle Sap ecosystem. Of the 197 species mentioned by IUCN, 24 are critically endangered, 39 are endangered, and 53 are vulnerable. In the Tonle Sap ecosystem, 5 critically endangered species (2 fish species, 2 bird species, and the Siamese crocodile) are potentially still present. However, none of these species is endemic to Tonle Sap. As a consequence of 3 decades of unrest, access to the project area has been at times difficult, and a biodiversity inventory of the Tonle Sap ecosystem is far from complete.

In Cambodia, 22 species are classified as data deficient. This could mean that some of these species are threatened, though data are insufficient to assess their condition in full. Several fish species, particularly among those that grow large, are endangered. In its 2004 Red List, IUCN classified the giant Mekong catfish (*Pangasianodon gigas*) as critically endangered. The heavy exploitation of crocodile and the endemic Tonle Sap Watersnake (*Enhydris longicauda*) also is of particular conservation concern. The Siamese crocodile (*Crocodylus siamensis*) is critically endangered in the wild, though it is widely bred and kept in captivity. *Orcaella brevirostris*, the freshwater Irriwaddy dolphin that is found in the Mekong, is occasionally also seen in the Tonle Sap Lake. The biodiversity in the Tonle Sap is best known for birds. Of the 104 water bird species that have been recorded in the Tonle Sap, 89 are abundant, while 14 are considered internationally significant. The two core areas of the Tonle Sap Bird Reserve, Prek Toal and Lake Chhmar, have the most endangered species. Prek Toal is the most important breeding area.

3.3.4 Land and Crops

The continuous expansion of agricultural land into the floodplain to address the rising population and low productivity of paddy fields has come at the expense of the natural flooded forest vegetation. The competition between the natural assets of flooded forest and rice and other agriculture crops is increasingly undermining the productivity of the Tonle Sap ecosystem. The foreshore of the Tonle Sap's permanent lake and the river banks provide land, even only seasonally, to the landless poor, who also benefit from being in the vicinity of water for their crops.

3.3.5 Livestock

Livestock is important for the livelihood of many people. Pigs are held widely in floating villages and throughout the floodplain. Cattle provide traction for rice farmers, and flooded forest is burned in places to promote the growth of grass for cattle grazing. Even the poorer households can afford ducks and chicken. Ducks also generate income through their use in pest control in rice fields.

3.4. Economic development

Most of the activities in the Tonle Sap area are based on fisheries or agriculture. Fish processing is widespread, while agriculture focuses on rice production in most places. Infrastructure facilities are largely absent, particularly in the floating or stilted villages. The few access roads are mostly in poor condition. Although ports and landing sites lack basic infrastructure, they contribute effectively to livelihood generation. The lake is used for transportation of people and goods, including petroleum products and fish. Most of the people transported are foreign tourists. Low water levels in the dry season limit the size and traffic of boats.

3.5. Social and cultural resources

More than 1.2 million people in the Tonle Sap area depend on fishing for their livelihood. People typically live in villages, grouped in communes. Many fisher folk are highly mobile, migrating within the floodplain and lake to find fishing opportunities. The Tonle Sap fish and floodplain resources are also part of the livelihood strategies for many people living outside the project area. The distribution and quality of health and education facilities vary. Both are lacking in lake-based communities. The historic temple complex of Angkor Wat, located in the area, is an important tourist attraction. Buildings and features of archaeological and historical significance (e.g., Khmer Empire era temples and shell mounds) are scattered throughout the area.

3.6. Importance of the Tonle Sap wetland system for fisheries

Cambodia has the world's most productive inland fishery. A single hectare of floodplain can produce up to 230 kilograms of fish a year. In terms of value, the overall fishing sector accounts for 10 to 12 percent of gross domestic product (GDP) and contributes more to income, jobs and food security than in any other country. The inland fisheries has an annual catch conservatively estimated at about 400,000 tons. Tonle Sap fisheries account for almost two-thirds of the total catch in Cambodia. In 2006, the Inland Fisheries Research and Development Institute of the Fisheries Administration estimated the value of fisheries and other aquatic resources of the Tonle Sap Lake conservatively at $233 million a year (Baran et al., 2007).

3.6.1 Relationship between fish production/catches and flood characteristics

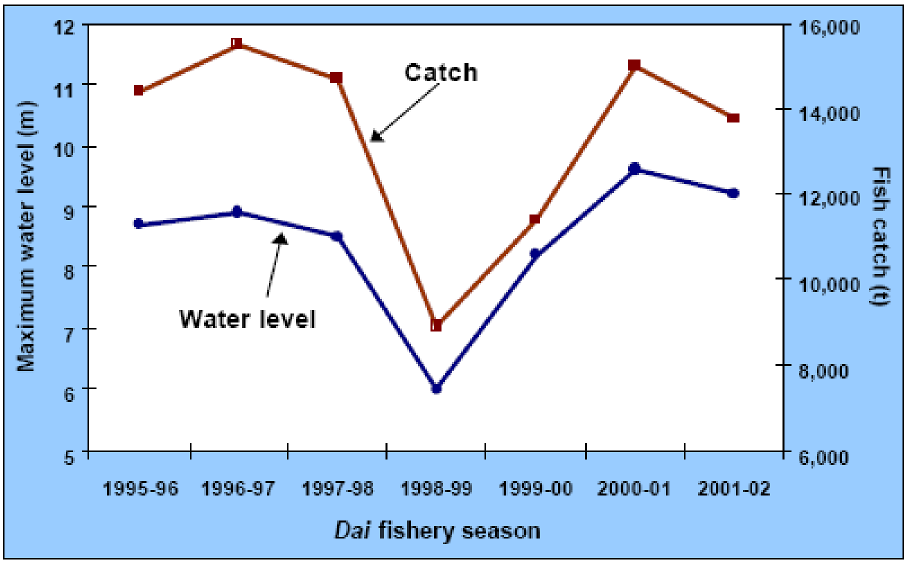
Based on literature on other large river systems elsewhere in the world Baran et al. (E. Baran, N. van Zalinge, Ngor Peng Sun, Floods, floodplains and fish production in the Mekong Basin: present and past trends, MRC miscellaneous publications, not dated) identified a number of factors that determine fish production in the Mekong Basin. They are discussed below:

(f) Water level

The correlation between the *total catch* and the river discharge in the same year has been extensively documented for large river systems around the world. It has also been shown more specifically that catches could be strongly related to the high-water flood regime at the beginning of each season, and that fish grow more quickly when flood levels are higher.

Also for the Lower Mekong it has been shown that higher floods directly result in higher fish production. Although many factors are involved, higher floods produce larger amount of fish and keep a number of important habitats viable. Observations on the bag-net (Dai) fishery for migrating fish in the Tonle Sap River during 1995–2002 indicate that year-to-year variations in maximum Mekong River flood levels and related Tonle Sap floodplain inundation strongly affect the fish yield, see Figure 2.

Figure 2: Relationship between the maximum flood level of the season and the fish catch of the Dai or Bag net fishery in the Tonle Sap River.



High fish yields in years with high floods is explained by a number of factors. Firstly spawning success of fishes is related to available spawning grounds: higher floods inundate larger floodplain areas, so creating larger spawning areas. Secondly, a high flood also means that fishing activities are dispersed more evenly over larger areas giving better possibilities for young fishes to survive. The above stated is not valid for all fish species: the fishing lot catch of snakehead (*Channa micropeltes*) was highest one year after a high flood (Van Zalinge et al. 2003).

Other factors of importance are the sediment concentrations of the floodwater and the dissolved oxygen conditions. Sediments carried by the Mekong waters to the Tonle Sap Lake bring in the essential nutrients that enter into the lake's food webs. The higher the flood the more sediment is brought in. This leads to improved survival and growth of fish and hence to higher fishery yields (see also Section 6.1.6).

(g) Duration of the flood

A longer period of flood provides a longer growth period for fishes, and therefore a higher yield. This strong correlation between the annual fish production and the duration of the flood has been clearly demonstrated for many river systems. However, as the process is linked to organic matter decay and nutrient release, the relationship seems to be asymptotic, a plateau being reached after a certain duration.

(h) Timing of the flood

Most tropical fish species release eggs just before or during the flood, which results in their spreading into floodplains. In the Mekong River, rising waters trigger spawning in adults of many species such as Pangasiids and juveniles drift towards the Tonle Sap system where they grow. Timing of the flood and duration of the flood season during which the juveniles can grow are therefore two parameters that will influence the total production (see also Section 7).

Delays in the onset of the flood will result in delays in the arrival of oxygen-rich waters. Dissolved oxygen levels in Tonle Sap water generally decline during dry season, until the inflow of oxygen-rich water at the beginning of flood season. While fish may swim to more oxygenated waters, eggs and larvae are unable to move and may be adversely affected if the arrival of the flood is delayed. Flow changes also have an impact on the drift of fish larvae and juveniles.

(i) Regularity of flooding

After early rainfalls and river level rise have prompted migration and spawning, small drought periods can cause massive mortality of eggs, fish larvae and fry as well as amphibians. Sticky fish eggs can become suddenly exposed on vegetation, while larvae and juveniles can get killed as the water recedes and small ponds dry up. This factor has scarcely been mentioned in the literature, but sometimes happens in the Tonle Sap region where it can result in massive mortality.

(j) Characteristics of the flooded zone

For fishes, floodplains are favorable as a feeding zone (release of nutrients, primary production and detritus- based food chain), and because they provide shelter to juveniles against predation (shallow water, flooded vegetation). The importance of different flood plain habitats for the ecosystems functioning is partly unknown, but the diversity of food resources and habitats allows multiple strategies, species, sizes, stages and life cycle strategies. Flooded forests are essential in providing shelter and living habitats for large variety of biota, but on the other hand shrub and grass land provides often the largest variety of biodiversity. Grass land is obviously playing a major role in nutrient cycling and supports a high fish production.

(k) Physical/chemical conditions

The quality of flood waters has an impact on the flood plain ecosystem e.g. by bringing sediments and nutrients to the system. Nutrient bearing sediment is important for primary production driving the fish growth. Changes in the sediment load can cause major changes in the fish production.

In the Tonle Sap area, sediments are largely being trapped at the interface between the oxygen-rich waters of the lake and rivers and the oxygen-poor waters of the floodplain, giving rise to a rich riparian vegetation of tall trees. The waters above the floodplain are much clearer than the lake waters, as nearly all sediments have been filtered out.

According to Van Zalinge (2003) this explains why the catch per hectare appears to be stable no matter whether natural habitats or agricultural lands are flooded. The biological productivity is derived from the sediments in the waters of the lake, rivers and especially their border areas and not from the extensive floodplains themselves. The sediments contain the nutrients needed by the phytoplankton. Phytoplankton blooms do not occur in the lake, because of intensive grazing by zooplankton and fish.

Oxygen conditions obviously affect where fish can live and reproduce and how different species have developed strategies for avoiding unfavorable conditions. Floodplains are by and large oxygen poor environments. Because of oxygen transport and dispersion, border areas between the well oxygenated lake proper and tributaries and floodplains have more favorable oxygen conditions than areas deeper in the floodplains. Open areas inside the floodplains such as lakes and fields offer better oxygen environments and safety zones for fish. Flow can transport large masses of anoxic water both in the horizontal and vertical direction and trap or kill fish in these limited areas. One explanation for the observed fish deaths may be the anoxic water inflow.

3.7. Fish migration

3.7.1. Introduction

The importance of migratory behavior among Mekong River fishes has been acknowledged for long, many economically important fish species are known to be highly migratory. Some species undertake longitudinal migrations, while others make only localized and lateral migrations. Longitudinal migratory fish species begin to spawn in the Mekong River at the beginning of the rainy season (May-August). Fish eggs and fry are carried by the current and swept into the floodplain areas around the Tonle Sap Great Lake and the areas south of Phnom Penh. When the flood recedes, most of fish species migrate to deeper waters in the lakes, rivers or tributaries (lateral migration), but many species will undertake longer migrations (longitudinal migrations) to the Mekong River

Based on their migration behavior two groups of fish are distinguished: white fish and black fish. When floodplains drain at the end of the wet season, water remains in lakes and scattered depressions, which continue to shrink in size and number during the dry season. Floodplain water bodies become hot, oxygen is depleted and food and shelter diminish, with many ponds drying-out completely. So the fish, which feed and grow on flooded areas must either return to the river as the waters recede, or remain and endure the poor conditions on the floodplain.

Species which leave flooded areas and return to rivers are referred to as longitudinal migrants or 'white fishes', as they spend most of their lives in turbid (white) river water. Most white-fish species migrate into flooded areas during the monsoon season and migrate over long distances to dry-season refuges at the end of the flood season. Representatives of this group are some of the cyprinids, such as *Cyclocheilichthys enoplos* (Soldier river barb or Chhkok) and *Cirrhinus microlepis* (Small mud carp or Prul/Kralang), as well as the river catfishes of the family Pangasiidae.

The species of fish which remain in lakes and swamps on the floodplain are known as lateral migrants or 'black fishes', as they spend their lives in relatively clear water that is tea-colored by chemicals dissolved from floodplain vegetation. Decomposition of vegetation causes floodplain water to be acidic and depleted in oxygen, stresses which black fishes can tolerate. Most black fishes can breathe air, while many species can survive out of the water for long periods, and most can move overland in search of new water bodies. A few species can bury themselves deep in the mud and wait until the next flood. Many black fishes are used in aquaculture and are transported alive to markets. They are normally referred to as non-migratory, although they perform short seasonal movements between permanent and seasonal water bodies. Examples of black-fish species in the Mekong are the climbing perch (*Anabas testudineus*), the clarias catfishes (e.g. *Clarias batrachus*) and the striped snakehead (*Channa striata*).

An additional group, intermediate between black-fishes and white-fishes is formed by the so-called greyfish. Species of this group undertake only short migrations between floodplains and adjacent rivers and/or between permanent and seasonal water bodies within the floodplain.

3.7.2. Spawning habitats

Spawning habitats are generally believed to be associated with either rapids and deep pools of the Mekong mainstream and tributaries or with floodplains (e.g. among certain types of vegetation, depending on species). River channel habitats are, for example, used as spawning habitats by most of the large species of pangasiid catfishes and some large cyprinids such as *Cyclocheilichthys enoplos*, *Cirrhinus microlepis*, and *Catlocarpio siamensis*. Floodplain habitats are used as spawning habitats mainly by black-fish species.

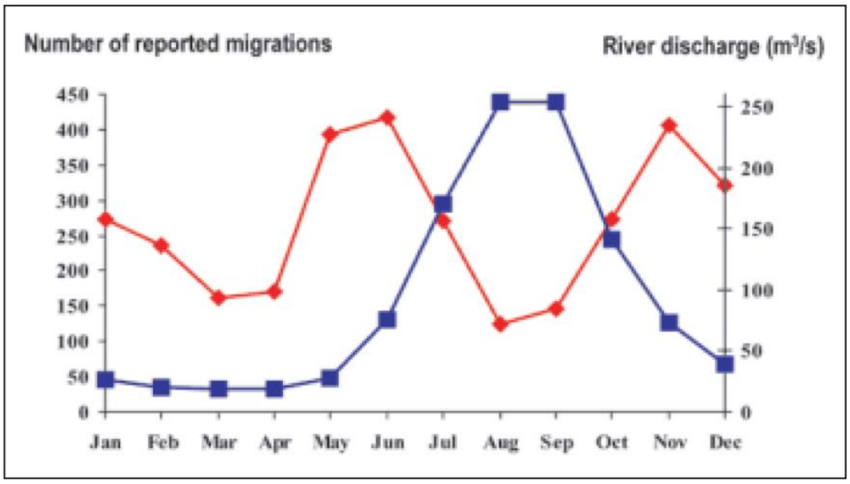
Many species that spawn in river channels in the open-water column rely on particular hydrological conditions to distribute the offspring (eggs and/or larvae) to downstream rearing habitats. Information on spawning habitats for migratory species in the river channels of the Mekong Basin is scarce. Only for very few species, spawning habits are well described. For many species, in particular for deep-water mainstream spawners such as the river catfish species, spawning is virtually impossible to observe directly. Information about spawning has been obtained indirectly from observations of ripe eggs in fishes

For fishes that spawn in main river channels, spawning is believed to occur in stretches where there are many rapids and deep pools, e.g. (1) the Kratie - Khone Falls stretch; (2) the Khone Falls to Khammouan/Nakhon Phanom stretch; and (3) from the mouth of the Loei River to Bokeo/Chiang Khong. The Kratie-Khone Falls stretch and the stretch from the Loei River to Luang Prabang are particularly important for spawning.

3.7.3. Fish migration and hydrology

There is a clear relationship between fish life cycles, fish habitats, and hydrology. Migrating fishes respond to hydrological changes and use hydrological events as triggers for the timing of their migrations. This is illustrated in the figure below, where peak migration periods are correlated with the annual hydrological cycle. Most species migrate at the start of the annual flood and return at the end of the flood, producing the two peaks shown in the figure.

Figure 3: Relationship between migratory activity levels and water discharge in the Lower Mekong Basin. Blue Line: average monthly discharge (m3/sec) of the Mekong River at Pakse, Red Line: number of migrations reported (based on 50 species from 51 sites along the Mekong mainstream) (after Poulsen et al, 2002)



Also, the spawning season is tuned according to river hydrology, and almost all species spawn at the onset of the monsoon season. Only a few species, spawn during the dry season.

3.7.4. Major migration systems in the Mekong

Different species have developed different life strategies to cope with the environmental circumstances, however, generalizations can be made, e.g. on migratory patterns. Three main migration systems associated with the lower Mekong River mainstream have been identified. These three systems are called the Lower Mekong Migration System, the Middle Mekong Migration System, and the Upper Mekong Migration System. Although these different systems are inter-connected and, for many species, overlapping, the Lower Mekong Migration System is the most important system for the Tonle Sap fisheries.

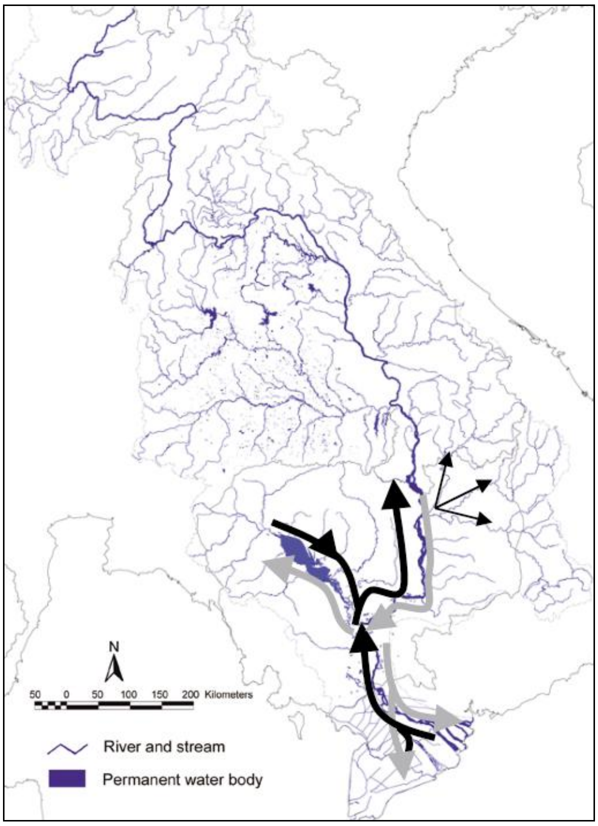
The Lower Mekong Migration System covers the stretch from the Khone Falls downstream to southern Cambodia, including the Tonle Sap system, and the Mekong Delta in Viet Nam. The migration is driven by the spatial and temporal separation of flood-season feeding and rearing habitats in the south with dry-season refuge habitats in the north. The rise in water levels at the beginning of the flood season triggers many migrating fishes to move from the dry season habitats just below the Khone Falls, e.g. in deep pools along the Kratie - Stung Treng stretch, towards the floodplain habitats in southern Cambodia and the Mekong Delta in Viet Nam. Here they spend the flood season feeding in the fertile floodplain habitats. Some species spawn on, or near the floodplain, whereas others spawn far upstream, i.e. above Kratie, and rely on the water current to bring offspring to the floodplain rearing areas. The Tonle Sap Great Lake system is one of the key factors for the integrity of this system.

As a result of increasing water discharge from the Mekong River at the onset of the flood season, the water current of the Tonle Sap River changes its direction, flowing from the Mekong into the Tonle Sap River and towards the Great Lake. This enables fish larvae and juveniles to enter the Tonle Sap from the Mekong by drifting with the flow. Together with the floodplains of the Mekong Delta in south Cambodia and Viet Nam, these floodplains are the main ‘fish factories’ of the lower basin.

An important group of species, which undertakes this type of migration, belongs to the genus *Henicorhynchus*. In terms of fisheries output, these fishes are among the most important of the Lower Mekong. For example, in the Tonle Sap River Dai fishery, species of the genus *Henicorhynchus* account for 40 percent of the total annual catch. Larger species, such as *Catlocarpio siamensis*, *Cirrhinus microlepis*, *Cyclocheilichthys enoplos*, and *Probarbus jullieni*, as well as several members of the family Pangasiidae, also participate in this migration system.

The Sesan tributary system (including the Sekong and Srepok Rivers) deserves special attention here. This important tributary system is intimately linked with the Lower Mekong Migration System, as evidenced by many species such as *Henicorhynchus* sp. and *Probarbus jullieni* extending their migration routes from the Mekong River mainstream into the Sesan tributary system. In addition, the Sesan tributary system also appears to contain its own migration system. Many of the species (e.g. all the species mentioned above) are believed to spawn within the Mekong mainstream in the upper stretches of the system (from Kratie to the Khone Falls, and beyond) at the beginning of the flood season in May-June. Eggs and larvae subsequently drift downstream with the current to reach the floodplain feeding habitats in southern Cambodia and Viet Nam. The main characteristics of the Lower Mekong Migration System are shown in Figure 4.

Figure 4: The Lower Mekong Migration System. Black arrows indicate migrations at the beginning of the dry season, grey arrows indicate migration at the beginning of the flood season



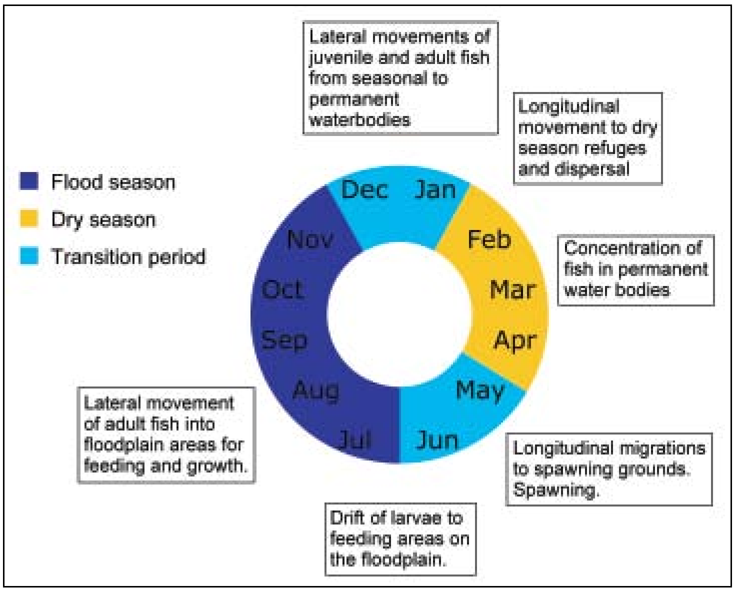
The importance of drifting larvae and juveniles has been documented through intensive sampling of larvae fisheries in the Mekong Delta in Viet Nam. During a sampling period of only 45 days in June-July 1999 127 species were identified from the larvae and juvenile drift.

A general 'migration calendar', as it is valid for an average year and the 'average Mekong fish species is given in Figure 5 after Poulsen et al (2004). Triggers for initiation of migrations are not well understood, although it is generally assumed that increased discharge in itself is a main trigger for migrations: fish typically start to migrate upstream to spawning grounds when the water level starts to increase, spawning while the water level is still increasing to ensure that the current brings eggs and larvae into nursery areas on the floodplain further downstream.

After spawning, the adult fish also move into the flooded areas. During the flood season the fish feed intensively in the flood zone, growing and building up fat layers for the following dry season, when food is scarce.

As the water level starts to drop and the floodplain dries, most fish seek refuge in permanent water bodies, mainly in deeper parts of the main river channel. Fish following this pattern thus utilize three distinct habitats (spawning grounds, feeding habitats and dry season refuges).

Figure 5: General migration calendar for Mekong fish species



3.7.5. Key issues for the maintenance of the Tonle Sap/Lower Mekong fisheries

Although emphasis is on issues related to migratory fishes, the issues are equally relevant for all fish species and indeed for the ecosystem as a whole. Basically, the most important issue in relation to the ecological functioning of the Mekong River from the point of view of migratory fishes is that critical habitats are maintained in time and space. This includes the maintenance of connectivity between them, i.e. through migration corridors. The annual hydrological pattern, including its role in the creation of seasonal floodplain habitats, as well as its role as a distributor of fish larvae and juveniles through passive drift, is of a high importance.

The following key ecological attributes for migratory species are identified:

Dry season refuge habitats	Deep pools in the Kratie-Stung Treng stretch of the Mekong mainstream. These habitats are extremely important for recruitment for the entire lower Mekong Basin, including floodplains in southern Cambodia (including the Tonle Sap Great Lake System) and the Mekong Delta in Viet Nam.
Flood season feeding and rearing habitats	Floodplains in the Mekong Delta in Viet Nam, in southern Cambodia, and in the Tonle Sap system. These habitats support the major part of Mekong fisheries.
Spawning habitats	Rapids and deep pool systems in the Kratie - Khone Falls, and in the Sesan catchment. Floodplain habitats in the south (e.g. flooded forests associated with the Great Lake).
Migration routes	The Mekong River from Kratie - Stung Treng to southern Cambodia and the Mekong Delta in Viet Nam. Between the Mekong River and the Tonle Sap River (longitudinal connectivity). Between floodplain habitats and river channels (lateral connectivity). Between the Mekong mainstream and the Sesan sub-catchment (including Sekong and Srepok Rivers).
Hydrology	The annual flood pattern responsible for the inundation of large areas of southern Cambodia (including the Tonle Sap system) and the Mekong Delta is essential for fisheries productivity of the system. The annual reversal of the flow in the Tonle Sap River is essential for ecosystem functioning. If the flow is not reversed (or if reversal is delayed), fish larvae drifting from upstream spawning sites in the Mekong River cannot

	access the important floodplain habitats of the Tonle Sap System. A delayed flow reversal would also lead to a reduced floodplain area adjacent to the river and lake, and thus, reduced fish production. Changed hydrological parameters e.g. as a result of water management schemes, result in changed flow patterns, which in turn may change sedimentation patterns along the river. Examples of this already exist in some tributaries where hydropower dams have been constructed, resulting in sedimentation, and thus in disappearance of deep pool habitats.

The importance of (longitudinal) migratory fish that rely strongly on the ecological connectivity between floodplains and river channels, in the total fish catch is considerably. Van Zalinge et al. (2000) estimate that longitudinal migrants contribute 63% to the catch of the major Tonle Sap fisheries. Poulsen et al. (2002) estimate the contribution to be 48%.

The remaining proportion of the floodplain yield originates from the black-fish species, i.e. species that spend their entire life on the floodplain. However, many black-fishes are predators, including the abundant *Channa* (snakeheads), and it may be assumed that they feed heavily on whitefishes which have moved into their floodplain habitat.

3.8. Conclusions

Based on above review of the literature a number of conclusions can be drawn that are of importance for the impact assessment:

- Alteration of the hydrology of the Tonle Sap Lake system would cause the following changes and impacts :
  - The maximum water level during the flood season is a very important factor for the productivity of the system. Lower maximum flood level would
    - decrease availability and areas of inundated nesting, breeding, spawning, feeding habitats in floodplain, resulting in impacts on fish productivity and overall biodiversity due to wetland ecosystem alteration and conversion
    - decrease sedimentation, which lowers the nutrient supply, resulting in impacts on soil fertility, primary productivity, and agricultural/aquatic/forest production
    - increase drought problems on ricefields and agro-ecosystems, resulting in impacts on rice production and agricultural production
  - The minimum water level during the dry season is a very important factor for defining wetland habitats. Higher minimum water level would
    - provide more dry season refuge for fish
    - increase permanent inundation of seasonally terrestrial habitats at the edge of the Lake, resulting in degradation of the flooded forests and other terrestrial and submerged aquatic vegetation, which would impact a number of species typical to these areas
  - The duration of flooding determines the proportion in which wetland conditions (aquatic and terrestrial or wet and dry conditions) prevail in the floodplain. Shorter/longer duration of flooding would
    - change wetland habitats availability and thus have an impacts on fish/aquatic production and livestock production (likely to decrease)
    - change wetland habitat characteristics, leading to impacts on vegetation zonation, flora/fauna habitats and distribution, and biodiversity, which would impact people's livelihoods (also likely to increase the invasion of alien species)
  - A decrease in water level fluctuation range would decrease the width of the wetland zone, the maintenance of wetland habitats and their biodiversity.
- Tonle Sap Great Lake has a high and unique ecological value, harboring a large number of rare and endangered flora and fauna species;
- The socio - economic value of the Tonle Sap fisheries is extremely high. Longitudinal migrating (between Tonle Sap and the main river) fish make up for probably more than 50% of the yield;
- To maintain ecosystem integrity and ecosystem production, it is important that:
  - fish migration should not be hindered. It is extremely important that free floating eggs and larvae should be allowed to drift into he Tonle Sap area in the period May till mid-July;

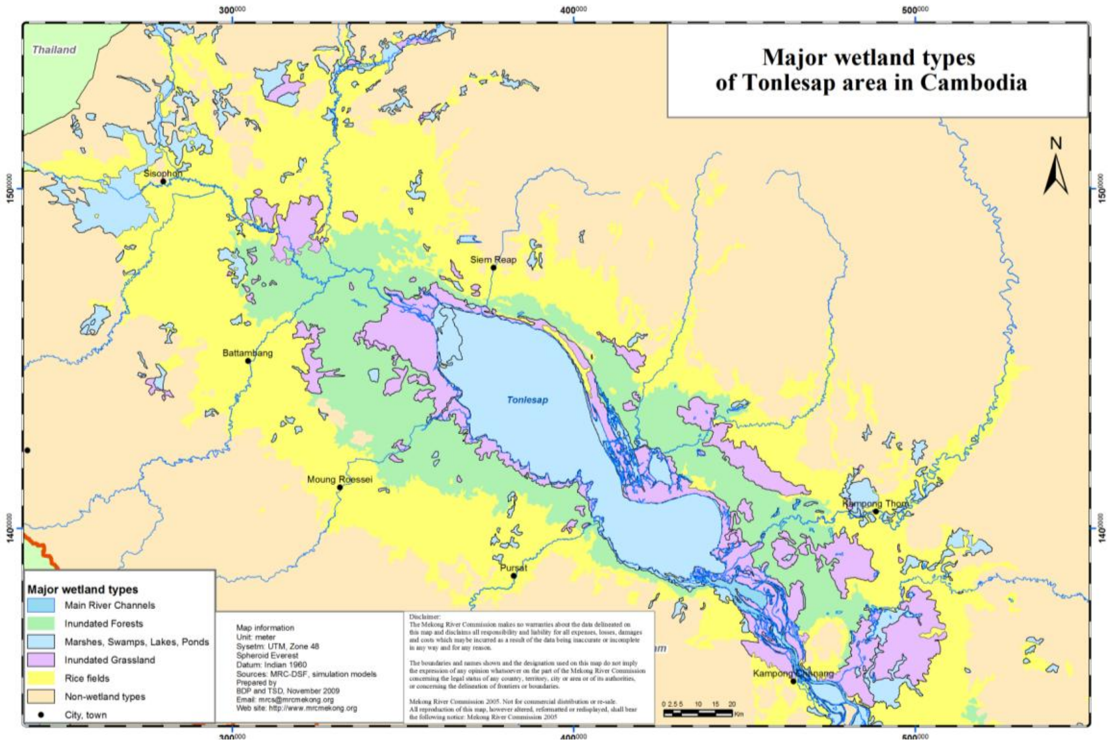
- early flooding of the area is also important because at the end of the dry season the water quality in the remaining refuges may become very poor (anoxic). Inflow of oxygen-rich floodwater has to improve this situation, if not the lateral migrating species (black fish) may not survive;
- the deeper the flood and the larger the flooded area, the higher the fish production will be;
- inflow of fine sediments is of crucial importance for the maintenance of the productivity of the system;
- a variety of floodplain habitats is important for the functioning of the system. Although shrub and grasslands are probably more important than flooded forests, the latter habitat is of crucial importance as well. The impacts of deeper and longer flooding on the flooded forests is not well known at the moment and requires further investigation; and
- at the start of the dry season (February) longitudinal migration to the dry season refuges should be possible.

4. Impacts of BDP scenarios

4.1. Introduction

Wetland habitats are of crucial importance for the ecological functioning of the Tonle Sap Great Lake ecosystem. Structure and functioning of the wetlands is narrowly linked to the seasonal flooding of the area: as stated in Chapter 3 not only the size of the flooded area is of importance, but also the depth, duration, volume and timing of the flood. In the following section changes in flood characteristics that would result under the various scenarios are described. Figure 6 shows the distribution of the important wetland types over the area.

Figure 6: Wetland map of the Tonle Sap area



4.2. Changes in abiotic conditions

4.2.1 Flooded areas

Flooded areas in the Tonle Sap basin under the various scenarios are given in Table 1.

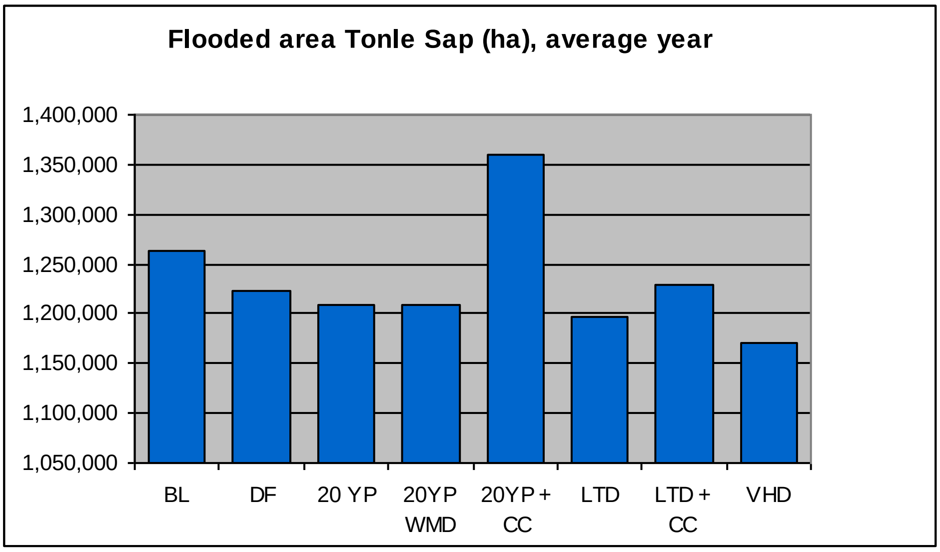
Table 1: Changes in flooded area for a dry, average and wet year under the various scenarios

	Average year	Dry year	Wet year
Baseline	1,263,060	1,120,931	1,407,601
Definite Future	1,223,221	1,082,797	1,388,181
Change from baseline (ha)	-39,839	-38,134	-19,420
Change from baseline (%)	-3.2	-3.4	-1.4
20 Year Plan	1,208,232	1,029,996	1,391,067
Change from baseline (ha)	-54,828	-90,935	-16,535

Change from baseline (%)	-4.3	-8.1	-1.2
20 Year Plan WMD	1,208,594	1,031,865	1,388,198
Change from baseline (ha)	-54,465	-89,065	-19,403
Change from baseline (%)	-4.3	-7.9	-1.4
20 Year Plan + CC	1,359,020	1,187,911	1,498,754
Change from baseline (ha)	95,960	66,980	91,153
Change from baseline (%)	7.6	6.0	6.5
Long-Term Development	1,197,243	1,014,882	1,383,428
Change from baseline (ha)	-65,816	-106,049	-24,174
Change from baseline (%)	-5.2	-9.5	-1.7
Long-Term Development + CC	1,229,681	961,575	1,396,041
Change from baseline (ha)	-33,378	-159,356	-11,560
Change from baseline (%)	-2.6	-14.2	-0.8
Very High Development	1,171,291	1,011,231	1,381,747
Change from baseline (ha)	-91,769	-109,700	-25,855
Change from baseline (%)	-7.3	-9.8	-1.8

The table shows that, when comparing the 20 Year Plan scenario with the Baseline, the total flooded area in the Tonle Sap area will reduce with some 55,000 ha (4.3%) in an average year. Nearly 40,000 ha (over 3%) of this reduction is already the result under the Definite Future scenario. Reductions are larger in a dry year (91,000 ha or 8.1 %) and less in a wet year (17,0000 ha or 1.2%). Not building the mainstream dams does not change the situation very much. Under the Long-term Development and the Very High Development scenarios, flooding further reduces with at maximum 9.8% of the flooded area in a dry year under the Very High Development scenario. Climate change will reverse the trend: under the 20 Year Plan + CC scenario the flooded area increases with 95,000 ha (+7.6%) compared to the Baseline, on the long run (2060) there will be a decrease again, be it only -2.6% compared to the Baseline, see Figure 7.

Figure 7: Flooding in the Tonle Sap area in an average year under the various scenarios



Reduction of the overall flooded area would impact the alternate dry and flooded conditions in the Tonle Sap floodplain, alter plant communities and the complex cycle of natural nutrient exchange processes between terrestrial and aquatic food webs, reduce the overall natural productivity of the Tonle Sap ecosystem, and thus lower fish production and reduce catch.

Table 2 shows that the reduction in flooded area of valuable wetland types, in an average hydrological year, is limited to around 1% for the flooded forests and marshes under the Definite Future and 20 Year Plan scenarios, and around 3% for the inundated grasslands, the area of flooded rice fields is reduced by some 20%. More than half of these changes already result under the Definite Future scenario. Under the Long-Term Development and Very High Development scenarios, the trend continues: under the Very High Development scenario 2.1% of the forest, 1.4% of the marshes, 5.4% of the grasslands and 30% of the ricefields will not be flooded anymore. In the medium term (2030) climate change will compensate the impacts of the reservoir construction: flooding of each of the habitats increases somewhat as compared to the Baseline under the 20 Year Plan + CC scenario. In the long run, climate change is not able to compensate for the reduction in flow due to reservoir construction. See Table 2 and Figure 8.

Table 2: Areas of valuable wetland types flooded in an average hydrological year under the various scenarios

	Forests	Marshes	Grasslands	Ricefields	Total
Baseline	451,915	309,381	276,654	207,354	1,263,060
Definite Future	449,682	307,463	271,342	177,042	1,223,221
Change from baseline (ha)	-2,233	-1,919	-5,312	-30,312	-39,839
Change from baseline (%)	-0.5	-0.6	-1.9	-14.6	-3.2
20 Year Plan	448,051	306,727	268,794	167,008	1,208,232
Change from baseline (ha)	-3,864	-2,655	-7,860	-40,346	-54,828
Change from baseline (%)	-0.9	-0.9	-2.8	-19.5	-4.3
20 Year Plan WMD	448,096	306,742	268,862	167,240	1,208,594
Change from baseline (ha)	-3,819	-2,639	-7,791	-40,114	-54,465
Change from baseline (%)	-0.8	-0.9	-2.8	-19.3	-4.3
20 Year Plan + CC	455,705	313,090	284,137	288,316	1,359,020
Change from baseline (ha)	3,790	3,709	7,483	80,963	95,960
Change from baseline (%)	0.8	1.2	2.7	39.0	7.6
Long-Term Development	446,498	306,076	266,755	160,303	1,197,243
Change from baseline (ha)	-5,417	-3,305	-9,899	-47,051	-65,816
Change from baseline (%)	-1.2	-1.1	-3.6	-22.7	-5.2
Long-Term Development + CC	450,430	308,320	273,010	180,197	1,229,681
Change from baseline (ha)	-1,485	-1,061	-3,644	-27,156	-33,378
Change from baseline (%)	-0.3	-0.3	-1.3	-13.1	-2.6
Very High Development	442,289	304,912	261,702	144,958	1,171,291
Change from baseline (ha)	-9,626	-4,469	-14,951	-62,396	-91,769
Change from baseline (%)	-2.1	-1.4	-5.4	-30.1	-7.3

In a dry hydrological year losses are bigger: 5% less forest will be flooded, some 1.5% less marshes, 10% less inundated grasslands, and 30% less ricefields under the 20 Year plan scenarios as compared to the Baseline. Flooding further decreases under the Long-Term Development and Very High Development scenarios. Climate change again compensates. As is to be expected the losses are much more limited in a wet hydrological year: in general less than 0.5% of the important wetland types will not flood anymore, with the exception of the area of flooded ricefields, which reduces with some 5 to 7%. See Tables 3 and 4 and Figure 8.

Figure 8: Areas of flooded valuable ecosystems under the various scenarios

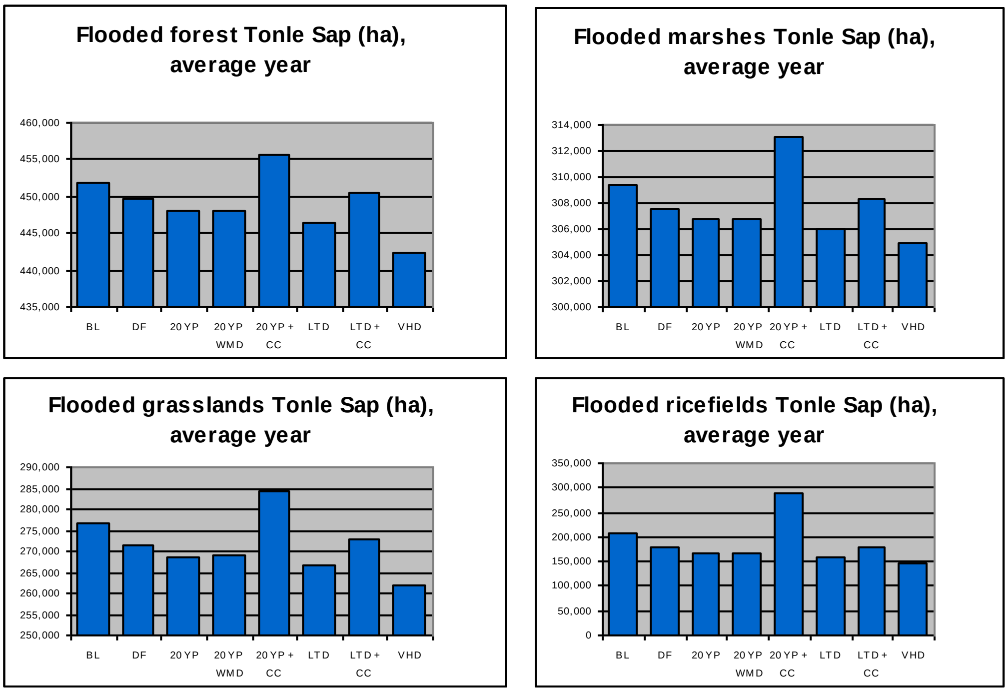


Table 3: Areas of valuable wetland types flooded in a dry hydrological year under the various scenarios

	Forests	Marshes	Grasslands	Ricefields	Total
Baseline	431,872	302,329	246,392	122,952	1,120,931
Definite Future	425,002	299,822	236,056	104,555	1,082,797
Change from baseline (ha)	-6,870	-2,508	-10,336	-18,398	-38,134
Change from baseline (%)	-1.6	-0.8	-4.2	-15.0	-3.4
20 Year Plan	408,872	298,417	221,733	83,641	1,029,996
Change from baseline (ha)	-23,000	-3,912	-24,659	-39,311	-90,935
Change from baseline (%)	-5.3	-1.3	-10.0	-32.0	-8.1
20 Year Plan WMD	409,352	298,502	222,169	84,509	1,031,865
Change from baseline (ha)	-22,520	-3,827	-24,222	-38,444	-89,065
Change from baseline (%)	-5.2	-1.3	-9.8	-31.3	-7.9
20 Year Plan + CC	446,236	305,974	266,370	151,719	1,187,911
Change from baseline (ha)	14,364	3,645	19,978	28,767	66,980
Change from baseline (%)	3.3	1.2	8.1	23.4	6.0
Long-Term Development	404,704	297,351	216,984	78,530	1,014,882
Change from baseline (ha)	-27,168	-4,978	-29,407	-44,423	-106,049
Change from baseline (%)	-6.3	-1.6	-11.9	-36.1	-9.5
Long-Term Development + CC	397,774	293,841	205,716	46,950	961,575
Change from baseline (ha)	-34,098	-8,488	-40,676	-76,003	-159,356
Change from baseline (%)	-7.9	-2.8	-16.5	-61.8	-14.2
Very High Development	403,611	297,148	215,836	77,329	1,011,231
Change from baseline (ha)	-28,261	-5,181	-30,555	-45,624	-109,700
Change from baseline (%)	-6.5	-1.7	-12.4	-37.1	-9.8

Table 4: Areas of valuable wetland types flooded in a wet hydrological year under the various scenarios

	Forests	Marshes	Grasslands	Ricefields	Total
Baseline	456,676	315,709	287,812	329,632	1,407,601
Definite Future	456,286	314,743	286,433	312,948	1,388,181
Change from baseline (ha)	-390	-966	-1,379	-16,685	-19,420
Change from baseline (%)	-0.1	-0.3	-0.5	-5.1	-1.4
20 Year Plan	456,365	314,884	286,647	315,399	1,391,067
Change from baseline (ha)	-311	-826	-1,165	-14,233	-16,535
Change from baseline (%)	-0.1	-0.3	-0.4	-4.3	-1.2
20 Year Plan WMD	456,286	314,743	286,435	312,963	1,388,198
Change from baseline (ha)	-390	-966	-1,377	-16,670	-19,403
Change from baseline (%)	-0.1	-0.3	-0.5	-5.1	-1.4
20 Year Plan + CC	457,083	320,581	292,470	410,850	1,498,754
Change from baseline (ha)	407	4,872	4,657	81,217	91,153
Change from baseline (%)	0.1	1.5	1.6	24.6	6.5
Long-Term Development	456,191	314,228	285,834	309,403	1,383,428
Change from baseline (ha)	-485	-1,481	-1,978	-20,229	-24,174
Change from baseline (%)	-0.1	-0.5	-0.7	-6.1	-1.7
Long-Term Development + CC	456,488	315,178	286,683	319,922	1,396,041
Change from baseline (ha)	-188	-531	-1,130	-9,711	-11,560
Change from baseline (%)	0.0	-0.2	-0.4	-2.9	-0.8
Very High Develpment	456,166	314,202	285,716	307,892	1,381,747
Change from baseline (ha)	-510	-1,508	-2,096	-21,741	-25,855
Change from baseline (%)	-0.1	-0.5	-0.7	-6.6	-1.8

Reduction of areas of different types of wetlands would lead to the reduction of the Tonle Sap ecosystems' net primary production (i.e. increase in plant biomass), and thus lower fish production and fish catch, and affect people's livelihoods. According to Hortle and Bamrungrach (2009), indicative estimates (minimum value) of net primary production (i.e. increase in plant biomass) in different types of wetlands are 20 ton/ha/year (dry weight) for marshes/swamps and forests, 25 ton/ha/year for grassy/herbaceous swamps or inundated grasslands and 8 ton/ha/year for ricefields. Permanent water bodies are estimated to have a net primary production is 5 ton/ha/year. Ricefields that flood for part of the year probably have a much higher primary production, here a primary production of 15ton/ha/year has been assumed.

Assuming above given primary production rates and applying changes in flooded areas as given in Table 4 changes in primary production due to changes in flooded areas have been calculated. Note that in the calculations an open water area of the Tonle Sap system of 250,000 ha has been used, in Table 5 these 250,000 ha are incorporated in the land use class marshes.

The calculations show that the primary production of the system could decrease with 3 to 7.5% for the various scenarios as compared to the Baseline. Note that this reduction has to be attributed to changes in flooded areas only. Changes resulting from changes flood depth and duration, changes in sediment supply etc. have not been taken into account here.

Table 5: Changes in primary production (ton dry weight/ha/yr) due to changes in flooded area for the various scenarios

	Forests	Marshes	Grasslands	Ricefields	Open water	Total
Baseline	9,038,304	1,187,624	6,916,347	3,110,305	1,250,000	21,502,580
Definite Future	8,993,646	1,149,251	6,783,549	2,655,627	1,250,000	20,832,074
Change from baseline (ha)	-44,658	-38,372	-132,798	-454,678	0	-670,506
Change from baseline (%)	-0.5	-3.2	-1.9	-14.6	0.0	-3.1
20 Year Plan	8,961,027	1,134,531	6,719,859	2,505,118	1,250,000	20,570,536
Change from baseline (ha)	-77,277	-53,092	-196,488	-605,187	0	-932,044
Change from baseline (%)	-0.9	-4.5	-2.8	-19.5	0.0	-4.3
20 Year Plan WMD	8,961,928	1,134,838	6,721,560	2,508,598	1,250,000	20,576,924
Change from baseline (ha)	-76,376	-52,786	-194,787	-601,707	0	-925,656
Change from baseline (%)	-0.8	-4.4	-2.8	-19.3	0.0	-4.3
20 Year Plan + CC	9,114,106	1,261,804	7,103,434	4,324,747	1,250,000	23,054,091
Change from baseline (ha)	75,802	74,180	187,087	1,214,442	0	1,551,510
Change from baseline (%)	0.8	6.2	2.7	39.0	0.0	7.2
Long-Term Development	8,929,956	1,121,517	6,668,884	2,404,538	1,250,000	20,374,894
Change from baseline (ha)	-108,348	-66,107	-247,463	-705,768	0	-1,127,686
Change from baseline (%)	-1.2	-5.6	-3.6	-22.7	0.0	-5.2
Long-Term Development + CC	9,008,604	1,166,398	6,825,250	2,702,958	1,250,000	20,953,210
Change from baseline (ha)	-29,700	-21,226	-91,097	-407,347	0	-549,370
Change from baseline (%)	-0.3	-1.8	-1.3	-13.1	0.0	-2.6
Very High Development	8,845,775	1,098,236	6,542,562	2,174,367	1,250,000	19,910,941
Change from baseline (ha)	-192,529	-89,388	-373,785	-935,938	0	-1,591,639
Change from baseline (%)	-2.1	-7.5	-5.4	-30.1	0.0	-7.4

4.2.2 Water levels and lake volume in the dry season

In the dry season average water levels in the Tonle Sap will be higher under the various scenarios as compared to the Baseline. The increase will be 22 cm between the Baseline and the Definite Future and 36 cm under the 20 Year Plan scenario. No or fewer mainstream dams reduce the water level increase to about 27 cm. Water levels increase slightly more under the Long-Term Development scenario (up to 34 cm). Under the Very High Development scenario the increase is only 16 cm compared to the Baseline. The scenarios that take climate change into account result in a water level rise of 50 to 60 cm. see Table 6 for the details.

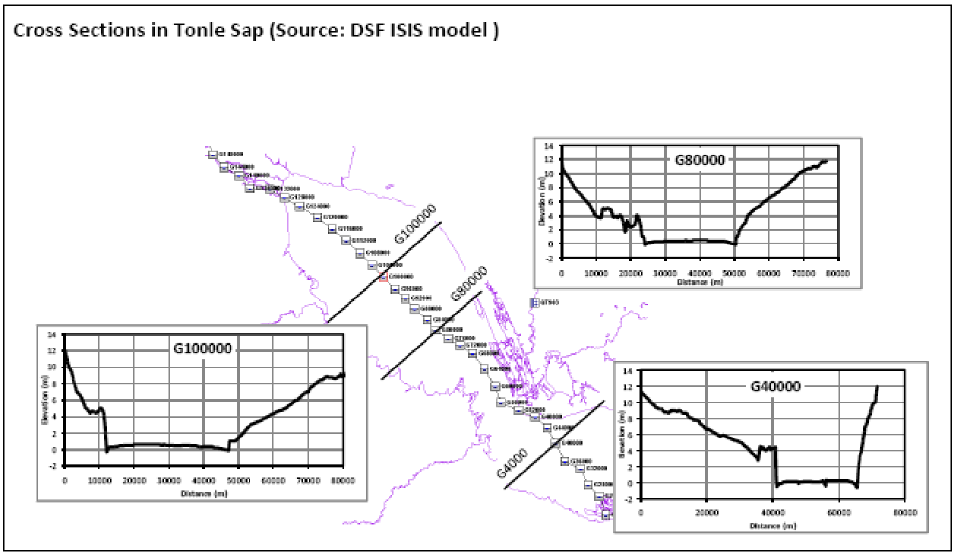
However, this will not influence the 'permanent flooded' area around the lake, since the cross section of the lake is such that an increase of water levels in the dry season does not result in an increase in the flooded area, see Figure 9.

Table 6: Increase in dry season water level (in cm) at Kampong Luang under the various scenarios

	Increase in water level (in cm)								
	DF	20 YP	20Y w/o MD	20Y w/o LMD	20Y w/o TMD	LTD	VHD	20-CC	LTD-CC
March	0.23	0.32	0.29	0.32	0.32	0.29	0.03	0.49	0.57
April	0.24	0.43	0.37	0.38	0.38	0.39	0.27	0.50	0.59
May	0.19	0.36	0.27	0.27	0.27	0.33	0.17	0.48	0.56
Average	0.22	0.37	0.31	0.32	0.32	0.34	0.16	0.49	0.57

However, the volume of the lake in the dry season will increase considerably. With a dry season area of about 250,000 ha, an increase in water level of 22 to 37 cm equals an increase in lake volume with about 550 to 925 MCM, a considerable addition to the present 1,500 MCM lake volume in an average dry season. Under the long term climate change scenario the lake volume would nearly double.

Figure 9: Cross sections of the Tonle Sap Lake



4.2.3. Flood depth

Reductions in flood depth under the various scenarios and for the various hydrological years are quite significant. When comparing the Baseline scenario with the Definite Future scenario, it appears that in 95% of the area the reduction of flood depth between 0.3 and 0.4 m in an average year. Under the 20 Year Plan, the Long-Term Development and the Very High Development scenarios flood level reductions are just over 0.5 m in more than 90% of the area. Under the 20 Year Plan scenario with climate change, flood levels increase with 10 to 20 cm. Climate change in the long term offsets reductions in flood levels somewhat, but still there will be a reduction of 30 to 40 cm in most of the area.

Table 7: Reduction in flood depth in an average year for the various scenarios against the Baseline

Change in water level	Reduction						Increase
	>0.5 m	0.4 - 0.5	0.4 - 0.3	0.3 - 0.2	0.2 - 0.1	-0.1 - +0.1	0.1 - 0.2
DF vs BL, %	0.0	0.3	95.4	1.7	1.3	1.3	0.0
20 YP vs BL, %	93.0	1.7	1.4	1.3	1.3	1.3	0.0
20 YP+CC vs BL, %	0.2	0.1	0.1	0.2	0.3	1.0	98.2
LTD vs BL, %	92.1	1.8	1.5	1.6	1.5	1.1	0.4
LTD vs BL+CC, %	2.7	1.9	8.7	76.6	5.8	2.7	1.6
VHD vs BL, %	92.2	1.8	1.6	1.6	1.4	1.0	0.4

More detailed analysis shows a somewhat irregular pattern, the deep flooded forest area (>3.0 m) decreases with 40,000 ha (12%) between the Baseline and the 20 Year Plan. Also the area that if flooded by 0.5 – 1.0 m decreases, the shallow flooded area (0 – 0.5 m) increases with more than 200%, which is equivalent to an increase in area with nearly 7,500 ha, see Table 8. Going from the 20 Year plan to the Long-Term Development and Very High Development scenario, the trend continues: the deep flooded area reduces further.

Table 8: Flooded forests, change in flood depth under the various scenarios, average year

Inundated area	0 - 0.5 m	0.5 - 1.0 m	1.0 - 3.0	> 3.0
Baseline	3,460	11,492	101,021	335,941
Definite Future	10,920	8,716	121,406	308,640
Change from baseline (ha)	7,459	-2,776	20,385	-27,301
Change from baseline (%)	215.6	-24.2	20.2	-8.1
20 Year Plan	11,554	9,841	130,795	295,861
Change from baseline (ha)	8,094	-1,651	29,774	-40,080
Change from baseline (%)	233.9	-14.4	29.5	-11.9
20 Year Plan WMD	11,551	9,781	130,542	296,223
Change from baseline (ha)	8,091	-1,711	29,521	-39,719
Change from baseline (%)	233.8	-14.9	29.2	-11.8
20 Year Plan + CC	2,753	2,897	56,278	393,778
Change from baseline (ha)	-707	-8,596	-44,744	57,836
Change from baseline (%)	-20.4	-74.8	-44.3	17.2
Long-Term Development	11,672	10,861	138,586	285,379
Change from baseline (ha)	8,212	-631	37,565	-50,563
Change from baseline (%)	237.3	-5.5	37.2	-15.1
Long-Term Development + CC	9,470	8,712	114,648	317,600
Change from baseline (ha)	6,010	-2,780	13,627	-18,342
Change from baseline (%)	173.7	-24.2	13.5	-5.5
Very High Development	9,008	17,118	160,658	255,505
Change from baseline (ha)	5,548	5,626	59,636	-80,437
Change from baseline (%)	160.4	49.0	59.0	-23.9

Analysis of the flood maps learnt that when comparing the Baseline scenario with the 20 Year Plan scenario, flood levels in an average year reduce with just over 0.5 m in more the 95% of the forest area. Of this reduction 0.3 to 0.4 m is already the result of the Definite Future scenario. Under the Long-Term Development and Very High Development scenarios further reductions are limited.

Inundated grassland show a trend comparable to the forests: a shift from deep flooded to more shallow flooded, see Table 9. In more than 95% of the grassland area the decrease will be just over 0.5 m in an average hydrological year, when the 20 Year Plan is compared with the Baseline. Again, the Definite Future scenario accounts for 0.3 to 0.4 m of this reduction. Under the Long-Term Development and Very High Development scenarios further reductions are limited.

Table 9: Inundated grasslands, change in flood depth under the various scenarios, average year

Inundated area	0 - 0.5 m	0.5 - 1.0 m	1.0 - 3.0	> 3.0
Baseline	7,282	17,339	73,353	178,680
Definite Future	15,892	15,112	67,899	172,438
Change from baseline (ha)	8,610	-2,227	-5,453	-6,242
Change from baseline (%)	118.2	-12.8	-7.4	-3.5
20 Year Plan	17,768	15,801	65,083	170,143
Change from baseline (ha)	10,486	-1,538	-8,270	-8,537
Change from baseline (%)	144.0	-8.9	-11.3	-4.8

20 Year Plan WMD	17,737	15,793	65,157	170,175
Change from baseline (ha)	10,455	-1,546	-8,196	-8,505
Change from baseline (%)	143.6	-8.9	-11.2	-4.8
20 Year Plan + CC	5,405	6,662	68,746	203,325
Change from baseline (ha)	-1,878	-10,677	-4,607	24,645
Change from baseline (%)	-25.8	-61.6	-6.3	13.8
Long-Term Development	18,423	17,118	62,906	168,308
Change from baseline (ha)	11,141	-221	-10,447	-10,372
Change from baseline (%)	153.0	-1.3	-14.2	-5.8
Long-Term Development + CC	14,097	15,239	69,793	173,881
Change from baseline (ha)	6,815	-2,100	-3,560	-4,799
Change from baseline (%)	93.6	-12.1	-4.9	-2.7
Very High Development	15,979	21,755	58,375	165,593
Change from baseline (ha)	8,697	4,416	-14,978	-13,087
Change from baseline (%)	119.4	25.5	-20.4	-7.3

Flood depth changes in the marshes are comparable to those in the flooded forest and grassland areas: a decrease with more than 0.5 m in over 99% of the area, again, largely attributable to the Definite Future scenario.

In a dry hydrological year flood depths are less, compare Table 8 with Table 10 and Table 9 with Table 11. Analysis of the flood maps shows hat reduction of flood depths, going from the Baseline scenario to the 20 Year Plan scenario, is still just over 0.5 m in about 95% of the flooded forest and flooded marsh area, and in 85% of the inundated grassland area. Nearly 10% of the inundated grasslands have a flood depth reduction of 0.4 – 0.5 m.

Table 10: Flooded forests, change in flood depth under the various scenarios, dry year

Inundated area	0 - 0.5 m	0.5 - 1.0 m	1.0 - 3.0	> 3.0
Baseline	20,101	16,092	195,841	199,837
Definite Future	22,840	20,322	207,665	174,174
Change from baseline (ha)	2,739	4,231	11,824	-25,663
Change from baseline (%)	13.6	26.3	6.0	-12.8
20 Year Plan	15,810	43,259	227,787	122,015
Change from baseline (ha)	-4,292	27,168	31,946	-77,822
Change from baseline (%)	-21.3	168.8	16.3	-38.9
20 Year Plan WMD	15,761	42,718	227,744	123,129
Change from baseline (ha)	-4,340	26,626	31,903	-76,708
Change from baseline (%)	-21.6	165.5	16.3	-38.4
20 Year Plan + CC	11,639	11,155	139,788	283,653
Change from baseline (ha)	-8,463	-4,936	-56,053	83,816
Change from baseline (%)	-42.1	-30.7	-28.6	41.9
Long-Term Development	17,834	47,276	226,979	112,614
Change from baseline (ha)	-2,267	31,184	31,138	-87,223
Change from baseline (%)	-11.3	193.8	15.9	-43.6
Long-Term Development + CC	36,375	40,481	219,494	101,424
Change from baseline (ha)	16,274	24,390	23,653	-98,414
Change from baseline (%)	81.0	151.6	12.1	-49.2

Very High Development	19,144	48,051	226,210	110,206
Change from baseline (ha)	-958	31,959	30,369	-89,631
Change from baseline (%)	-4.8	198.6	15.5	-44.9

Table 11: Inundated grasslands, change in flood depth under the various scenarios, dry year

Inundated area	0 - 0.5 m	0.5 - 1.0 m	1.0 - 3.0	> 3.0
Baseline	23,096	17,156	48,778	157,361
Definite Future	23,725	15,953	43,039	153,338
Change from baseline (ha)	630	-1,203	-5,739	-4,023
Change from baseline (%)	2.7	-7.0	-11.8	-2.6
20 Year Plan	17,171	19,578	40,466	144,518
Change from baseline (ha)	-5,925	2,422	-8,313	-12,843
Change from baseline (%)	-25.7	14.1	-17.0	-8.2
20 Year Plan WMD	17,209	19,681	40,464	144,815
Change from baseline (ha)	-5,886	2,525	-8,314	-12,546
Change from baseline (%)	-25.5	14.7	-17.0	-8.0
20 Year Plan + CC	18,692	17,342	62,227	168,108
Change from baseline (ha)	-4,403	186	13,448	10,747
Change from baseline (%)	-19.1	1.1	27.6	6.8
Long-Term Development	16,511	20,123	38,601	141,749
Change from baseline (ha)	-6,585	2,967	-10,178	-15,612
Change from baseline (%)	-28.5	17.3	-20.9	-9.9
Long-Term Development + CC	20,706	10,642	36,008	138,359
Change from baseline (ha)	-2,389	-6,514	-12,770	-19,002
Change from baseline (%)	-10.3	-38.0	-26.2	-12.1
Very High Development	16,600	19,792	38,462	140,982
Change from baseline (ha)	-6,496	2,636	-10,316	-16,379
Change from baseline (%)	-28.1	15.4	-21.1	-10.4

Figures 10 and 11 show the differences in flood depth in the flooded forest in a dry hydrological year as compared to an average hydrological year.

In a hydrologically wet year, flood depth changes in over 95% of the flooded forest area, the inundated grassland area and the flooded marsh areas reduce with only 10 to 20 cm between the Baseline scenario and the 20 Year Plan scenario. These changes can be completely attributed to the Definite Future scenario.

Figure 10: Flood depths in the flooded forests in an average year

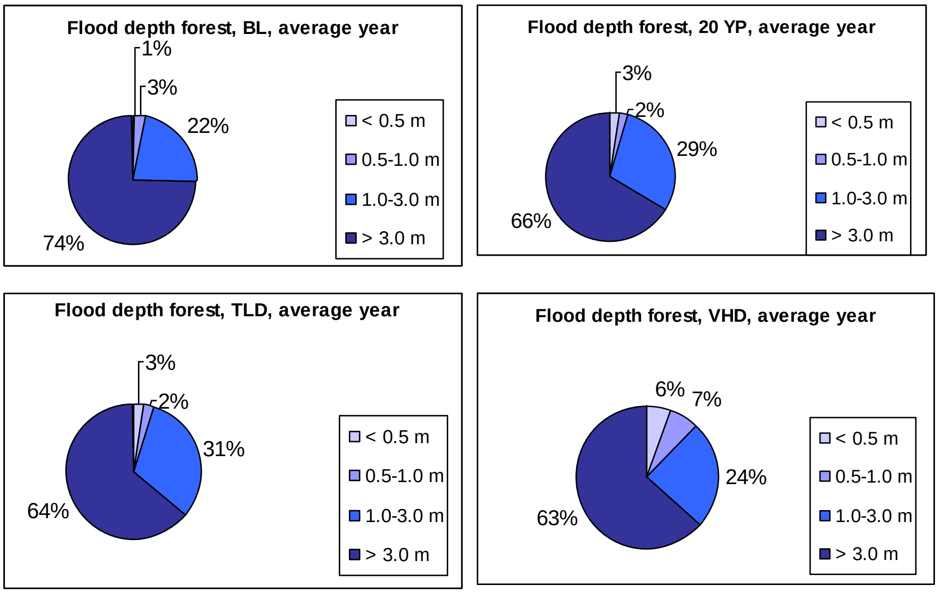
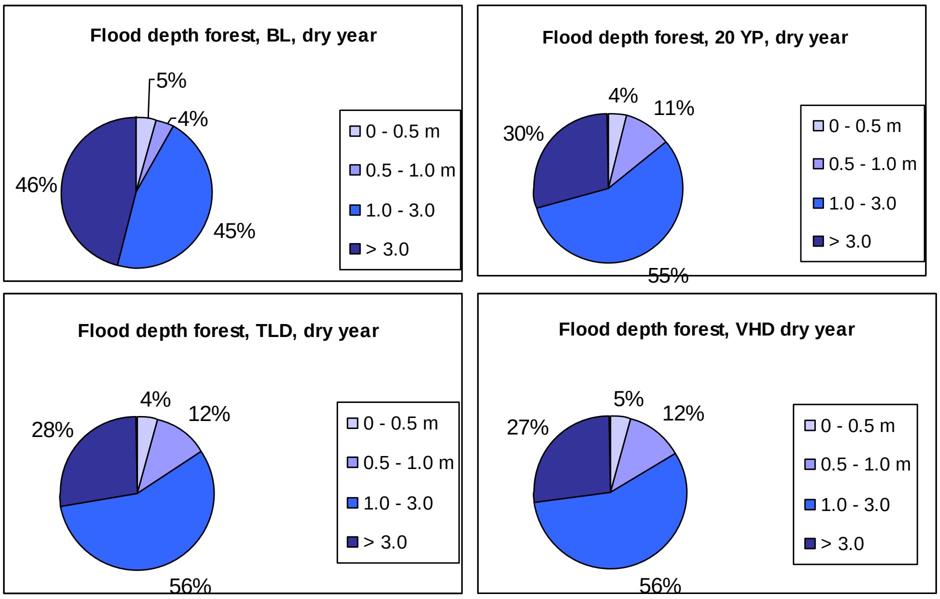


Figure 11: Flood depths in the flooded forests in an average year



In summary it can be concluded that flood levels in an average year decrease with some 50 cm, most of this reduction (30 to 40 cm) is already the result of the Definite Future scenario. In a hydrologically wet year the reductions are more restricted: 10 to 20 cm only, again largely already under the Definite Future scenario. Climate change at the medium term (2030) reverses the trend: water levels increase with 10 to 20 cm. In the long term (2060) the climate change effect reduces again, but still compensates part of the loss due to the reservoir construction induced flow changes: flood levels are only 20 to 30 cm lower than under the Baseline scenario.

4.2.4 Flood duration

Analysis of food duration maps for the various scenarios show a somewhat more complex pattern of changes than the observed changes in flood depth.

In an average hydrological year, flood duration in 70% of the flooded forest area reduces with less than 2 weeks, going from the Baseline to the 20 Year Plan scenario (see Table 12). Under the Definite Future scenario, 80% of the area experiences a flood duration reduction of less than 2 weeks. Flood duration further decreases going to the Long-Term Development and Very High Development scenarios: under the Long-Term Development scenario 46% of the flooded forest area if flooded more than 2 weeks shorter as compared to the Baseline scenario. Under the Very High Development scenario flooding is reduced with 0.5 to 1 month in 59% of the flooded forest area, whereas the reduction in flood duration is even more than 1 month in 9% of the area.

The situation is a bit different in a dry hydrological year: flood duration decrease with less than 2 weeks in 39% of the flooded forest area, and with between 2 weeks and 1 month in 56% of the area going from the Baseline scenario to the 20 Year Plan scenario. Under the Definite Future scenario reductions are less than 2 weeks in 92% of the flooded forests. Going to the Long-term Development and Very High Development scenarios the reduction in flood duration increases: under the Very High development scenario flood duration is reduced with more than 1 month in over half the flooded forest area. In a wet year flood duration reduction is less than 2 weeks in over 90% of the flooded forest area unde the Definite Future, the 20 Year Plan and the Long-Term Development scenarios. Under the Very High Development scenario reduces with more than 2 weeks in 27% of the flooded forest area.

The impact of climate change is not quite clear, in an average year flood duration increases in part of the area, but reduces in another part.

In summary, flood duration in an average year decreases with up to 1 month in an increasing portion of the flooded forests, 10 to 60% going from the Definite Future to the Very High Development scenario. In a dry year changes are bigger (culminating in a reduction of flood duration of 1 to 2 months over 50% of the flooded forest area under the Very High Development scenario). In a wet year changes are much more restricted.

Table 12: Changes in flood duration of flooded forests (% of area) for the various hydrological years, going from the Baseline to the 20 Year Plan scenario

Flooded Forest		Decrease in flood duration				Increase in flood duration			
		2 - 3 m	1 - 2 m	0.5 - 1 m	< 0.5 m	< 0.5 m	0.5 - 1 m	1 - 2 m	2 - 3 m
DF vs BL	Dry year	0	0	6	92	1	0	0	0
	Avg year	0	4	10	80	5	1	0	0
	Wet year	0	0	2	95	2	0	0	0
20 YP vs BL	Dry year	0	4	56	39	0	0	0	0
	Avg year	0	3	25	70	1	0	0	0
	Wet year	0	0	5	94	0	0	0	0
20 YP + CC vs BL	Dry year	0	6	31	6	8	19	27	1
	Avg year	0	5	27	15	48	4	1	0
	Wet year	0	0	1	78	10	9	2	0
LTD vs BL	Dry year	0	36	47	16	0	0	0	0
	Avg year	0	5	41	54	0	0	0	0
	Wet year	0	1	9	90	0	0	0	0
LTD + CC vs BL	Dry year	8	87	2	2	1	0	0	0
	Avg year	0	2	34	9	33	13	8	0
	Wet year	0	39	36	25	0	0	0	0
VHD vs BL	Dry year	0	52	36	12	0	0	0	0
	Avg year	0	9	59	32	0	0	0	0
	Wet year	0	2	25	74	0	0	0	0

Of the inundated grassland area changes in flood duration are different from those observed in the flooded forest areas: flood duration locally increases. In an average hydrological year 24% of the grassland areas experiences a flood duration reduction of less than 2 weeks going from the Baseline scenario to the 20 Year Plan scenario, in 34% of the area, the reduction in flood duration is between 2 weeks and 1 month. However, flood duration increases with up to 1 month in 25% of the inundated grasslands and with even more than 1 month in 7% of the area. Going to the Long-Term Development scenario and the Very High Development scenarios, the reduction in flood duration increases, while at the same time the areas having an increased flood duration reduce. Climate change tends to increase flood duration as compared to the scenarios without climate change.

In a hydrologically dry year flood duration increases in 32% of the grassland area, again going from the Baseline to the 20 Year Plan. In the remaining area flood duration decreases with on average less than a month. In a hydrologically wet year average flood duration mainly decreases: with less than 2 weeks in 69% of the area, and with 0.5 to 1 month in 14% of the area. In 17% of the grassland area flood duration increases, but with less than 1 month, see Table 13.

Table 13: Changes in flood duration of inundated grasslands for the various hydrological years, going from the Baseline to the 20 Year Plan scenario

Grasslands		Decrease in flood duration				Increase in flood duration			
		2 - 3 m	1 - 2 m	0.5 - 1 m	< 0.5 m	< 0.5 m	0.5 - 1 m	1 - 2 m	2 - 3 m
DF vs BL	Dry year	0	1	9	47	23	20	1	0
	Avg year	0	7	11	40	21	21	0	0
	Wet year	0	0	2	71	20	7	0	0
20 YP vs BL	Dry year	0	7	29	31	3	10	19	0
	Avg year	0	10	34	24	11	14	7	0
	Wet year	0	0	14	69	11	6	0	0
20 YP + CC vs BL	Dry year	0	7	17	4	29	12	29	2
	Avg year	1	5	43	10	30	9	2	0
	Wet year	0	1	4	37	24	24	8	1
LTD vs BL	Dry year	1	24	22	22	3	9	16	1
	Avg year	0	12	36	29	5	12	5	0
	Wet year	0	2	22	62	8	4	1	0
LTD + CC vs BL	Dry year	6	57	4	3	7	4	17	1
	Avg year	0	1	35	3	9	18	30	2
	Wet year	1	33	34	30	1	0	0	0
VHD vs BL	Dry year	1	27	22	26	19	3	2	1
	Avg year	1	16	41	28	10	2	1	0
	Wet year	0	2	32	58	5	1	1	0

Changes in flod duration in the marsh areas are complex and hard to understand. Flood duration in less than half (42%) of the flooded marshes area reduces with up to 2 months in an average hydrological year, going from the Baseline scenario to the 20 Year Plan scenario. However, in 58% of the area, flood duration increases, generally with less than 1 month (See Table 14). In a dry hydrological year flood duration in over 70% of the flooded marsh area increases, in 44% of the area even with 1 – 2 months. In a wet year there is generally a reduction of flood duration (65% of the area) and changes are generally less than 2 weeks.

Table 14: Changes in flood duration of flooded marshes for the various hydrological years, going from the Baseline to the 20 Year Plan scenario

	Decrease in flood duration (month)			Increase in flood duration (month)		
	1.0 - 2.0	0.5 - 1	< 0.5	< 0.5	0.5 - 1	1.0 - 2.0
Average year	8	16	18	19	30	9
Wet year	2	10	53	20	15	1

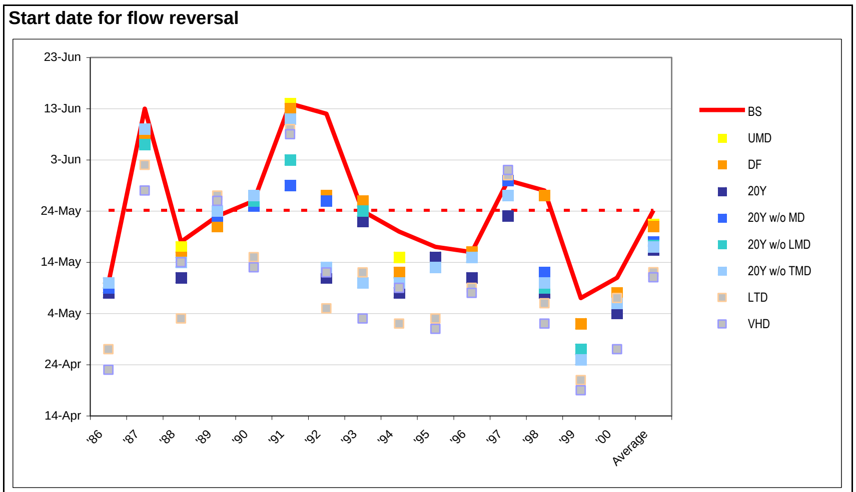
Dry year	4	14	11	5	23	44

4.2.5 Reverse flow of the Tonle Sap

Flow reversal occurs in the Tonle Sap River when floods rise in the mainstream and levels there exceed those in the Tonle Sap Lake, causing the river to reverse its flow into the lake. As the mainstream floods recede and levels fall there comes a point when the levels in the lake exceed those in the mainstream and normal flows resume. Two analyses have been conducted on flow reversal at the Prek Dam monitoring site. The first is to determine the likely impacts on the timing of when flow reversal occurs and the second is to assess changes in flow volume. As described in Chapter 3 these parameters are of importance for the ecological functioning of the Tonle Sap system and wider LMB.

The dates of when flow reversal occurs have been abstracted for each year for each scenario and averaged. In comparison to the baseline, reversal occurs slightly earlier in each scenario, but only by typically 3 days under both the Definite Future Scenario (within a natural range of +/-19 days). See Figure 12.

Figure 12: Start date of the flow reversal under the various scenarios



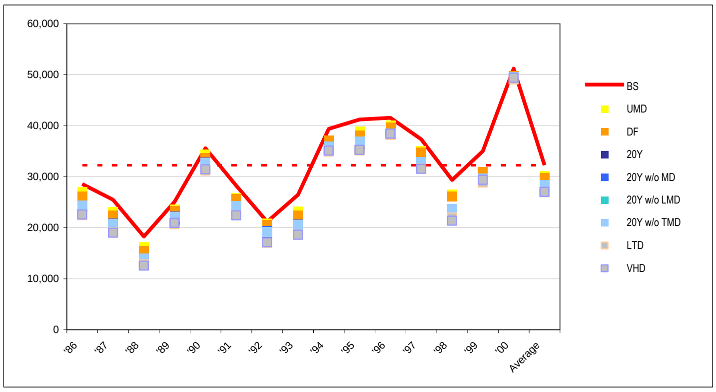
	BS	UMD	DF	20Y	20Y w/o MD	20Y w/o LMD	20Y w/o TMD	LTD	VHD
Average start date	24-May	21-May	21-May	16-May	18-May	17-May	17-May	12-May	11-May
Days earlier	0	3	3	8	6	7	7	12	13
Max-min start date	38	43	42	47	40	40	47	49	50
Range increase (days)	0	5	4	9	2	2	9	11	12

Under the 20-year Foreseeable Future Scenario the flow reversal date advances by 8 days, with no or fewer mainstream dams the change is somewhat smaller, 6 or 7 days. Under the Long-Term Development and Very High Development scenarios the flow reversal date is expected to advance with 12 to 13 days. In general the scenarios increase the variability of the start date, from +/- 19 days under the Baseline up to between +/- 25 days under the Very High Development scenario.

A similar analysis has been conducted on the average volume of flow that occurs each year during the flow reversal period (See Figure 13). The results are that under the Definite Future scenario there is a predicted decrease in flow reversal volume of 8% rising to 13% under the 20 Year Plan scenario, and to 16% under the Long-Term Development and very High Development scenarios, see Figure 13. Also the range between the minimum and maximum volume of the flow reversal increases gradually from the Baseline scenario to the Very High Development scenario. Under the latter scenario, the range is 12% bigger than under the Baseline scenario.

Figure 13: Volumes of flow reversal under the various scenarios

Volume of flow reversal MCM



	BS	UMD	DF	20Y	20Y w/o MD	20Y w/o LMD	20Y w/o TMD	LTD	VHD
Average volume	32,259	30,145	29,740	27,993	28,358	28,339	28,340	26,937	27,008
Change from BS	0%	-7%	-8%	-13%	-12%	-12%	-12%	-16%	-16%
Max-min volume	32,950	33,530	34,286	36,065	35,833	35,633	35,631	36,270	36,855
Range increase (MCM)	0%	2%	4%	9%	9%	8%	8%	10%	12%

Source: DSF post-processed outputs

The picture that emerges from these calculations is that higher water levels predicted in the mainstream at the end of the dry season will cause flow reversal to occur earlier with a reduction in the inflows to the lake.

4.2.6 Sediment inflow

Changes in expected suspended sediment loads are discussed in the report on geomorphological changes (Carling, 2010).

Carling stated that within a timeframe of 20 years sediment delivery to Cambodian and Vietnamese floodplains (including Tonle Sap) will not diminish. Sediment concentrations and deposition in kg/ha will remain unchanged and changes in grain size distribution of the sediment will not be noticeable. The total sedimentation area will reduce as a result of lower flood levels. At a time horizon of 50 years concentrations and deposition rates will decrease somewhat, but changes will still be very limited. The same is valid for the grain size distribution. Probably the D_{max} value will remain as it is, D_{50} may increase a little.

However, during an expert meeting in March 2010 (Carling, Kondolf and Koponen), these conclusions were revised and it was concluded that there would be immediate reductions in quantity (and changes in size distribution) of the sediments reaching the floodplains in Cambodia and Viet Nam, due to the dams in China and the dams in Upper Lao PDR. It was also concluded that additional mainstream dams would further reduce floodplain sedimentation. Impacts are expected to become noticeable in less than a decade.

This implies that, also given the fact that the reverse flow to the Tonle Sap area will reduce with 8 to 16 percent, the total amount of sediments brought to the system will decrease considerably, on the short term already. Furthermore there will be a gradual shift towards somewhat coarser sediments, that are less fertile than fine sediments.

4.2.7 Water quality

Under the various scenarios, irrigated rice cropping in the Tonle Sap Basin will increase in area. The use of agro-chemicals (fertilizers, pesticides etc.) will also increase, as will the population in the basin. As a result nutrient loads of the rivers discharging into the lake will increase, see the Annex on Water Quality (Annex E, Impacts on Water Quality) for details. Impacts on the water quality will be biggest in the dry season, when lake volumes and river discharges are lowest.

Dry season rice cropping in the Tonle Sap basin takes place in the months January, February and March. N losses under the Definite Future scenario are 1,280 ton, as compared to 10,559 ton under the

Very High Development scenario. P losses range from 166 ton (Definite Future) to 1,428 ton (Very High Development scenario). Applying the nutrient retention rate of 67% (See Annex E) and modeled future discharges of the Tonle Sap River over the months of January, February and March results in changes in concentrations as given in Table 15.

Table 15: Amounts of N and P discharged from the Tonle Sap basin into the Tonle Sap Lake and discharged via the Tonle Sap River

	Load (ton)		Discharge	Concentration increase(mg/l)	
	N	P	(MCM)	N	P
Present	427	55	20,460	0.021	0.0027
20 Year Plan	1,248	169	19,350	0.065	0.0087
20 Year Plan + CC	1,248	169	19,469	0.064	0.0087
Long-Term Dev.	1,507	204	17,230	0.087	0.0118
Long-Term Dev. + CC	1,507	204	18,805	0.080	0.0108
Very High Dev.	3,519	476	16,848	0.209	0.0282

Liljestrom (2007) calculated annual nitrogen and phosphorous fluxes at Prek Kdam. The results show that the annual net nitrogen flux (in a hydrological year) ranges between approximately 15,000 ton into the lake to 15,000 ton out of the lake. The annual net phosphorus flux ranges between approximately 1,200 ton into the lake to 1,700 ton out of the lake. The variation and ranges are large and the net fluxes are spread quite evenly over the entire range. The average values of the net fluxes indicate that the lake, on average, acts as a nitrogen sink and as a phosphorus deliverer. It has to be noted that these observations are based on a relatively short observation period: 7 years only.

However, the results on nutrient flux calculations for the Prek Kdam monitoring site suggest that there is a large variation in nutrient transportation into and out of the Tonle Sap Lake via the Tonle Sap River. According to the results, the lake acts during some hydrological years as a nutrient sink, and during others as a nutrient source. Nitrogen and phosphorus fluxes vary independently from each other.

The large variation in the net nutrient fluxes between hydrological years indicates that the nutrient movement and transformation processes are complex. More research is needed on factors that influence and contribute to the lake’s nutrient dynamics.

The increase in loads of approximately 1,500 ton (N) and 200 ton (P) in the dry season under the 20 Year Plan and Long-Term Development scenarios is relatively small compared to the annual flux of 15,000 ton (N) and about 1,500 ton (P). Therefore, also given the very large variation of fluxes over the years, increased nutrient loads to the lake are thought not to have significant impacts. The fact that the volume of the lake will increase significantly under the various scenarios further strengthens this conclusion. Locally, in areas where large amounts of domestic wastewater is discharged to the syatem, problems will occur and standards will be violated. Under the very high development scenario N and P loads in the dry season are much higher and the lake volume decreases again, hence violation of standards on the more regional level may also occur.

Until now there are no signs of any basin significant pollution with herbicides, pesticides and fungicides in the Mekong River’s water and sediments: pesticide levels were below detection limits in river water studies conducted between 2003 and 2004 (MRC, 2007). Pesticide applications are low in Cambodia, but expected to increase considerable going from the Definite Future to the Very High Development scenario. However, it is very hard to predict whether or not this will lead to detectable concentrations in the surface water and river sediments. Locally, intensive cultivation may result in concentrations that are above the thresholds values, as is already reported from certain parts of the basin.

4.3. Consequences for the biotic system

Overall changes in the biotic conditions in the Tonle sap system, going from the Baseline to theVery High Development scenario, can be summarized as follows:

- Reduction of the flooded area with 40,000 ha (3.4 %) under the Definite Future scenario in an average year, to 90,000 ha (7.3%) under the Very High Development scenario. Losses are bigger in a dry year (up to 110,000 ha or 9.8% under the Very High Development scenario) and smaller in wet years (at maximum 25,000 ha or less than 2%). Climate change reverses the trend, flooding increases with about 8% (96,000 ha) under the 2030 Climate change scenario and only reduces with 2.6 % (33,000 ha) under the 2060 climate change scenario.
- Reduction of the area of flooded forest ranging from 2,200 (0.5%) to 10,000 ha (2.1%) going from the Definite Future to the Very High Development scenario in an average year. In a dry year losses are bigger, up to 28,000 ha (6.5%) under the very High Development scenario. In a wet year losses are very limited, less than 0.1% (500 ha) under all scenarios. Climate change reverses the trend on the medium term and moderates the reductions on the long term.
- Reduction of the area of inundated grasslands ranging from 5,000 ha (1.9%) to 15,000 ha (5.4%) going from the Definite Future to the Very High Development scenario in an average year. In a dry year losses are bigger, up to 31,000 ha (12.4%) under the very High Development scenario. In a wet year losses are smaller: 0.7% (2,100 ha) under the Very High Development scenario. Again, climate change reverses the trend on the medium term and moderates the reductions on the long term.
- Reduction of the area of flooded marshes ranging from 2,000 ha (0.6%) to 4,500 ha (1.4%) going from the Definite Future to the Very High Development scenario in an average year. In a dry year losses are bigger, up to 5,200 ha (1.7%) under the Very High Development scenario. In a wet year losses are smaller: 0.5% (1,500 ha) under the Very High Development scenario. Again, climate change reverses the trend on the medium term and moderates the reductions on the long term.
- Reduction of the area of flooded ricefields ranging from 30,000 ha (14.6%) to 63,000 ha (30.1%) going from the Definite Future to the Very High Development scenario in an average year. In a dry year losses are bigger (% wise), up 37.1% (46,000 ha) under the very High Development scenario. In a wet year losses are smaller: 6.6% (22,000 ha) under the Very High Development scenario. Climate change reverses the trend on the medium term and moderates the reductions on the long term.
- Reduction of flood depth of just over 0.5 m in an average and dry year for most of the area, under the 20 Year Plan, Long-Term Development and very High Development scenarios. Under the Definite Future scenario there is already a reduction of 30 to 40 cm. Climate change on the medium term, 2030, increases flood depths with 10 to 20 cm, on the long term, 2060, climate change will moderate the impacts of the Long-term Developments: reductions in flood levels will in general be 20 to 40 cm, compared to over 50 cm without climate change.
- Reduction of flood duration of the flooded forest area in an average year with generally less than 2 weeks under the 20 Year Plan scenario, but increasing to 2 weeks to a month under the Long-Term Development and the Very High Development scenarios. In a dry year reductions are bigger, in a wet year smaller. Climate change moderates the impacts.
- A reduction of the reverse flow with 8 (Definite Future) to 13% (20 Year Plan) and ultimately 16% (Long-Term Development and Very High Development scenario). No or fewer mainstream dams only has a limited effect on the reverse flow: the reduction will be 12% instead of 13%.
- Increase of the water level in the dry season with about 20 cm under the Definite Future scenario, 37 cm under the 20 Year Plan scenario and reducing again under the Long-Term Development scenario (34 cm) and the Very High Development scenario (16 cm). Under the 2 climate change scenarios water levels will rise with 50 to 60 cm. These increases in waterlevel result in a considerable increase in volume of the lake: 550 MCM (Definite Future) to over 1,400 MCM (under the long term climate change scenario) compared to the actual average dry season volume of about 1,500 MCM.
- Shift of the flow reversal date of 3 to 13 days (earlier), going from the Definite Future to the Vert High Development scenario.
- Reduction of sediment inflow in the system of at least 8 to 16% (due to reduced inflow alone), but probably much more, taking into account reduced sediment concentrations in the flood water.
- Overall reduction of primary production of 3.1 (Definite Future) to 7.4% (Very High Development scenario), only taking into account the reduction in flooded areas. When also taking into account the reduction in flood depth, food duration and the reduced sediment inflow, total reduction may easily amount to 20 to 30%.

- An overall increase in nutrient (and agro-chemical) inflow into the lake; and
- Blockage of the migration paths (by mainstream dams under the 20 Year Plan scenario, the Long-Term Development and Very High Development scenario) of a large number of ecologically and commercially important fish species.

Considered separately, most of above changes could be interpreted as fairly small, however, the cumulative impact on the Tonle Sap ecosystem could be very significant. Generally the 'Flood Pulse' is considered vital for the Tonle Sap ecosystem, species composition, and the internal nutrient cycle within the lake and its floodplain. The Tonle Sap ecosystem productivity depends on nutrient availability, fish migrations and the level and duration of the floods (fluctuation between terrestrial and aquatic phases) which determine the floodplain structure and habitat diversity.

Changes in maximum flood level and volume (lowered) during the flood season, water level fluctuation range (decreased) and flood depth and duration (generally shorter) will:

- Reduce natural decay and organic nutrients;
- Reduce input of sediments into Tonle Sap Lake and adversely affect the recycling of nutrients, threatening dry-season habitats, especially in areas with high fish productivity;
- Decrease habitat availability and fish spawning ground, following the decrease of inundated forests and grasslands in the floodplain; and
- Probably induce invasion of alien species e.g. Mimosa pigra.

As a very rough first estimate it could be reasoned that the reduction in flooded area, the reduced inflow and water and sediment and the change in flood duration and depth could result in an overall reduction of the primary productivity of the system of 20 to 30%. The increase in lake volume in the dry season and the increased inflow of nutrient may compensate part of these wet season losses.

Fish productivity is related to the availability of inundated habitats since the floodplain vegetation plays a crucial role by providing habitats, substrate areas, and food for fish and other aquatic organisms. As described in Chapter 3, fish catches in the area are directly related to maximum flood levels, sediment concentrations, duration of the flood (the longer the flood lasts the longer the fish can grow, provided there is enough food) and the characteristics of the flooded zone, grasslands playing an important role in nutrient cycling. With inundated grassland area decreasing with 2 to 4%, (average and dry year), decreasing flood depth and duration and lower sediment inputs, fish production could reduce with up to 15% under the Definite Future scenario. Construction of the mainstream dams under the 20 Year Plan scenario would seriously affect the migratory white fish species. Up to 75% of the fish catch in Tonle Sap depends on fish that migrate to the deep pools found from Kratie to Siphandon and beyond for dry season refuge. As a consequence (white) fish production could fall to well below 50% of the production under the Baseline scenario.

On the other hand a number of developments could also have a positive impact on the system and its resources: increased water levels and volume of the lake in the dry season will improve water quality in the dry season, the reduction in nutrient brought to the system with fine sediments could be offset by an increased inflow of nutrients from agricultural fields and waste water discharges, and the advanced onset of the reverse flow will reduce the water quality problems at the end of the dry season, so increasing the survival rate of black fish residing in the lake and its floodplains.

Impacts on biodiversity are expected to be considerable. The 2004 International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species mentions 197 species in Cambodia considered at risk of extinction, endangered, critically endangered, or vulnerable. Of the 197 species mentioned by IUCN, 24 are critically endangered, 39 are endangered, and 53 are vulnerable. Many of these are found in the Tonle Sap ecosystem: the Tonle Sap inundated forests form one of the most important breeding sites for at least 7 large waterbirds in Asia, including Globally Endangered Greater Adjutant *Leptoptilos dubius* and White-winged Duck *Cairina scutulata;* Globally Vulnerable Spot-billed Pelican *Pelecanus philippensis*; Milky Stork *Mycteria cinerea,* Lesser Adjutant *Leptoptilos javanicus*; Globally Near-threatened Oriental Darter *Anhinger melanogaster* and Painted Stork *Mycteria leucocephala.* Loss of inundated forest area, combined with a likely decrease in the ecosystems quality due to changing flood conditions, will further jeopardize the survival of these rare and endangered species.

Also depending on the system are the Critically Endangered Siamese Crocodile *Crocodylus siamensis* (one of the Mekong Flagship species); Hairy-nosed Otter, >5 commercial species of water snakes (caught and traded) and the endemic Tonle Sap watersnake *Enhydris longicauda*.

Not only the Siamese Crocodile, but also the other 3 flagship species (the Mekong Giant Catfish, the Irrawaddy Dolphin and the Sarus Crane) are depending on the Tonle Sap ecosystems, as well as at least 6 endemic species (5 endemic fish species and 1 endemic reptile species) out of 13 endemic species for the whole Lower Mekong Basin (or 46%). Table 16 gives an overview of the Critically Endangered, Endangered, Vulnerable and near-threatened species that depend on the Tonle Sap ecosystems.

Any change in area or conditions of these ecosystems/habitat will have an impact on the viability of their populations.

Table 16: Globally threatened species depending on the Tonle Sap system

BIRDS : 2 CR, 2 EN, 9 VU, 6 NT; 1 Flagship species				
No.	**Critically Endangered (CR)**	**Endangered (EN)**	**Vulnerable (VU)**	**Near-threatened (NT)**
1	Bengal Florican *Houbaropsis bengalensis*	White-winged Duck *Cairina scutulata*	Manchurian Reed-warbler *Acrocephalus tangorum*	Oriental Darter *Anhinga melanogaster*
2	White-shouldered Ibis *Pseudibis davisoni*	Greater Adjutant *Leptoptilos dubius*	Greater Spotted Eagle *Aquila clanga*	Grey-headed Fish Eagle *Ichthyophaga ichthyaetus*
3			Eastern Sarus Crane *Grus antigone sharpie* (Flagship)	Painted Stork *Mycteria leucocephala*
4			Masked Finfoot *Heliopais personata*	Asian Golden Weaver *Ploceus hypoxanthus*
5			Lesser Adjutant *Leptoptilos javanicus*	Black-headed Ibis *Threskiornis melanocephalus*
6			Milky Stork *Mycteria cinerea*	Black-necked Stork *Ephippiorhynchus asiaticus*
7			Spot-billed Pelican *Pelecanus philippensis*	
8			Eastern Imperial Eagle *Aquila haliaca*	
9			Yellow-breasted Bunting *Emberiza aureola*	
FISH : 2 CR; 4 EN; 1 Flagship species; 5 Endemic species				
1	Mekong Giant Catfish (Flagship & Endemic) *Pangasianodon gigas*	Mekong Freshwater Stingray *Dasyatis laosensis*		Tonle Sap ecosystems also support another 3 Endemics : Eye-spot Barb *Hampala dispar*, Thicklip Barb *Probarbus labeamajor*, Giant Barb *Catlocarpio siamensis*
2	Giant Pangasius *Pangasius sanitwongsei* (Endemic)	Jullien's Golden Carp or Seven-line Barb *Probarbus jullieni*		
3		Laotian Shad *Tenualosa thibaudeaui*		
4		Tricolor Sharkminnow *Balantiocheilos melanopterus*		
MAMMALS : 1 CR, 4 EN, 2 VU, 1 NT; 1 Flagship species				
1	Irrawaddy Dolphin (Mekong Population) *Orcaella brevirostris* (Flagship)	Hairy-nosed Otter *Lutra sumatrana*	Smooth-coated Otter *Lutrogale perspicillata*	Silvered Langur, Silvered Leaf Monkey, Silvery Lutung *Trachypithecus cristatus*
2		Fishing Cat *Prionailurus viverrinus*	Greater Slow Loris *Nycticebus cougang*	
3		Eld's Deer *Rucervus eldii*		
4		Hog Deer *Axis porcinus*		
REPTILES : 2 CR, 2 EN, 5 VU, 1 NT; 1 Flagship species; 1 Endemic species				
1	Siamese Crocodile *Crocodylus siamensis* (Flagship)	Yellow-headed Temple Turtle *Hieremys annandalii*	Malayan Snail-eating Turtle *Malayemys subtrijuga*	Asiatic Rock Python, Burmese Python *Python molurus*
2	River Terrapin, Mangrove Terrapin *Batagur haska*	Asian Giant Softshell Turtle *Pelochylys cantorii*	Asian Box Turtle *Cuora amboinensis*	The Endemic species : Tonle Sap Watersnake *Enhydris longicauda* .
3			Black Marsh Turtle *Siebenrockiella crassicollis*	
4			Giant Asian Pond Turtle *Heosemys grandis*	

5			Asiatic Softshell Turtle *Amyda cartilaginea*	
PLANTS : 1 VU				
1			Legume species *Cynometra inaequifolia*	

Note: Status derived from: MRC (2010), WWF, and IUCN Red List

4.4. Consequences for the use of Timber and non-timber products

As described in Chapter 3.3.2 the natural floodplain vegetation is used for the collection of a variety of wood and non-wood forest products for a variety of uses. Some forest animals and their products are collected, including bee wax and honey, whereas birds are hunted for food, pets, and trade. Eggs are collected for consumption. Aquatic plants are collected for human consumption, as feed for farm animals, or for further cultivation (e.g., lotus).

Reduction of the flooded forest area or decrease in the quality of the ecosystem will negatively affect the use that local people can make of this resource for their sustenance.

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