I I

MRC SEA FOR HYDROPOWER ON THE MEKONG MAINSTREAM

AQUATIC SYSTEMS BASELINE ASSESSMENT WORKING PAPER

8 March 2010

The MRC SEA of Hydropower on the Mekong mainstream comprises 4 main phases: (i) scoping, (ii) baseline assessment, (iii) opportunities & risks assessment, and (iv) avoidance, enhancement and mitigation assessment.

The Baseline Assessment Report has two volumes:

VOLUME I: Summary Baseline Assessment Report

VOLUME II: Baseline Assessment Working Papers

This working paper is one of eight in Volume II of the baseline assessment report. The two volumes formally conclude the baseline assessment phase of the SEA and documents the outcomes of the baseline consultations and SEA team analysis.

Disclaimer

This document was prepared for the Mekong River Commission Secretariat (MRCS) by a consultant team engaged to facilitate preparation of a Strategic Environment Assessment (SEA) of proposals for mainstream dams in the Lower Mekong Basin.

While the SEA is undertaken in a collaborative process involving the MRC Secretariat, National Mekong Committees of the four countries as well as civil society, private sector and other stakeholders, this document was prepared by the SEA Consultant team to assist the Secretariat as part of the information gathering activity. The views, conclusions, and recommendations contained in the document are not to be taken to represent the views of the MRC. Any and all of the MRC views, conclusions, and recommendations will be set forth solely in the MRC reports.

This document incorporates a record of stakeholder consultations and subsequent analysis. Whether they attended meetings or not all stakeholders have been invited to submit written contributions to the SEA exercise via the MRC website.

For further information on the MRC initiative on Sustainable Hydropower (ISH) and the implementation of the SEA of proposed mainstream developments can be found on the MRC website: *http://www.mrcmekong.org/ish/ish.htm* and *http://www.mrcmekong.org/ish/SEA.htm*

The following position on mainstream dams is provided on the MRC website in 2009.

MRC position on the proposed mainstream hydropower dams in the Lower Mekong Basin

More than eleven hydropower dams are currently being studied by private sector developers for the mainstream of the Mekong. The 1995 Mekong Agreement requires that such projects are discussed extensively among all four countries prior to any decision being taken. That discussion, facilitated by MRC, will consider the full range of social, environmental and cross-sector development impacts within the Lower Mekong Basin. So far, none of the prospective developers have reached the stage of notification and prior consultation required under the Mekong Agreement. MRC has already carried out extensive studies on the consequences for fisheries and peoples livelihoods and this information is widely available, see for example report of an expert group meeting on dams and fisheries. MRC is undertaking a Strategic Environmental Assessment (SEA) of the proposed mainstream dams to provide a broader understanding of the opportunities and risks of such development. Dialogue on these planned projects with governments, civil society and the private sector is being facilitated by MRC and all comments received will be considered.

CONTENTS

1 Setting the scene 4

2 Past Trends and current situation 9

2.1 Description of the main Mekong aquatic ecosystems 9

2.1.1 Zone 1 – China to Chiang Saen 9

2.1.2 Zone 2 – Chiang Saen to Vientiane 11

2.1.3 Zone 3 – Vientiane to Pakse – 13

2.1.4 Zone 4 – Pakse to Kratie, ... 15

2.1.5 Zone 5 – Kratie to Phnom Penh and the Tonle Sap 18

2.1.6 Zone 6 – Phnom Penh to the sea 20

2.2 Longitudinal trends 22

2.3 Hydrological processes and key aquatic habitats 26

2.4 Ecosystem services of each zone 32

2.5 Maps 36

References 37

AQUATIC ECOSYSTEMS BASELINE

Key Issues

1. **Mekong aquatic productivity and biodiversity** - Will changes in aquatic habitats caused by the construction of the mainstream dams reduce the productivity and biodiversity of the Mekong aquatic systems?
2. **Mekong aquatic ecosystem services** - Will other ecosystem services provided by the Mekong River and its floodplain be changed by the mainstream dams?

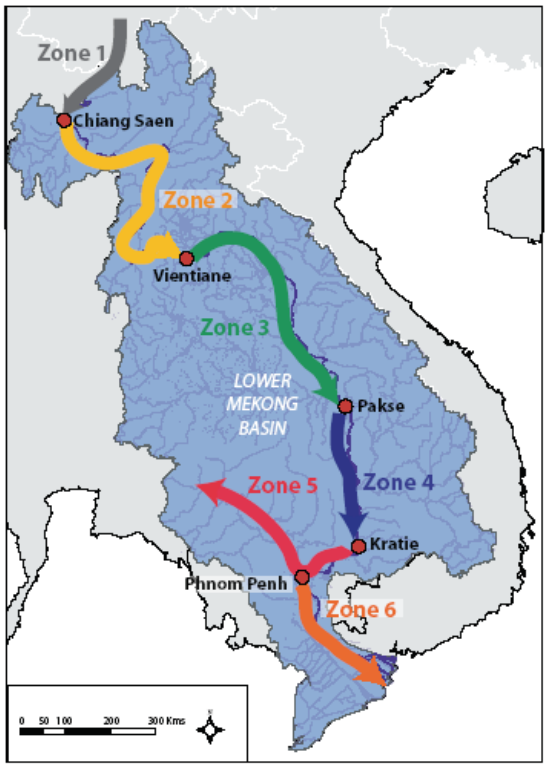
1 SETTING THE SCENE

Information on this theme paper is drawn from a number of different reports listed at the end of the paper. In particular the IBFM process undertaken by MRC between 2004 and 2005 has provided the structure of this theme paper and valuable information on the status of the different zones which has been complemented by other reports of surveys and studies. The Report on the Overview of present knowledge of the LMB ecosystem and its uses (MRC, 2005) pulled together both the reviewed literature and the specialist reports of surveys at key sites in each zone.

The ecological zones used by the IBFM process as presented in the IBFM reports no 5 and 7 (MRC, 2005) will be used as a basis to describe the main Mekong aquatic ecosystems. These are shown in Figure 1. The profile of the river from source to delta, with the gradient and catchment area, is illustrated in Figure 2.

Following the IBFM process, different aspects describing these zones have been provided since thes characterize the zones, including hydrology, river morphology, water quality, vegetation, aquatic invertebrates, fish, river dependent birds, mammals and amphibians and reptiles. The descriptions below also indicate the current status in terms of the ecological health of the river in each zone, its productivity, biodiversity. This then leads on to current pressures and the past changes and trends, followed by a discussion on predictions for the future status of the river in each zone.

Figure 1: Main aquatic ecological zones of the Mekong



Ecological zones considered:

- **Zone 1** – China to Chiang Saen – headwaters and mountain river
- **Zone 2** – Chiang Saen to Vientiane – upland river in steep narrow valley
- **Zone 3** – Vientiane to Pakse – the Thai/Lao midstream section and tributaries
- **Zone 4** – Pakse to Kratie, including wetlands of Siphandone, Khone Falls, Stung Treng and Kratie, including a number of significant tributaries
- **Zone 5** – Kratie to Phnom Penh and the Tonle Sap - Floodplains and the Great Lake
- **Zone 6** – Phnom Penh to the sea – Mekong delta, tidal zone

The MRC work on the water quality and ecological health deserves special mention because it provides a systematic assessment of the zones at selected sites. Results for the Mekong mainstream have been abstracted from the MRC (2007) report on water quality which summarized the status of selected sites down the Mekong mainstream as shown in the Table 1:

Table 1: Assessments of Water quality characteristics at selected sites on Mekong mainstream (MRC 2007)

Zone	Locality	Organic Matter	Nitrogenous matter	Nitrates	Phosphorous matter	Mineralisation	Acidification
Zone 1	Chiang Saen						
Zone 2	Louangprabang						
Zone 3	Vientiane						
	Nakhon Phanom						
	Khong Chiam						
Zone 4	Pakse						

(based upon the French water quality classification system. Blue = very good, Green = good, Yellow = fair, Red = bad)

Figure 2: Mekong River Profile from headwaters to mouth

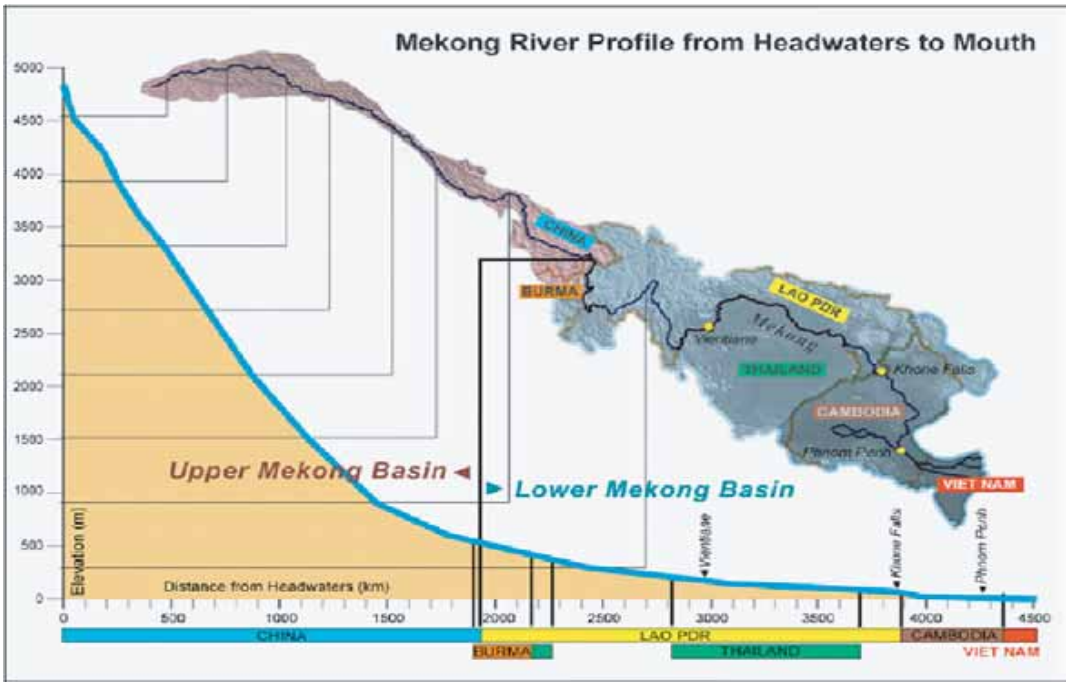


Figure 3 shows the hydrological contributions of the different tributaries and zones to the mean monthly flows in the river,

Figure 3: Contributions of different tributaries to mean monthly flows in the Mekong mainstream

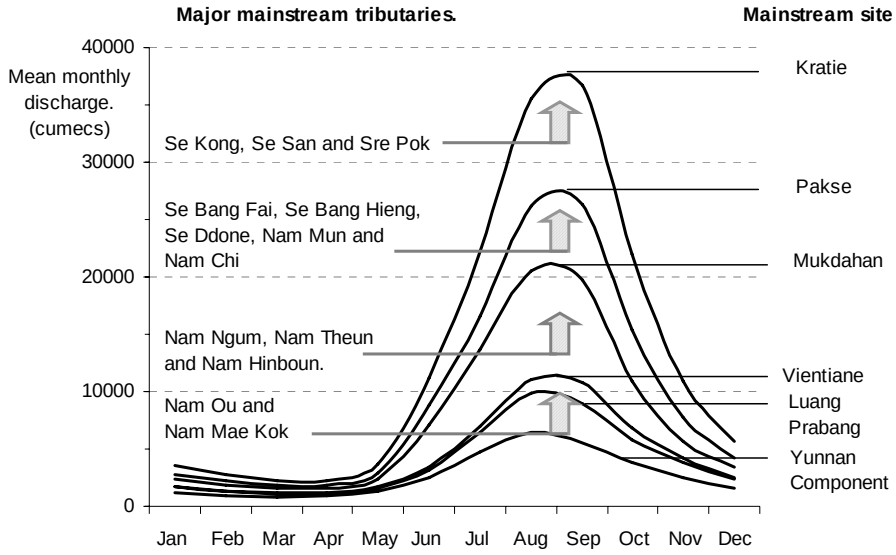


Table 2: Ecological health assessment at selected sites down the Mekong mainstream

Ecological Health from Card	Sample site	2004	2005	2006	2007	2008
Zone 1	LXT	C				D
	TCS					B
Zone 2	LPB	A	A			B
	LVT	C			B	C
Zone 3	TSM				C	A
	TNP					C
Zone 4	LDN				A	A
	CMR		B	A	B	B
	CKT	A		A		A
Zone 5	CSK			C		B
Zone 6 Bassac	CKL			B		C
	VKB					B
	VDP					C
	VLX			C		B
	VCT			C		B
Zone 6 Mekong	VTP					C
	VTT					C
	VCL			C		C
	VVL					C

Key	Code
Excellent	A
Good	B
Moderate	C
Poor	D

(note: samples sites arranged in order of distance down the Mekong from Chinese border to the Delta)
(Source: MRC Report Card December 2009)

The MRC Report Cards on Aquatic Ecological Health, assesses the proportion of littoral macroinvertebrates, benthic macroinvertebrates, benthic diatoms and zooplankton at different sites in Mekong mainstream and tributaries and compares them to reference sites. It grades the ecological health of the river at those sites and has been conducted progressively since 2004, and most comprehensively in 2008. The results are shown in Table 2:

The IBFM specialist studies and overview made an assessment of the ecological status of different zones based upon the different character and organisms found in that zone. The results of their assessments are shown in Table 3:

Table 3: Results of the IBFM specialist assessments of ecological status of different zones in the river[1]

Discipline	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Geomorphology (channel form)	B+	B+	A	B+	C
Water Quality (chemical only)	B	B	B	B	B-E
Vegetation - In Channel/River bank	C	C* / D#	B* / C#	D* / B-E#	C-D
Invertebrates	B	B	B+	B-	C
Fish	C	C	C	C	D
Water Birds	C	C	D+	D+	D+
Frogs/Reptiles	C / B-	C / B-	D+ / C+	D+ / C+	D+ / C+

A Excellent. ***Unmodified, natural***. Close to the probable condition in the absence of human intervention in the catchment.
B Good. ***Largely natural***. Modified from the original natural condition but not sufficiently to have produced measurable change in the nature and functioning of the ecosystem.
C Satisfactory. ***Moderately modified***. Changed from the original condition sufficiently to have measurably altered the nature and functioning of the ecosystem, although the difference may not be obvious to a casual observer. Efforts should be made to ensure that no further deterioration occurs.
D Room for Improvement. ***Largely modified***. Sufficiently altered from natural for obvious impacts on ecosystem nature and functioning to have occurred. Management agencies should be developing strategies to improve the conditions.
E Improvement Necessary. ***Seriously to critically modified***. Important aspects of the original nature and functioning of the ecosystem are no longer present. The area is heavily impacted by human interventions.

[1] Note that IBFM sites and zones were numbered slightly differently, so the zone numbering in Figure 6 has been altered to make it compatible with the zones used in this paper

2 PAST TRENDS AND CURRENT SITUATION

2.1 DESCRIPTION OF THE MAIN MEKONG AQUATIC ECOSYSTEMS

2.1.1 ZONE 1 – CHINA TO CHIANG SAEN

This zone covers the headwaters and mountain river section in China, and as it flows between Myanmar and Laos to the Golden Triangle with Thailand at Chiang Saen. The river profile shown in Figure 2. shows that it flows through China for over 1900 km and reaches Chiang Saen after 2260 km from the source, or 2240 km from the mouth. It is a steep mountain river, flowing through narrow gorges with a very small catchment and relying heavily upon the meltwaters from the glaciers at the source. The key hydrological feature is that the about 16% of the total annual flow in the Mekong at the Delta originates in China, as well as about 40% of the sediments. An additional 5% of the flow is contributed from tributaries in northern Laos and Myanmar.

After it flows through between Laos and Myanmar, the river continues through a series of massive rocky outcrops and rapids alternating with deep pools and exposed sandbars in the low flow season. As it approaches Chiang Saen it widens and slows somewhat adopting a more meandering course, with associated wetlands and reedbeds to the south of Chiang Saen. The water quality as measured by MRC monitoring shows an overall excellent quality, with high Total Suspended Solids (as is to be expected, since this area is a principal source of sediments) but with some evidence of toxicity (arsenic, chromium and mercury) in the sediments at the Chinese border, possibly as a result of industrial and urban pollution upstream. This benthic toxicity probably underlies the poor ecological health of the river at Ban Xieng Kok just downstream from the Chinese border.

Overview of ecological status – ecological health, productivity, biodiversity. The ecological status of the river in China can not be commented on at this point (we wait for information from the Chinese collaborators on this SEA) However as will be shown below the river is in the process of being significantly modified in China, and we would expect disturbances to the ecological status there. The species list of fish in the Lancang river shows that there are 162 species of fish recorded, of which at least 61 species are common with fish species in the Lower Mekong Basin.

Geomorphologically, the river still has the appearance of being relatively intact although a number of the major rapids have now been removed in the section downstream of the Chinese border. The water quality is generally good, but noting areas of concern south of the Chinese border. In terms of vegetation, whilst the surrounding landscapes are generally forested (mixed deciduous), only a very small proportion of primary forest remains, and the rest is secondary forest having been heavily logged along the river valley, with some slash and burn agriculture, and replacement growth of bamboo. River bank vegetation is generally intact, and small shrubs grow on the more stable sandbars and rocky

outcrops. The aggressively invasive plant, *Mimosa pigra*, is spread by water, and has established itself even far upstream in Zone 1 taking over areas of river bank and sandbars. Aquatic invertebrates are typical of such fast flowing rivers, with mainly species adapted to living in such conditions. The presence of at least 157 species of fish was recorded in surveys in 2003 and 2004 for the stretch between Xieng Kok and Louangprabang. Fishing activities tend to be focused around the small communities for local livelihoods, using deep pools and rocky and shoal areas. Of the river dependent birds, a total of 87 species were reported in the above surveys. No information is available on reptiles and amphibians or river dependent mammals, but it is probable that the river corridor remains good, largely natural. (Meynell et al, 2003 and Dubeau et al, 2004)

Current Pressures, changes and trends. There have been a number of changes to the river system in Zone 1. Three hydropower dams in China have now been completed (Manwan 1996, Dachaoshan 2003, Jinghong, and Xiaowan is now reported to be filling). In 1992, when Manwan was being built, there was a significant drop in TSS reported at Chiang Saen and Luangprabang, with wide fluctuations in TSS load over 2,000 mg/l before 1992, and with smaller fluctuations up to 1,000 mg/l since then. (MRC, 2007). It is interesting that the lowest Chinese dam, Mengsong, has been cancelled due to the impact that it would have on fish migrations. (Kang et al 2008)

Navigation has increased significantly since 2003, with ships up to 150 tonnes regularly moving between Chiang Saen and China (in 2004-5, there were a total of 2,160 commercial boat trips in this zone). The river channel modifications removing 11 major rapids and shoals and 10 scattered reefs was completed by 2004, under the Lancang-Mekong Navigation Channel Improvement project. There has been an increase in the risks of water pollution (organic matter, oil spills etc) as a result of this navigation traffic, and the construction of a port in Chiang Saen and river embankment schemes. There are also reports of increased river bank erosion, disturbance of fishing craft and nets as a result of this increased traffic (Lazarus et al, 2006).

Other pressures on the natural resources of the river come with increased access – both navigation and roads – and include increased hunting and fishing for both subsistence and wildlife trade.

Predictions for the future. The dams in China will have an increasing impact upon the hydrology of this zone, with over 75% of the flow at Chiang Saen being derived in China. There will be an increasing tendency for markedly increased dry season flows and lower wet season flows, which will have an impact upon all aspects of the river morphology and ecology.

The increased dry season flows will benefit navigation and this is likely to be further enhanced by further removal of 51 rapids and shoals to make the waterway navigable by vessels up to 300 DWT for at least 95% of the year - Phase 2 of the Lancang-Mekong Navigation Improvement Project. In Phase 3 it is proposed that canalisation of the river would enable ships of up to 500 DWT to pass up the river. The navigation channel would be extended from Chiang Saen to Louangprabang. With increased navigation

traffic both in size and frequency there will be additional pressures on the ecological health of this zone, from the increased water pollution, river bank erosion, increased access and disturbance both of biological resources and local river users. (Lazarus et al, 2006)

2.1.2 ZONE 2 – CHIANG SAEN TO VIENTIANE

In this zone, which extends for some 800 km between km 2380 and km 1585 from the mouth, the river progresses as an upland river in steep narrow valley, down a single-thread, bedrock confined channel. There are areas where it spreads out in a local floodplain e.g. downstream of Chiang Saen down to the border between Thailand and Laos, and from the confluence with the Nam Ou down to Louangprabang, and then as it enters the Vientiane plain at the southern end of the zone. About 8% of the annual flow in the Mekong is contributed from tributaries such as the Mae Nam Ing and Mae Nam Kok from Thailand, and the Nam Tha, Nam Beng and Nam Ou from Laos. In between Louangprabang and Vientiane there are only very small tributaries, contributing a total of only 3% of the flow.

The river morphology, considered largely natural, consists of a changing pattern of rocky outcrops, rapids and deep pools, shoals, riffles and sandbars creating a wide variety of aquatic habitats along this zone. The river bank is generally steep and rocky, with some large sandbars being exposed as the water recedes at the end of the wet season. There is a major area of deep pools around the confluence with Nam Ou, and four other localities where deep pools are found – near Chiang Kong/HouayXai, in Xaiyabouly and at Chiang Khan.

Overview of ecological status – ecological health, productivity, biodiversity. Water quality is considered to be generally very good, with low nitrogenous nutrients, throughout this zone until Vientiane is reached. At Vientiane, the water quality shows a raised organic matter, mineralization and acidification. Louangprabang and Vientiane both have slightly raised heavy metal content ascribed in MRC (2007) to high tourist boat traffic in the former and high urban populations in the latter city. The ecological health card report (MRC 2008) shows that conditions appear to be deteriorating from excellent health at Louangprabang in 2004 and 2005 to good health in 2008, whilst in Vientiane the ecological health has varied between being rated as moderate to good.

The vegetation on the hillsides of the valley throughout this zone are generally secondary forests which have been logged or cleared for slash and burn cultivation. There are some small areas of teak plantation near some of the riparian communities. The riparian vegetation, which may not be very wide, has usually been cleared near these communities, and river bank gardens may be planted, and there is some use of the sand banks for cultivation of maize, groundnuts and vegetables as well. In some areas, especially lower down the zone in Xayabouly and Vientiane provinces, there are extensive wetland areas in channel that are exposed during the low flow season. These may be unvegetated, or on the more stabilized areas vegetated with *Homonia* shrubs and large grasses and *Phragmites* reeds. These habitats are important fish breeding and productive areas and it is noticeable that fishing activities are often

focused around these. Personal observation would rate these wetland vegetated areas as good, largely natural in comparison to the lower rating of the IBFM team. The zone is also an important area for the collection of "river weed" which is a characteristic mix of Cladophora and other filamentous algae, and which is collected for sale in the shallow areas during the low flow season. Its production and collection depends upon seasonal fluctuations in water levels, and is reported to have decreased in the Mekong in Northern Laos as a result of hydrological changes (Lazarus, 2006). Invertebrates in this zone are also rated as good, largely natural and would be representative of the wide variety of habitats in the river channel.

There are 140 species of fish in 30 families represented in this zone, which forms a transition zone between the upper Mekong fish species and those typical of the slower more lowland type of river. Migratory species use this stretch of river, most notably the Mekong Giant catfish, which supports a culturally important fishery around Chiang Khong, and which is known to breed nearby. The gravel beds and riffles, and vegetation in the in-channel wetlands are favoured places for fish breeding. The zone also provides for at least three habitats for river dependent birds – open sand bars and mudflats, tall grass/reed beds, and exposed bedrock and vertical earth banks. Four Important Bird Areas (IBAs) have been identified in this zone – Chiang Saen Basin (also containing a Ramsar site), Upper Lao Mekong (the river channel in Bokeo, Oudomxay and Xaignabouly provinces), Mekong Channel in Pak Chom, and the Mekong channel upstream of Vientiane. All are considered important for congregatory water birds, the River Lapwing and Small Pratincole. There are at least 17 species of amphibians and 25 species of reptiles that could exist in these zones, although a systematic survey has not been undertaken here. There are regular reports of softshell turtles (*Amyda cartilaginea*) being caught by fishermen as far upstream as Bokeo. In general, the IBFM ratings for the biological component of this area as being satisfactory, moderately modified are appropriate.

Current Pressures, changes and trends

No major river channel modification has taken place yet under the Lancang-Mekong Navigation project, although this remains one of its objectives. There are no major schemes abstracting water for irrigation, but there are plans for a cascade of eight dams on the Nam Ou being developed. Various pressures include the disturbance (especially noise from the speedboats) and pollution caused by tourist boats operating between Houay Xai and Louangprabang. There is some limited navigation with 30 DWT boats between Vientiane and Louangprabang in the high flow season. There are a number of logging operations and riverbank sawmills along the stretch between Louangprabang and Sanakham, which may cause some pollution or organic matter and possibly wood preservative chemicals (presumed?). Pollution pressures from the urban centres of Vientiane and Louangprabang persist and will increase as urban populations grow.

Predictions for the future

Generally this zone is one of the most dramatic and unspoilt landscapes of the Mekong, appreciated by an increasing number of tourists. The hydrological changes caused by the Chinese dams will continue to be significant in this zone, since the contribution of the Yunnan component is just under 50% of the total annual flow at Vientiane. The flows below Louangprabang will also be affected by the cascade of changed hydrology of the Nam Ou when the cascade of dams is completed. This will mean higher dry season water levels – possibly by as much as 1 metre, which will change the distribution and appearance of deposited sandbars, reduce the areas of in-channel wetlands that dry out and become vegetated in the low flow season. There will also be less sediment coming down the river as more is trapped behind the Chinese dams. This could be as much as

2.1.3 ZONE 3 – VIENTIANE TO PAKSE –

Zone 3 covers the stretch of river between Vientiane and Pakse, the joint Thai/Lao midstream section and its tributaries. It extends from km 1585 to km 870 from the mouth, a distance of some 700 km. The river flows generally eastwards from Vientiane until the Nam Kading, when it turns south-eastwards and south towards Thakek/Nakhon Phanom, thence to Savannakhet/Mukdahan and eventually to Pakse. During this zone, there is significant contribution to the flows from the Lao tributaries including the Nam Ngum, Nam Kading, Nam Theun, Nam Hinboun, the Xe Ban Fai and the Se Don. On the Thai side the Nam Songkhram and Mun/Chi catchments make further significant contributions. Between Vientiane/Nong Khai and Nakhon Phanom, a total of about there is a contribution of about 22% to the annual flow in the Mekong, of which 18% comes from the left bank (Laos) tributaries. Between Nakhon Phanom and Mukdahan, there is a further 4%. Between the tributaries between Mukdahan and Pakse contribute a further 10% with about 6% coming from the Mun/Chi catchment.

The river in this zone is characterized by a generally broad, slower flowing river in a single-thread alluvial channel with a local propensity to develop large-scale braids in the form of isolated lozenge-shaped islands. The river channel is mostly sand and finer sediments, with bedrock becoming increasingly scarce downstream until the confluence with the Mun river. The zone has numerous sandy islands, some mid-channel and some partially attached to banks. Many probably have rock cores. Between Mukdahan and Pakse, the river cuts through some impressive sandstone escarpments on both Thai and Laos sides, and in this section it again passes through a series of narrow channels between rocky outcrops, rapids and shoals. There are six localities where deep pools are found – often associated near the confluences with major tributaries.

Overview of ecological status – ecological health, productivity, biodiversity. In terms of water quality, the zone has been classified as generally good, but with raised organic matter (pollution from urban areas of Vientiane, Nakhon Phanom and Khong Chiam, and with increased acidification with passage downstream. There has been a concern about high salt concentrations draining from the Khorat plateau,

brought in through the Songkhram and Mun/Chi Rivers, but these would appear to be largely diluted by the larger flows in the Mekong mainstream. The ecological health of the river downstream of Vientiane appears generally excellent, although there may be local areas, e.g. around Nakhon Phanom where the ecological health indicators decline.

The vegetation on the river banks has largely been modified, especially where villages and towns have been established together with agricultural cultivation. Agricultural development is high on the Thai side. River bank gardens are also a significant feature along this zone, associated with such riparian communities. Seasonally inundated floodplains occur in places behind the levees and more extensive floodplains where major tributaries enter the Mekong. The inner banks of the levees support soft-stemmed, fast-growing plants such as *Phragmites*, and scattered woody plants may occur on their tops. The actual mix of species depends on the slope of the river bank, with shallower slopes supporting species such as burdock (*Xanthium*), *Melilotus* and *Phylla*. The floodplains behind the levees receive annual doses of fertile sediments and flood water, and comprise very productive landscapes. The rice lands on these floodplains contain scattered remnants of a short-tree forest with species endemic to this area, and wetland plants such as sedges, reeds and water lilies. Tree species on higher areas include *Dipterocarpus*, *Hopea* and *Croton*, with many introduced species, among cultivated areas of papaya, cassava, banana and tobacco. On some of the rocky islets upstream of the Mun river confluence, the scattered, rheophytic trees - *Anogeissus rivularis*, can be found. These are trees of the channel woodland typical of braided channels found in Siphandone and Stung Treng. The major habitats for aquatic invertebrates include the sandy deposits, which generally have lower numbers of species and populations than the more diverse habitats upstream. Nevertheless there are abundant large palengeiid mayflies that burrow into the softer sediments and provide food for the fish. There are also a number of snail, shrimp and mussel species that are eaten by local people. No surveys of fish species in the Mekong mainstream in this zone have been undertaken, although a number of studies have been done in the Nam Songkhram, Nam Hinboun and Mun rivers indicating high biodiversity (over 200 species). No surveys of birds have been reported in this stretch, though the presence of sandbars and fine sediments exposed during the dry season make good feeding grounds for birds, and the high cut river banks make good nesting sites. A short distance from the Mekong and linked to it through the backflows up the Songkhram river is the Thai Ramsar site of Bung Khong Long, important for wintering migrant birds and for several endemic species of fish. Similarly there are no surveys of amphibians and reptiles, and water dependent mammals in this Zone. The IBFM specialists rated this zone as satisfactory, moderately modified.

Current Pressures, changes and trends – The hydrological influence of the Chinese dams will be becoming less significant in this zone, as about 40% of the total flow in the Mekong comes from tributaries along this stretch of the river. Thus the contribution of the Yunnan component is only 22% at Pakse. However, there are some large hydropower developments on the tributaries for example six dams in the Nam Ngum basin, the Theun-Hinboun hydropower complex, and Nam Theun 2, and the

flows in the Mun/Chi rivers modified by irrigation reservoirs and hydropower dams. In the short term, the dry season discharge at Savannakhet may increase by 70% corresponding to a water level increase of 65 cm, and during floods, the discharges may be reduced by around 10% corresponding to a reduction in water levels of 85 cm. (Norplan, ADB. Nam Theun 2 CIA, 2004)

There are regular pumped offtakes of water from the river on both Thai and Laos sides for irrigation. There is less navigation or tourist traffic in this zone, and ferry crossings between Nakhon Phanom and Thakek, Mukdahan and Savannakhet have been much reduced by the construction of new bridges across the Mekong. Pollution from urban areas and agricultural run-off may cause local pollution pressures. Fishing pressure and use of illegal fishing methods may increase with increasing populations.

Predictions for the future – with all the hydropower development in Yunnan and in the Lao tributaries the Nam Theun 2 CIA predicted that the dry season flows at Savannakhet might increase by 135% corresponding to a water level increase of 1.2 m and during floods the discharge might be decreased by 20%, corresponding to a lowered water level of 1.6 m. The localized impact of Nam Theun 2 will be to reduce the flows in the Mekong between Pak Hinboun and Xe Bang Fai by about 2 cm in the dry season and 23 – 29 cm in the wet season. These general increases in water level will tend to reduce the diversity of habitats and productivity, with less exposure of the sandbars and river banks in the dry season. (Norplan, ADB. Nam Theun 2 CIA, 2004)

2.1.4 ZONE 4 – PAKSE TO KRATIE,

Zone 4 covers perhaps the most spectacular reaches of the river between Pakse in the South of Laos to Kratie in Cambodia, including the border between these two countries. It extends from 870 km to 560 km upstream of the mouth of the river, with the border lying at 722 km. It includes Siphandone and the Khone-Phapheng Falls, the Stung Treng Ramsar site, between the border and Stung Treng town and the reach between Stung treng town and Kratie. Between Pakse and Kratie town there is one major tributary entering from the left bank – the combined flows of the 3S river – Sekong, Sesan and Sre Pok, which contribute about 22% of the flow of the Mekong, with a further 2% being contributed from smaller right bank tributaries. The 3S rivers together, the main rivers draining the Central Highlands, are considered to contribute over 50% of the sediment in the Mekong reaching the Delta (Adamson 2009, quoting Clift et al 2004).

The river in this zone may be characterized initially as a single-thread channel with local development of multiple channels in the upstream portions of the zone, which develops into major multiple-channel, braided, bedrock-confined reaches in the lower portion of the zone immediately upstream of Khone Falls. This extends below the Falls to Stung Treng and to some extent as far as Kratie. The river width varies from a single channel of about 700m at Pakse, to over 10 km with multiple channels in Siphandone, and down to Stung Treng. There are a wide variety of different channel morphologies determined by the underlying bedrock and seasonal distribution of sediments in sandbars.

This is an area of significant development of deep pools, especially both around and below the Falls, and down to Kratie. The MRC Hydroacoustic survey of deep pools (MRC Technical Paper No 11, 2006) in the area surveyed 30 deep pools, of which the deepest was 77 m, (Koh Kan Din) is about 10 km upstream of Stung Treng town. Chan et al (2005) provides details on the location, depth and dimensions of 95 pools in both Stung Treng and Kratie provinces.

Overview of ecological status – ecological health, productivity, biodiversity. Generally this zone is considered by the IBFM specialists as the most natural, least modified part of the river channel. At Pakse the water quality is generally good, and this is maintained through the system to Kratie, although one bioassay test (2003) carried out by MRC at Kratie indicated toxicity. WWF (2009) have carried out studies on the causes of mortality of the Irrawaddy dolphins in the area and have found raised tissue levels of Persistent Organochlorine Pesticides such as DDT and PCBs as well as mercury, which would indicate bioaccumulation of these immuno-toxic chemicals, that may contribute to the high mortality of this endangered mammal living in the zone. The MRC bioassessment shows generally good to excellent health of the zone based upon plankton and macroinvertebrates, and this is confirmed by the IBFM macroinvertebrate specialist report. Also the recent reports by fishermen of excessive growths of filamentous algae, probably *Hydrodictyon* sp. possibly indicates a trend towards eutrophication (Allen et al 2008).

The Siphandone area is a zone of wide slow-flowing water dotted with countless islets. Distinctly different plant communities occur on sandy, rocky or silty substrata, with that on the rocky islets being endemic to the area. The emergent shrubby rheophytes on the rocky islets, including Homonia, Telectadium and *Rotula,* are highly valued by the Lao people. Islands with silty deposits over bedrock cores support a variety of pioneer species including lianas and the invasive alien species, *Mimosa pigra*. Stout trees, including *Anogeissus, Acacia, Eugenia* and *Gymnosporia* occur in succession from water level up the banks of the river. The widening channel and slowing of flow cause suspended sediments to be deposited, resulting in an increase in water clarity and growth of a unique community of algae. Vegetation classifications found in Stung Treng Ramsar site include unique seasonally flooded forest - channel woodland (*Anogeissus, Acacia*); channel bushland (*Phyllanthus, Telactadium*) sand and grass on sand bars, riparian forest, tall grassland on floodplains, and agriculture. The terrestrial habitats include mixed deciduous, dry dipterocarp and semi-evergreen forests. Wet grasslands and seasonal ponds are found amongst these terrestrial habitats (Allen et al (2008). Similar vegetation for the reach between Stung Treng and Kratie described in detail in Bezjuin et al (2008).

Biodiversity is greatest in this zone, because of the diversity of aquatic habitats. This has been recognized in the designation of the Stung Treng Ramsar site, that extends from just upstream of Stung Treng town to a few kilometres short of the border with Laos. This part of the river is recognised internationally as a biodiversity hotspot for freshwater snails, with around 120 species having been described from the area. One of these, *Neotricula aperta*, is a host for schistosomiasis. Other common

invertebrates are baetid mayflies and shrimps. Dry-season emergence of mature aquatic flies is sufficiently abundant to form an important source of food for fish. In Stung Treng Ramsar site, IUCN surveys have indicated 19 mollusc species being collected regularly and being sold in Stung Treng market, and 17 species of dragonflies (Allen et al. 2009). WWF surveys in the area between Kratie and Stung recorded 17 edible mollusc and 6 crustacean species (Bezuijen et al 2005).

Khone Falls and the 3S rivers are major migration routes for fish at all seasons. Consolidation of species reports of fish for the area from Baird (2001), Allen et al (2008) and Bezuijen et al (2008), indicated above in Table 4, show that there are 168 fish species in 34 families in Siphandone and 204 species in 37 families in the Stung Treng area (Baran, pers com). The IBFM specialists considered that the fisheries status of the area was satisfactory, moderately modified.

The area is also recognized as an Important Bird Area, both Dong Kalo and Siphandone in Laos and from Laos border to Kratie (Laos IBA 021 and 022) and (Cambodia IBA 023) which are important for congregatory waterbirds, River Lapwing, and various globally threatened species such as White-shouldered ibis, Spot-billed pelican and Lesser Adjutant.

Of reptiles, there is evidence that very small, isolated populations or even individuals of the critically endangered Siamese Crocodile still exist in the Stung Treng Ramsar site. At least 7 of the 44 species of Cambodian amphibians have been found in Stung Treng, (Allen et al. 2008) and 12 amphibian species between Kratie and Stung Treng (Bezuijen et al 2008). Hard and soft-shell turtles are also found in the river, using the sandy banks as nesting areas.

The most important river dependent mammal species in the zone extending from the Laos border below Khone Falls to Kratie, is the Irrawaddy Dolphin, which is critically endangered, inhabiting a number of the deep pools during the low flow season, and spreading out during the high flow seasons, occasionally moving well up the 3S tributaries. Beasley et al (2003) estimated that there were between 100 and 140 individuals of the dolphin in this zone of the Mekong, and WWF (2009) estimates that there have been 88 recorded dolphin deaths since 2003, and the current population lies between 66- 86 individuals. Other water dependent mammals include otters (Smooth-coated and Hairy-nosed otter), but these have suffered heavily throughout the region due to a lucrative trade in live animals and body parts.

Current Pressures, changes and trends – Whilst there has to date been little infrastructure development on the river in this zone, and habitats have remained largely intact, pressures from increasing use of natural resources, such as fish, other aquatic animals are showing a trend in terms of reduced populations, if not loss of some species. Use of illegal methods, hunting and the trade in wildlife has also taken its toll in many species populations. WWF reports that there is a high risk of extirpation of most of the large mammal species in the Stung Treng to Kratie area, population declines of at least 23+ bird species, 6 turtle species, large lizards and snakes, and population decline of Cantor's Giant softshell turtle due to egg collection and capture, Bezuijen (2008) Changes in land use surrounding the river has

also been responsible for loss of gallery forest and riverine vegetation, conversion into agricultural areas and concessions that are reported to have damaged local fisheries. Mortality due to disease and accidental capture in fishing nets of Irrawaddy Dolphin is extremely serious, and is likely to lead to their local extirpation in the next decade. There is an expanding tourism interest in the Dolphin, both in Cambodia and Laos, and disturbance from boat engines and pollution may add pressure on the population. Weed invasion by *Mimosa pigra* and the excessive blooms of filamentous algae, both point to a stressed environment.

The construction of hydropower dams on the 3S rivers, especially the recently approved Lower Sesan 2 HPP at the confluence between the Sesan and the Sre Pok rivers will effectively block fish migration and the overall connectivity of the river system. Dams upstream on the 3S rivers will trap a large majority of the sediment coming down the river.

Whilst measures have been suggested for conservation in Siphandone, Stung Treng Ramsar site and the reach between Kratie and Stung Treng (Allen et al 2008) and Bezuijen et al (2008), little effective conservation management measures have been put in place. A protection zone for the Irrawaddy Dolphins has been proposed by WWF focused around the key deep pools inhabited by the dolphins, e.g. at Kampi. Government measures to prohibit use of nets in certain deep pools are also in place.

Predictions for the future – The pressures on the zone from developments and land use change in this area are increasing and without adequate planning and management controls will continue to degrade the riparian and riverine ecosystem. Whilst it will continue to be the most biodiverse area of the Mekong, there will inevitably be losses of both fish and river dependent species. The fish resources will continue to decline with changes in habitat, overfishing and use of illegal methods. The potential changes in water quality, indicated by the bioaccumulation of POPs and mercury in dolphins, and the blooms of filamentous algae will need to be monitored and analysed more closely.

2.1.5 ZONE 5 – KRATIE TO PHNOM PENH AND THE TONLE SAP

Zone 5 covers the lowland river section between Kratie and Phnom Penh – km 560 to km 225 from the mouth of the river, and the Tonle Sap system – the Great Lake and Tonle Sap river. Kratie is generally considered the point where the hydrology and hydrodynamics of the Mekong change significantly. The Tonle Sap catchment contributes about 9% of the total annual flow of the Mekong, but the flows in Tonle Sap are in a dynamic relationship with the flows in the Mekong, flowing up the river into the Great Lake at times of high flow in the Mekong, and reversing as the water level in the Mekong falls. The hydrology is extremely complex because of the very low gradients and the focus is upon assessment of water level, over-bank storage and flooding and the hydrodynamics that determine the timing, duration and volume of the seasonal flow reversal into and out of the Great Lake. During the low flow season the depth of the lake may be about 1m, increasing to up to 10 m during the high flow season. The area of the Great Lake may expand up to six times in the wet season, creating extensive wetlands around the

entire water body. The Lake retains about 80% of the nutrients and sediments that flow into it during flow reversal. The seasonal storage of water in the Tonle Sap system provides significant regulation of the water flows downstream to the Delta.

This is an area where the Mekong floodplains extend from around Kampong Cham southwards to the Delta. The river morphology of this reach consists of a meandering alluvial channel with a propensity to develop, at the simplest, divided channels composed of only two main channels, and at the most complex, large-scale meandering reaches that consist of multiple channel networks. Only one minor area of deep pools exist, upstream of Kampong Cham as the river emerges on to the floodplain.

Overview of ecological status – ecological health, productivity, biodiversity. Generally, the IBFM geomorphology and water quality specialists considered that this reach was good, largely natural. Water quality assessments at Kampong Cham and downstream indicate excellent water quality for protection of aquatic life. (MRC Water Quality Report Card, 2008). However, water quality in the Tonle Sap river may not be as good relative to the Mekong – there are indications of elevated levels of total heavy metals in the sediments at Prek Kdam in the Tonle Sap river, attributed to boat traffic and some industrial activities. In particular there were higher levels of arsenic, chromium, lead and mercury at this location. Also there was an almost 4-fold difference in the Toxicity Equivalent Index (which measures toxicity of dioxins and furans) comparing samples of sediments at Kratie, which were very low, with samples at Prek Kdam, which were well above the threshold requiring specific attention (MRC Technical Paper no 15, 2007). When bioassessment was carried out at Prek Toal at the northern end of the Great Lake, the ecological health was considered moderate to good.

Kampong Cham marks the northerly limit of a vast natural floodplain that once stretched from central Cambodia to the Mekong delta. Natural levees up to 10 m tall retain river water within the main channel at the onset of the monsoon season but also trap flood water on the floodplains at the end of the dry season. Historically, the floods covered a vast system of scrubby and tall forests for several months each year, but most of this is now converted to rice fields and drained urban areas. The macro-invertebrate species in this reach are predominately mussels, snails, shrimps and chironomid midges. Other notable features of the zone are bivalves and large snails, an abundant dry-season emergence of aquatic flies and abundant insect-eating birds living along the river.

The fish biodiversity in this zone is very high, with 282 species being recorded in the Tonle Sap of which 160 species are the same as in the Stung Treng to Kratie reach. There are 31 endemic species found here. The fish migrations from the Tonle Sap in the early part of the year may be a response to declining water quality conditions in the Great Lake as the water level drops. The *dai* fishery on the Tonle Sap river as it approaches the confluence with the Mekong takes advantage of this massive movement of fish.

Although the general water bird populations along the Mekong mainstream are quite depleted, the floodplains carry significant diversity and populations of water birds. There are a number of Important Bird Areas including Stung Sen /Santuk/Baray (IBA 021) which is one of the largest remaining tracts of seasonally inundated grassland within the Tonle Sap floodplain and an important breeding ground for the Bengal Florican. Prek Toal (IBA`003) is a protected area of flooded forests at the north western end of the Great Lake containing some spectacular congregations of waterbirds. The whole of the Tonle Sap lake and surrounding area has been designated as a UNESCO designated Biosphere Reserve, which also contains the Ramsar site of Boeung Chhmar (IBA 015). The zone as a whole supports the largest global colony of Spot-billed Pelican and the largest South-east Asian colonies of Darter, Black-headed Ibis, Painted Stork, and Greater Adjutant stork, the largest mainland colony of Milky Storks, the largest colony of Asian Openbill stork in Indochina, the only breeding colony of Glossy Ibis in Cambodia, and large colonies of Lesser Adjutant stork and Little Egret. Nevertheless, the IBFM ornithological specialists considered that this zone was largely modified with room for improvement.

The reptiles and amphibians in zone 5 were similarly considered largely modified. One of the features of the Tonle Sap system is the large number of water snake species, mostly homalopsids. Over 6.9 million snakes are removed annually, the largest harvest of an assemblage of snakes in the world, and reports from hunters indicate that the harvest has declined by 74 – 84% in the period between 2000 and 2005. (Brooks et al 2006). There are many crocodile farms on the Tonle Sap, mostly hybrids of the Siamese Crocodile, with some escapees, but no wild individuals.

Current Pressures, changes and trends

Some industrial and municipal wastes as well as storm water run-off discharge directly into the Tonle Sap river near Phnom Penh. Domestic wastes are also released from river bank and floating communities. Agricultural run-off with higher nutrient loads and other agricultural chemicals contribute to the pollution in this zone. There are pressures on the fisheries and water snake harvest from over-exploitation and illegal methods of fishing. Lamberts (2006) suggests that current natural resource use of the Tonle Sap has exceeded the optimum supported by its ecosystem productivity base.

Predictions for the future - Changes in the hydrology of the flood pulse as a result of the Chinese dams, will alter the dynamic in the Tonle Sap system, but it is difficult to predict how this will show in terms of its aqautic biodiversity and productivity. The pressures of fishing and hunting will continue to reduce the fish populations. The water quality in the Tonle Sap near the floating fishing villages and in the river near Phnom Penh will continue to give cause for concern.

2.1.6 ZONE 6 – PHNOM PENH TO THE SEA

At Phnom Penh (km 225 from the sea) the mainstream divides into two main distributary channels – the Mekong and the Bassac rivers. As the river passes into Vietnam it further sub-divides into a complex and

increasingly controlled and artificial system of branches and canals. By the time the river reaches the sea, there are nine distributary channels in the Delta. The key features of this zone are tidal influences and salt-water intrusion. Every year, 35 to 50 per cent of this zone is flooded during the rainy season.

Overview of ecological status – ecological health, productivity, biodiversity - Geomorphologically the river is significantly modified in this zone by the creation of a system of canals and embankments, especially on the Vietnamese side of the border. In terms of water quality, the IBFM specialist studies considered that water quality ranged from being good, e.g. in protected areas such as Tram Chim National Park to being seriously to critically modified. The MRC water quality report card for 2008 indicates that generally the water is good to excellent for protection of aquatic life in many parts of the Delta, however, the concentrations of nutrients, especially total phosphorus is highest in the Delta sampling stations, and organic matter as measured by COD is also highest here. Toxic contamination indicated by bioassay tests are also highest at Neak Loung in Cambodia, Tan Chau and Chau Doc in Vietnam. Sediments at Koh Khel and Chau Doc on the Bassac River downstream of Phnom Penh. have the second highest levels after Prek Kdam near Phnom Penh. In Chau Doc the metals contributing most to these high results were copper, nickel and arsenic. The Delta sampling stations tend to have a higher than usual TEQ values for dioxins and furans. The ecological health indicators show that the Bassac River tends to be in good health compared to the Mekong which is in moderate health.

The Mekong delta has now been largely converted from a wetland of very high biodiversity and productivity to very productive agricultural lands, often with three crops of rice per year. The Tram Chim National Park gives some idea of the former nature that gave rise to the area being called the Plain of Reeds. Lacking the high levees of Zone 4, the entire delta was probably originally a continuous floodplain, from upstream marshlands supporting submerged or floating plants such as *Hydrilla* and *Najas*, to downstream mangrove systems dominated by *Melaleuca*. Large areas of the invasive alien species *Mimosa pigra* cover river and canal banks, with seeds spread by flood waters.

The macro-invertebrate fauna are snails, shrimps, polychaete worms, odonates (dragon flies) and chironomid midges that live in the silt or clay riverbanks and silty riverbed. Tram Chim National Park, representative of the Plain of Reeds in the upper part of the Delta, is a freshwater wetland with regulated water levels and a high abundance of fish, amphibian, reptile and waterbird species.

The fish diversity in the Delta is the highest in the Mekong river system with over 481 species and 73 families. 210 of these species are also found in the Tonle Sap system of Zone 4. Many fish are also tolerant of the brackish water, or come in from the sea. Aquaculture in floating pens is a characteristic feature of the delta.

In Cambodia there three Important Bird Areas – Basset Marsh, Boeung Veal Samnap and Bassac March lying in the floodplains adjacent to the river and are important for Spot-billed pelicans. In Vietnam, there are five IBAs, and several wildlife sanctuaries. These include Tram Chim National Park and Lang Sen

Provincial protected area, which are representative of the original Plain of Reeds ecosystem and important for dry season roosting and feeding of the Sarus Crane and migratory waterfowl. Along the coast are several IBAs including Chua Hang, Tra Cu and Bac Lieu. The Plain of Reeds was a vast wetland depression of about 13,000 km^2 encompassing the provinces of Dong Thap, Tien Giang, and Long An in Viet Nam, and parts of Svay Reang in Cambodia, but most parts of the Plain have been converted to rice production over the past 40 years. A large part of the Plain in Viet Nam (368,000 ha known as Dong Thap Muoi) is composed of acid-sulphate soils. The Plain lies in a flat lowland region subject to seasonal flooding (July - December) and, at the flood peak (September - October), the Plain effectively becomes a vast lake with some areas flooded to a depth of nearly 4 m. Except for scattered ponds and swamps, the Plain dries out during the dry season. The wetland habitats in the Plain of Reeds include: seasonally inundated grasslands, inundated semi-natural Melaleuca forests and Lotus swamps. The Plain of Reeds supports the only known Indochinese population of Grass Owl, which is dependant on undisturbed grassland. Recently, the Government of Viet Nam has initiated protection of two of its largest remnants: the Tram Chim National Park, in Dong Thap Province, and Lang Sen, in Long An Province lies approximately 23 km north east of Tram Chim and is the only area in the former Plain of Reeds where remnant natural Melaleuca forest occurs on a river channel, and thus has an important biodiversity value.

Current Pressures, changes and trends

The city of Phnom Penh, with almost 2 million inhabitants discharges much of its sewage that drains into the Bassac River. Pollution is also derived from sewage and industrial wastes from the many urban areas in the Delta, from the floating fish farms and the nutrients and agrochemicals in agricultural run-off from the extensive paddy fields in the Delta. Boat traffic is very intense and may give rise to oil and grease contamination. The impact of road embankments and similar infrastructure developments on the movement of flood water is increasingly important**.** Nearer the coast, saline intrusion threatens agricultural productivity. Shrimp farms have caused loss of extensive areas of natural coastal habitats.

Predictions for the future – Increasing population pressure will continue to add to the pollution load from urban waste waters, and agricultural run-off. Climate change and sea-level rise is considered a very serious threat to the integrity of the delta, and this will be exacerbated by hydrological changes resulting from Chinese dams and dams in the tributaries. The trapping of sediments behind dams in China and from the Central Highlands in the long term will cause the delta to erode.

2.2 LONGITUDINAL TRENDS

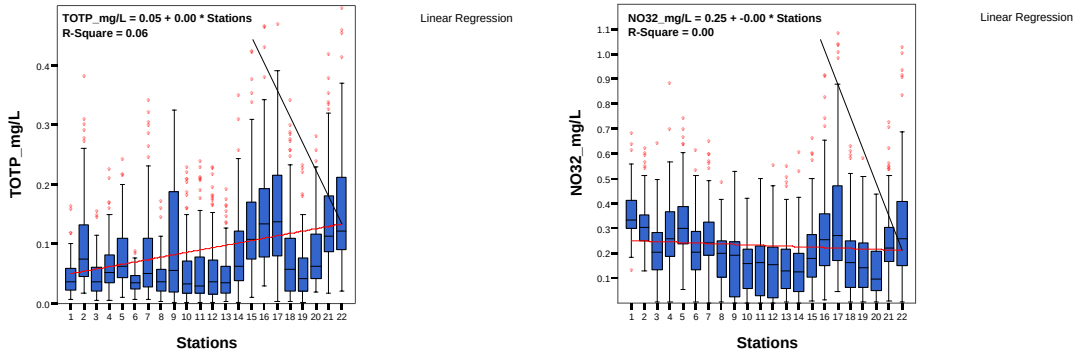
A number of the physico-chemical characteristics of the river show trends with passage downstream, under the influence of the contributions of solids and chemicals from different parts of the catchment and the dilution effect of the water already in the river. These longitudinal trends include:

- Temperature – the temperature of the water tends to increase from upstream to downstream stations, with average values for Chiang Saen being 23.4°C to 26.9 °C at Pakse

- High and increasing Total Suspended Solids are observed between upstream sample stations and Vientiane, where they average 400 mg/l. Downstream of Vientiane the average concentration of TSS in the river drops to 200 mg/l. The average TSS in the tributaries tends to be lower or much lower than in the mainstream stations downstream of Vientiane. The contribution of TSS by the 3S rivers joining at Stung Treng, raises the overall TSS levels in the mainstream again, since over 50% of the sediments in the Mekong are contributed from the Central Highlands.

- Total phosphorus content tends to increase with passage downstream as shown in Figure 4. There has also been a gradual increase in total phosphorus content over the past decade. The nitrate concentrations do not appear to follow the same trend downstream, although there has also been a tendency for nitrate levels to be increasing slightly with time.

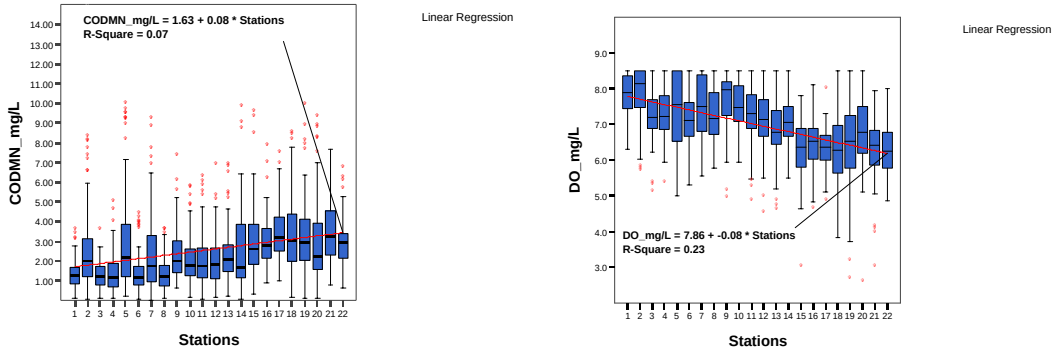
Figure 4: Variation in total phosphorus and nitrite and nitrate (mg/L) at 22 stations along the Mekong (1–17) and Bassac Rivers (18–22) 2000–2008. Stations 15, 16, 17 and 21 are located in the Mekong Delta



(Source: MRC State of Basin report 2009)

- The COD and Dissolved Oxygen contents show a longitudinal trend, with increasing COD and decreasing Dissolved Oxygen with passage downstream, as would be expected from the pollution sources entering the river, and the lower aeration capacity in the downstream slower moving river, as shown in Figure 5.

Figure 5: Variation in COD and dissolved oxygen (DO) (mg/L) at 22 stations along the Mekong (1–17) and Bassac (18–22) Rivers, 2000–2008. Stations 15, 16, 17 and 21 are located in the Mekong Delta.

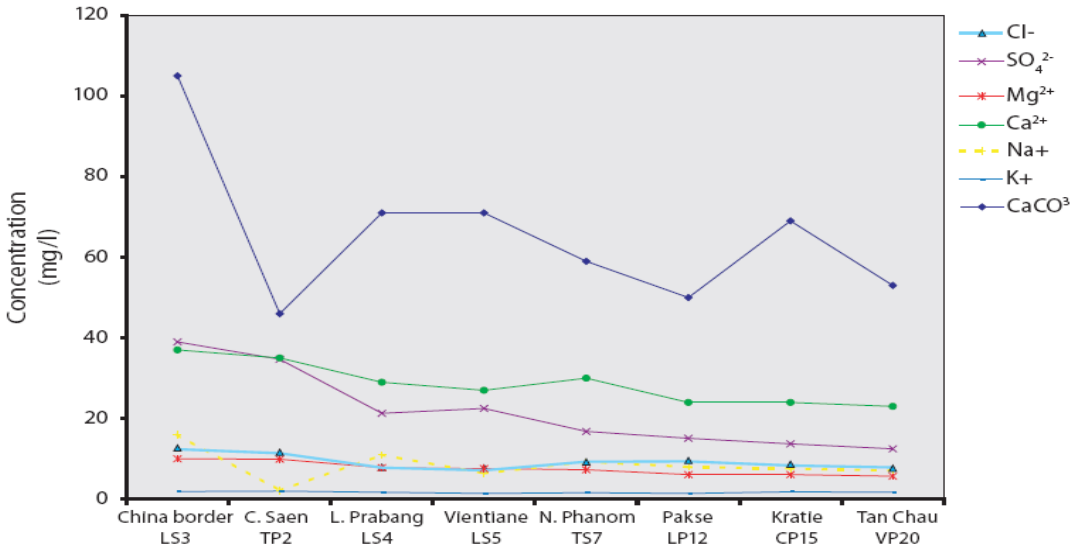


(Source: MRC State of Basin report 2009)

- Mineralisation in the river tends to decrease from Chiang Saen to Pakse, falling from average values of 2402 to 1873 uS/cm, caused by the dilution effect. Even the contribution of high mineralized water from the Mun/Chi basin due to natural salt deposits in the Khorat plateau and irrigated agriculture are diluted by the time Pakse is reached.

- The concentration of ions in the water also tends to decline with passage downstream as shown in the Figure 6

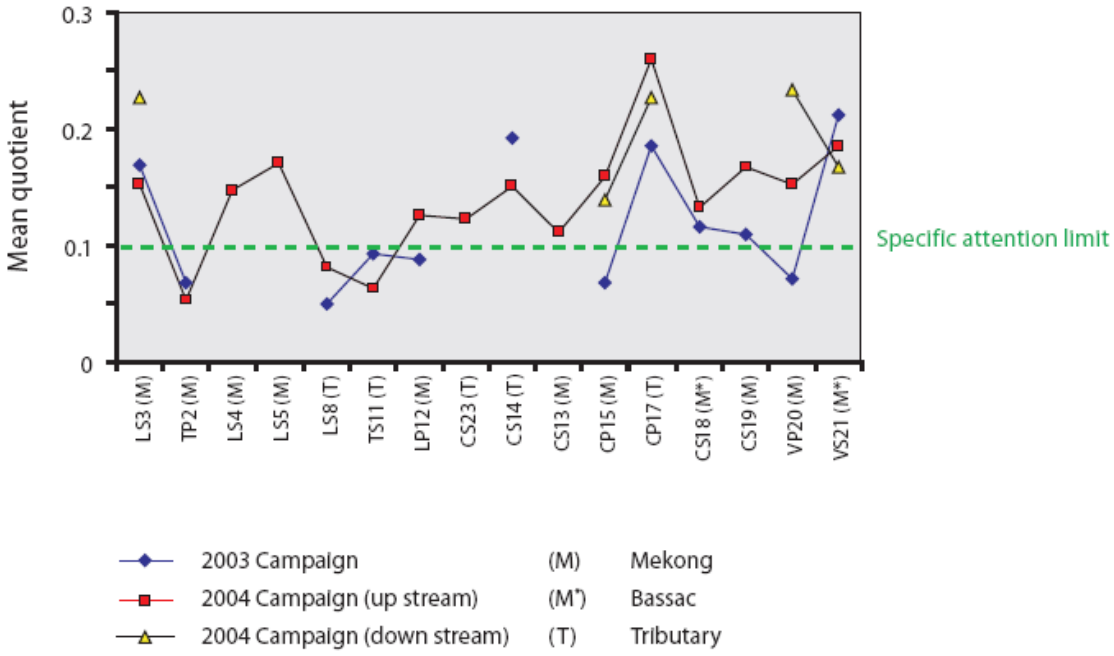
Figure 6: Major ion profiles in the Mekong from upstream to downstream



(Source: MRC Technical paper 15, 2007)

- Determinations of heavy metal concentrations and toxicity of sediments has shown concern over arsenic and mercury which have reached TEC (Threshold Effect Concentration) levels at some stations, including high levels in some tributaries. As shown in Figure 7.

Figure 7: Mean quotient of arsenic and heavy metals recorded in the 2003 and 2004 campaigns



(Source: MRC Technical paper 15, 2007)

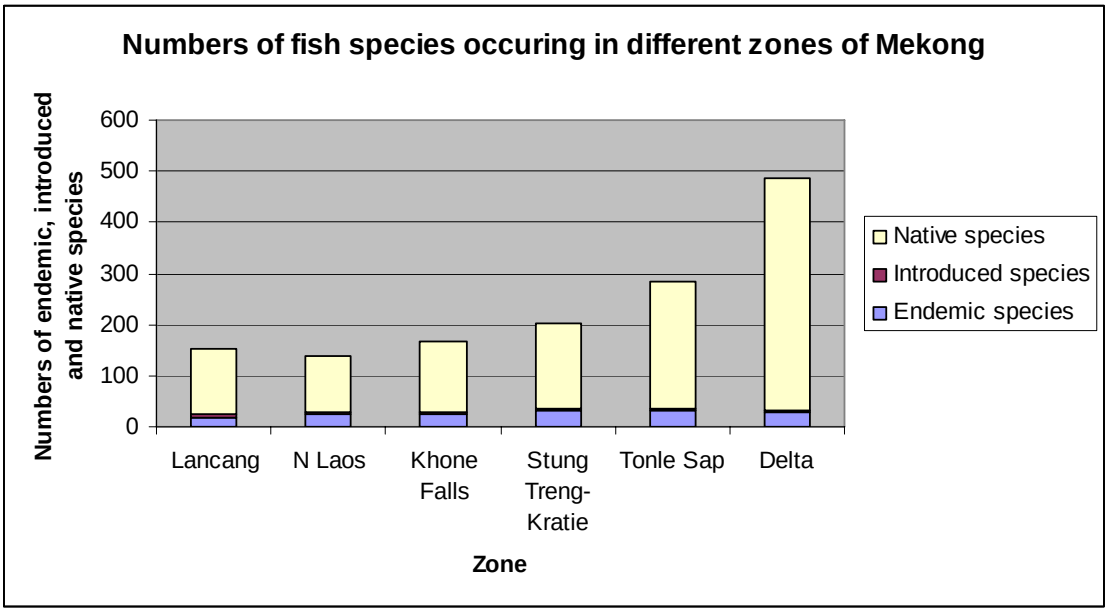
- Multi-criteria analysis of several different parameters, including heavy metals, pH, PCDD/PCDF (Dioxins and furans) and toxicity bioassays showed high values at the Chinese Lao border, at Prek Kdam and Neak Leang in Cambodia and at Chau Doc in the Delta. These are recognized areas in or downstream of heavily polluted areas. The importance of the Mekong River system in diluting pollution has been recognized.

- In terms of fish biodiversity, there is a longitudinal trend towards increasing numbers of fish species and families with distance down the river as shown in Table 4 and Figure 8

Table 4: Numbers of fish species in different zones of the Mekong

Zone	1	2	4	4	5	6
	Lancang	N Laos	Khone Falls	Stung Treng-	Tonle Sap	Delta
Endemic species	19	26	25	33	31	28
Introduced species	7	4	4	1	4	3
Native species	125	110	139	170	249	455
Total species	151	140	168	204	282	481
Total families	21	30	34	37	45	73
Species present in upstream zone		36	71	120	160	210

Figure 8: Numbers of fish species occurring in different zones of the Mekong



2.3 HYDROLOGICAL PROCESSES AND KEY AQUATIC HABITATS

Hydrological processes sustain important ecosystem features and aquatic habitats. The character of the Mekong hydrograph described in the hydrology theme paper contains the following elements:

- Mekong hydro-biological seasons (seasonal variability)
- Flood regime (peak water levels and flow provenance)
- Flood pulse (timing & duration)
- Groundwater connectivity and recharge

Other elements associated with sediment and nutrient transport include:

- Transport energy & Sediment transport capacity
- Sediment load and provenance
- Nutrient transport pathways and loading
- Saline intrusion
- Coastal sediment plume

The hydrograph of the Mekong working on the underlying geology of the river basin has created the unique diversity of river morphology and aquatic habitats. Changes in the overall hydrograph and its local variations will start to change the river morphology and the diversity of the aquatic habitats. As the diversity of habitats is lost, so there will be pressures upon the biodiversity that has developed to inhabit these habitats. The matrix below (Table 4) shows the ecological importance and relationship with the hydrological processes outlined above. Table 5 shows estimates of the proportions of the different habitats in the zones.

Table 5: Relative proportion of river habitats in each zone

	Proportion in each zone						
	1	2	3	4	5a	5b	6
Rapids and rocky outcrops							
Riffles and gravel beds							
Deep pools							
Sand bars							
Vegetated River banks							
Islands							
In channel shrublands							
In channel flooded forests							
Floodplains							

High	
Medium	
Low	
Absent	

Table 6: Ecological importance and relationship of aquatic habitats to hydrological processes

Aquatic habitat	Ecological importance	Relationship to hydrological processes
Rapids and rocky outcrops	Provide aeration and mixing of water and sediments. Important habitat for macro-invertebrate filter feeders. Eddies and backwaters provide niches for migrating fish to pass up the rapids. Fishermen use the rapids and rocks as places to catch migrating fish	Bedrock forms the channel in many places and determines the hydrodynamics of the reach. Slow but constant erosion from water, moving bedload, and suspended solids. Increase in erosion during times of seasonal high flows. Sometimes catch large logs and floating vegetation to form temporary blocks.
Riffles and gravel beds	Shallow areas that are less turbulent than rapids, but provide good aeration of the water. Important areas for fish spawning, maintaining the flow of oxygen over the eggs until they hatch. In some areas riffles and gravel beds are covered in river weed during the low flow season, which is harvested by riparian communities	Gravel beds are temporary deposits of the bedload moving downstream, usually in similar places each year, dependent upon channel configuration and velocity of the water. Gravel will tend to be deposited at the end of the wet season, and be moved on at the beginning of the flood season.
Sand bars	Exposed sandbars during the low flow seasons provide important breeding places for turtles and some river birds – River Lapwing, Pratincoles. Remnant pools in the sandbars are good breeding places for amphibians and crustacean. Sandbars are usually unvegetated.	Sandbars are formed each year in similar places where the velocity is lower than where gravel is deposited. The configuration of sandbars may change each year depending upon the character of the last floods of the high flow season.
Deep pools	Deep pools have been recognized as dry season refuges for fish and dolphins. They are an important part of the wider fish migration system. Different deep pools are favoured habitats by different groups of fish. A total of 335 deep pools have been identified between the Chinese border and Khone Falls, the deepest being 90.5 m and the longest 9.9 km. They occur frequently along the Mekong except in the alluvial zone between Vientiane and Savannakhet. The deepest pools occur between Pak Lay and Vientiane and between Mukdahan and Pakse. Conlan 2008)	Deep pools range from 10 m to more than 60 m in depth. They are caused and maintained by scouring of bedload during seasonal high flows of the Mekong. They are often found associated with rapids, where the velocity of the water and bedload have been increased. The majority of pools are associated with constrictions of the valley or local outcrops of bedrock within the channel. At the end of the wet season, the deep pool will deposit sediments, (sometimes forming waves or "dunes") (Conlan 2008)

Aquatic habitat	Ecological importance	Relationship to hydrological processes
River banks	Mekong river banks are usually vegetated seasonally as the water recede. Typical vegetation includes grasses and herbs including Phragmites. River banks are very productive with nutrients deposited each year. Worm action important for productivity, breaking down vegetation as flood water recedes. River bank gardens are a key feature for the use of river banks by riparian communities. Some trees grow on the upper levels of the river bank and are able to withstand inundation for several weeks a year. Such vegetation serves to stabilise the banks. On the top of the banks, gallery forests and tall floodplain grasslands can occur.	Mekong river banks may be more than 10 - 12 m above dry season water levels, and may be steep sided and eroding, or more shallow with sand bars deposited at the base. River banks are created and maintained by the seasonal high water flows, especially as the water is receding. The out-of-channel floods that occur every 2 -3 years are most important for channel and river bank formation. Sudden changes in flow tends to increase river bank erosion, as does the wash from large ships.
Islands	Many of the smaller islands are vegetated, retaining natural vegetation and riparian forest cover. They provide habitat for a wide variety of invertebrates and water birds. Larger islands usually have small communities, using the fertile land for agriculture and forestry, and in some areas for tourism, e.g. in Siphandone.	Characteristic lozenge-shaped islands develop in the Mekong mainstream, often with a bedrock base which forms the nucleus for patterns of annual deposition of sediment especially at the leading and tail ends of the island.
In channel shrublands	The in-channel shrublands are often vegetated with plants that can withstand extended inundation with floods for several months a year. The typical vegetation varies with the length of exposure, and the type of substrate. They include plants such as *Homonia, Phyllanthus* and *Telactadium.* These shrublands are important refuge and feeding areas for fish in times of high flows	The in-channel shrublands grow where the substrate is more stable, i.e. rocky channel areas, and more stable sand and mud banks. Deposition occurs in such areas tends to be retained more than the unvegetated sandbars
In channel flooded forests	Characteristic trees grow in the channel from at least the Mun river confluence down to Kratie, especially in Siphandone, Stung Treng and Kratie. The most spectacular in-channel flooded forests occur in Stung Treng, and are dominated by *Anogeissus rivularis*. Another channel woodland contains	The survival of in-channel flooded forests are determined by the substrate (rocky or sandy areas), the length of dry season exposure and the velocity of the high flow waters. Trees in the channel sometimes exhibit extreme adaptation to the current, growing at a steep

Aquatic habitat	Ecological importance	Relationship to hydrological processes
	Acacia harmandiana – which grows in channels with a longer dry season exposure and abundance of sand (Allen 2008). Flooded forests used to occur around the Tonle Sap and are now focused in the north west end of the Great Lake, where they form an important sanctuary for fish and birds for spawning and nesting. Delta flooded forests consist largely of *Melaleuca* forests, now usually in plantations, and existing as natural river bank vegetation in Lang Sen, Long An province, and coastal mangroves.	angle, or with many prop roots on the downstream side. Flooded forests around the Tonle Sap area are different in that they are not "in-channel" and are less affected by the current and more by the duration and depth of inundation. The types of Mangrove forests in the Delta are a feature of the salinity gradient as the freshwater meets the sea
Floodplains	The floodplains are largely responsible for the fertility and productivity of the Mekong, allowing the primary production of vegetation that develops after the recession of the flood waters to be incorporated into the overall productivity of fish. Fish migrate from the mainstream into the floodplains to breed and grow during the high flow season and return to the mainstream, especially to the deep pools during the low flow seasons. Some pools and backswamps retain water through the dry season and serve as biological reservoirs.	Floodplains form where the river regularly overtops the banks of both mainstream and tributaries at times of high flow. The water flows through both up the side channels and in lateral sheet flow across the flat lands. The length and depth of inundation determines the ecological character of the floodplain. Floodplains also occur where the Mekong backs up tributaries at times of high flow, for example the Tonle Sap and the Songkhram Rivers. The Zone from Phnom Penh to the sea is an extensive floodplain, with the Plain of Reeds being a depression in the floodplain.

As an example of the character of the reaches in the different zones, the extent of the dry season and wet season channel areas is estimated for the reaches likely to be affected by the proposed mainstream dams (Table 7).

Table 7: Channel characteristics of the reaches likely to be affected by the mainstream dams

Zone	Dam and reservoir area	Length of reach	Average width	Area of wet season channel	Area of dry season channel	Area exposed in dry season	Number of deep pools	Area of deep pools - sq km					Area of rocks and rapids	Area of plain sand bars
		km	m	sq km	sq km	sq km	>10m deep in dry season	10 - 20 m	21 - 30 m	31 - 50	> 50 m	Total area	sq km	sq km
1														
2														
3	Ban Koum	151	673	123.46	72.9	50.56	166	12.07	4.15	1.63	0.29	18.14	50.2	0.3
4	Latsua	9.7	821	9.12	8.16	0.96	14	2.63	0.57	0.20	0.29	3.69	0.06	0.89
	Stung Treng	60		116.3	48.5	67.8	85	4.82	0.84	0.27	0.01	5.94	3.25	2.1
	Kratie to Stung Treng													
5														
6														

In the Stung Treng area of Zone 4 the composition of the river channel includes 116 sq km of wet season channel that dries to 48.5 sq km of dry season channel, exposing 67.8 sq km of in-channel wetlands forming a mosaic of productive habitats. For Latsua at the top end of Zone 4, only 1 sq km of dry season wetland is exposed, and for Ban Koum, 50.6 sq km will be exposed in the dry season, and a lot of this will be rocky outcrops. [Further examples to be added, and the table completed]

Estimates of the net primary productivity of wetlands are very difficult, but Mitsch and Gosselink (1993) indicate that for riparian wetlands the net primary productivity ranges from 0.6 – 1.4 KgC/m^2/yr. Swamps and marshes have very high net primary productivity of 2.0 KgC/m^2/yr, while streams and lakes have NPPs at about 0.5 KgC/m^2/yr. Riparian wetlands are generally more productive than their adjacent uplands because flooding provides adequate water supplies; nutrients are supplied and favorable alteration of soil chemistry results from the periodic flooding (nitrification, sulfate reduction, nutrient mineralization, all of which make the nutrients more available to the plants) and flowing water offers a more oxygenated root zone than if the water were stagnant. This range is taken as a first estimate of the primary production of the in-channel wetland areas (including all mosaic of the exposed areas – rocky outcrops, sand bars, river banks, in channel grasslands and shrublands) that are exposed during the dry season. It is argued that this seasonal exposure of in channel wetland areas is largely responsible for the generally high productivity of the Mekong river. Without this seasonal exposure the Mekong would be a much less productive ecosystem.

2.4 ECOSYSTEM SERVICES OF EACH ZONE

This section examines the important ecosystem services provided by the river and its associated wetlands, and provides a comparison of the significance of these services in each of the zones. The Table below shows the key ecosystem services identified for wetlands by the Millenium Ecosystem Assessment, together with an explanation of the significance of these ecosystem services in the context of the Mekong River system. Table 8:

Table 8: Significance of ecosystem services for the Mekong River system

Ecosystem services	Significance for the Mekong River system
Provisioning	
Food production of fish, wild game, fruits, and grains	Very significant. Mekong river basin provides over 2 million tonnes of freshwater fish and aquatic products per year. One of the most productive freshwater fisheries in the world
Fresh water storage and retention of water for domestic, industrial, and agricultural use	Very significant. Mekong river provides most of the freshwater for water supply, irrigation and industrial uses for some 60 million people in the basin
Fiber and fuel production of logs, fuelwood, peat, fodder	Moderate significance of the mainstream, though some riparian wetlands will provide sources of fibre for handicrafts, fishing gear and fodder for livestock for riparian communities
Biochemical extraction of medicines and other materials from biota	Low significance
Genetic materials genes for resistance to plant pathogens, ornamental species, and so on	Low significance
Regulating	
Climate regulation source of and sink for greenhouse gases; influence local and regional temperature, precipitation, and other climatic processes	Mekong river provides a strong local influence upon the climate of the basin, though most of the precipitation occurs in the highlands of the catchment. Dry season exposure of in-channel wetland areas increases the primary productivity and sink capacity for green house gases of the river
Water regulation (hydrological flows) groundwater recharge/discharge,	Seasonal discharge, flood pulse is very important for the ecological functioning of the Mekong basin, including groundwater recharge in floodplains
Water purification and waste treatment retention, recovery, and removal of excess nutrients and other pollutants	The dilution effect of the Mekong river is pronounced in reducing effects of pollution from urban areas, and salinity (e.g. from Khorat). Aeration due to the turbulence of rapids and varied river bed is important
Erosion protection and retention of soils and sediments	Patterns of erosion of river banks and deposition of sediments characterize the flows of the Mekong, with bed load and

Ecosystem services	Significance for the Mekong River system
	suspended sediments passing down at peak flows. Bank erosion is a feature in some areas. Floodplains allow dispersion of sediments and nutrients in a very wide area contributing to the fertility of the lower areas of the Mekong, Tonle Sap and its Delta
Natural hazard regulation, flood control, storm protection	Beneficial annual flooding is a characteristic feature of the Mekong and its tributaries, with more serious and damaging floods occurring less frequently. Temporary storage of flood waters in floodplains and wetlands down the Mekong system provide significant regulation of floodwaters and protection against high floods
Cultural	
Spiritual and inspirational source of inspiration; many religions attach spiritual and religious values to aspects of wetland ecosystems	Mekong River has created a cultural character of all the riparian countries, including boat racing festivals, fish dominated food and cuisine, mythical animals, such as Nagas, and spiritual sites and practices. Mekong Giant catfish and dolphins represented in 3000 year old rock paintings, and in Angkorian bas-reliefs are still a cultural inspiration for riparian people.
Recreational opportunities for recreational activities	Mekong based recreation and tourism opportunities are very strong, and provide a context for the tourism attraction of the region
Aesthetic - appreciation of natural features	The natural beauty and dramatic landscapes of the Mekong river at different stages down the river and at different seasons are appreciated by visitors and residents alike
Educational opportunities for formal and informal education and training	Mekong river provides and important educational resource for all areas of study – e.g. natural resources, socio-economics and provide easily accessible case study material
Supporting	
Biodiversity - habitats for resident or transient species	Mekong aquatic biodiversity is the third highest in the world (after Amazon and Congo). The diversity of aquatic habitats and the uniqueness of systems such as the Tonle Sap contribute to the range of biodiversity. Fish migration is a key feature of the Mekong
Fish spawning and nursery areas	Fish nursery and spawning areas are dispersed through the system, and used by the diversity of fish species
Soil formation sediment retention and accumulation of organic matter	Sediment flows from China and the Central Highlands represent 90% of the sediment in the Mekong reaching the Delta. They contribute to the continued progression of the Delta, and the fertility of the floodplains

Ecosystem services	Significance for the Mekong River system
Nutrient cycling storage, recycling, processing, and acquisition of nutrients	Nutrients associated with sediments are responsible for the fertility f floodplains and the Delta. Generally dissolved nutrients in the water are relatively low.
Pollination habitat for pollinators	Less significant except in areas of flooded forest, and riparian vegetation

This is then followed by Table 9 which attributes a current assessment of importance of each ecosystem service in each zone on a High, Medium or Low scale of importance. In the light of the pressures and changes affecting each zone described above, predictions about the future without the mainstream dams is indicated by a change in colour and/or an arrow indicating the direction of the change.

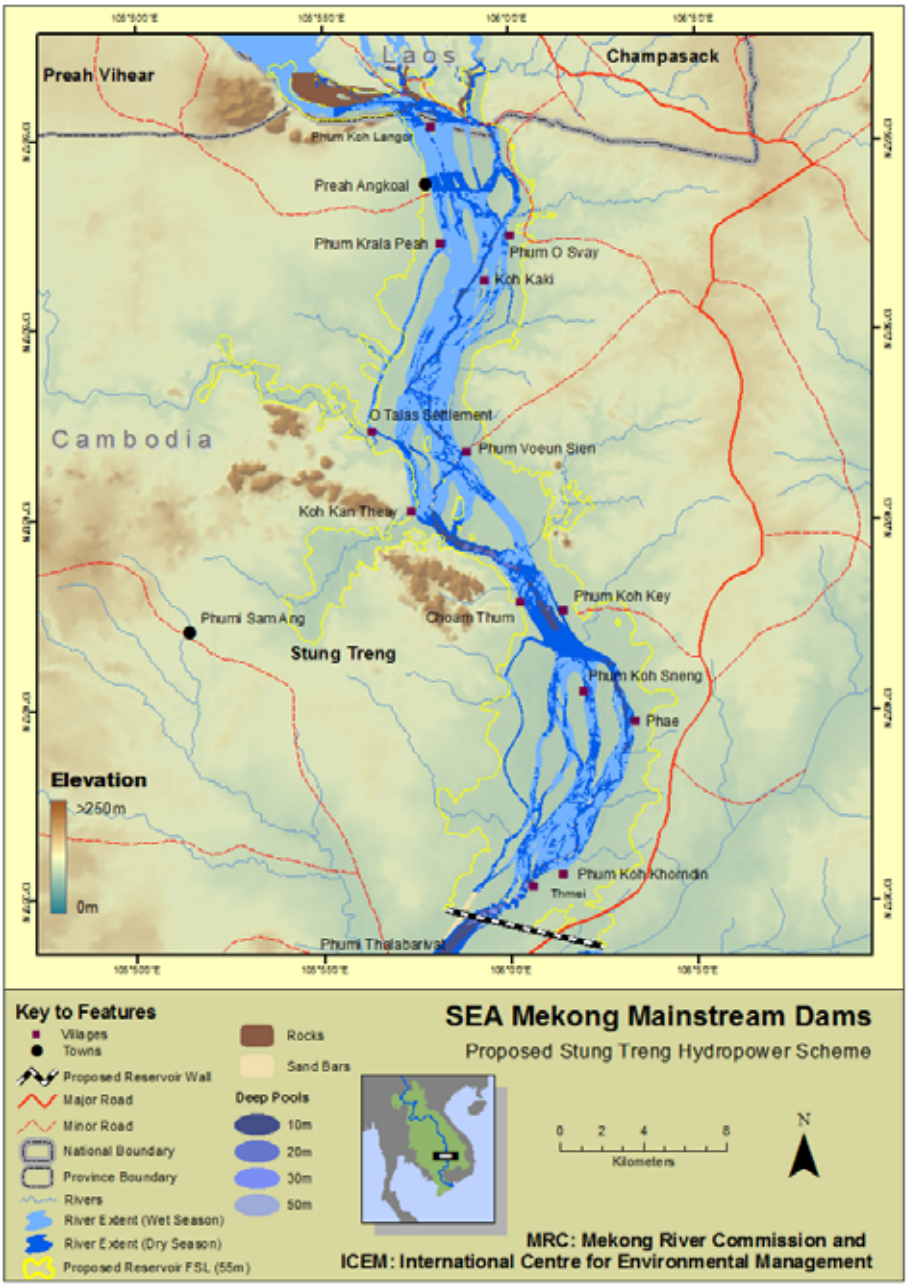
Table 9: Importance of Ecosystem services for each ecological zone and indication of direction of change in response to trends without the mainstream dams

Ecosystem services	Zone 1		Zone 2		Zone 3		Zone 4		Zone 5a		Zone 5b		Zone 6	
Provisioning	**Present**	**Future**	**Present**	**Future**	**Present**	**Future**	**Present**	**Future**	**Present**	**Future**	**Present**	**Future**	**Present**	**Future**
Food production of fish, wild game, fruits, and grains	Low	↓	Medium	↓	High	↓	High	↓	High	↓	High	↓	High	↓
Fresh water storage and retention of water for domestic, industrial, and agricultural use	Low	↑	Low	↑	Medium	↑	High	↑	High	↑	High	↓	High	↑
Fiber and fuel production of logs, fuelwood, peat, fodder	Low	→	Low	→	Low	→	Low	→	Low	→	Low	→	Low	→
Biochemical extraction of medicines and other materials from biota	Low	→	Low	→	Low	→	Low	→	Low	→	Low	→	Low	→
Genetic materials genes for resistance to plant pathogens, ornamental species, and so on	Low	→	Low	→	Low	→	Low	→	Low	→	Low	→	Low	→
Regulating														
Climate regulation source of and sink for greenhouse gases; influence local and regional temperature, precipitation, and other climatic processes	High	→	High	→	High	→	High	→	High	→	High	→	High	→
Water regulation (hydrological flows) groundwater recharge/discharge,	High	↓	High	↑	High	↑	High	↑	High	↑	High	↑	High	↑
Water purification and waste treatment retention, recovery, and removal of excess nutrients and other pollutants	High	↓	High	↓	High	↓	High	↓	High	↓	High	↓	High	↓
Erosion protection and retention of soils and sediments	High	↓	High	↓	High	→	High	→	High	→	High	→	High	→
Natural hazard regulation, flood control, storm protection	High	↑	High	↑	High	↑	High	↑	High	↑	High	↑	High	↑

Ecosystem services	Zone 1		Zone 2		Zone 3		Zone 4		Zone 5a		Zone 5b		Zone 6	
	Present	**Future**	**Present**	**Future**	**Present**	**Future**	**Present**	**Future**	**Present**	**Future**	**Present**	**Future**	**Present**	**Future**
Cultural														
Spiritual and inspirational source of inspiration; many religions attach spiritual and religious values to aspects of wetland ecosystems	High	↓	High	↓	High	↓	High	↓	High	↓	High	↓	High	↓
Recreational opportunities for recreational activities	Low	→	High	→	Medium	→	High	→	Medium	→	High	→	Medium	→
Aesthetic - appreciation of natural features	High	→	High	→	High	→	High	→	Medium	→	High	→	Medium	→
Educational opportunities for formal and informal education and training	Low	→	Medium	→	Low	→	Medium	→	Low	→	Medium	→	Low	→
Supporting														
Biodiversity - habitats for resident or transient species	High	↓	High	↓	High	↓	High	↓	High	↓	High	↓	High	↓
Fish spawning and nursery areas	Medium	↓	Medium	↓	Medium	↓	High	↓	High	↓	High	↓	Medium	↓
Soil formation sediment retention and accumulation of organic matter	High	↓	Medium	↓	Medium	↓	High	↓	Medium	↓	Medium	↓	High	↓
Nutrient cycling storage, recycling, processing, and acquisition of nutrients	High	↓	Medium	↓	Medium	↓	High	↓	Medium	↓	Medium	↓	High	↓
Pollination habitat for pollinators	Low	→	Low	→	Low	→	Medium	→	Medium	→	Medium	→	Low	→

2.5 MAPS

Map 1: Existing river channel at Stung treng showing wet and dry season channel and aquatic habitats



REFERENCES

1. Adamson, P.T (2005) An assessment of the Statistical nature of the IBFM flow seasons and indicators and their potential vulnerability to regional water resources development. Draft IBFM report.
2. Adamson, P.T. (2009) An exploratory assessment of the potential rates of reservoir sedimentation in five Mekong mainstream reservoirs proposed in Lao PDR
3. ADB Atlas of the Environment,
4. Allen, D et al (2008) – Integrating people in Conservation Planning Stung Treng Ramsar Site. IUCN Cambodia Country Office, Phnom Penh
5. Bezuijen et al. (2008) Biological surveys of the Mekong River between Kratie-Stung Treng. WWF Greater Mekong, Cambodia Country Programme
6. Brooks, S. E., Allison, E. H., Reynolds, J. D. (2006) Vulnerability of Cambodian water snakes: initial assessment of the impact of hunting at Tonle Sap Lake. in Biological Conservation. Elsevier
7. Conlan, I et al (2008) Sediment transport through a forced pool on the Mekong River: sand dunes superimposed on a larger sediment wave
8. Conlan, I. et al (2008) The geomorphology of Deep pools on the Lower Mekong River. Report to MRC.
9. Dubeau, P et al (2004) MWBP 2004. L.W.2.10.05 Mekong_Biodiversity_Survey_Oct2004.pdf
10. Hill, M. and Hill, S. (1994). Fisheries ecology and hydropower development in the Mekong River: an evaluation of run-of-river projects. Report for Mekong Secretariat
11. Lagler, K.F. 1976. Fisheries and integrated Mekong *r*iver basin development. The University of Michigan, School of natural resources. pp. 363.
12. Lazarus, K. et al (2006) An Uncertain future: Biodiversity and Livelihoods along the Mekong River in Northern Lao PDR. IUCN, Bangkok.
13. Meynell, P.J. et al. (2003) MWBP 2003. L.W.1.10.05 Mekong_Biodiversity_Survey_Aug2003.pdf
14. Mitsch, W.J. and J.G. Gosselink. (1993). Wetlands. New York: Van Nostrand Reinhold. 722 p.
15. MRC (1998) State of the fisheries report,
16. MRC (2005) Hydrology of the Mekong Basin,
17. MRC (2005) IBFM zones (IBFM reports no 7).
18. MRC (2008) The Mekong River Report Card on Aquatic Ecological health 2004 - 2007
19. MRC (2008) The Mekong River Report Card on Water quality (2000 – 2006)
20. MRC (2009) The Mekong River Report Card on Aquatic Ecological health 2008
21. MRC (2010) State of the Basin report 2010 (draft)
22. MRC Flood reports 2006 and 2007
23. MRC Technical Paper no 11. 2006. Hydroacoustic survey of deep Pools in the Mekong River in Southern Lao PDR and Northern Cambodia
24. MRC Technical Paper No 13 (2006) Biomonitoring of the Lower Mekong River and selected tributaries

25. MRC Technical Paper No 15. 2007. Diagnostic study of water quality in the Lower Mekong Basin
26. MRC Technical Paper No 20 (2008) Biomonitoring of the Lower Mekong River and selected tributaries, 2004 – 2007.
27. MRC Technical Paper No 23 (2009) Report on 2006 biomonitoring survey of the Lower Mekong River and selected tributaries
28. MRC Technical Paper No 23 (2009) Report on 2007 biomonitoring survey of the Lower Mekong River and selected tributaries
29. Timmins et al (2006) Biodiversity surveys between Stung Treng – Khone Falls: MWBP.
30. WWF 2009. Mortality investigation of the Mekong Irrawaddy River Dolphin in Cambodia based on necroscopy sample analysis. WWF Cambodia.