Mekong River Commission Secretariat

Procedures for Notification, Prior Consultation and Agreement (PNPCA)

Proposed Xayaburi Dam Project – Mekong River

PRIOR CONSULTATION PROJECT REVIEW REPORT

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Prepared by:

Mekong River Commission Secretariat

This document is subject to incorporation of comments from MRC Member Countries in Annex 7.

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ACRONYMS AND ABBREVIATIONS

BDP	Basin Development Plan (MRC)
BOD	Biological Oxygen Demand
CA	Concession Agreement
CFD	Computation Fluid Dynamics
COD	Chemical Oxygen Demand
CODS	Committee on Dam Safety (ICOLD)
DEM	Digital Elevation Model
DFS	Definite Future Scenario
DO	Dissolved Oxygen
DOE	Department of Energy (Lao PDR)
DSMS	Dam Safety Management System
DSRP	Dam Safety Review Panel
DWT	Deadweight tons
EA	Edible Algae
EdL	Electricite du Laos
EGAT	Electricity Generating Authority of Thailand
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
EG	Expert Group
EP	Environment Programme (MRC)
EPC	Engineering Procurement Construction
EPP	Emergency Preparedness Plan
FEG	Fisheries Expert Group
FFS	Foreseeable Future Scenario
FS	Feasibility Study
FSL	Full Supply Level
HEC	Hydrologic Engineering Centers (USACE)
HNL	Highest Navigable Level
HOL	Highest Operating Level
IBFM	Integrated Basin Flow Management
ICOLD	International Commission on Large Dams
ICCS	International Cooperation and Communication Section (MRC)
IKMP	Information and Knowledge Management Programme (MRC)
ISH	Initiative on Sustainable Hydropower (MRC)
IUCN	World Conservation Union
IWRM	Integrated Water Resources Management
JC	Joint Committee
JCWG	Joint Committee Working Group
LEPTS	Lao Electrical Power Technical Standards
LMB	Lower Mekong Basin
LNL	Lowest Navigable Level
LOL	Lowest Operating Level
MCE	Maximum Credible Earthquake
MEM	Ministry of Energy and Mines (Lao PDR)
MNL	Mean High Navigable Level
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat

MASL	Meters Above Sea Level
N	Nitrogen
NOL	Normal Operating Level
O&M	Operation and Maintenance
OAA	Other Aquatic Animals
P	Phosphorous
PC	Prior Consultation
PDG	Preliminary Design Guidance for Proposed Mainstream Dams in the Lower Mekong Basin
PMF	Probable Maximum Flood
PMFM	Procedures for Maintenance of Flows on the Mainstream
PNPCA	Procedures for Notification, Prior Consultation and Agreement
PWUP	Procedures for Water Use Monitoring
PWQ	Procedures for Water Quality
RAS	River Analysis System (USACE)
SEA	Strategic Environmental Assessment
SEG	Sediment Expert Group
TG	Task Group
UAP	Useful Aquatic Plants
USACE	United States Army Corps of Engineers
WG	Working Group

Executive Summary

Cambodia, Lao PDR, Thailand and Viet Nam established the Mekong River Commission (MRC) by signing the Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin on 5 April, 1995. The Agreement defines principles and processes in cases where one or more countries propose to use waters of the Mekong or its tributaries within the boundaries of the Lower Mekong Basin (LMB). The types of water use include mainstream hydropower developments.

The proposed Xayaburi hydropower project in Lao PDR is the first mainstream project submitted for consideration by the MRC. The proposed dam, the third in a cascade of six proposed dams upstream from Vientiane, is subject to the "prior consultation" process of MRC's Procedures for Notification, Prior Consultation and Agreement (PNPCA) approved in 2003. The Mekong Agreement defines prior consultation as a process *"that would allow the other member riparians to discuss and evaluate the impact of the* Proposed *use upon their uses of water and any other affects (sic)."*

The Lao National Mekong Committee (LNMC) submitted prior-consultation documents on the Xayaburi project to the MRC Secretariat on 20 September, 2010. After checks and clarifications, the documents were circulated and received by all MRC Joint Committee members by 22 October, 2010. The Joint Committee set up a Working Group, which met three times between October 2010 and March 2011. The MRC Secretariat set up an internal Task Group to analyse questions related to dam design and operations, hydrodynamic modelling, fisheries, sediment transport, river morphology, nutrient balance, water quality and aquatic ecosystems, dam safety, navigation and the social implications of the project. The Secretariat also set up two expert groups on fisheries and sediment and commissioned other individual experts including international engineering experts on dam layout and operation and on navigation locks. The prior consultation process for the proposed Xayaburi project is scheduled to be completed by 22 April, 2011. An extension is possible if the Joint Committee considers it necessary.

The project review by the MRC Secretariat highlights a number of areas of uncertainty on which further information is needed to address fully the extent of transboundary impacts and mitigation measures required. Some of these have implications for the financing and operation of the proposed project as well as its long-term sustainability. The findings and recommendations included in the review report have implications for the consideration of Member Countries in forming their views on the proposed use and for the next stages of planning and design. Lao government agencies and the developer have indicated their intention that the project should fully incorporate international good practice.

With regards to hydrology, the review highlighted significant differences between natural fast flows — with high diversity of flow conditions prevailing seasonally around Xayaburi — and the expected slow movement within a future reservoir and possible negative impacts. The river flow regime during construction would need to be further elaborated in relation to fish migration as well as the expected rapidly-changing fluctuation of water levels downstream from the dam during peak hydropower operation. The calculation of probable maximum flood requires a consistent approach for all projects in the proposed cascade and MRCS can assist in reviewing this aspect.

The Fisheries Expert Group found that the proposed dam and reservoir at Xayaburi could affect between 23 and 100 species including five in the IUCN Red List of Threatened Species. The cascade of 6 dams would block about 39% of the Lower Mekong Basin's accessible habitat to migrant species from downstream. The estimated basinwide capture fishery yield is 2.5 million tons a year, of which an estimated 6% could be lost as a result of the cascade of 6 projects. Experience from other areas suggests that most of the loss would be associated with construction of the first dam in the cascade. These figures need to be verified with an indication of the loss distribution between countries where possible.

While the project provides for some elements of an effective fish bypass, the Expert Group concluded that the proposed design of the fish ladder for upstream migration and the provision for downstream migration of adult fish as well as larvae and fry will be ineffective. The group proposes alternative designs and operation regimes including a longer and more natural bypass channel with higher flow rates working in conjunction with a separate fish lift and modifications to use the navigation channel for upstream migration. For downstream migration, the assessment indicates the risk of fish not passing remain very high due to the considerable reduction in water velocities in the reservoir that compromises the natural drift of larvae. This is not possible to mitigate and would result in species loss over time.

The likelihood that species longer than 150 cm can successfully bypass the dam upstream is low implying there is strong possibility of the naturally-migrating Mekong giant catfish becoming extinct. Impacts on Irrawaddy dolphins near Khone Falls are not expected as a result of the cascade. The dolphins would be at risk from other projects proposed in that vicinity.

Gaps in knowledge — on the number of migratory fish species, their biomass and their ability to pass a dam and reservoir — lead to considerable uncertainty about the scale of impact on fisheries and associated livelihoods, both locally and in a transboundary context. This raises significant questions about whether the full extent of impacts can be estimated and adequate mitigation measures planned.

The alternative mitigation arrangements proposed by the Fisheries Expert Group are based on international best practice. They have not yet been tested for the diversity and biomass experienced in the Mekong. Improvement can be expected but there is no certainty that the fish-passage facilities will be sufficiently effective. In addition to mitigation, compensation on a transboundary scale would need to be considered to substitute for the loss of fisheries-based livelihoods.

The Sediment Expert Group concluded that the project design does not yet reflect either the MRC's Preliminary Design Guidance for Proposed Mainstream Dams in the Lower Mekong Basin or international best practice for sediment management. Significant reduction in water flows, for example, from about 1 m/s to 0.1 m/s, would result in sediments settling along the length of the reservoir, which would be about 100 km long. It is expected that under proposed operating conditions, the reservoir would effectively lose about 60% of its capacity due to sedimentation after 30 years, thereby compromising power generation in the medium to long term. This could be reduced to a 30% loss with adaptation of the flushing operations which — if routinely used — could then be maintained at this level.

The loss of sediment and changes in the nutrient balance downstream from the proposed dam would be small compared to the amount already reduced as a result of the large storage dams upstream in China which are estimated to cause up to 45 percent loss of sediment. Since the cumulative effects of multiple-dam developments on the mainstream and in tributaries would be significant, an adaptive sediment-management regime at Xayaburi is important to protect its long-term generating capacity while minimising bank erosion and scouring of the riverbed. Amending the design and operation would come at the cost of reducing power generation in the short term during sediment-routing operations while protecting long-term capacity. This proposal is consistent with that of the Fisheries Expert Group to lower sill levels to facilitate fish passage during the second phase of construction.

With regards to water quality and aquatic ecosystem health, the review found that the design of the Xayaburi project as well as management and mitigation plans do not yet reflect the MRC's Preliminary Design Guidance or international best practice. Areas of potential impact are identified and associated mitigation measures proposed relating to water quality, aquatic ecosystem health, including habitats for fauna and flora, and establishing constraints on the flow regime downstream to minimise adverse impacts on ecology including those associated with peaking power. An associated integrated monitoring regime — including the establishment of a baseline — is needed for flow, physical, chemical and biological parameters.

A preliminary assessment suggests that provisions for navigation in the MRC Preliminary Design Guidance are generally addressed. Some issues still need to be dealt with including operating levels, backwater effects, and approach and exit conditions. Provisions for adding a second navigation lock have not been fully addressed, nor have the issues of institutional arrangements and management of lock operations. The final assessment is currently under preparation.

The earthquake near Xayaburi in February emphasised the need for an independent review of the project according to international safety standards. **The project documents demonstrate a commitment to observing international standards for dam safety including consideration of a Maximum Credible Earthquake.** Review of the adequacy of the design for earthquake loading would come under the role of the Dam Safety Review Panel proposed in the MRC's Preliminary Design Guidance. The panel would need to be commissioned from the early design phase to the construction and operation phases to provide transparent monitoring, review and reporting as well as reassurance to downstream communities and countries that necessary provisions for dam safety are in place. As part of the risk assessment, a dam-break analysis — with a full range of scenarios including upstream dams in China — would be needed.

The construction of the proposed Xayaburi dam will not materially affect the quantity or timing of river flows in the Tonle Sap or the Mekong Delta. Cumulative impacts of this project and others planned for the Lower Mekong Basin would progressively increase the scale of impacts in these areas. Preliminary assessments carried out by the MRC would need to be further investigated.

Appropriate monitoring programmes would need to be in place to fill existing knowledge gaps that have been identified. Such programmes would be required to assess impacts if the project goes ahead, and provide information to adapt mitigation and management measures to minimise negative effects.

The MRCS review of transboundary social issues related to the Xayaburi project focused mainly on the consequences of environmental impacts. Social issues related to resettlement and other local impacts are outside of the scope of the MRCS review. There are nevertheless examples of international best practice being adopted in Lao PDR including the increasing trend towards project-based benefit-sharing mechanisms for affected communities. These can be used as a basis for mitigation measures at Xayaburi. For the cascade of 6 dams upstream from Vientiane excluding proposed tributary dams, incremental effects regarding fish losses due to reduced capture fisheries are estimated at about 66,000 tons per year. The livelihoods of about 450,000 people would be at risk to some extent. The distribution of the number of affected people among countries would need to be further analysed based on more extensive social information.

If the project proceeds, the Secretariat recommends that further discussion on the detailed recommendations in this report would be required to ensure relevant provisions are incorporated into the Concession Agreement and Power Purchase Agreement. A number of implications have also been identified for implementing the Procedures for Notification, Prior Consultation and Agreement and the work plans of MRC programmes.

1. Background

1.1 1995 Mekong Agreement and Procedures

The Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin signed by Cambodia, Lao PDR, Thailand and Viet Nam on 5 April 1995 defines a set of principles and processes that Member Countries have specifically committed to in cases where one or more countries proposes to utilize the waters of the Mekong and its tributaries within the boundaries of the four Member Countries of the Lower Mekong Basin (LMB). It established the Mekong River Commission (MRC) with three bodies (Council, Joint Committee and Mekong River Commission Secretariat) as an international organization to ensure implementation of the 1995 Mekong Agreement through its provisions and to adopt procedures to facilitate addressing such issues in a cooperative and amicable manner.

The types of water use under the 1995 Mekong Agreement include proposed mainstream hydropower developments, such as the Xayaburi project in Lao PDR. As this is the first time a mainstream project has been submitted for consideration by MRC, it undoubtedly will serve as an important precedent for other mainstream hydropower dam proposals. Key chapters and articles of the 1995 Mekong Agreement in this respect are:

Chapter II: Definitions of Terms
Article 1: Areas of cooperation
Article 3: Protection of the Environment and Ecological Balance
Article 4: Sovereign Equality and Territorial Integrity
Article 5: Reasonable and Equitable Utilization
Article 6: Maintenance of Flows on the Mainstream
Article 7: Prevention and Cessation of Damages of Harmful Effects
Article 8: State Responsibility for Damages
Article 9: Freedom of Navigation
Article 10: Emergency Situations
Article 26: Rules for Water Utilization and Inter-Basin Diversions
Chapter V: Addressing Differences and Disputes

Article 5 of the 1995 Mekong Agreement sets out the nature and requirements for any proposed use of waters of the Mekong River system and the extent to which the process of notification, prior consultation and/or agreement is needed among Member Countries at the Joint Committee level.

Depending on the type, time and place of water use, one of three different processes apply. The applicable process depends on (i) whether the water use proposed by the notifying country is on the Mekong mainstream or a tributary; (ii) whether it involves use of water in the wet or the dry seasons; and (iii) whether it involves transfer of water within sub-basins of the LMB (intra-basin use) or outside of the Mekong basin (inter-basin diversion). Implementation of Article 5 is supported by the Procedures for Notification, Prior Consultation and Agreement (PNPCA) prepared under Article 26 and approved by the MRC Council at its 10th Meeting on 29-30 November 2003. The MRC Joint Committee at its 22nd Meeting on 31 August 2005 approved guidelines on Implementation of the PNPCA. Decisions taken by the Joint Committee under Articles 5 and 26 of the 1995 Mekong Agreement need to be reported to the MRC Council under the Rules of Procedures of the Joint Committee (Rule 14).

The Xayaburi project proposed by Lao PDR involves constructing a dam across the Mekong mainstream for in-stream hydro-electricity generation in both wet and dry seasons. It is in the category of a mainstream, dry season intra-basin use under Article 5(B)(2)(a) and is thereby subject to a process of 'prior consultation, which aims at arriving at an agreement by the Joint Committee'.

Apart from the Procedures for Notification, Prior Consultation and Agreement approved in 2003 and the Rules of Procedures of the Council and of the Joint Committee adopted by the Council on 3 August 1995, this assessment also considers:

- Procedures for Data and Information Exchange and Sharing (2001)
- Procedures for Water Use Monitoring (2003)

- Procedures for Maintenance Flows on the Mainstream (2006)
- Procedures for Water Quality (2011)

1.2 Prior Consultation Process

The term *"prior* consultation*"* is defined in Chapter II of the 1995 Mekong Agreement as a process *"...that would allow the other member riparians to discuss and evaluate the impact of the Proposed use upon their uses of water and any other affects (sic), which is the basis for arriving at an agreement. Prior consultation is neither a right to veto the use nor unilateral right to use water by any riparian without taking into account other riparians' rights'."*

To guide the process, the PNPCA sets out in Section 3 five principles each of which generally has an established interpretation under international law:
(a) sovereign equality and territorial integrity,
(b) equitable and reasonable utilization,
(c) respect for rights and legitimate interests,
(d) good faith, and
(e) transparency.

Section 5 of the PNPCA covers the case of prior consultation in more detail and sets out the role of the various parties, the process for review, the need for timely submission, and the forms to be used for both the submission by the notifying country and the responses by the other countries. It includes a provision to establish a JC Working Group, which has been done in the case of the Xayaburi submission.

Section 5.4.3 of the PNPCA describes the overall aim for the JC to reach an agreement related to the proposed use and issue a decision including any conditions agreed upon. It outlines the responsibility of the notifying state not to implement the proposed use until the opportunity for its consideration has been provided through the PNPCA process and for any concerns or reservations to be placed on record.
The PNPCA states in Article 5.5.1 and the Guidelines further clarify the timeframe for the prior consultation process of six months from the date documents are received by the JC from the MRC Secretariat and that this process should be timely and take place before commencement of project implementation. It notes that in practice, because of the potential scale and complexity of such projects and potential impacts, the process would be started much earlier (see Section I [B][1] of the Guidelines on PNPCA) as the MRCS will require up to one month to process any prior consultation submission. If necessary, the JC may agree to extend the timeframe of the process.

1.3 Remarks on Main Principles Governing the Prior Consultation Process

MRC Member Countries have agreed to Article 5 of the 1995 Mekong Agreement, which is based upon the universally-accepted doctrine of *"reasonable and equitable utilization"*, have committed to the process of prior consultation outlined briefly above and the principle of good faith negotiations. The process is consistent with the general spirit of cooperation as expressed in the 1995 Mekong Agreement and is the accepted practice within MRC to find a consensus on basin developments and water management issues. The nature of the responses from each Member Country will form the basis of discussions by the JC, and is the result of individual national processes according to the prevailing context in each country.

The definition of prior consultation implies that substantive issues affecting other countries that have been raised as a part of the prior consultation process will be taken into consideration by the notifying country before commencing implementation of a proposed project. It states that the process *"is neither a right to veto the use nor unilateral right to use water by any riparian without taking into account other riparians' rights".*

The process provides an opportunity for all parties to collectively assess the reasonableness and potential impacts of the action relative to the rights, interests and obligations of all Member States, and to mitigate or minimize any harmful effects (Article 7) and to recognize State responsibility for damages in the event that any harmful effects do occur as a result of a water use (Article 8). Equally important as an underlying expectation of the 1995 Mekong Agreement is that the process would enable and encourage other Member States to cooperate and participate in this and future projects of a similar nature.

2. The Xayaburi Dam Project Prior Consultation

2.1 *The Prior Consultation Road Map*

The Lao National Mekong Committee (LNMC) submitted documents for prior consultation on the Xayaburi Dam Project to the MRCS on 20 September 2010. After MRCS checks and LNMC clarifications, the documents were circulated and received by all JC Members by 22 October 2010. At its first meeting on October 26, a **PNPCA Joint Committee Working Group** (JCWG) endorsed a Road Map on Prior Consultation for the Proposed Xayaburi Project (see ***Annex 1A***). The third JCWG meeting on February 14, 2011 included a two-page statement by the Lao government (see ***Annex 1B***). The 6-month timeframe for prior consultation will end on 22 April 2011. The JC may determine if it is necessary to extend the period.

The analysis and findings of this review report are based on key MRC documents and are presented to assist Joint Committee Members and Member Countries in their own assessments and discussions. ***Table 1A*** illustrates the key milestones of the process.

Table 1A: Key milestones of the Prior Consultation Process for the Xayaburi Dam Project

20 Sept 2010	MRCS receives LNMC submission on proposed Xayaburi dam project
20 - 22 Oct 2010	JC Members receive LNMC submission after MRCS seeks clarifications
26 Oct 2010	1st JCWG Meeting (Vientiane) - Discussion of Road Map on Prior Consultation
29 – 30 Nov 2010	2nd JCWG Meeting (Luang Prabang) - Xayaburi site visit, Scoping Assessment
Dec 2010/Jan 2011	Expert inputs and drafting process for review report
14 Feb 2011	3rd JCWG Meeting (Vientiane) Consideration of 1st draft of Project Review Report
22/23 March 2011	33rd Meeting of JC - Consideration of 2nd draft Project Review Report; discussion of preliminary country responses
22 April 2011	End date of PC process - JC conclusion

2.2 *Process for Preparing the Prior Consultation Project Review Report*

As agreed at the first JCWG meeting, the MRCS supports the JC by reviewing, analyzing and providing technical advice during the process. The final output of this support is this Prior Consultation Project Review Report, which builds upon an earlier Scoping Assessment presented at the second JCWG meeting. The assessment identified the main issues and gaps in documents submitted on the Xayaburi dam project.

Other MRC mechanisms to guide and undertake the prior consultation process have included:

- **A PNPCA Task Group** within the MRCS. This is a cooperative mechanism among MRC programmes which has been responsible for synthesizing the results of its analyses in this review report. MRCS inputs include hydrodynamic modelling (Information Knowledge Management Programme) and issues related to fisheries (Fisheries Programme), water quality (Environment Programme), hydropower (Initiative on Sustainable Hydropower) and navigation (Navigation Programme). Overall coordination came from the Mekong Integrated Water Resources Management Project under the MRC Planning Division, which also oversees the Basin Development Plan programme and the Initiative on Sustainable Hydropower.
- **Expert Groups on Fisheries and Sediments,** two issues that require very specific expertise beyond that available in the MRC Secretariat. The groups established consist of international and regional experts to ensure the analysis adequately reflects international good practice and standards while reflecting the regional Mekong context (see ***Annex 1c***). Their findings have been integrated into this report and include reflections on the project documents, implications of possible negative local and transboundary impacts addressing potential cumulative effects, possible mitigation measures and recommendations for the different sectors.

- **Other individual experts** were commissioned on an "as-needed" basis including an international engineering expert on dam layout and operation, who supported the various technical experts in better understanding those issues, and experts in modelling and sustainable hydropower.

2.3 Key Documents Used in the Review

Over the past two years, MRC has developed or commissioned key reports which address issues related to mainstream hydropower dams in the LMB and provide a framework of basin-wide analysis, including transboundary and cumulative effects, within which individual projects can be considered. They include the following documents, which are also summarised in Chapter 3:

- the IWRM-based **Basin Development Strategy** prepared by the Basin Development Plan Programme and approved by the MRC Council at its 17th Meeting on 26 January 2011 together with the underlying basin-wide development scenario assessments and sector assessments[1];
- the **Strategic Environmental Assessment of Hydropower on the Mekong Mainstream (SEA)** commissioned by MRC and completed on 15 October 2010 as part of an open 14-month process involving the National Mekong Committees and MRC stakeholders[2];
- the **Preliminary Design Guidance for Proposed Mainstream Dams in the Lower Mekong Basin (PDG)** endorsed by the JC in 2009[3], which has been developed by MRC Programmes in a process coordinated by the Initiative on Sustainable Hydropower consulting with a Technical Working Group of Member Countries ;
- other guidance material has been considered for aspects not fully covered in the PDG and for which references to international good practice will be made. Other guidance includes MRC Programme assessments of good-practice standards related to the five PDG topics (fish passage, navigation locks, sediment management, water quality and environmental flows and dam safety) and other topics relevant to Integrated Water Resources Management practice and sustainable hydropower. ? Documents and references consulted by the experts groups are listed in ***Annex 2***.

2.4 Scope of the Review Report

This review report is prepared to inform the Member Countries and ultimately the JC discussion about the potential trans-boundary impacts, risks and consequences of the proposed Xayaburi dam project. It is also an opportunity to reflect on the extent to which the project design incorporates the principles of sustainable hydropower and Integrated Water Resource Management (IWRM), which are central to MRC's mandate, and good international practice. Since decisions on the economic and financial viability of the project are the responsibility of others, the report focuses more on environmental and social aspects. The social aspects covered relate mainly to those resulting from potential changes to ecosystem services such as fisheries, the aquatic environment and flow regime rather than local impacts in the immediate project area related to resettlement, which are a Lao national issue.

The report also considers cumulative impacts, thereby providing guidance to the proponents of many other projects being considered on the mainstream of the Mekong River.

The scope of this review report is to consider the potentials for transboundary and cumulative impacts associated with the construction and operation of Xayaburi dam as the third in a potential cascade of six hydropower dams on the Mekong mainstream above Vientiane and in relation the existing and planned Mekong tributary dams.

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[1] http://www.mrcmekong.org/17thCouncil/IWRM-based-Basin-Dev-Strategy-approved-by-MRC-Council-260111.pdf
[2] http://www.mrcmekong.org/ish/sea.htm
[3] http://www.mrcmekong.org/download/free_download/Preliminary-DG-of-LMB-Mainstream-dams-FinalVersion-Sept09.pdf

Transboundary and cumulative considerations mainly address impacts of the proposed project on the Preliminary Design Guidance topics of (i) fisheries, (ii) sediment transport, morphology and nutrient balance and (iii) water quality, ecosystem health and environmental flow. Transboundary implications regarding dam safety and navigation are of a different nature and are also addressed.

This basin-wide approach:

- facilitates the task of the MRC countries to understand the Xayaburi dam project in its basin-wide context and to better understand transboundary implications in terms of possible impacts and risks;
- connects the national with the international level regarding transboundary coordination mechanisms;
- supports the countries in joint river basin management and basin-wide decision making towards their sustainability objective; and
- follows the aims and philosophy outlined in the 1995 MRC Mekong Agreement.

Chapter 3 of this report deals with the transboundary context of the project while Chapter 4 contains technical reviews of its design and issues related to hydrology, fisheries, sediment, water quality, navigation, safety and social aspects. Key conclusions and recommendations are contained in Chapter 5.

3. Xayaburi Dam Project and its Transboundary Context

3.1 Basin-Wide Hydropower Context

The Mekong River is one of the world's largest rivers, flowing through Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam. The Lower Mekong Basin (LMB) downstream from China is characterised by a mainstream which is currently not dammed by hydropower schemes. With the exception of the Ba Lai distributary in the delta, the Mekong River is free flowing downstream from China before entering the sea.

Hydropower development is assuming an important role in the Mekong Basin. In the Chinese province of Yunnan in the Upper Mekong Basin, the Mekong is dammed by four hydropower schemes in a cascade of up to eight planned storage projects. Most of the tributaries in the Lower Mekong Basin (LMB) have cascades of hydropower dams. This hydropower development is considered in the scenarios of the MRC Basin Development Plan and the Strategic Environmental Assessment of Hydropower on the Mekong Mainstream as well as this project review report. In the baseline year of 2000, 15 dams were operating in LMB tributaries. Another 26 tributary dams are expected to be in place by 2015 (Definite Future Scenario) and an additional 30 hydropower schemes could be operating by 2030 (Foreseeable Future Scenario), increasing the overall number of tributary hydropower schemes to 71.

To date, 12 hydropower projects have been proposed for the LMB mainstream of which 11 involve dams. Ten projects are planned in Lao PDR, including two on the Lao-Thai reach. Another two have proposed in northern Cambodia. Ten of the proposed dams would span the entire mainstream. Of the two projects at Khone Falls in Lao PDR, one involves partly damming one of several branches of the mainstream (Don Sahong) while the second involves a diversion around the falls without a dam (Thakho).

The proposed dam at Xayaburi, about 100 km downstream from Luang Prabang, would be the third in a cascade of six mainstream dams In Lao territory (see ***Figure 1A***).

The Lao Government commissioned France's Compagnie Nationale du Rhone for an Optimisation Study on the mainstream reaches of the Mekong that would be affected by the six hydropower schemes upstream from Vientiane. The figures in this study are based on the dam design as submitted to the MRC for Prior Consultation.

Figure 1A: Location of the proposed Xayaburi dam project (MRC SEA, 2010)

Figure 1B: Proposed Xayaburi dam project site in early dry season (November 29, 2010).

3.2 Transboundary and Cumulative Aspects

Transboundary impacts and possible cumulative effects that may result from hydropower or other infrastructure projects need to be considered in the context of the overall river basin. Implications of impacts are therefore shown for both local and basin-wide scales so the relevance of any individual proposed project is reflected for all riparian countries.

Cumulative effects are additive consequences that may occur from multiple hydropower schemes on both the mainstream and tributaries or other interventions. They can occur in both a downstream direction (e.g. water quality deterioration, changes in sediment flows and fish migration) and an upstream direction (e.g. interrupted fish migration).

3.3 Frameworks of Basin-wide Analysis

Transboundary and cumulative aspects have been addressed in particular within the scenarios under the MRC Basin Development Plan (BDP) and the Strategic Environmental Assessment of Hydropower on the Mekong Mainstream (SEA). The MRC Preliminary Design Guidance for Proposed Mainstream Dams in the Lower Mekong Basin (PDG) builds upon those documents and incorporates the basin-wide perspective.

3.3.1 The IWRM-based Basin Development Strategy and its scenario assessment[4]

Assessment of a range of basin-wide development scenarios has been an important step in basin development planning in the LMB. Scenario assessments undertaken by the BDP Programme brought together water and related resources at the sub-basin and national levels to assess future development policies, plans and projects against a set of 42 criteria. Each scenario was evaluated in terms of 13 economic, environmental, social and equity objectives, developed through a participatory process.

The assessment has considered the transboundary development and impacts in relation to a **baseline** (1985-2000 simulated hydrology and 2008-2009 environmental and socio-economic status). The basic set of scenarios can be summarised as:

- **Definite Future Scenario by 2015** addresses ongoing water resources development by 2015, i.e. developments that have been in place since year 2000, and those under construction or already firmly

[4] http://www.mrcmekong.org/17thCouncil/IWRM-based-Basin-Dev-Strategy-approved-by-MRC-Council-260111.pdf

committed including hydropower development on the Lancang-Upper Mekong Basin (China), 26 tributary reservoirs in the LMB and irrigation areas as of 2008.

- **Foreseeable Future Scenario by 2030** addresses LMB water resource development over the next 20 years including a further 30 tributary dams (up to 71 overall), 12 proposed mainstream projects and projected water supply needs including plans to increase irrigation coverage from 1.2 to 1.8 million hectares.
- **Long-Term Development Scenario by 2060** with two possible levels of future development in addition to those in the 2030 scenario.

Developments over the next 20 and 50 years have been assessed with and without the potential influence of climate change. The results, together with other basin-wide assessments, provide a basis for discussion and negotiation of mutually-beneficial levels of water-resource development and associated levels of transboundary environmental and social impacts. This leads to a shared understanding of what could be considered as development opportunities and required actions to optimize the opportunities and minimize the associated risks. These shared views are reflected in the IWRM-based Basin Development Strategy that will now guide national planning, decision making and regional activities towards sustainable basin development.

The proposed Xayaburi dam project and its possible impacts are considered as part of combined planned developments in the foreseeable future scenario to 2030 together with five other hydropower schemes in upper Lao PDR (those upstream of Vientiane). Assessments are compared to the baseline case, on-going developments and (iii) planned developments without mainstream dams. The Foreseeable Future Scenario has been further disaggregated in the fisheries and sediment sections to look at the impacts of just the 6 proposed mainstream dams in the cascade north of Vientiane. Impacts related to these projects can therefore be separated from those of future tributary dams downstream.

Based on the scenario assessments and its implications, the Strategy sets out the negotiated position of the MRC on issues such as mainstream dam development and provides 12 Strategic Priorities for basin development and management.

In Section 3.2, the Strategy recognizes the *"the high potential financial and economic returns from proposed mainstream projects in terms of meeting electricity demands and generating revenues for development.*" At the same time, it recognizes that "*the uncertainty of the 12 proposed mainstream projects in the LMB is large and their cumulative negative impacts would be severe.*" It also puts priority on developing this knowledge base, including the scale and distribution of risks and possible avoidance, mitigation and benefit and risk-sharing options. Necessary frameworks must be in place "*to provide assurance that risks can be effectively minimized and transboundary assessment through the PNPCA is completed before construction decisions on the projects are made.*"

The Strategy also recognizes "there is an opportunity to consider some mainstream hydropower, provided the major uncertainties and risks associated with mainstream dams are fully addressed and the opportunity is provided for Member Countries to consider and address jointly the transboundary impacts of any proposed project (through the PNPCA)."

3.3.2 The Strategic Environmental Assessment of proposed mainstream dams

Formulation of the IWRM-based Basin Development Strategy coincided with a Strategic Environmental Assessment commissioned by MRC. The MRC foresaw the need for a transboundary and cumulative assessment to act as a framework of analysis within which any individual mainstream project could be reviewed when submitted by a Member Country under a PNPCA process for prior consultation.

The four stages of the SEA (scoping, baseline assessment, impact assessment and mitigation) were conducted as an open, structured consultation process over 16 months engaging with government agencies and a wide range of other stakeholders including civil society, private sector and development agencies. This process was consistent with IWRM principles and helped ensure the full range of stakeholder expectations, views and opinions was captured on the issues. The final recommendations of the SEA were those of the consultants.

Broadly, the SEA sought to identify the potential opportunities and risks, as well as the contribution of the proposed projects to regional development, by assessing alternative mainstream Mekong hydropower development strategies. In particular, the SEA focused on regional distribution of costs and benefits with respect to economic development, social equity and environmental protection.

The SEA supports the wider BDP process by complementing its assessment of basin-wide development scenarios with more in-depth analysis of power-related and cross-sector impacts to inform discussion on balancing the development risks and opportunities of proposed LMB mainstream projects. The findings of the SEA on potential impacts and risks of mainstream hydropower projects were similar in nature to those of the BDP scenario assessments.

The SEA and BDP differ in terms of scenarios analyzed and methodology used. While the BDP covers 16 scenarios related to the countries, the SEA focuses on three BDP scenarios and relates these to 6 hydro-ecological zones: (1) Lancang River, (2) Chiang Saen to Vientiane, (4) Vientiane to Pakse, (5) Pakse to Kratie and (6) Kratie to Phnom Penh. Projects in each zone were considered in relation to the nine themes identified by consensus during the scoping stage, namely energy and power, economics, hydrology and sediment, aquatic ecosystems, terrestrial and agriculture systems, fisheries, social systems, navigation and climate change.

The SEA makes comprehensive recommendations for different strategic options to guide the LMB countries on whatever course of action they finally decide to take concerning mainstream development. The recommendations are subdivided in four groups: (i) the PNPCA Process, (ii) the basin planning process, (iii) guidance and standards and (iv) a Mekong Fund***.***

3.3.3 MRC Preliminary Design Guidance for Proposed Mainstream Dams

The Preliminary Design Guidance (PDG)[5] was agreed through a regional Technical Review Group and approved by the MRC Joint Committee. It has been available since September 2009 to provide overall guidance for Mekong mainstream hydropower schemes in the form of performance targets, design and operating principles for mitigation measures as well as monitoring and suggestions for adaptive management.

The PDG has been used as an important and objective assessment basis for the technical review of the Xayaburi dam project and applied as a cross-check tool. Indicators of the project documents have been compared to specific performance targets, design and operating principles for mitigation and management measures. The MRC PDG addresses the following five topics, which have been used for the cross-check and are reflected in this review report:

(i) fisheries/fish passage,

(ii) sediment transport and morphology,

(iii) water quality, aquatic ecosystem health and environmental flows,

(iv) navigation

(v) safety of dams.

First outcomes of this cross check have been presented at the 2nd PNPCA JC Working Group meeting (November 2011) and are part of the MRCS Scoping Assessment Report, where details can be found.

The Scoping Assessment aimed among other objectives to get a first impression if the proposed dam project is aligned with MRC Preliminary Design Guidance for Mainstream Dams as well as other international good practice and to identify gaps and uncertainties to develop this technical review.

[5] http://www.mrcmekong.org/download/free_download/Preliminary-DG-of-LMB-Mainstream-dams-FinalVersion-Sept09.pdf

4. Technical Review

4.1 Xayaburi Hydropower Dam Design and Operation

4.1.1 Basic information on project layout, design and construction sequence

(i) General layout

The Feasibility Study (March 2010) summarizes conceptualization and optimization of the project. The Design Report (September 2010), summarizes the main calculations, results and findings during the Outline Design stage for Engineering-Procurement-Construction (EPC) tendering.

The basic layout of the Xayaburi project (***Figure 2***) has been devised to provide facilities necessary to achieve objectives selected and defined in the Preliminary Design Guidance. The primary function of the project is to provide hydropower generation capability comprising seven turbine-generator units of 175 MW capacity or a total of 1,225 MW for export to Thailand, and one unit of 60 MW capacity for use in Lao PDR. The main facilities are the dam structure itself (820 m long, 32.6 m high, rated head of 18.3 m), the spillway for discharge of river flow greater than the powerhouse discharge capacity, sluices for bypassing of suspended sediment at the powerhouse inlets, navigation locks and fish bypass facilities (see ***Figure 2***).

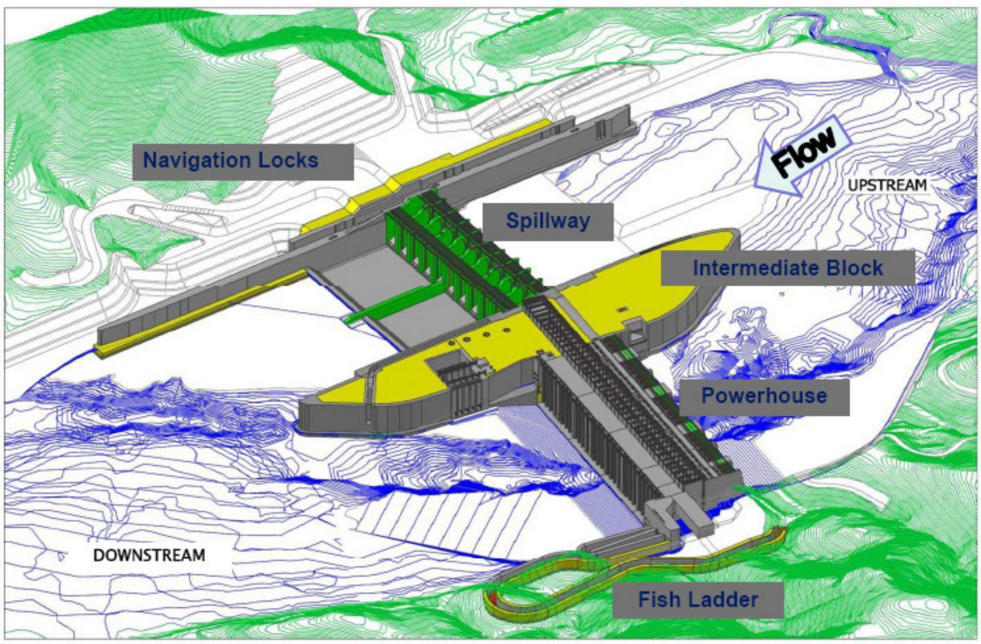

Figure 2: Overall layout of Xayaburi dam project (Layout Report, 2010). The structure is 820 m long and 32.6 m high. The spillway facility comprises ten radial gates, 19 m wide and 21 m high. Gross reservoir volume is 1,300 m^3 or 1.3 km^3

Based on and independent review conducted by MRCS, the general layout of the project appears consistent with the site conditions and the required facilities. The arrangement has been selected following evaluation of costs and benefits of alternatives. The range of alternatives evaluated in the Feasibility Study appears logical and consistent with conventional hydropower and dams design practice. The project layout derived in the Feasibility Study was adopted for preparation of the Project Design Report, which forms the basis for the EPC contract for project construction.

A reservoir level at elevation 275 m was selected to provide the head for power generation. Based on an optimisation study conducted for the Lao Government, the normal operating range of 2.5 m in the reservoir will provide storage for diurnal peaking to meet power demands. The water level will be controlled during flood events with the objective of preventing flooding in Luang Prabang upstream.

The arrangement selected for optimization during the Feasibility Study assumed operation of the power station to maximize energy generation, which may be affected by several subsequent adjustments needed to improve performance related to sediment management and fisheries. Comments on plant operation are given in ***Section 4.2.2.*** Key differences between the Feasibility Study and the Design Report are the reduction of the reservoir level during floods to mitigate flooding at Luang Prabang and an increase of the diurnal peaking operation of the reservoir. The lower reservoir level during floods will have some benefit in sluicing sediment through the reservoir (details on the efficacy of the sediment management proposals are provided in ***Section 4.4*** of this report). This would be improved with spillway design modifications.

(ii) Design of project facilities

The powerhouse layout is a conventional design arrangement for Kaplan turbines, which are appropriate for the available generating head at the site. Seven of the turbine-generator units are dedicated for energy exports to the Electricity Generating Authority of Thailand (EGAT). One smaller unit is dedicated for energy supply to Electricite du Laos (EdL). The supply to EdL is not electrically connected to the supply to Thailand so an outage of the single EdL unit will disrupt the supply to EdL only. Supply to Thailand uses multiple units so maintenance and other unit outages can be managed with few disruptions to continuity of supply.

Fish-collecting galleries are provided across the upstream and downstream faces of the powerhouse structure (see ***Figure 3***). The downstream fish-collecting gallery is combined with a water-feed system to attract fish from inlets at the left end of the spillway and the right end of the powerhouse. The downstream fish-collecting gallery flows to the fish ladder located at the left bank of the powerhouse. The main fish ladder is intended to collect fish from across the width of the powerhouse and from the spillway, providing an upstream migration route. The upstream fish-collecting gallery aims to provide a downstream migration route by discharging past the powerhouse. Downstream migrating fish are also expected to pass through the turbines and over the spillway.

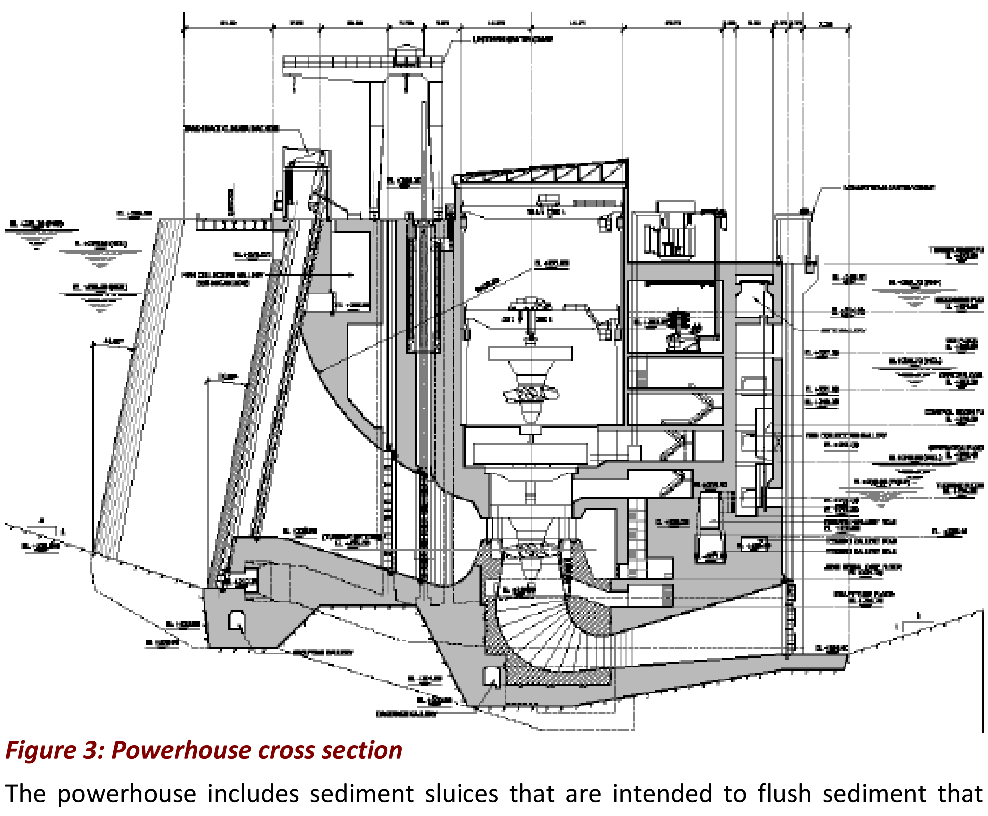

Figure 3: Powerhouse cross section

The powerhouse includes sediment sluices that are intended to flush sediment that may accumulate in front of the turbine inlets during outages. Depending on the flow conditions, the sediment sluices would be used to discharge flow continuously or used only for a flushing period prior to unit start up.

The spillway facility is a conventional dam design arrangement that comprises ten radial gates, 19 m wide by 21 m high. The gates are large but within international precedents. A stilling basin is provided for dissipation of energy from the spillway flow. The spillway is designed to discharge floods up to the Probable Maximum Flood, which is consistent with dam safety standards. The stilling basin is designed for floods up to a return period of 50 years. This approach assumes that the stilling basin can be dewatered at intervals for inspection and repair of any damage that may occur as a result of larger floods

The arrangement of the spillway (see ***Figure 4***) does not provide low-level discharge capacity as suggested in the Preliminary Design Guidance. The spillway has a common crest level at elevation 254 m for all of the gates. An alternative design arrangement with some of the spillway gates arranged as low-level sluices is possible if improved reservoir flushing is required.

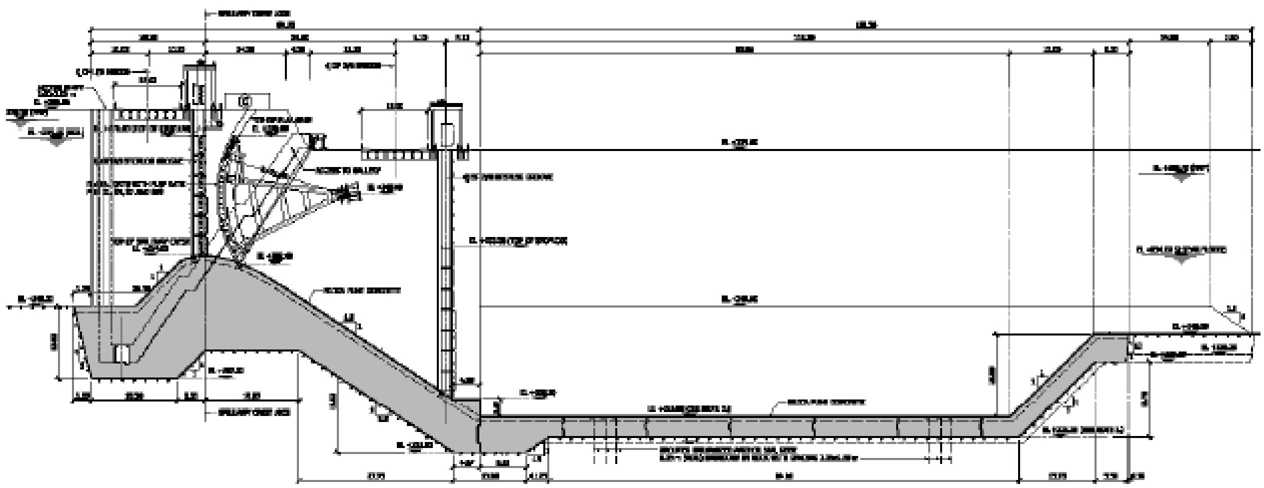

Figure 4: Spillway cross section.

The use of low-level sluices would also offer the significant benefit of lowering the upstream water level during the period when the powerhouse cofferdams are constructed. With the present design, the cofferdams must be closed with water flowing over the crest of the spillway, resulting in high velocity through the closure section.

The spillway will operate with gates fully opened during the entire period when the powerhouse is being constructed. The level of the navigation lock is devised with a minimum operating level at elevation 255.5 m to ensure that navigation can continue through the construction period.

The arrangement shown in the Project Design Report has a channel downstream from the spillway stilling basin with an invert at elevation 240 m. The bed of the river channel in this area will be below elevation 230 m and the minimum tail-water level reported in the Project Design Report is below elevation 240 m. The channel level at the outlet of the stilling basin will not provide for dissipation of all energy to the tail-water level during low flow conditions. Flow can be expected to cross the short spillway outlet channel and then accelerate to the main river channel. The navigation lock inlet is close to the end of the spillway discharge channel and will be affected by the flow disturbance from the spillway during construction.

This flow condition is not likely to occur during operation when the powerhouse will be operated during low-flow periods and the spillway will be closed. The spillway outlet channel at elevation 240 m does restrict the flexibility to modify some of the spillway bays as low-level outlets to improve sediment flushing.

Review recommendation: *Alternative arrangement of this channel would be possible if a low-level spillway is considered.*

The navigation lock arrangement appears generally consistent with the specific requirements of the Preliminary Design Guidance. Details should be confirmed as the detailed design is developed (see section 4.6). The approaches to the locks upstream and downstream should be examined as part of hydraulic modelling to ensure that boat traffic is not endangered during plant or spillway operation.

(iii) Construction

Construction would commence with a six-month period for site preparation and building the access road. The main contract period, for 7 years and 9 months, includes two main phases when the river is modified by cofferdams.

The first phase is scheduled for three years and will involve right-bank construction of the spillway, navigation lock and part of the intermediate block (see ***Figure 5***). The river will remain in the original channel during this period and cofferdams will be used to isolate the work areas. Fish migration, navigation, and other in-stream uses are in the left river channel.

Review recommendation: *Detailed design studies are required to confirm that the changes in flow velocity during this period will not affect these in-stream uses,*

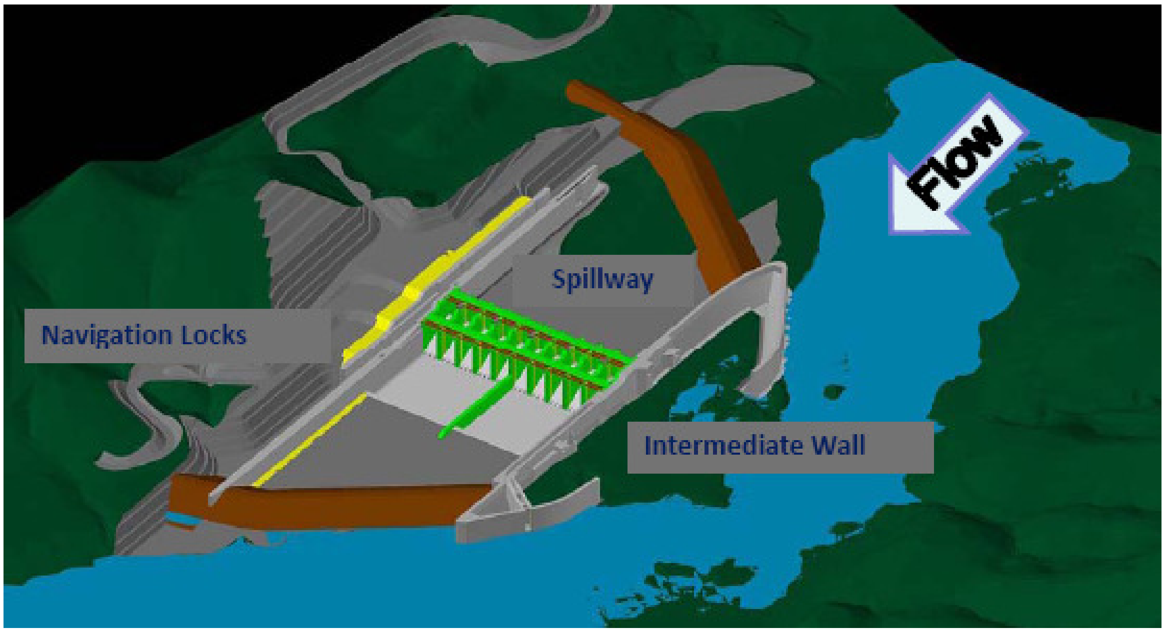

Figure 5: First phase of construction proposed in the design documents

Construction of the intermediate block wall is critical during this period because of its role for connection of the cofferdams. The main spillway construction will commence when the intermediate wall is completed sufficiently for the cofferdams to control flood conditions at the site.

The second phase of the construction involves completion of the remainder of the intermediate block, the powerhouse, and the left bank fish passing facilities (see ***Figure 6***). During this period, the reservoir will fill with water being discharged through the open spillway gates and over the sill of the spillway. The reservoir level will vary depending on the river flow. Navigation will be through the locks, which are designed for operation with the river levels during this period.

Upstream fish migration during the second construction stage appears to be restricted to the use of the navigation lock as the head difference across the spillway will be too large, while downstream migration is deigned to occur through the spillway (see ***Annex 4***). The Fisheries Expert Group therefore recommended that fish-passage facilities are implemented in a phased approach with a nature-like fish pass constructed during the first phase of the dam construction to be operational in the second phase.

During construction, water levels upstream and downstream from the dam will fluctuate with the natural flow of the river as there should be no re-regulation of the discharge other than that occurring due to the reservoir operating at low level with free spillway outflow.

Powerhouse civil works construction is planned for three years during the second phase of construction (see ***Figure 6***) followed by completion of the electrical and mechanical works. Cofferdams will be used to isolate the powerhouse work during this period. The first generating unit will be commissioned after 7 years and 3 months with the subsequent units entering service approximately at one-month intervals.

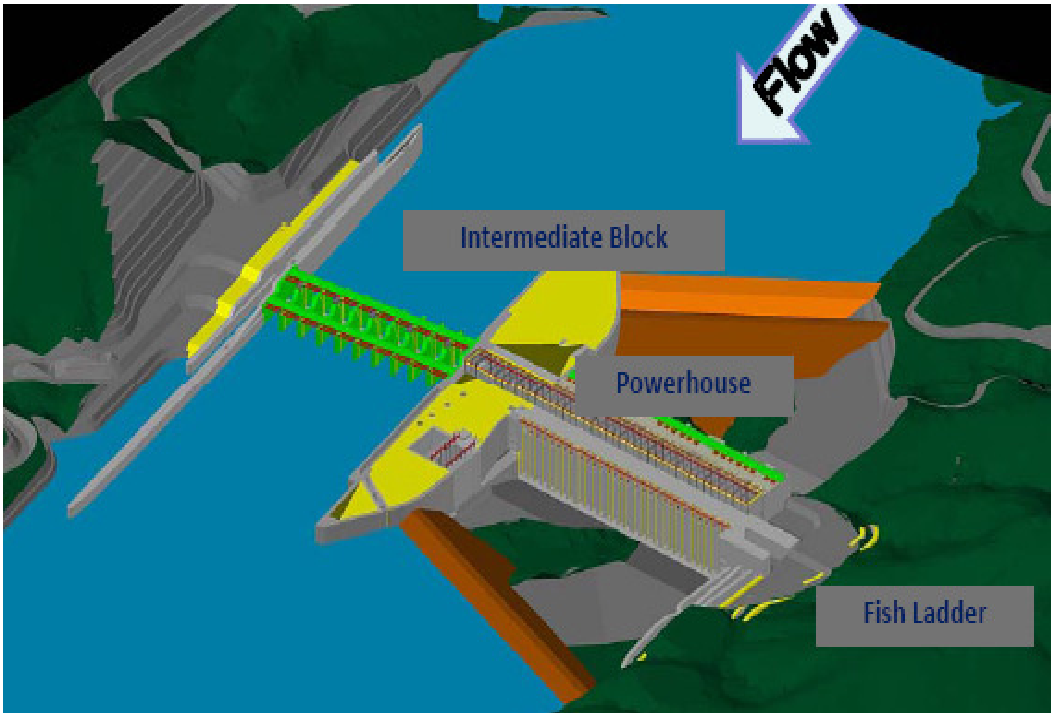

Figure 6: Second phase of construction proposed in the design documents

The time periods assigned for construction appear reasonable as a basis for preliminary planning. Opportunities for some reduction in the construction period could be devised during detailed construction planning.

4.1.2 Overview of the dam operation plan

The Xayaburi developer has stressed in the presentations to the PNPC JC Working Group that the project will be nominally operated as a run-of-river project, with reservoir inflow equal outflow at the plant when measured over a period of several days. The plant will have a Normal Operating Level (NOL) of 275 m above sea levelmasl. While essentially conceived for a run of river operation, the plant will have the possibility of a daily peaking operation in dry season, allowing moderate daily fluctuations of the headwater and tail-water levels. The Design Report provides for a 2.5 m operating range in the reservoir, which can be used for weekly peaking operations.

Daily peaking can be expected to maximize revenue according to the power purchase agreements. Normal peak period hours of 16 hours daily for six days and 72 hours weekly of off-peak and transition period operations could be expected. The largest off-peak period is on a Sunday when 24 hours are scheduled off peak. The storage available in the reservoir can be used to reschedule flow from the off-peak to the peak periods resulting in a predominately diurnal variation. Some weekly off-peak to on-peak scheduling will be possible during low flow periods. During periods with river flow rate greater than 5,140 $m^{3/}s$ there should be no variation in the headwater level due to power generation operations.

Review recommendation: *There is a need for information on operating constraints such as daily operating periods, ramping rates for starting and stopping units, minimum flows for environmental or navigation periods, and other details affecting the external impacts of the project.*

The Design Report states that the head water level will be lowered during flood conditions to mitigate the possibility of flooding at Luang Prabang. The report suggests that the water level at the dam will be lowered as the flood magnitude increases. With a 2-year return period flood the headwater level at the dam is to be lowered to el 265.9 m and the spillway gates would be opened fully. Larger floods would also be discharged with the gates opened and the headwater level will be a function of the flow rate. For example, the 30 years return period flood would have a headwater level at 270.6 m above sea level and the probable maximum flood (PMF) would have headwater level at the dam of 279.8 m above sea level. The backwater will extend upstream along the reservoir.

The tail-water level for energy generation purposes will range between 236.00 masl and about 255.70 masl. Once the downstream Pak Lay plant will be built, the minimum tail-water level is expected to raise to 240.00 masl, without appreciable increase of the maximum tail-water level. This compares to the current seasonal fluctuation of more than 1 m during wet season and approximately 0.3 m during dry season Once the downstream Pak Lay plant will be built, the minimum tail-water level is expected to raise to 240.00 masl, without appreciable increase of the maximum tail-water level. The tail-water level will fluctuate daily and seasonally with the variation of the flow rate through the powerhouse, spillway, navigation locks, and fish bypass works.

Flow Capacity of Xayaburi Structures

- Turbine Flow - 5,140 $m^{3/}s$
- Sand Flushing - 3,500 m^3/s
- Fish Passage /Attraction flow - 190 m^3/s below 5000 m^3/s river flow and 450 m^3/s above
- Navigation lock (minimal flow?)
- Sum of the above: 9090 m^3/sec
- Spillway: designed for PMF of 47,500 m^3/s)

Flow capacity of individual structures

- Rated turbine discharge
  - EGAT- 7 units @ 665 m^3/s
  - EdL - 1 units @ 230 m^3/s
- Rated flow flushing outlets below turbines
  - 7 outlets @ 500 m^3/s each
- Spillways
  - (10) radial gates 19 m wide and 21 m high

River flows at Xayaburi site (m^3/s)

Average natural flow	3,971
1 in 10 year	22,033
1 in 100 year	29,146
Q1,000	37,100
Q10,000	45,000
PMF	47,500

(i) General concept of operation

Releases would be through a combination of paths including turbines, spillways, fish passage structures and navigation locks.

The reservoir impounded behind the dam would be maintained at 275 m above sea level at all times of the year (with exceptions noted below). This corresponds to the level that the river would reach in a 1:000 year flood (a flow of 37,100 m3/s). The reservoir (or back water effect) would extend up the Mekong from the dam to Luang Prabang town, a distance of 100 km.

The water level in the Mekong mainstream downstream of the Xayaburi dam would vary seasonally depending on the river flow. The downstream level would rise and fall with flow pattern changes between the dry and wet seasons. The water level would typically vary up to 19 m between 236.0 masl in the dry season to about 255.7 masl in the flood season (excluding exceptional flood events such as a PMF). The elevation of 236.0 masl is the lowest tail-water level for operating turbines, before the commissioning of Pak Lay, for a river flow of 1,000 m^3/s.

The potential daily or weekly variations in water levels both upstream (in the reservoir) and downstream of the dam in the dry and wet season would depend on how the project is operated to optimize power generation. The power station could be operated for intermediate power system load peaking during the dry season. The Design Report makes reference to provision for 16 hours of daily peak load and 72 hours of off peak periods within each week. The flow rate through the powerhouse would be varied to shift water into the peak periods by using the storage in the head pond, which is constrained to not more that 2.5 m fluctuation in the Design Report.

Strategies to operate the dam in cases of exceptional floods, emergency events and for environmental flow or sediment management releases that may be decided (i.e. operation of the ten radial gate spillways and the seven 3m x 3m box culvert sand flushing outlets located below each of the seven main turbines) have not been described in detail in the available reports.

Review recommendation: *There is a need to define operating constraints as part of any concession agreement negotiated for the project. These constraints would then affect the conditions accepted as part of the power purchase agreements.*

Dry and wet season operation

The accompanying box shows data on different pathways for releasing water through the dam and related infrastructure. It is important to distinguish between dry and wet seasons to consider these operating factors and understand the implications.

In the dry season (typically November to May)

- The Feasibility Reports suggest a minimum flow of 800-1,000 m^3/s at the Xayaburi site, based on time series data, before consideration of upstream flow regulations.[6]
- Regulation of upstream Chinese dams (Xiaowan and Nuozhadu projects) is expected to add 1,000 to 1,200 m^3/s to flow at the Xayaburi site during the dry season.
- For river flows less than 5,140 + 3,500 m^3/s, most flow would be from a combination of turbines and flushing outlets.
- At river flows below about 5,140 m^3/s most of the flow would be through the turbines with only intermittent use of the flushing outlets.
- Sand flushing outlets below each turbine unit would be open only when turbines are not operating[7].

In the wet season (typically June to October)

- All turbines (7 for EGAT + 1 for EdL) operate constantly when river flows exceeds the powerhouse capacity (5,140 m3/s).
- Flushing outlets would be open at all times in high flows.
- The 10 radial spillways would pass the remaining river flow up to the PMF (47,500 m^3/s)
- Spillways would be opened sequentially, beginning with the spillways immediately adjacent to the centre block, and operated according to flow conditions and optimized spillway operation.

To illustrate what this means in practice, in a 1:10 year flood event that is rated at 22,030 m^3/s, a little over 40% of the flow would be through dam structures other than the spillway, 60% would be through the spillway (12,940 m^3/s). For an average flow in August of 15,160 m^3/s[8], the situation would be reverse (on average), that is 60% of the flow would be via the dams structures other than the spillway and 40% would be via the spillway section.

The water levels immediately downstream of the proposed Xayaburi dam in the wet and dry seasons would depend also on whether the Xayaburi scheme is a single project, or part of a cascade; that is whether the proposed Pak Lay scheme downstream is developed. This is illustrated in ***Table 1B*** below extracted from the Design Report that shows the tail-water level immediately downstream of the Xayaburi dam in the cases with and without Pak Lay.

[6] Reportedly in 2010 the minimum flow in this stretch of the Mekong mainstream was closer to 650 m^3/s.
[7] The Design documents note that dry season operation of the sand flushing requires further study. The decision was taken not to provide a sand flushing outlet for the smaller EdL unit.
[8] with Xiaowan and Nuozhadu Projects. See Table B2.3-1 in the Design Report.

Table 1B: Xayaburi tail-water level rating curves[9]

Mekong Flow (m^3/s)	Tail-water Level (masl)			Mekong Flow (m^3/s)	Tail-water Level (masl)	
	Natural	W.Pak Lay			Natural	W.Pak Lay
500	233.59	240.15		10,000	250.16	250.40
1,000	235.88	240.55		12,000	251.90	252.03
2,000	239.84	241.76		15,000	253.91	253.99
3,000	241.84	243.04		20,000	256.71	256.82
4,000	243.37	244.26		25,000	259.28	259.38
5,000	244.86	245.42		30,000	261.64	261.73
6,000	246.13	246.53		35,000	263.82	263.90
7,000	247.27	247.59		40,000	265.85	265.91
8,000	248.29	248.57		45,000	267.77	267.82
9,000	249.24	249.50		47,500	268.69	268.74

Upstream variations in water levels in the reservoir due to operation

Upstream of the Xayaburi dam site, variations from the normal operating level of 275 m above sea level would occur depending on three sets of operational factors. These including (i) any daily peaking, or weekly operation as referred to the Design Report (ii) any drawdown of the reservoir for sediment flushing, or other special environmental releases and (iii) draw down in advance of floods to mitigate flood risk in Luang Prabang. In the case of exceptional floods, such as a 1:10,000 year flood or a PMF event, the reservoir would rise above the normal operating level. A PMF (47,500 m^3/s) would see the reservoir behind the Xayaburi dam rise about 3 m beyond 275.0 m to 278.3 m above sea level, described in the design documents as the maximum exceptional water level.

The reservoir that extends 100 upstream of the dam site would remain wholly within Lao territory. The Xayaburi dam site is 1,930 km upstream from the mouth of the Mekong river. The border with Thailand upstream is 360 km from the site, which means there would be no water level fluctuation in Chang Rai province in Thailand due to the Xayaburi reservoir.

Downstream variations in water level due to operations

The Design Report indicates an independent project that can accommodate a High Operating Water Level for the downstream Pak Lay Plant at elevation 240 m above sea level if the two projects are developed. With the Xayaburi project alone, the water level downstream will vary according to seasonal river flows. Elevation of 236 m above sea level is the lowest tail-water level for operating turbines for a river flow of 1,000 m^3/s.

Downstream flow variations of a daily or weekly nature would be due to operations that have been described previously. According to the feasibility study for the project, "*a tail-water level fluctuation up to 1-1.5 m should be acceptable from environmental point of view*". Downstream of the Xayaburi site, the Mekong mainstream flows wholly in Lao territory for 200 km until it reaches the border with Thailand on the right bank (Loei Province). The Lao border with Cambodia is 1,242 km downstream from the Xayaburi site. Any downstream fluctuations in Lao territory would be governed by Lao regulations on permissible limits. The main transboundary question then becomes what level of water fluctuations, if any, would be in the river in the dry season when it reaches the Lao-Thai border (Loei Province).

[9] Table B2.3-3 from the design report

Constraints on operations

The Design Report and Feasibility Study allude to some operating constraints but these do not appear to be formalized through the required concession agreement or power purchase agreement. Operating constraints need to be developed to include factors such as:

- daily to weekly turbine operating ranges;
- permissible water levels changes with respect to (i) total water level (ii) ramping rates (rates of hourly water level changes). Ramping rates are commonly determined from power system needs but should be specified if there are environmental, navigation or other external constraints that should govern the plant operations. This has not yet been determined. It is noted also that China has established a ramping rate of 1 m/hr for the upper Mekong based on navigation needs;
- minimum flow rates;
- minimum number of navigation transits; and
- fish bypass operating conditions considering upstream and downstream migration and the differences in plant, sluice, and spillway flow rates from dry to wet season.

Any operating constraints necessary for environmental, navigation, water supply or other external uses need to be defined for implementation in the power purchase agreement.

4.2 Hydrology

4.2.1 Scope of the review

The reference for this section is the Feasibility Study as well as EIA of the proposed Xayaburi dam project and its context relative to the 1995 Mekong Agreement and associated procedures. Six hydrological zones or reaches of the river were defined under the MRC Water Utilisation Programme (WUP). Xayaburi is located in the Lao zone, accounting for about 35 percent of flow contribution.

The objectives of the review presented in this chapter are to provide flow records and water levels, likely changes in flow regime including velocities (specific emphasis on any transboundary impacts), estimation of total reservoir volume and flood issues. This review does not focus on interpreting hydrological flows for design, feasibility or operation. A number of aspects of the study are related to hydrology and covered in other sections including dam operation, Probable Maximum Flood (PMF) estimation, water quality, environmental flows, sediments, morphology and nutrient balance, navigation, and dam safety. These issues are not repeated.

4.2.2 Summary of flow changes considered and measures proposed

The Feasibility Study and EIA of the proposed Xayaburi dam project contain tables and plots of the hydrological data used. The methodology for deriving long-term records at the Xayaburi dam site is not described in detail.

Some analysis regarding the quality of gauging records is presented in the submitted documents. It was concluded that the Luang Prabang record from 1960-2005 was appropriate for calculation as well as modelling. Other records have been questioned regarding their quality and not used. The results used in the submitted documents include modelling of the two main Chinese dams, Xiaowan and Nuozhadu, and the Nam Ou tributary in Lao PDR by applying the stochastic streamflow generation programme HEC-4[10]. A simulated time series is also presented.

Statistics of flood event peak flows are presented. Extreme flood conditions such as 1:10,000 year are estimated as 45,000m^3/s and are most important when addressing transboundary issues that may result

[10] HEC-4 has been developed by the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC).

form the proposed Xayaburi dam project in relation to dam safety. The Probable Maximum Flood (PMF) used in the Design Report is 47,500 m^3/s.

To predict the effects of the proposed Xayaburi on the rating curve at Luang Prabang as well as on the tail-water rating - with and without downstream dams - an HEC RAS model[11] was applied. The EIA of the proposed dam concludes that there is not much effect on the Luang Prabang rating above 5,000m^3/s. A graph of the rating curve at Luang Prabang - with and without the proposed project - is presented. Its interpretation needs clarification due to the difficult reading of presented details. It appears that there could be a rise in water level for a given flow above 5,000 m^3/s that is limited to approximately 1 m. It has been recommended to open the spillway fully above 18,000 m^3/s. Hydrological effects and possible downstream impacts are neither addressed nor quantified.

The dam will create a water pond with a length of 100 km. There are no indications regarding an estimated total impounded volume.

The documents conclude that water fluctuations and consequent bank erosion upstream/downstream the dam will therefore be avoided and not occur. Velocity of flows is not specifically considered.

The submitted documents do not include programmes for hydrological monitoring during construction.

4.2.3 Findings of the MRCS Technical Review

The MRCS review is focussing on potential transboundary impacts that can result from the proposed dam project. For hydrological analysis, such alterations are likely to be effects due to changing flow and sediment regime consequently having the potential to impact other parameters like water quality, fisheries and ecosystem health. As indicated above, impacts on the sediment regime and other issues are addressed in the respective chapters of this review report and are not covered here. This section provides some base data for other considerations including the gross reservoir volume.

The main gap in the submitted documents is that the flow regime for environmental analysis needs to consider more than just flow rate. It is important to consider other changes such as velocity. There is an uncertainty relative to the impact of the storage reservoirs in China. The study has made a reasonable estimate of the effects. The PMF analysis used for spillway capacity checking is based on outdated MRC study of 1994 which needs to be updated. Flow data from surveys of a number of cross sections are not available in MRCS. It would be useful to have access to such data for any future studies. Conditions during construction are not considered including the likelihood of coffer dams being overtopped and washed away creating potential impacts and pollution incident downstream.

(i) Flow records and water Levels

The analysis of flows presented appears reasonable for the purposes stated. Some differences in terms of the impact of dams in China are noted relative to recent MRC discussions. As noted in the recent SEA report, there is a range of estimates particularly regarding the increase in flows in the dry season. The estimation of PMF is important for dam safety issues and is further discussed in ***Section 4.6*** of this chapter.

The HEC RAS model that has been applied for backwater appears in good agreement with observed data and with the MRCS Isis model results of the reach.

(ii) Gross reservoir volume

The indication of the gross reservoir volume upstream of the Xayaburi dam is important due to its further significance regarding water quality, ecosystem health and sedimentation consideration. The total gross reservoir volume derived and used in this review is 1,300 million m^3 or 1.3 km^3.

The volume between the dam and Luang Prabang was estimated with the best available digital elevation model (DEM) in MRCS for this reach using a raised flat water surface of 275 m. Because of the run of river nature of the scheme, the zone of influence of the reservoir varies with flow. Just downstream of Luang

[11] Hydrologic Engineering Centers - River Analysis System (HEC- RAS) of the U.S. Army Corps of Engineers.

Prabang was used as a reasonable upstream limit for calculation (see ***Annex 3***, which shows that backwater at low flow may extend up to 200 km). The MRCS DEM includes processing of the navigation chart soundings and land contours at 1:20,000 scale to give a representation of the volume of water below the current water surface as well as the surrounding landscape that may be inundated. Pixel size in this DEM is 25m.

The calculation was done in a number of ways including grid (raster) based processing and use of ArcGIS 3D analyst all giving similar volumes. Because of some discrepancies in the DEM observed in a few places at the join between the below water soundings of the navigation survey and the surface fitted to the land contours, an additional DEM was generated that used only the soundings part of the full DEM combined with the basin DEM. Because of the coarser scale of the grid (50 m) and source of data used in the MRCS basin DEM, this would be expected to give slightly smaller values of the volume where there are steep hillsides and this is the case but is still of the same order. The GIS processing was then further crosschecked using the sectional area and distance within the hydrodynamic model (with 4 km sections) taking into account the backwater effects at 2,000m^3/s (water level at Luang Prabang) and further the volume of deep pools. In addition, hand calculation was performed.

It needs to be noted that the figure 1.3 km^3 gross reservoir volume differs from a number of other studies in the public domain as well as the MRCS hydropower database that uses lower storage figures based on simplified calculation methods as shown in ***Table 2***. Live storage volume for turbine operation between 268 m and 275 m is 391 million m^3. There is no dead storage as the sediment sluices are close to the minimum bed level.

Table 2: Estimates of reservoir volume

		Reservoir Storage (km^3)			Comment
Source	**Date**	**Live**	**Dead**	**Gross**	
1. MRCS PNPCA Calculation[12]	Jan 2011	0.391	0 (0.909 inactive)	1.3	Estimated from DEM and model sections to Luang Prabang
2. Xayaburi Design/Feasibility Studies	Mar/Sep 2010	Not known	Not known	Not known	Not able to find value used in reports available
3. SEA Mainstream Dams	Jul 2010	0.212	0.514	0.726	Origin of data not stated
4. MRCS Hydropower Database/BDP	Dec 2008	0.225	0.479	0.703	Valley slope/width calculations

(iii) Likely expected changes in flow regime

The Xayaburi Feasibility Study states that the Xayaburi dam will not change the flow regime. This review concludes that the issue of “flow regime” needs to be seen in a broader contest: significant differences in the response of character of fast flows with high diversity of flow conditions that prevail currently in the reach and the slow movement within a reservoir are expected including possible negative impacts.

Respective modelling has been performed by the MRCS – with and without the dam in place. The results show that upstream velocities would decrease to between 5% and 10% of their original values near the dam at a dry season flow of 2,000 m^3/s. At a wet season flow of 10,000 m^3/s, the equivalent change is 30-40% of current values. The importance and implications regarding impacts of such changes are assessed in other chapters of this report.

[12] MRCS estimates of gross storage using different methods vary from 1.1 km^3 (coarser dem) to 1.34 km^3. Model Section based calculations taking account of backwater at 2,000 m^3/s gives 1.34 km^3.

Based on a backwater analysis, the review further concludes that the water levels are expected to rise up to a maximum of 200 km upstream of the Xayaburi dam, specifically at lower flows. At higher flows, the effect is expected to be limited to around 100 km. The zone of influence expected, all within Lao territory, is further than stated in the Xayaburi Feasibility Study.

Regarding the reflection of the transboundary scale to the LMB countries, the review considered the case of flow variation on a diurnal basis - as is very common for hydropower schemes even if it occurs only in times of water shortage – to reflect if water level variations will be seen outside of Lao territory. The MRCS modelling calculated for variations in output of about 100% between night time generation and peak hours that the fluctuation died out quickly within 50-100 km and was not detectable 200 km downstream near the Thai border.

The capacity of the reservoir is small relative to the annual volume of flow. A a more significant impact on flows downstream could possibly be detected downstream if filling or draining down the reservoir pondage took place during the dry season. For example, filling the reservoir if the flow was 2,000 m^3/s could lead to significant reductions in flow downstream over two weeks. This could have a significant downstream impact on river users and could be avoided by specifying an acceptable downstream flow regime to maintain.

Assessment of potential flooding effects in Section B.3 of the Design Report does not consider the possibility that morphological responses in the backwater reach upstream of the reservoir (for example, shoal formation and bed aggradation), could lead to increased flood probability at Luang Prabang. The results of preliminary modelling performed by the MRCS suggests that this is unlikely. Further investigations should be performed to confirm this.

(iv) Flood levels

Flood control water levels at the dam are presented in the Design Report based on the estimated existing conditions. Actual operating levels should be selected based on prototype water levels, which will change as reservoir sedimentation affects water levels. Preservation of flood protection upstream may require that the operation of the power station and spillway be adapted as sediment accumulates in the reservoir.

The change in backwater curve at Luang Prabang presented in the Xayaburi Feasibility Study illustrates a modest increase in flood water levels. The modelling of MRCS confirms this result and could be worsened by sedimentation.

It is suggested in the Feasibility Study that gates would be fully opened on reaching flood-warning level. It is recommended that this must be carried out carefully to avoid increasing flood flows downstream at a critical time and further consideration is needed on how best to achieve this.

(v) Hydrological monitoring

Monitoring of flow conditions in the river during construction - particularly where a major diversion such as the proposed dam project is expected – is considered international best practice. Currently such monitoring is not foreseen. The risk of high flows creating scour holes and loss of coffer dams or excessive runoff on construction slopes should be regularly monitored to reduce risk of failure and pollution incidents.

Key review findings

Flow records and water levels used for project planning appear reasonable for the purposes stated. The gross reservoir volume – which is important for impact considerations including sediment transport, nutrient balance and ecosystem health – is assessed and used with 1.3 km^3 *in this review. The submitted documents conclude that no changes in flow regime are to be expected due to the proposed dam project. This review concludes that significant differences in the response of characteristics of fast flows, with high diversity of flow conditions that prevail currently in the reach and the slow movement within a reservoir, have to be expected including possible negative impacts. The review confirmed the modest increase in flood water levels as presented in the submitted documents. It is recommended that the full opening of spillway gates to reach flood-warning level be carried out carefully to avoid increasing flood flows downstream at a critical time. Monitoring of flow conditions in the river during construction is not addressed in the submitted documents and a revision is needed.*

4.2.4 Gaps and uncertainties

Compared to other parameters, the hydrology of the river system is relatively well known. The major uncertainty relates to future modifications of the hydrological regime as a result of climate change. Preliminary results from MRC's work on downscaling climate-change models to the basin has been incorporated into the modelling of basinwide scenarios by the BDP and this will be further developed as more information becomes available.

4.2.5 Conclusions and recommendations

The likely diurnal power operation during different events needs to be set out clearly including allowable rate of change and typical patterns including releases for sediment sluices, flushing and operation during a flood event with analysis to show any transboundary impact.

In certain flow conditions, the backwater effect will be experienced further upstream than suggested in the design documents, up to 200km, and further study is required. The main change upstream will be to slow down the water velocities. The backwater extends further in the dry season as the reservoir design level of 275m is above normal water levels for much greater distance upstream at low flows. For example, at Luang Prabang, when the flow is 2,000m3/s in the normal pre-dam condition, water level is 273 m (5.7 m gauge) and water level is very definitely raised over 2m by Xayaburi even without any additional friction effects. At 10,000 m3/s, water level is already 280.6m, or 5m above the Xayaburi design water level and it is thus only friction affects that raise it further. At higher flows the increase in level at Luang Prabang for a flow close to flood warning is 0.3- 0.5m but the documents indicate that they will no longer maintain 275m at such a flow hence reducing backwater at high flows. The increased gradient upstream means that there is no discernable effect within model accuracy at the Thai border.

The feasibility study and hydrological studies should be updated with the latest available information including the use of monitoring data for flows, ratings, water quality and sediments.

The filling and drawing down rates of the reservoir (for routine flushing and in an emergency) need to be considered so that changes in gate setting (e.g. in case of a flood warning) are known beforehand.

The reservoir volume and expected operations are not likely to affect downstream flows and thus it is not expected to be necessary to demonstrate possible impacts downstream using the full suite of Decision Support models. If a flushing regime is proposed, this should be checked to demonstrate the impact outside of Lao territory.

Regulations regarding permissible water level fluctuations and ramping rates (upstream and downstream) need to be clarified for short-term (hourly) variation and longer-term daily changes. This is likely to take account of expected variation in releases out of peak generation time.

The hydrological monitoring program needs to be reviewed, revised and improved.

Data on cross-section, local surveys and monitoring needs to be shared with MRCS for consolidation.

4.3 Fish Passage and Fisheries Ecology

4.3.1 Scope of the fisheries review

The key documents include (i) the MRC Preliminary Design Guidance, (ii) the Xayaburi Design Report (2010), (iii) the Xayaburi EIA (August 2010) and (iv) the Xayaburi Feasibility Study (March 2010).

The objectives of the review presented in this section include providing an introduction to fisheries and its importance in the Mekong Basin, setting the scene regarding principles in fish-bypass facility design to respond to the conditions in the LMB and reviewing the extent of impacts identified and proposed mitigation measures. It also aims to reflect the findings of the technical review regarding fish-bypass facilities, fisheries management, monitoring and socio-economic implications. In addition, this section aims to provide recommendations and mitigation measures to minimize negative impacts, identify remaining gaps and uncertainties and outline the transboundary and cumulative implications of the proposed Xayaburi dam project in the basin-wide context of the LMB.

4.3.2 Fisheries in the Mekong Basin

Fisheries play a very important role in the Mekong Basin due to its ecological as well as socio-economic uniqueness and therefore significance. The Mekong fish communities are characterised by high diversity of fish species with many exhibiting complex life cycles that involve migration between different areas of the river, particularly upstream migration to spawning areas. Three main groupings of migration patterns can be identified in the Mekong River Basin: (1) lower zone below the Khone Falls, (2) zone upstream from the Khone Falls to Vientiane, (3) a zone upstream of Vientiane (see ***Figure 7***). These zones were developed as a basis for fisheries studies and are distinct from the 6 hydro-ecological zones presented in Section 3.3.2

There are a number of species that migrate between these zones, and potentially some species (possibly as many as 30 and often commercially-valuable white fishes) that migrate longer distances. **Completing these migrations requires unobstructed passage within the Mekong River and its tributaries**. Furthermore, the capacity for adults, larvae and juveniles to migrate or drift downstream needs to be ensured. **The timing of these upstream and downstream migrations is variable** depending on life cycles. Based on a village survey, species spawn at various times during the year with peaks apparent in the dry season (February-March), early in the flood (June-July) and then when the water is receding (November).

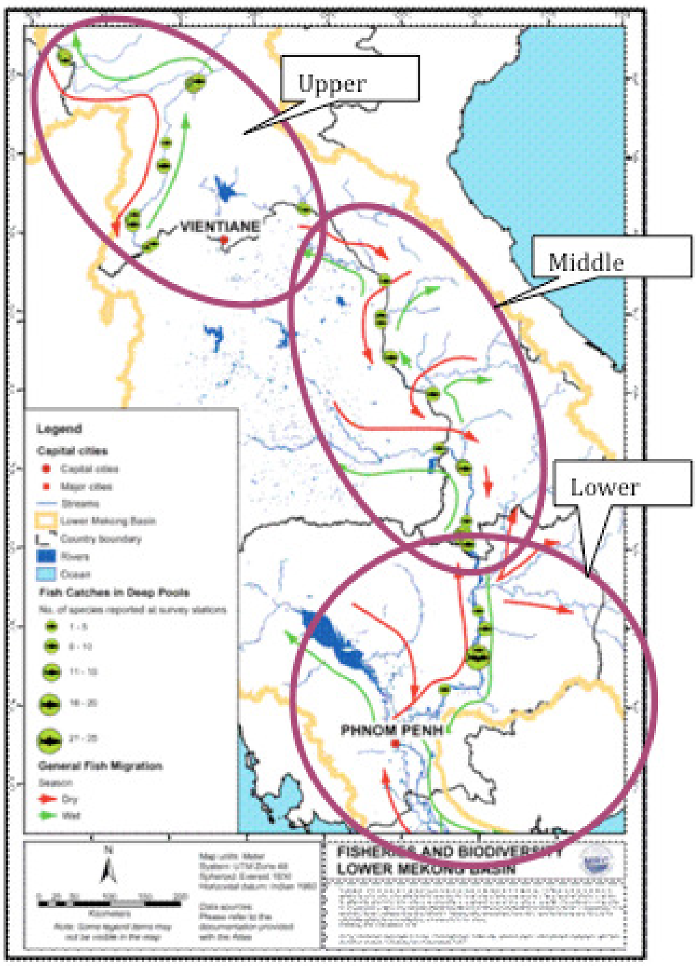

Figure 7: Generalized migration systems in the Lower Mekong Basin (Source: Poulsen et al. 2002a)

Key facts regarding fisheries in the Xayaburi dam area and comments on the Environmental Impact Assessment

*Fisheries are significant in the Mekong basin due to their ecological and socio-economic importance and scale. The precise number of species in the region is unknown, about 200 have been recorded from the MRC's fisher catch monitoring near Luang Prabang (also see **Annex 4**).*

Fisheries are a key component of sustainable livelihoods in the LMB and fisheries activities are important in this zone using a variety of fishing techniques and gears.

At least five IUCN Red List fish species are found in the area of the proposed Xayaburi reservoir. The five species are the *Mekong giant catfish (*Pangasianodon gigas*) and the Pangasid catfish (*Pangasius sanitwongsei*), both critically endangered, and the endangered Mekong freshwater stingray (*Dasyatis laosensis*), Jullien's golden carp (*Probarbus jullieni*) and Laotian shad (*Tenualosa thibaudeaui*). The dam area is central to the upper Mekong migration system (****Annex 4****), immediately downstream of important fish-spawning habitats and refuge areas for young of the year.*

Monitoring of fry conducted by MRC during May-August 2010 showed that there are many fish species breeding in this zone. Peak densities of fry appear to be much lower than in Cambodia (Phnom Penh) and the Viet Nam delta. The samples also showed abundant large mayfly nymphs and shrimp post-larvae.

Especially, the stretch between Xayaburi and Luang Prabang (the potential Xayburi reservoir) contains a relatively high number of deep pools. These deep pools are key habitats during the dry season for Mekong fishes, in particular the white fishes, and some species also rely on the pools for spawning.

Many of these aspects have not been sufficiently considered in the EIA. More details are given in Section 4.3.5.

The report of the international Fisheries Expert Group provides a detailed picture on fish biodiversity, fish migration, fisheries activities and considerations on the fish pass (see ***Annex 4****).*

4.3.3 Considerations for fish-bypass facilities

Fish migrate when they cannot complete their life cycle in a single habitat, especially for reproduction and feeding purposes. Many of these fish species exhibit various migration patterns throughout the year. It should be noted that an Expert Group of biologists, ecologists and engineers convened by the MRC in 2008 concluded that there was no evidence that fish-passage facilities used for fish migrating upstream in large tropical rivers in Latin America, Africa and Asia could cope with the massive fish migrations and high species biodiversity in the Mekong. The best evidence from South America was that the success of fish ladders and lifts was low even though the number of species and volume of migration there is lower than in the Mekong. The group agreed that the technologies used on high dams in North America and Europe had been developed for a very limited range and number of fish species, mostly salmonids which have remarkable jumping abilities that enable them to scale waterfalls and fish ladders more successfully than any other group of fish. The biomass of fish involved is elatively small, at around 3 million fish per year on the Columbia River. This experience from North America and Europe contrasts with the Mekong where there are at least 50 important migrant and biomass is in the order of 100 times greater. For fish migrating downstream, most experience in developing technologies that allow migration has also been in North America and Europe. The Expert Group found little evidence regarding the performance of such fish-passage facilities on the Mekong or any other tropical rivers.

The fundamental biological characteristics of fish (also see ***Annex 4***) are critical to develop effective fish passage including for the proposed Xayaburi dam project[13]. A summary how these characteristics relate to fish-bypass design as well as their implications for fish passage at the proposed Xayburi dam project is provided below:

Season

- Upstream migration of different groups of fishes occurs at different intensities throughout most of the dry and wet seasons, with less activity in the middle of the dry season.
- There are few data on migration during peak flows because this coincides with the least fishing pressure. In other large bio-diverse tropical rivers, high levels of fish migration occur in peak flows.

Implications for fish passage at proposed Xayaburi dam project

- Fish passage is required from low flows to peak flows.

[13] So far, the EIA does not address those biological characteristics in sufficient depth.

Biomass

- The migratory biomass of the Mekong is one of the largest of any river in the world. In the early wet season, when large pangasiid catfishes and large cyprinids are migrating and the migratory biomass in the upper migration zone is estimated to be 36,000 tonnes , there may be 10,000 kg of fish per hour passing, if we assume the migration is evenly distributed over five months. There is also likely to be pulses of higher biomass with seasonal and dial peaks[14].
- The middle and lower migration systems have much greater migratory biomass. Fish-passage solutions developed for Xayaburi may not be transferable to these zones. For example, between 200,000 and 260,000 kg of fish per hour is estimated to migrating upstream in the lower migration system (using the MRC estimate of 0.75-0.95 million tonnes migrating per year in the lower system [Barlow *et al*. 2008], spread over five months.
- Migration should be recognised as cyclic and, as well as upstream migration, considerable biomass, mostly of larvae, juvenile and returning individuals can be expected to migrate downstream.

Implications for fish passage at proposed Xayaburi dam project

- Effective fish passage at Xayaburi would need to pass a migratory biomass that is likely to be much higher than previously recorded in any fish-passage facility globally. Hence, flow, space and volume, i.e. the scale of the fish-passage facility will need to be much greater than used in other river systems.

Biodiversity

- Approximately 200 species including the Mekong giant catfish are considered to utilise the LMB area upstream of Vientiane. These comprise many ecological guilds with specific ecological needs and swimming abilities.

Implications for fish passage at proposed Xayaburi dam project

- Effective fish passage at Xayaburi would need to pass a range of species of different sizes and swimming capabilities. Consequently, fish-passage facilities will need to accommodate small body length individuals as well as those with weak swimming abilities. It should be noted that the Xayaburi project is unlikely to have any impact on Irrawaddy dolphins below the Khone Falls.

Fish size

- The small cyprinids and pangasiids migrating upstream are generally between 15 and 30 cm long and the large cyprinids and pangasiids between 60 and 150 cm long. There are a small number of larger species migrating upstream that are between 150 and 300 cm, including the Mekong giant catfish.
- Downstream migration would include the same size groups plus drifting larvae and fry.

Implications for fish passage at proposed Xayaburi dam project

- The small fish of 15-30 cm determine the maximum water velocity and turbulence in the fish bypass facility and collection galleries. These fish can negotiate water velocities of < 1.0-1.4 m/s (equivalent to 5-10 cm head differential between pools in a pool-type fish-bypass facility) over short distances (10 cm) and turbulence of less than 30 W/m3. In channels with laminar flow, such as collection galleries, these fish can negotiate 0.3 to 0.4 m/s over longer distances.
- The large fish, along with the maximum biomass, determine the minimum depths, widths and volumes in the fish-bypass facility and this is influenced more by behaviour of the fish than physical dimensions. To enable migration of the Mekong giant catfish through the fish-bypass facility, the narrowest parts of the present river channel can be used as guide to behaviour. Hence, provisional criteria could include a fish-bypass facility that is generally 10 to 20 times the fish width (equivalent to a narrow section of river channel) with short sections (equivalent to the distance between two large boulders) and with a minimum width of three times the fish width. The fishway depth should be equal to the thalweg depth

[14] This figure is for the LMB as a whole and migratory biomass at Xayaburi, which is located in the LMB upper migration zone, is much less than the middle and lower Mekong reaches

(deepest part of the river channel) at low flows or at least 2/3 of this. It should be noted that this recommendation does not guarantee passage of Mekong giant catfish as no definitive information is available on their swimming capacities.

- To guide adult fish that are migrating downstream, screens of less than 2 cm spacing would be required with low approach velocities to prevent impingement and approach vectors that guide fish across the screen to a bypass.
- Non-salmonid larvae and fry have high mortalities (30-100% depending on the species) in high-head turbines, mainly due to sudden pressure change and shear stress. As it is not practical to screen larvae and fry drifting downstream, due to their small size, the main mitigation of this impact would be to stop or minimise power generation during peak larvae migrations and maximise passage either through the spillway, which would need to be assessed, or using the sediment sluice gates with no head differential.

Fish behaviour

- The high diversity of fish includes surface, midwater and bottom dwelling fishes, including fish that orient to the thalweg (deepest part of the river channel).
- Migrating fish are attracted to flow often following a path of low water velocities adjacent to high water velocities.

Implications for fish passage for the proposed Xayaburi dam project

- To provide sufficient attraction for migrating fish, effective upstream fish passage at Xayaburi and other dams proposed on the mainstream Mekong River would need to pass 10% (100 m3/s) of low flows and 1% (230 m3/s) of the maximum design flow (currently the regime is unmodified by China developments).
- Fish will be attracted to the flow from the turbines and will approach the flow from surface, midwater, along the river bottom and along the thalweg. Hence, fishway entrances need to accommodate these behaviours.
- Fish will be attracted to either side of the spillway and will be able to swim upstream to different positions along each abutment, depending on the flow and the operation of the gates. Hence, fish passage is required on either side of the spillway and physical modelling is needed to determine the shape of the abutments and the location of the fishway entrances.

4.3.4 Summary of impacts considered and measures proposed

The impacts on fisheries addressed by the submitted documents relate mainly to the interruption of fish-migration routes and therefore river and habitat continuity. To mitigate those impacts, the construction of fish-bypass facilities in the upstream and downstream directions of the proposed Xayaburi dam was considered, taking into account the preliminary design guidance of the MRC. The documents assume that the possible negative impacts will be sufficiently mitigated with no residual impacts.

As mitigation measures, the submitted documents propose a facility for fish passage in both the upstream and downstream directions. The detailed layout is provided and illustrated in the Xayaburi Design Report (2010) and summarised below:

(i) Upstream migration

- A vertical-slot pool-type fish pass
  - 5% gradient
  - 0.3 m head differential between pools, generating a maximum water velocity of 2.4 m/s.
  - 10 m wide, 6 m deep, 4-6 m long pools (indicative)
  - Intended for full headwater range, while dam is operational
  - Tail-water range is up to 1-in-2 year event (15,000 m3/s)
- Collection gallery above draft tubes of powerhouse; draft tubes from 209-221 masl and invert of collection gallery at 233 masl.
- Spillway entrance in intermediate block on left-hand side of spillway.

(ii) Downstream migration

- A surface bypass collector from 265 metres above sea level to full supply level
- Downstream migration facilities are only intended to operate during flood season.
- Spillway passage
- Passage through fish-friendly turbines

4.3.5 Findings of the MRCS technical review

The review findings relate to the current design of the fish-passage facility, taking the possible impacts on fish migration and therefore fisheries into account.

The fish-passage design criteria proposed were evaluated against requirements to meet the needs to maintain both upstream and downstream migration including the specifications of the MRC Preliminary Design Guidance.

Fish-bypass facilities are included in the submitted documents. Several significant issues with the proposed design at Xayaburi dam need adaptation in relation to suitability for the Mekong fish fauna. Therefore, adaptations and mitigation measures to minimise negative impacts are proposed as part of this review as well as recommendations regarding sufficient monitoring programmes to assess impacts in the future.

Details of the MRCS technical review of the proposed passage facility are provided in ***Annex 4***.

Review of the fish passage design

(i) Upstream migration

Vertical-slot pool-type fish pass

- Pass design is unlikely to pass the high biomass (see above) of fish expected in the Mekong;
- The design of the pass is unlikely to be effective for small fish passage because of the maximum water velocity of 2.4 m/s. This has been based on a standard for fish passes for salmon, which are capable of >5 m/s;
- The design of the pass is unlikely to pass the largest fishes, due to fish behavioural constraints. This is a common problem of under-sized fish-bypass facilities and in the Mekong is likely to lead to extirpation of Mekong giant catfish in the region.
- Pass design is unlikely to pass 10% of low flows or 1% of high flows (currently the regime is unmodified by China developments), whilst maintaining low turbulence for fish passage. These flows are required not only for attraction into the fish-bypass facility but also to pass the high biomass through the length of the fish-bypass facility.

Collection gallery

- No consideration is given to attract midwater, benthic or thalweg-oriented fish in the collection-gallery design.

Spillway entrance

- The single entrance on the left side of the spillway is not considered adequate for the range of flow conditions where fish would aggregate at different locations.

(ii) Downstream migration

Turbine passage

- The EIA does not provide experimental evidence to show that turbines are "fish-friendly" for Mekong fish species. It draws on literature that mainly targets salmonid species which are not comparable.
- Mortality of non-salmonids through high-head Kaplan turbines is between 10-40% for juveniles and up to 100% for adult fish, caused by high-pressure gradient, shear stress and, for large fish, blade strike.
- A major risk for the project arises if passage of fish through the turbines is not mitigated: mortality of adult and larval fishes will inevitably occur and thus the whole upper Mekong fish migration group is at risk and populations of those fish that migrate from the lower to the upper Mekong are at risk.

Surface bypass collector

- Collector design would not prevent entrainment of midwater- and bottom-dwelling species.
- It is not clear that the present screening has been optimised.

Spillway

- Undershot gates will cause injuries and mortalities of fish.
- Deflector and stilling basin endsill could injure fish.

Hydrodynamic barrier (or reservoir effect)

- Low water velocities caused by the impounded water of the dam would prevent downstream passage of drifting larvae and fry. These fish, particularly riverine species, would settle in sub-optimal habitats without suitable food and thus would likely result in high mortality. This represents a major risk for fish populations and for the Project.

***(iii)* Fish passage during construction**

- Fish passage during construction is not presently addressed in the Project.
- Partially blocking the river during construction over years will reduce the cross-sectional area of the river and will proportionally increase water velocities. If significantly narrower than existing sections elsewhere, this could impede fish passage, depending on the flow, water velocity and size of migrating fish.

Recommendations toward design improvement of fish-passage facility and impacts mitigation

To reduce the risk of non-performance of the fish-bypass facilities, the Fisheries Expert Group recommends that consideration be given to a series of improvements to the upstream and downstream passage design and operation as noted below and that these need considerably more data and study. Even with these modifications, there is no assurance that the biodiversity linkages will be fully maintained or the same scale of biomass will bypass the structure. Hence there will be a need for a comprehensive monitoring system, processes for adaptive management and also provisions for compensation measures for affected communities in the event that residual impacts occur.

(i) Upstream migration

- To pass the high biomass and biodiversity, three fish-pass facilities (bypass channel, fish lift and navigation lock), passing a high flow, are required, combined with optimised dam operation.
- Revise left-bank fishway concept to pass sufficient flow for the pass to function under different flows with sufficient space for for large-bodied fish and high biomass, and maximum water velocities of 1.4 m/s and turbulence less than 30 W/m3 for the passage of small-bodied fish. Potential options are a nature-like bypass on a low gradient (< 1:100), which will potentially allow upstream migration of Mekong giant catfish, or two large fish locks.
- Add solutions for mid-water, benthic and thalweg migrating fishes, including a benthic collection gallery underneath the draft tubes, or vertical slots between the draft tubes.
- Possibly modify the thalweg to lead directly to the fish-bypass facility.
- Include a high capacity fish pass in the intermediate block; most likely a fish lift or possibly two large fish locks. May need multiple entrances and/or shaping of the abutment for low, medium and high flows; to be refined in physical modelling.
- Modify the navigation lock to provide fish passage as well as navigation. Add gates, valves and possibly multiple entrances for low, medium and high flows.
- Optimise dam operation (turbines, attraction flow, fish-pass flow, spillway gates) for periods with high fish migration, based on physical model and 2d/3d CFD (Computational Fluid Dynamics) hydraulic model at different discharges and turbine operations.

(ii) Downstream migration

- During periods of abundant larvae drift and downstream migration:
  - the primary mitigation is to use the sediment sluice gates, with no differential head, which provides passage of larvae through the impoundment mitigating the hydrodynamic barrier of the impoundment and passage bypassing the turbines and spillway.
  - the secondary mitigation is to maximise spill flow and minimize turbine passage by reducing power generation.
- Use benthic, as well as surface, screens.
- Use physical and 2d/3d CFD model to optimise screens. Screen spacing of 2 cm is required.
- Provide one or multiple overshot gates on the spillway for fish passage.
- Lower the sill level of one or more spillway gates to the bottom of the reservoir to enable passage of bottom-orientated fishes.
- Design deflectors and endsill to eliminate impact areas and minimise shear stress for fish.
- Get baseline data on larval drift to assess risk and mitigation strategies.

(iii) Fish passage during construction

- Incorporate a fish-passage plan into the construction sequence.
- Investigate use of the navigation lock and intermediate block to provide fish passage during this period.

An outline proposal for the type of design that should be provided is given in ***Figure 8.***

Risk assessment of impacts of the proposed fish bypass facilities

The Expert Group performed a baseline risk assessment on the fundamental biological characteristics of fish ecology, the design of the fish-passage facility and the MRCS recommendations regarding fish-passage adaption. In principle the risk assessment indicates the:

(a) **likelihood of impacts** on key ecological parameters (fish life stage, fish behaviour, fish biomass) that can occur as a result of the proposed Xayaburi project, and

(b) the **level/consequence of impact** on both upstream and downstream fish migration.

The likelihood of impact is assessed in 5 categories (very likely, likely, possible, unlikely, very unlikely) that indicate the predicted impact of the proposed project on fish communities and fisheries. The level/consequence of impact is also assessed in 5 categories: very minor, minor, moderate, major, extreme.

The outcome of the qualitative risk assessment related to the design of the fish-passage facilities as proposed and after applying the recommendations and mitigation measures of the Fisheries Expert Group is shown in ***Table 3*** and ***Table 4.***

Risk assessment conclusions

The conclusions of the risk assessment clearly reflect the effect of the MRCS recommendations (see Section 4.3.3) and are the basis for further discussion with the developer to optimise the design of fish passage facilities. ***Table 3*** shows the assessment of the likelihood that risks resulting from the design as currently proposed and ***Table 4***, reassessment based on the mitigation measures proposed by the MRCS.

In particular, impacts regarding the upstream passage can potentially be reduced by a significant extent through a revised design. The minimisation of impacts on downstream migration is more difficult to mitigate and impacts will remain even with the optimised design proposal. Those difficulties in tropical rivers are well known. Further investigations and research are needed to advance the function of downstream fish migration aids.

The detailed risk assessment and its approach is part of ***Annex 4***.

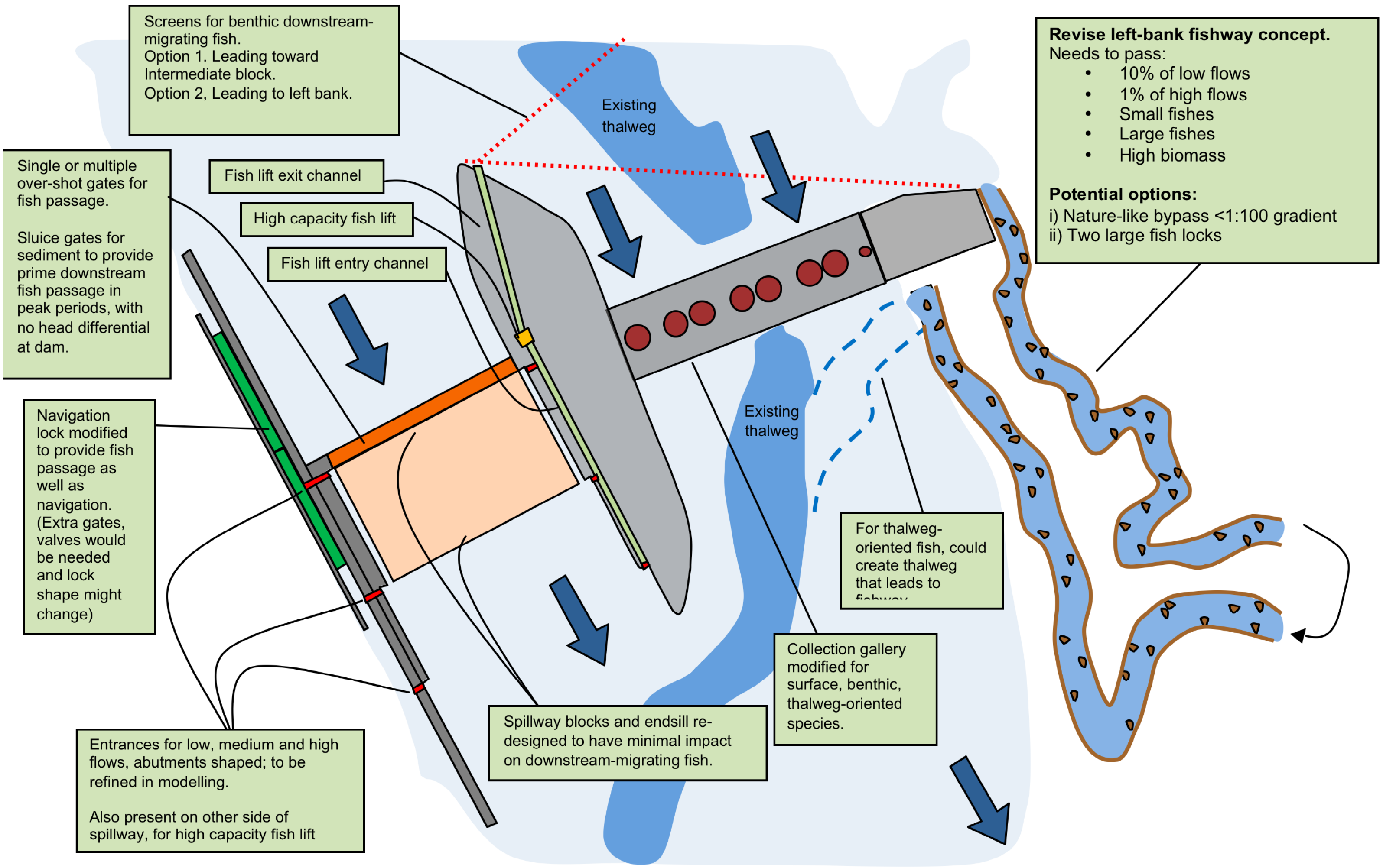

Figure 8: Fisheries Expert Group recommendations for adapting the fish bypass design at Xayaburi dam.

Table 3: Risk Assessment of fish passage design as proposed. The table scores risks for passage based on the likelihood criteria described above for each fish size class, behaviour category and biomass

	Upstream Migration			Downstream Migration			
	Limited attraction and entry into fish passage facilities	Limited ascent of fish pass	Ineffective exit – risk of fallback	Limited passage through impoundment	Limited attraction and entry into fish passage facilities	Limited passage and low survival at dam	Poor exit; risk of predation downstream
Life Stage							
Larvae & fry	N/A	N/A	N/A	Very High	Very High	Very High	High
Small-bodied species (15-30 cm)	Moderate	Very High	Moderate	High	High	Very High	Moderate
Medium-bodied species (30-150 cm)	Moderate	Moderate	Moderate	Moderate	Very High	Very High	Moderate
Large-bodied species (150-300 cm)	Very High	Very High	Moderate	Moderate	Very High	Very High	Moderate
Behaviour							
Surface	Moderate	Moderate	Moderate	N/A	Moderate	Moderate	Moderate
Mid-water	High	Moderate	Moderate	N/A	High	High	Moderate
Benthic (including thalweg)	Very High	High	Moderate	N/A	Very High	Very High	Moderate
High Biomass							
Powerhouse Operating	High	Very High	Moderate	Very High	Very High	Very High	High
Powerhouse and Spillway Operating	Very High	Very High	Moderate	Moderate	High	Moderate	High

Table 4: Reassessment of risk after applying the MRCS recommendations and mitigation measures to the fish passage designed as proposed

	Upstream Migration			Downstream Migration			
	Limited attraction and entry into fish passage facilities	Limited ascent of fish pass	Ineffective exit	Limited passage through impoundment	Limited attraction and entry into fish passage facilities	Limited passage and low survival at dam	Poor exit; risk of predation downstream
Life Stage							
Larvae & fry	N/A	N/A	N/A	Very High	Very High	Very High	High
Small-bodied species (15 -30 cm)	Moderate	Moderate	Moderate	High	High	High	Moderate
Medium-bodied species (30-150 cm)	Moderate	Moderate	Moderate	Moderate	Very High	High	Moderate
Large-bodied species (150-300 cm)	High	High	Moderate	Moderate	Very High	High	Moderate
Behaviour							
Surface	Moderate	Moderate	Moderate	N/A	Moderate	Moderate	Moderate
Mid-water	Moderate	Moderate	Moderate	N/A	High	High	Moderate
Benthic (including thalweg)	High	Moderate	Moderate	N/A	High	Very High	Moderate
High Biomass							
Powerhouse Operating	Moderate	High	Moderate	Very High	High	Very High	High
Powerhouse and Spillway Operating	Moderate	High	Moderate	Moderate	Moderate	Moderate	Moderate

Other review findings and recommendations

Impacts during construction period

In addition to fish-passage facilities and impacts on fish migration, the technical review also addresses impacts that may occur during the construction phase of the proposed Xayaburi dam. Considering the construction phase exceeds 7 years, these impacts are potentially long term and it is possible that the fish populations will not recover from any disruption of stocks if the construction process is not well managed. Therefore, impacts during the construction phase are equally as important as those during dam operation. Fisheries will potentially be heavily impacted during the construction phase. Construction impacts have been given little attention in the submitted documents. Respective impacts can arise from a number of sources:

- There is likely to be some diversion of flows during the construction phase and, without an effective fish pass in place, this could impede upstream and downstream fish migration.
- This issue is particularly critical during the second phase of construction when all flows will be diverted through the spillway – this could potentially be a barrier to upstream migration if the hydraulics of the spillway act as a barrier to fish migration.
- Construction inevitably increases sediment loading and pollution (e.g. oil leakages) in the downstream reaches and these may clog gills of fish and invertebrates (food of fish) leading to increased mortality and reduced growth rates.
- Most of the Mekong fishes are substrate spawners. Sediment and silt in the water can therefore bury and harm fish eggs. It is unlikely (as assumed in the ***EIA Page 5-12***) that there will be no significant effects on spawning activities of fish.
- Primary producers become less abundant in the impacted area because of the higher turbidity and siltation from the earth works. This will not only affect the low trophic level fauna, but eventually the whole ecosystem. Thus there is likely to be considerable impact on plankton and benthic fauna that will cascade to higher trophic levels and eventually fish productivity.

Stronger provisions need to be made in the design proposal to mitigate the above issues, including timing the construction and commissioning of the fish-passage facilities to overcome any potential problems arising. Earthworks also need to be staged and appropriate measures implemented to minimise erosion.

Mitigation measures other than fish-bypass facilities

- Other mitigation measures proposed appear weak and relate mainly to management of the fisheries production in the reservoir rather than mitigation and compensation mechanisms required to address losses of migratory species that do not successfully pass the dam structure.
- The information provided is a management response to enhance fisheries in reservoirs. This offers no real solutions to compensate for loss of fishery production and does not address social, economic issues or fishery-access issues or alternative exploitation tools and techniques.
- No indication is given what role the fisheries personnel to be funded will play, especially as building skills in aquaculture is unlikely to compensate local fishing communities for disruption to food security and livelihoods.
- Similarly, stocking measures are not considered an adequate solution because the impoundment above Xayaburi dam will be shallow, have a short retention time of approximately 3 days and be subject to approximately 0.5 m daily water-level fluctuations. This disrupts fish-recruitment dynamics and food production in the reservoir.

Recommendations on mitigation

It is recommended that a thorough situation analysis be carried out to determine the capacity of the local fishing communities to adapt to the potential changes that will arise from the proposed dam.

There is also a need to undertake an alternative-livelihoods analysis within the communities to identify possible compensation for losses incurred by the dam.

There is no definitive solution to mitigate the lost fish production in the Xayaburi dam area. The changes in topography and flow dynamics preclude alternative solutions such as stocking and cage farming and no single fisheries solution to lost livelihoods will probably have to be sought.

Monitoring programmes

Comprehensive monitoring programmes of fish-population dynamics and migratory behaviours are crucial to optimise fish passage and power generation. Outcomes of tailor-made monitoring programmes enable appropriate design of mitigation measures, offer opportunities to compensate for potential lost fish production as well as social disruption and allow the comprehensive assessment of any impacts on fisheries.

The submitted project documents do not hold sufficient information on monitoring before, during and after the construction of the proposed dam.

- Basic information is given on monitoring of fish populations and management of fisheries before, during and after the construction phase.
- The monitoring protocol proposed does not address some of the essential issues such as downstream-passage success and survival through turbines and appears to be underfunded. It is not clear how either would be maintained for the life of the project.
- The findings on fisheries-baseline conditions and impacts in the EIA are general. Many issues are not covered, especially the social and economic impacts as well as livelihood analyses.
- There are likely to be considerable impacts during the construction phase that have not been considered including environmental degradation, disruption to fish migration and loss of fish production.

Recommendations for the design of monitoring programmes

It is recommended that a comprehensive monitoring programme be established before, during and after dam construction which includes:

- composition, biomass, seasonality, *diel* patterns of migratory population: (i) approaching the dam from upstream and downstream, (ii) locating the fish passes, (iii) ascending the fish passes and (iv) leaving the fish passes and passing through the impoundment;
- composition of the fish community (i) upstream of the proposed reservoir, (ii) within the proposed reservoir and (iii) downstream of the proposed reservoir;
- migratory behaviour and fate of upstream and downstream migrating fishes (telemetry study of large fishes);
- a comprehensive review and field monitoring of shifts in hydrology and geomorphological characteristics of the river upstream and downstream from the dam during and after construction compared with the actual situation including options for environmental flows;
- transport and fate of larvae drifting into the low-water velocity of the impoundment and at the dam and turbines;
- monitoring linked to performance indicators and standards, and linked to dam operation.; and
- monitoring that covers all animal species and to some extent plants which are equally relevant as many fish species also eat these algae and other fauna.

The monitoring protocol needs to be targeted and more comprehensive to account for daily and seasonal variability in ecological characteristics related to hydrological conditions as well as establishing an early-warning system to be proactive to respond to potential impacts of the development.

Findings on socio-economic issues and fisheries

Importance of fisheries resources

Fisheries resources (fish, other aquatic animals and useful aquatic plants) have long been central to the lifestyles of four riparian countries of the Lower Mekong Basin (LMB), particularly to communities living in and around the corridor of 15 km of the river and its dependent floodplains. Across the whole LMB, some 40 million people or about two-thirds of the population are involved in the Mekong's fisheries at least part-time or seasonally.

In Lao PDR, more than 70% of rural households are dependent on fishing and collecting other aquatic animals (OAAs) and useful aquatic plants (UAPs) to varying degrees for subsistence livelihoods and additional cash income. This includes the river system and other important habitats such as wetlands and agricultural areas. Consequently, any risks and losses incurred by the Mekong terrestrial and aquatic ecosystems brought about by hydropower dam developments translate into threats to livelihoods – primarily through increasing food insecurity.

There is limited information on the socio-economic dimensions of the dam proposal in the impacted region including the importance of the fishery to food security and rural livelihoods, number of people affected and loss of ecosystem services to rural communities. In particular, the Xayaburi EIA report provides limited baseline and impact information on socio-economic conditions of people living in the mainstream hydropower project-affected areas and further information would be required before the scale of impacts can be more closely identified.

The submitted documents contain information on (1) public health and nutrition, (2) aesthetics, tourism and archaeology, (3) land use and (4) land transportation and navigation. They do not provide information and data on water resources related livelihoods, food security and nutrition.

Trans-boundary baseline and impact information on socioeconomics and livelihoods were not really considered in the EIA report. This information is needed to develop a realistic assessment and formulation of (1) effective mitigation measures, (2) a practical and scientific standardized monitoring programme, and (3) an environmental management plan to minimize negative impacts and gain positive impacts from the Xayaburi mainstream hydropower project

Recommendations

- There is a need for a detailed baseline study on the socio-economic impacts both in the immediate Xayaburi reach, including to the most upstream area likely to be impounded, and any trans-boundary areas likely to be impacted by the development. This should include information and data on socio-economics and water-resources-related livelihoods of people living within a corridor of 15 km either side of the Mekong River and its dependent tributaries and floodplains in the Xayaburi mainstream project area, other parts of Lao PDR (particularly the southern province of Champassack), Thailand (particularly the northern province of Chiang Rai), Cambodia (particularly the Tonle Sap Lake area) and Vietnam (particularly the Mekong Delta area).
- The baseline information required is outlined in ***Annex 4.*** The following indicators are proposed for long-term monitoring of the Xayaburi hydropower project:
  - baseline vulnerability of water-resources-dependent communities,
  - dependence on fish,
  - dependence on OAAs,
  - dependence on UAPs and/or edible algae (EA),
  - dependence on irrigation and riverbank cultivation,
  - resilience, and
  - risks/shocks and trends
- In cases where it is not possible to mitigate the impacts of major infrastructure on people's livelihoods, it may be necessary to compensate the impacted households financially going beyond the immediate impacted area.

4.3.6 Gaps and uncertainties

Data on disruption to fish migration

The MRC preliminary design guidance implies there is a proportion of migratory fish species and sets targets for both upstream passage (primarily spawning adults) and downstream passage (returning adults and larvae/fry). Fish passage in both directions has been considered. The level of information submitted on the underlying assumptions and design of the measures are insufficient to determine their effectiveness at this stage and should be the subject of a more detailed technical review, including modelling of the cumulative effects of reduced passage and increased mortality of fish on population dynamics.

Details on fish-bypass facility design are not clear

Further information is required. The initial finding is that the design of both the upstream and downstream facilities may need significant revision to account for the full range and sizes of species (not just commercial species) that are likely to require fish-bypass facilities (recognising the need to protect biodiversity). Such a revision could also determine the accessibility of the fish-bypass facilities. Alternative studies of fishway designs may be required to determine the most effective approach. Suggestions to optimise the design are included in this report.

Feasibility of fish-bypass facilities is not clear

It appears necessary to allocate funding for a more comprehensive feasibility study of fish passage involving world experts, with the results being used to guide the final design for the fish-bypass facilities. In the event that fish-bypass facilities are not considered feasible, alternative mechanisms should be outlined to mitigate and compensate for any impacts.

Lack of hydraulic information

The above assessments need to be coupled with an appropriate assessment of the hydraulic conditions likely to be encountered in the fish-bypass facilities and around entrances and exits.

No direct measures to mitigate or compensate for loss of fisheries are outlined

The information provided focuses on management responses to enhance fisheries in reservoirs which may be appropriate for communities living within the reservoir with lake type-specific species rather than riverine species. The management responses do not address any loss of natural fishery production further upstream or downstream. The extent and nature of any such loss is not included in the project mitigation measures. The information provided does not address social, economic and fishery-access issues or alternative-exploitation tools and techniques.

4.3.7 Transboundary and cumulative aspects

Transboundary effects and cumulative impacts resulting from multiple dams on fisheries have been analysed in two studies : (1) BDP - Basin Development Plan Programme - Assessment of Basin-wide Development Scenarios (MRC 2010) and (2) SEA MRC Strategic Environmental Assessment of hydropower on the Mekong mainstream (SEA, ICEM 2010). In addition, MRC Technical Paper No 25 examiners modelling the cumulative barrier and passage effects of mainstream hydropower dams on migratory fish populations in the Lower Mekong Basin.

On the basin-wide scale, transboundary and cumulative effects – as described in Chapter 3 - can be significant and impact fisheries through interruption of river continuity and therefore fish migration, inundation of refuge and spawning habitats as well as disconnection of the lateral connectivity and therefore wetlands/floodplains. Other factors include flooding and alteration of the hydraulic regime in lower parts of the Mekong River and Delta and alteration of sediment and nutrient balance. Details on these impacts and transboundary implications can be found in ***Annexes 3 and 4***.

The fisheries review refers to the BDP scenarios for transboundary reflections and focuses on scenarios 1, 2 and 4.

1. **Baseline – 2000:** three existing Chinese mainstream dams (Manwan, Dachaoshan and Jinghong), plus 15 tributary dams.
2. **Definite Future – 2015:** eight existing and planned mainstream Chinese dams, plus 26 tributary dams.
3. **Foreseeable Future Scenario 2030 (i):** eight existing and planned mainstream Chinese dams, plus 71 tributary dams.
4. **Foreseeable Future Scenario 2030 (ii):** eight existing and planned mainstream Chinese dams and six mainstream dams in Lao PDR, plus 71 tributary dams.
5. **Foreseeable Future Scenario 2030 (iii):** eight existing and planned mainstream Chinese dams, six mainstream dams in Lao PDR, five Cambodian dams, plus 71 tributary dams.

Emphasis has to be placed on existing knowedge gaps and uncertainties regarding distinct fisheries data including biomass, fisheries species and abundances.

The performance of tailor-made monitoring programmes to assess fisheries populations in the LMB, and in particular at the proposed Xayaburi dam site, will be crucial to fill these gaps and reduce uncertainties. The monitoring programme will have to include all necessary parameters for sampling and assessment to establish a fisheries baseline condition. The baseline condition will be an essential pre-condition for future impact assessment.

The availability of the information above will also allow the consolidation of the scenario assumptions.

To analyse the transboundary effects of the Xayaburi dam project and the other 5 mainstream dams in the proposed cascade in nothern Lao PDR, three scenarios are presented and compared below.

Scenario 1: Baseline – 2000

- About 21% of the LMB is blocked by tributary dams and inaccessible to fish species having to migrate to the upstream parts of the river network.
- Fish production in the region is based on a combination of capture fisheries from the river and associated floodplains, rain-fed agricultural areas (e.g. rice paddies), reservoir fisheries and aquaculture. In addition, other aquatic animals (OAAs) increase supply of products. Upstream from Vientiane, there is important production of algae (*Cladphora*).
- Total fish production in the LMB is 2.53 million t/yr (including 0.5 million t/yr OAA (freshwater shrimps, snails, crabs, frogs etc).
- Aquaculture production is 1.97 million t/yr mainly in the Mekong Delta.
- Biodiversity: 781 known fish species, and possibly up to 1,300, including iconic species such as the Mekong giant catfish that is known to utlilise long reaches of the river and migrate upstream to spawn above Luang Prabang. Other iconic aquatic animals include the Irrawaddy (Mekong) dolphin which inhabits the river below Khome Falls.

Scenario 2: Definite Future – 2015

Ecosystem impacts

- Reduced flooding and depleted natural replenishment of nutrients will reduce wetland areas (by 35,000 ha - 2.4%) and their productivity.
- River habitats will be diminished, noticeably in Lao PDR and Thailand.
- Environmental hotspots on the mainstream in northern Thailand and the Lower Sesan in Cambodia will be impacted.

Fisheries impacts

- A combination of ecosystem impacts and interruption of fish migration are caused mostly by committed tributary dam development in the LMB and will deplete capture fisheries. Estimated reduction from the baseline is 15% in Lao PDR, 3% in Thailand, 7% in Cambodia and 9% in Viet Nam. These values do not appear to account for the potential collapse of downstream drift and the impact on fish recruitment in downstream reaches.
- Reductions in sediment outflow from the tributary sub basins will negatively impact upon the productivity of the Cambodian floodplain, delta and coastal marine fisheries (see ***Chapter 4.4***).

Social impacts

- Combined impacts of principally reservoir construction and wetland productivity reduction are estimated to put the livelihoods at some degree of risk for up to 900,000 people within the LMB.
- Construction activities, new reservoir fisheries and aquaculture forecast are predicted to generate 370,000 new jobs. Any jobs created are unlikely to substitute for the loss of fisheries as they are likely to be in different sectors, often requiring capital investment that will not be available to rural poor. Aquaculture in particular requires both capital investment and recurrent financing for feed that is not readily available to the fishing communities without special support programmes. It should also be recognised that reservoir fisheries rarely achieve expected outputs and these figures are based on best-case scenarios.

Scenario 3: Foreseeable Future Scenario 2030 (ii)

Ecosystem impacts

- The presence of the mainstream dams is likely to cause significant impacts on local sedimentation, which will depend upon operation and effectiveness of sediment flushing, including timing of flushing in relation to floods. Reductions in sediment outflow are expected to negatively impact upon marine fisheries.
- Mainstream dams would have incremental environmental impacts arising from the conversion of the river in the northern part of Lao PDR into a series of slow-moving water bodies between the dams, the barrier effect on fish migrating in this part of the mainstream and further reduction in downstream replenishment of fisheries.
- Negative impact on local environmental hotspots is expected to new areas between Lao PDR and Myanmar as well as the Songkram River floodplain in northeast Thailand.
- Mainstream dams will have a severe impact on Mekong giant catfish numbers, and could lead to its extinction along with other species locally.
- The Xayaburi dam is the first of six dams, a cascade that would block 69 % of the accessible habitat for migratory fish.
- Mainstream dams result in a loss of 39 % of the riverine mainstream habitat, representing 90 % of the upper migration system.
- Migration of at least 23 fish species is blocked.
- The wild population of Mekong giant catfish is likely to become extinct even in if only one dam is built as the only confirmed spawning area is above Luang Prabang. No large migratory fish species are predicted to persist if all 6 dams are built.

Fisheries impacts

- A combination of ecosystem impacts and interruption of fish migration (69% of migrating fish) mostly by tributary dam development in the LMB, and loss of production area in Lao PDR is expected to deplete capture fisheries. Estimated reduction is 16% in Lao PDR, 5% in Thailand, 18% in Cambodia and 16% in Viet Nam.

- The reduction in the flooding regime of the Tonle Sap system and LMB wetland areas will remain and potentially increase marginally under this scenario depending on dam operation.
- Estimated fisheries losses given here are under-representative since they are a sum of local estimates and do not reflect the impact that a change in a given place (e.g. a breeding site upstream) can have on another place (e.g. a fishing ground downstream). Estimated losses would be probably much higher if spatial connectedness between habitats and dynamics of migratory populations are considered. This is also indicated by high losses of accessible and riverine habitats and cumulative and additive effects of habitat degradation and continuum disruption. Comprehensive monitoring data are necessary to overcome these uncertainties.

Social impacts:

- Exclusively 6 Lao PDR mainstream dams *without* LMB tributary dams:
  Incremental effects regarding fish losses due to reduced capture fisheries are estimated at about 66,000 tons per year and the additional livelihoods at risk to some extent are about 450,000 people within the LMB.
- 6 Lao PDR mainstream dams plus 71 LMB tributary dams and irrigation increase:
  Combined impacts of principally reservoir construction and wetland productivity reduction are estimated to put the livelihoods at risk of about 2 million people within the LMB.

Figure 9 illustrates the potential incremental impacts of the planned LMB mainstream dams in relation to the different scenarios, which are outlined above (taken from the SEA, 2010; BDP, 2010).

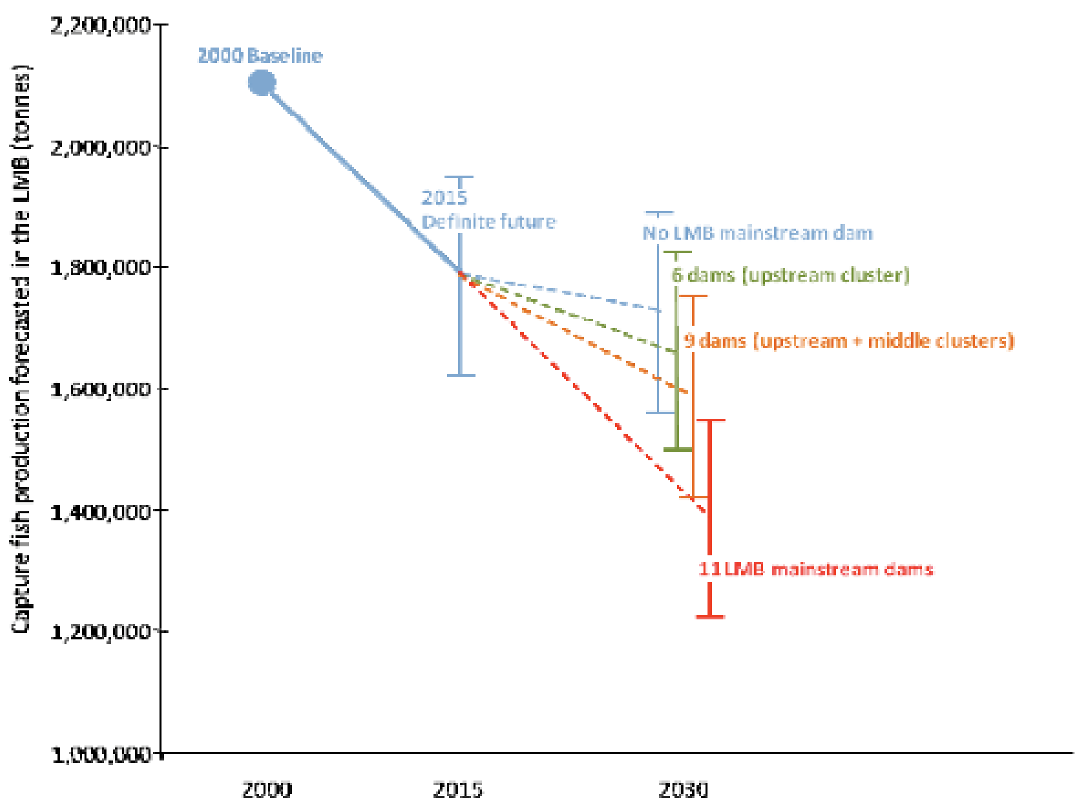

Figure 9: Potential incremental impact of LMB mainstream dams on fish production basin-wide (SEA, 2010; BDP, 2010).

Key conclusions on transboundary impacts on habitat and fishery for different scenarios

Migratory fish species substantially contribute to fisheries yield in all zones of the LMB and are the group of fish mainly affected by multiple dams. Fish migration will be blocked by dams in the LMB within and between the upper, middle and lower migration systems. Spawning and nursery habitats located upstream from Xayaburi dam are important for fish species and populations below the Xayaburi dam project.

The Xayaburi dam is the first of six dams, a cascade that would block 69 % of the accessible LMB habitat for migratory fish in both the mainstream and LMB tributaries. If the cascade is built, 39 % of the riverine habitat will be lost in the mainstream, representing 90 % of the upper migration system. At least 23 but probably more than 100 fish species will be directly affected by disrupted migration routes. Fish will have major problems in adapting to unstable and unsuitable habitat conditions in reservoirs resulting in probably 90 % loss of fisheries yield in reservoirs. Intended flushing of reservoirs might have detrimental effects on downstream fish communities in un-impounded river sections. In the case of multiple mainstream dams, viable fish populations of migratory species will not be maintained even if highly efficient fish-pass facilities are built. If the cascade of six dams above Vientiane is built, fisheries yield of river-floodplain wetlands will be reduced by 73 % in Lao PDR (16 % more than in the Definite Future Scenario).

If the cascade is built, the total loss of fishery yield will be 13-29 % within the LMB compared to 7-23 % in the Definite Future Scenario (i.e a 6 % increase in loss).Estimates of fishery losses are and widely underestimated when compared with lost accessible and riverine habitats, minimal reservoir yields and cumulated effects of habitat degradation. The estimated loss of fisheries production could lead to food security problems and loss of livelihoods for rural poor communities along the river corridor. Aquaculture and fish stock enhancement are unlikely to mitigate these problems due to investment requirements.

4.3.8 Conclusions and recommendations

(i) Fish ecology

One of the major problems highlighted in this review of Xayaburi is the lack of sufficient empirical data on how important the area is to fish migration in terms of biomass and species diversity. This partly arises from difficulties in studying fish populations in large rivers and also the lack of investment in primary studies in the region prior to the submission of the proposal and reliance on SEA documentation. The PDG is also not explicit in the information required to make such an assessment.

- **It is recommended that fundamental gaps in knowledge - about the ecology of the fish, status of the fisheries, livelihoods analyses in relation to operational design of the dam and upstream and downstream fishways - are addressed and made available to the MRC.** This should include evidence to justify the assumptions made in the design of the fishways.
- If such data are not available, and a decision to proceed with the project is taken, they should be collected during the construction phase and used where necessary to adapt the design criteria to ensure that the ecological needs of the fish, fisheries and other aquatic biodiversity are addressed.
- Full appraisal of the fisheries, species assemblage, life cycles, migratory behaviour and biomass need to be undertaken to underpin decisions on the mitigation measures proposed. This needs to include a meta-analysis of the composition and ecology of the fauna in areas adjacent to the dam site.

(ii) Modifications to upstream fish passage design

The need to address the issue of fish passage in both upstream and downstream directions has been recognised along with the need for continuous dialogue with the Government of Lao PDR and MRC.

The submitted design and feasibility assessment of the fishways (both upstream and downstream) are limited in both detail and scope. The fishway design is based on the Columbia River system for salmonid species in North America. A feasibility study has not been carried out on the potential likelihood of this design functioning or whether alternative options would be more appropriate.

- **The Fisheries Expert Group review recommends a full review of upstream/downstream passage options be considered, including a full cost-benefit analysis.**

One (previously two in the EIA) vertical-slot fish pass has been proposed with a collection gallery for upstream migration and a surface bypass collector for downstream migration with "fish-friendly" Kaplan turbines. MRCS is not aware whether a feasibility study for these designs has been carried out or whether alternative options, including different turbines, have been evaluated and considered.

The vertical–slot design proposed is considered unsuitable for the high biomass and the diverse size range, swimming abilities and behaviour of Mekong fishes expected near Xayaburi.

The documents submitted lack details of hydraulic conditions that are likely to be experienced or assessment of whether the target species will be able to tolerate the conditions encountered. Experience from other locations indicate that most fish migrating upstream are likely to tire when ascending this type of fishway and fall back, thus a comparative analysis of other systems is important.

Based on the review, the Fisheries Expert Group recommended that facilities for fish passage be reconsidered based on a more exhaustive scientific analysis and understanding of the capacities of different species to utilize successfully such facilities. The Expert Group proposed that three upstream fish passes needed to be built to facilitate passage of the high biomass and diversity. These fish passes need to accommodate the complex hydraulics that would occur during discharge from the powerhouse and spillway.

- **The left-bank fish pass needs to be revised to pass 10% of low flows with sufficient space for high biomass and low-water velocities for the passage of smaller species.** Potential solutions are a nature-like bypass on a low gradient (< 1:100) or two large fish locks. A second high-capacity fish pass, probably a fish lift, needs to be incorporated into the "intermediate block". The third potential fish pass is the navigation lock, which could be modified to pass fish and provide navigation.
- **The Fisheries Expert Group considers that with a revised design, the impact of the Xayaburi dam on upstream passage can potentially be reduced to a significant extent.**
- **A workshop is recommended with the MRCS, international experts (Fisheries Expert Group) and the Design Team to further evaluate the design and risks, and to develop solutions.**

The design of the upstream fishway entrances and exits lack detail, particularly on the hydraulic conditions, to evaluate fully whether the fish would be able to find the entrance and whether they would be entrained by the turbine inflows.

- **Fish pass entrances are a critical part of fish-passage design and physical modelling is recommended to optimise abutment shapes and spillway design to ensure they work in harmony with the fish-passage facilities.** Computer (CFD) modelling can also be used. These entrances, including the collection gallery, need to cover a variety of depths and locations to enable passage of surface, midwater, benthic and thalweg-oriented fishes.

There is no definitive information on the operating rules and hydrology associated with hydropower production at the dam. This is a fundamental requirement to understand how the fish passes will function and how the environmental conditions in the reservoir and downstream of the dam will be modified. This is also required to determine the effectiveness of any fish passage as it will be heavily influenced by the planned flow regime.

- **A feasibility study of fish passage by experts is recommended, with the results being used to guide the final designs of fish-passage facilities.** This feasibility study should include:
    - details of technical aspects of assessment of fish passage including use of performance standards, taking into account high water turbidity;
    - further hydraulic modelling, including use of the existing physical models to understand the conditions to be overcome and optimise the design of the fish-passage facilities in relation to all fish species and size; and
    - mitigation measures and their costs and benefits including measures at critical locations for life-cycle completion.

(iii) Downstream fish passage

Similar issues exist with the downstream passage facilities. **The limited information provided makes it difficult to interpret the design criteria and whether they would function as intended. This is particularly important given that all life stages (including eggs and larvae) and a range of sizes need to be accommodated and that one of the greatest risks to maintaining fish stocks is facilitating downstream movement.**

- **It is recommended to carry out a more detailed technical analysis of downstream fish-passage facilities including a fish-collector system appropriate to all species, life history stages and sizes including benthic species.** Mechanisms to improve downstream passage need to be integrated into the dam design.

For downstream migration, there are two major impacts to consider: (i) the hydrodynamic barrier (or reservoir effect) where low water velocities in the impoundment prevent passage of larvae downstream and (ii) passage at the dam. The first impact is not considered. It can be mitigated only by operating the sluice gates of the dam with little head differential. This may coincide with passing sediment and this overlap should be investigated and maximized where possible.

The surface bypass collector proposed for passage at the dam would be ineffective for benthic species. Benthic screens need to be included.

- **Downstream passage at the spillway can be provided by one or more overshot gates and an improved stilling basin design, which can both be developed using the physical model.**

There is a basic assumption that the modern Kaplan turbine design is fish-friendly and therefore fish survival is unlikely to be an issue.

- **Specifications of fish-friendly turbines, including performance standards, need to be specifically included in the design to justify this assumption.**
- **Assessment of turbine damage to Mekong species needs to be evaluated.**

(iv) Fish passage during construction

Fish passage during construction is not presently considered and needs to be incorporated into the project.

- **A full appraisal of impacts of dam development on fish and fisheries during and after the construction phase, including appraisal of loss of ecosystem services, is recommended.**

(v) Fisheries management and monitoring

There is limited information on the socio-economic dimensions of the dam proposal in the impacted region including the importance of the fishery to food security and rural livelihoods, number of people affected and loss of ecosystem services to rural communities. In particular, the Xayaburi EIA report provides only limited baseline and impact information on socioeconomic conditions of people living in the mainstream hydropower project-affected areas

- **There is a need for a detailed baseline study on the socio-economic impacts both in the immediate Xayaburi reach, including to the most upstream area likely to be impounded, and any transboundary areas likely to be impacted by the development.**
- **Full social and economic impact analysis of livelihoods of those dependent on the fisheries is also required with an alternative livelihoods analysis to identify options to compensate the fishing communities.**

Basic information is given on monitoring the fish populations and management of fisheries during and after the construction phase. The monitoring protocol proposed does not address some of the essential issues, such as downstream-passage success and survival through turbines, and appears to be underfunded. It is not clear how either would be maintained for the life of the project.

- **A detailed monitoring programme is recommended to address knowledge gaps in fish biology that can improve dam and fish pass design and operation as well as the impact of the dam on fish and fisheries, together with a response strategy for adverse impacts.**

The options of management of the fishery after construction are considered weak and fail to address a number of aspects of management of the fishways. These include how to control fishing in and near the fishways, how to limit predation in and near the fishways, what prevents upstream-swimming fish from immediately returning downstream and maintenance requirements.

- **Measures to prevent fishing near the dam wall including in and near the fishways**

Mitigation measures proposed are weak and more related to management of fisheries production in the reservoir impoundment rather than true mitigation and compensation mechanisms. They are orientated around stocking the impoundment, substituting lost fish production through aquaculture and providing fisheries staff to support development in the fishing community. These measures offer no real solutions, are unlikely to compensate for loss of fishery production and do not address social, economic or fishery-access issues or alternative exploitation tools and techniques.

- **As a matter of urgency, it is strongly recommended to carry out a comprehensive appraisal of measures to mitigate loss of fisheries and biodiversity, targeting both upstream and downstream fishing communities, together with realistic associated costs.**
- Details on how a fishery management system will be developed, monitored and sustained in the project area are required.
- The above review has that the fish passage facilities proposed in the submitted documents will be largely ineffective, that considerable gaps in understanding remain regarding design parameters for fish passage, that considerable changes would be required to increase the likelihood of maintaining fish migration in this reach of the river, and that in addition, other mitigation measures would be required to compensate affected communities where residual impacts remain.

4.4 Sediment Transport, Morphology and Nutrient Balance

4.4.1 Scope of the review

The context for the review by the Sediment Expert Group is provided by two relevant documents. The first is the "Preliminary Design Guidance for Proposed Mainstream Dams in the Lower Mekong Basin." The second is the ''Optimization Study of Mekong Mainstream Hydropower" published by the Lao Department of Electricity also in 2009. Their report is given in full in ***Annex 3*** and is summarised here, highlighting the impacts and risks associated with mainstream dams in relation to sediment transport and morphology.

MRC, the Lao Department of Electricity and the Developer all concur regarding the need to account fully for sediments, morphology and the nutrient balance in the design and operation of the proposed Xayaburi dam project.

The objectives of this review of sediments, morphology and nutrients include reviewing the potential impacts identified and the measures proposed to avoid, manage and mitigate them. Other objectives include identifying gaps and uncertainties and suggesting ways to close significant gaps, recommend modifications to avoid or mitigate sediment, morphology and nutrient impacts as well as reducing uncertainties to acceptable levels where possible. Where they cannot be reduced to an acceptable level, the aim is to put uncertainties on the "safe side" so that hydropower development is guided by "no regret" decision making. The review considers the potential for transboundary impacts and cumulative effects associated with the construction and operation of Xayaburi dam as one of a cascade of hydropower dams on the Mekong mainstream and its tributaries.

4.4.2 Introduction to riverine sediments, morphology and nutrient balance

Sediments are inorganic materials carried in rivers as suspended load or as coarse bed-load from upstream sources to the downstream areas of deposition. Sediments are produced by the weathering and erosion of mountains/rocks as well as soils. While the water passes quickly to the sea, sediment may stay in the catchment for periods ranging from a few years to thousands of years.

Initial erosion and input of sediments takes place in the upstream parts of river catchments. Transfer, deposition and re-mobilisation are characteristic for their middle parts and in the lower sections of most rivers (river banks, channel bars, beds of rivers, in the floodplains usually during floods, wetlands and seasonally flooded lakes), the majority of the remaining sediment transported from inland to sea is deposited within the delta, the estuary and in the coastal zone.

Sediments strongly characterise the morphological structure (morphology) of rivers. Further, they influence water quality regarding physico-chemical aspects (including nutrients) and also the ecological status. Rivers carry important nutrients (nitrogen and phosphorous) of which about one to two thirds are attached to fine sediments. A functioning nutrient balance – that is linked to the sediment balance – is crucial to sustaining riverine ecosystem health and services as well as biodiversity. For more on morphological principles, see ***Annex 3*****.**

Sediment transport affected by anthropogenic (human-induced) activities can impact on both a river's morphology and nutrient balance. Reservoirs of hydropower plants act as human-made sediment traps. Damming affects the hydrology and morphology of the river upstream and especially downstream, mainly by interrupting the continuity of sediment transport. In case of missing and appropriate sediment management and mitigation measures, dams disturb the balance between sediment supply and transport capacity, leading to significant sediment reductions downstream from the dam. This can alter transfer and storage areas of the natural sediment supply, leading to adverse physical and environmental impacts.

Adverse alterations to a river's morphology and nutrient balance generated by a disturbed sediment load can cause respective responses:

- in bedrock-controlled reaches, sediment bar and bed features can be lost;
- in alluvial reaches, the channel may be destabilised by bed and bank erosion, leading to complex morphological changes;
- incision of the river bed into the terrain caused by the relatively clear water, leaving reservoirs and limited sediment supply;
- floodplains and seasonally-flooded wetlands may be eroded;
- in the delta, the balance between river and coastal processes may be disturbed, leading to erosion;
- changes in nutrient supply regarding nitrogen and phosphorous; and

- eutrophication of both the river itself and the receiving sea, consequently causing significant impacts on ecosystem health.

In all cases, there will be consequential impacts on sediment resources, ecosystem services and biodiversity depending on the extent of the change in sediment movement.

4.4.3 Sediment issues related to the proposed Xayaburi project

(i) Sediment and morphology

In addition to the Feasibility Study and EIA, the documents reviewed with respect to sediment impacts and measures included academic papers on sediment, morphology and hydropower, reports and publications relevant to sediment and morphology in the Mekong River[15]. Sediment impact and management provisions in the design documents were evaluated with respect to the MRC Preliminary Design Guidance. Provisions regarding sediment and its management are outlined in Section 4 of the MRC PDG, which provides background on strategies to sustain reservoir capacity, mitigate downstream sediment starvation and managing sediment in cascades of dams.

Nature of potential impacts: the principle concerns as they relate to potential local and transboundary impacts of Xayaburi dam are dealt with in paragraphs 90 and 91 of the MRC PDG. In relation to the Xayaburi dam, these include:

Sediment deposition in backwater reach upstream of the reservoir, which could result in:

- morphological changes including shoal formation and bed aggradations, possibly leading to increased flood probability upstream including Luang Prabang. The assessment of potential flooding effects presented in Section B.3 of the Design Report does not account for this possibility.

In-reservoir sedimentation, which could lead to:

- reduced depths and water quality in deep pools within the reservoir reach;
- reduced reservoir volume, leading to decreased storage capacity.
- possible increase in the probability of landslides.
- dam overtopping during extreme flood conditions if the attenuation capacity of the reservoir were compromised.

Localized sedimentation close to the dam, which could:

- adversely affect the powerhouse intakes and operation of the low-level sluices;
- increased sediment concentrations in water flowing through the turbines, with the potential for accelerated turbine abrasion damage, particularly if the quartz content of the sediment is high.

Reduction in sediment discharged downstream, which (as described in paragraphs 95 to 97 of the PDG) could:

- adversely affect the fluvial geomorphology of the river due to “sediment hungry” water released downstream of the dam.
- reduce the extent and sediment concentration of the plume offshore of the Delta.
- trigger adverse morphological responses including: loss of existing sediment features in non-alluvial reaches; channel instability (bed degradation, bank retreat, planform changes) in alluvial

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15 (a) Xayaburi Hydroelectric Power Project, EPC Contract Document, Exhibit II: Scope of Work and Particular Requirements, Appendix 1, Design Report, September 2010. (Referred to as the “design report”); (b) Xayaburi Hydroelectric Power Project, Lao PDR, Physical Hydraulic Model Studies, Interim Report on River Diversion (Stages 1 and 2), December 3, 2009.

reaches; reduced sediment supply to floodplains and wetlands including the Tonle Sap; and result in significant erosion and land loss in the Mekong Delta and along the adjacent coastline.

Possible mitigation measures: Pages 18 to 21 of the PDG describe possible sediment management measures that may be employed to avoid or mitigate these potential impacts depending on the specific situation. They include:

Upstream of the reservoir:

- Sediment traps (paragraph 110) - structures constructed in the river upstream of the reservoir to capture part of the sediment load.

In-reservoir

- *Sediment routing* (paragraphs 99 – 101) – operating the dam to transport as much of the sediment load as possible downstream by maintaining a high sediment transport capacity during the period when the sediment concentration and discharge are highest.
- *Sediment bypass channel (paragraph 102) - to* convey sediment around the reservoir and discharge it downstream. This means releasing sediment laden water and impounding sediment free water.
- *Reservoir flushing* (paragraphs 103 – 108) – re-mobilizing previously deposited sediment and flushing it downstream of the dam. This is only feasible if river-like flow conditions can be re-created in the reservoir by drawing down the water surface elevation using a low-level spillway that has the ability to pass free surface flows at very low elevations at the dam.

Localized sediment deposition:

- *Pressure flushing* - flushing deposited sediment through low-level conduits to keep intake structures clear and minimize the sediment that passes through the turbines.

Downstream of the dam:

- *Sediment augmentation* (paragraphs 112 – 115) - introducing sediment into the river to replace that trapped in a reservoir upstream and so reduce the extent and intensity of adverse impacts caused by 'sediment hungry' water.

(ii) Nutrient balance and consequential environmental impacts

The review regarding nutrient balance and respective impacts is based on the submitted documents, academic papers, preliminary calculations and analysis of the MRC Sediment EG and on international experience gained through the operation of other dams worldwide. Further, the MRC PDG has been used as a guideline:

- Paragraph 120 in the MRC-PDG requires that mainstream dams pass fine suspended sediment and, therefore the associated nutrients, in a way that most closely mimics the natural timing of sediment transport dynamics in the river.
- Paragraph 142 further notes that healthy riverine ecosystems support the livelihoods of many people living along the banks of Mekong River (e.g. nutrition and income).
- The supply of nutrients is in several reports recognised as important to ecological services in the entire Lower Mekong Basin including the Delta, the Tonle Sap and other floodplain wetlands, as well as in the river itself. It is for these reasons that mainstream dams should avoid significantly inhibiting downstream transport of nutrients.
- Finally, paragraph 161 of the PDG requires that operation of the dam should aim to maintain sufficiently high levels of dissolved oxygen (DO) and sufficiently low levels of phosphorus, nitrogen, and biological oxygen demand (BOD).

The effects of a hydropower dam and reservoir on the nutrient balance in the river system can have significant environmental impacts, depending on the design and operation of the dam.

In-reservoir, these impacts are primarily related to:

- Trapping of nutrients attached to sediments.
- Reduced turbidity (increased light penetration in the water column) due to sediment settling out of suspension.
- Increased algae growth due to accumulation of nutrients, reduced turbidity and increased water retention time.
- Changes in fluvial conditions and sediment features in the reservoir.

Thermal stratification of the water in a reservoir can amplify all of these impacts.

Downstream of the dam, nutrient-related environmental impacts result mainly from:

- Release of nutrient deficient water due to sediment trapping during normal operations.
- Changes to the nutrient balance (e.g. reduced nutrient input to downstream ecosystem).
- Release of water with unnaturally high concentrations of sediment and associated nutrients during flushing operations.

A significant proportion of the nutrients phosphorous (P) and nitrogen (N) in a river may be associated with the sediments. Consequently, when sediment is trapped in a reservoir, nutrients are also retained and this leads to nutrients accumulating in the reservoir through time.

Transport, trapping and biological availability of P and N attached to sediments depends on how the nutrients are bound to the sediment particles and the size of the sediment particles to which the nutrients are attached. Unfortunately, no detailed data on nutrient binding and the size of particles involved is currently available for the Mekong River system.

While detailed data are unavailable, the MRC Water Quality Report (2008) mentions that, on average, a third of the total P in the Lower Mekong Basin is found as soluble orthophosphate (PO4-P). This suggests that about two thirds of the phosphorous is associated with sediments.

Data from the MRC data base show that, at Luang Prabang in 2004-05, soluble phosphate on average makes up 70% of total P, suggesting that only 30% is associated with sediments. The proportion of soluble phosphate varies between 50 and 90%. In data collected further downstream in the Mekong River at Prek Kdam (between Phnom Penh and the confluence with the Tonle Sap River), bio-available P bound to sediment constitutes 30 to 40% of the total P. Similarly, the soluble proportion at the hydrometric stations up- and downstream of Xayaburi (Chaing Sean and Vientiane) made up, on average, only 30% of total P in 2004-5. This finding corresponds closely to the general level reported for the Lower Mekong Basin as a whole.

Implications for sediment and nutrient management at the proposed Xayaburi dam

The possible sediment management techniques proposed in the PDG have been reviewed, leading to the conclusion that the techniques feasible for implementation at the proposed Xayaburi dam are sediment routing, reservoir flushing and pressure flushing. Routing and reservoir flushing could be used in tandem to reduce local and trans-boundary effects. Pressure flushing is only able reduce the local effects of sediment accumulation immediately in front of the powerhouse intakes. Sediment routing and flushing could also be effective in reducing the tendency for nutrients to be retained in the reservoir as well as accumulated in deep pools located within the reservoir. The basics for these conclusions and details of the review regarding specific impacts and mitigation measures are provided in the subsequent chapters.

4.4.4 Summary of impacts considered and measures proposed

The Feasibility Report makes multiple references to sediment impacts and measures included in the preliminary design to manage or mitigate them. ***Annex 3*** presents a table of impacts and measures considered, together with a response (agree/disagree) and comments made by the Sediment Expert Group. That table provides the basis for the remainder of this sub-section, which deals in turn with impacts and measures relating to Sediments, Morphology and Nutrients.

(i) Sediments

The Executive Summary of the Feasibility Report clearly recognises that sediment is an issue. On page 1-4 it is stated that, in designing the dam, the project will,

"Maintain sediment passage by installing sluices for sediment flushing, protecting the turbines, avoiding deposits upstream of the barrage, as well as not reducing sediment inflow downstream, which may cause subsequent bank erosions and less protein for fish consumption and less nutrient in water for agriculture."

Section 1.6 of the Executive Summary of the submitted documents introduces the PDG document by reference to 5 aspects of the river, including Sediment Transport and River Morphology. Specifically, on page 1-8 it is noted that,

"preliminary design in the feasibility study is designed to maintain sediment passage by installing sluices for sediment flushing, avoiding deposits upstream of the barrage, as well as not reducing sediment inflow downstream."

It is noted that further investigations will be required before the design will conform to the PDG. Specifically, the next paragraph on page 1-8 states that,

"For the next study, Outline design, the hydraulic lab will be carried out and the result from the model will be used to design a sand flushing in conformity with the MRC's Design Guidance."

There are few detailed statements concerning sediment (including gravel, sand, silt and clay) in the body of the Feasibility Study. The few references to sediment in the Environmental Impact Assessment (EIA) include an indication that sediment trapping will be avoided as,

"*Sediment sluice gates will be constructed for sediment drainage."*

As a general assumption of the proposal, it is expected that no sediment entering the reservoir from upstream will be trapped either in the reservoir or behind the dam. With regard to local sources of sediment, the EIA notes that soil erosion during construction could be as high as 380.7 tonnes/hectare/year, with an average rate of 196.3 t/ha/yr (page 5-9). A rate of 15 t/ha/yr is considered 'severe' according to the Table on page 5-8 of the EIA. Once construction is complete, the EIA predicts that,

"During the operation period, the impact on erosion can be defined as no impact."

(ii) Morphology

As elevated sediment production is expected only during construction, and given that it is concluded that the reservoir will not trap sediment during the operating period, only limited morphological impacts downstream are expected. Similarly, because the proposed design is classified as a run-of-river dam, the Feasibility Report concludes on pages 11-12, that downstream fluctuations in stage will be avoided - so that downstream bank erosion will not be generated through dam operations. Notwithstanding this, it is stated on page 6-7 of the EIA that morphological impacts will be mitigated by plans to, *"construct the river bank protection downstream from the barrage"*. This suggests that downstream morphological impacts on the Mekong River sufficient to necessitate mitigation are expected.

(iii) Nutrient balance

The EIA foresees that impacts on water quality will be inevitable, noting on page 5-12 that,

"During construction period water quality in the river will have affected by the turbidity and siltation from earth work in the project area. High turbidity loaded in downstream of Mekong River is expected."

It further notes that, with respect to the nutrient balance, impacts will relate to:

- sediments released during construction (Mitigation: establish sediment traps and utilise the high degree of dilution in the river).
- increase in pH due to concrete construction (No mitigation - rely on dilution effect).
- increase in pollution with BOD and nutrients and solid waste from staff (Mitigation: install septic system and sewage treatment as well as solid waste disposal).
- increased oil contamination (Mitigation: construct oil/grease trap for waste water from all construction activities).

Impacts and mitigation measures addressed

(i) Sediments

The submitted documents state that there will be no sediment trapping in the reservoir because Xayaburi dam will be designed and operated as a "run-of-river" hydropower dam and that increased erosion will cease once construction is complete. Management and mitigation measures to minimise the temporary increase in sediment input to the Mekong River due to local erosion during construction need to rely on the very high dilution factor due to the great size of the river together with the adoption of international best practice in erosion-control practices. Since no sedimentation is expected either within or upstream from the reservoir during the operating period, sediment- management measures suggested are limited to sand-flushing conduits designed to flush sand deposited immediately upstream from the powerhouse. No measurements of suspended-sediment loads are included in the proposed long-term monitoring program.

(ii) Morphology

Limited impacts on river morphology (bank erosion) are expected based on on the dam design and operation plans. The documents do not consider impacts on the deep pools upstream from the dam that are important fish habitats (see previous chapter). Proposed mitigation measures are limited to the construction of bank protection downstream from the dam.

(ii) Nutrient balance

The documents state that impacts on water quality and therefore nutrients will be inevitable and will mainly occur during the construction of the dam. Best-practice management and mitigation measures regarding impacts on nutrients are proposed during the construction phase. The EIA concludes that no significant impacts on water quality (including nutrients) are expected during the operation period because the dam is run-of-river and inflow equals outflow on a daily basis. Consequently, no mitigation measures are proposed.

4.4.5 Findings of the MRCS technical review

(i) Sediment and morphology

Localized deposition in the vicinity of the dam

The project expects that sediment will accumulate in front of the power intakes and suggests using low level conduits to pressure flush sediment through the dam.

The Sediment Expert Group (SEG) concludes that this should be possible through pressure flushing, which is performed by maintaining a high water surface elevation while releasing water through the low-level outlets (***Figure 10***). Experience from many other dams demonstrates that pressure flushing will remove localized deposits from close to the powerhouse and not have an effect on sediment depositions more generally within the reservoir.

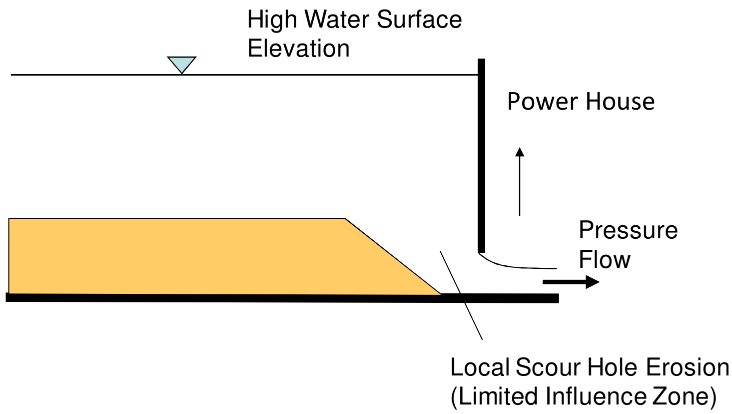

Figure 10: Pressure flushing to remove localized sediment deposits

In-reservoir sedimentation:
The review concludes that ***Sediment Routing*** is feasible at Xayaburi and that, if the spillway gates as currently designed were opened completely during high flow events with high sediment concentrations, it might be possible to generate sufficient transport capacity throughout the reservoir to pass a substantial proportion of the incoming sediment without its ever settling in the reservoir (***Figure 11***).

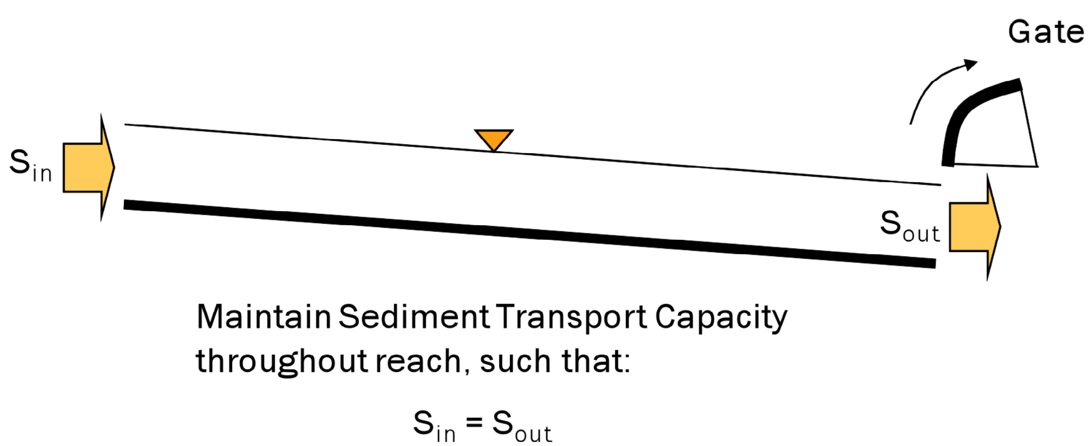

Figure 11: Concept of operating the project to route sediment through the dam during periods of high sediment concentration

If no attempt is made to sustainably manage sedimentation in the reservoir with an effective strategy, it is likely the reservoir would lose a significant portion of total capacity in the long term. The time taken for this to occur is currently not possible to predict as it depends on future sediment inputs to the reservoir that will be affected by multiple influences including trapping in reservoirs upstream, climate change, land use change. Consideration of the results of preliminary calculations and 1-dimensional modelling suggest that, in the long term, optimum sediment routing alone (without flushing as described in the next section) could generate a new equilibrium condition in the reservoir, limiting sedimentation to about 60% of the original volume of the reservoir.

If the timing of annual sediment routing operations could be matched to key periods of fish migration, the required design modifications could possibly help minimise the impacts of the dam on fish as well as sediments. This needs further study. Also, if the routing is implemented during a period of high discharge, it might be possible to continue hydropower generation during sediment routing operations, provided the sediment concentration of the flowing water is not too high and sufficient discharge were available for concurrently passing water through the turbines.

Sediment flushing requires operators to draw the water level at the dam down and increase the water surface slope through the reservoir, creating river-like flow conditions that re-suspend previously deposited sediment from the bed and banks and carry it downstream of the dam through the low-level outlets (***Figure 12***).

Flushing of sediment from the reservoir that has already settled would not be feasible at Xayaburi with the current dam design because the sluices planned for the powerhouse are too small and the spillway is too high to accomplish drawdown flushing. Hence, design modifications would be required to implement flushing operations. Specifically, it would be necessary to install large, low-level outlets capable of conveying flushing flows through the dam without impediment, so recreating flow conditions in the reservoir that mimic natural, pre-dam conditions.

Preliminary estimates made by the Sediment EG suggest that modifiying the design of the dam and successfully implementing flushing could limit long term sedimentation in the reservoir to about 30% of the original reservoir volume. Implementing flushing and routing operations could significantly extend the time to reach equilibrium to hundreds or thousands of years, depending on how future sediment inputs respond to trapping in upstream reservoirs, climate and land use changes.

Sediment concentrations would be unnaturally high during flushing and so it would be essential to comply with the advice provided by fisheries and environmental experts to avoid adverse impacts on fish and wildlife. It would not be possible to generate hydropower during flushing operations, because the water level for flushing under free flow conditions would normally be below the minimum elevation of 268 m.a.s.l. for energy production, and otherwise the aim is to avoid heavy sediment concentrations moving through turbines during flushing operations.

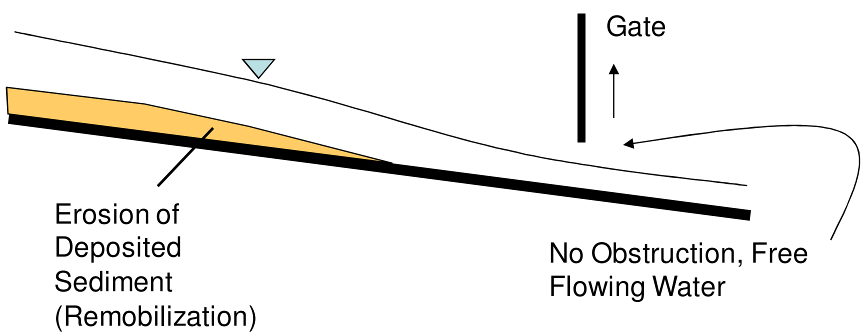

Figure 12: Reservoir flushing operations to remobilise sediment already deposited require the presence of large capacity low-level outlets that can draw the river down to create free-flowing conditions at the dam. This flow condition re-mobilises sediment deposited and passes the re-suspended sediment downstream through the dam

(ii) Nutrient balance

In-reservoir nutrient trapping

Assuming that about two thirds of the phosphorus and half of the nitrogen carried by the river is associated with the fine sediment (silt, clay and fine sand) this review estimates, for the current design and proposed operating regime, nearly half of the incoming total P and a third of the total N are at risk of being retained in the reservoir. Design modifications to the dam and its operation to optimise sediment routing and flushing as proposed above have the potential to reduce these upper bound estimates to as little as 5%.

Detailed modelling suggest that sediment routing and flushing could also be effective in reducing the tendency for nutrients to accumulate in deep pools located within the reservoir. It is likely that fine sediment would accumulate in the deep pools if the dam were built and operated as proposed, especially during the dry season. Simulation of the effectiveness of flushing during the high flow period indicates a limited capability to re-suspend fine material that has settled in deep pools. This could adversely impact the nutrient balance and habitat quality in these parts of the reservoir.

According to an MRC Water Quality Assessment made in November 2008, the annual total P transport at Luang Prabang constitutes approximately one third of the transport at the hydrometric stations further downstream (Nakhon Phanom, Kong Chiam, and Pakse). Consequently, the impacts of Xayaburi on nutrient loads and balances in the river would decrease with distance downstream. Based on this SEG review estimate of sediment trapping behind Xayaburi Dam with the proposed design and operating regime, the dam would be likely to result in a reduction of up to about 15% in total P in the lower reaches of the Mekong, which would be likely to lead to consequential environmental impacts that are both measurable and significant to habitats and ecosystems.

Such impacts are avoidable. Implementing the design and operation modifications recommended here to optimise sediment management could reduce the impact in P to the point that it would not be detectable. The data necessary to support an equivalent assessment for total nitrogen are currently unavailable.

In summary, interpretation of preliminary calculations and analysis of modelling results performed for this review, coupled with experience gained through the operation of other dams worldwide suggest that, it should be possible to maintain the nutrient balance in the river after construction of the Xayaburi Dam by passing and flushing most of the sediment-associated nutrients downstream provided that recommended modifications are made to the design and operation of the hydropower dam to optimise the dam's capability for adaptive management of future sediment inputs from upstream. This would result in reduced power generation and would require further modelling to arrive at an optimum solution.

The interpretation of potential nutrient loads and balances in this report is based on preliminary calculations and modelling and it is recommended that additional surveys, monitoring and analyses are performed to determine the size of sediment (clay, silt or fine sand) to which nutrients are primarily attached and reduce uncertainty concerning the quantities of nutrients that could be routed or flushed downstream under different design and operational scenarios.

Water quality

These preliminary estimates concur with the view expressed in paragraph 144 of the PDG that relatively short retention times will limit algal growth and water quality problems. If retention times approached the maximum possible value during the dry season there would be a risk of undesirable algal blooms that would require management through adaptive adjustments to the operating regime. The capability to deal with any algal blooms adaptively would depend on implementation of a monitoring programme to support adaptive management of water quality issues in the reservoir to avoid undesirable environmental impacts, especially during the dry season. Monitoring would, in any case, be necessary to fulfil the relevant criteria set out in the PDG.

The review conclusions align with the statement in paragraphs 144 and 149 of the PDG, that the probability that water might become thermally stratified in long, narrow reservoirs like that planned for Xayaburi is relatively low. This conclusion is based on estimated retention times and modelled velocities. The risk of adverse impacts on water quality due to siltation, algal blooms, weed growth and the accumulation of other organic debris in deep pools in the reservoir should be established through monitoring and additional assessments. Risk assessment should explicitly account for effects of water exchange/stratification and the oxygen balance in deep parts of the reservoir.

Findings on retention times and algal growth are covered in ***Section 4.5***.

Habitats

Sedimentation will change the fluvial environment and thereby the type of bed sediment unless sediment routing or flushing can carry incoming sediment and organic debris downstream through the dam. In the upper part of the reservoir and backwater reach, sedimentation may result in bed aggradation and the formation of bars and shoals. Such changes will alter habitat conditions available for aquatic life at these locations. Changes within the reservoir may include accumulation of fines and organic sediments especially in the deep pools.

The existing functioning of the river as a riverine ecosystem will be converted into that of a reservoir even if no additional sediment accumulates in the reservoir. In general, changes will favour a biotic system dominated by species that prefer lower velocities and calmer conditions. Nevertheless, if heavy, siltation may still negatively impact the emerging ecosystem, resulting in less than optimal biodiversity.

In this context, it is likely that sediment routing and flushing would be beneficial to physical habitats and the reservoir ecosystem, as these operations temporarily recreate river like conditions that would reduce the tendency for silt and organic debris to accumulate, especially in the deeper parts.

Local nutrient inputs

Raised water surface elevations, together with current and wave action may lead to bank erosion along the margins of the reservoir. Where retreating banks undercut steep hill slopes, this could induce landslides in any marginally stable slopes. From a sediment-associated nutrient perspective, this could contribute additional sediment and organic, nutrient rich material to the reservoir that could accumulate there, especially at the margins and in the deep pools. If excessive, local inputs from bank erosion and landslides could have significant, negative impacts on in-reservoir habitats.

To gauge whether the likelihood of problems requiring mitigation, a risk assessment for significant bank erosion and landslide activity, together with an impact assessment for the impacts on habitats within the reservoir is required. The potential exists for erosion by currents and waves coupled with the effects of raised and changing water levels to trigger failure of banks and slopes that are presently marginally stable. This justifies assessment of the likelihood of problems requiring mitigation to reduce consequential risks to people, property and habitats that might result from bank erosion and landslide activity along the shores of the reservoir.

Downstream impacts

Increased erosion downstream of dams on alluvial rivers has been observed following implementation of many hydropower projects worldwide. This may involve bed and/or bank erosion. The EIA carried out for Xayaburi Dam recognised this problem and mitigation measures were outlined to reduce such erosion. In practice, it should be possible to identify and mitigate local morphological responses to contruction and operation of Xayaburi dam. It will be more difficult to identify the contribution of Xayaburi to regional responses due to the cumulative effects of the other dams built in the Mekong Basin under the DFS.

In non-alluvial reaches the channel boundaries would not be eroded by sediment-deficient flows. They may still erode pre-existing sediment features within the channel and river corridor. With the current design, this is likely in the non-alluvial, bed rock controlled reaches of the Mekong between the dam site and Vientiane. The outcome would be to reduce the extent and diversity of sediment-related habitats, as well as reducing the availability of sediment-associated nutrients.

If, as suggested, hard bank protection were installed to prevent erosion in the alluvial sub-reaches, this would further inhibit natural flora and fauna unless designed from an ecological perspective. The outcome could be a significant change in the river ecosystem with a reduction in biodiversity.

The risk of adverse environmental impacts occurring downstream of run-of-river hydropower dams is real. For example, damming of the River Danube in Austria resulted in a significant lowering of the channel bed downstream in Slovakia. Environmental consequences included lowering of the groundwater table and reduced water and nutrient availability in adjacent forests and wetlands. A detailed assessment of the potential for such impacts downstream of Xayaburi Dam should, therefore, be performed.

Avoiding sediment trapping and ensuring practically unchanged nutrient transport to downstream river reaches, wetlands and lakes is likely to require periodic flushing of accumulated sediments as well as sediment passing by routing operations. The PDG recommends flushing at least every 2 to 5 years. If a significant amount of sediment is allowed to accumulate before flushing, this could result in extremely high concentrations of sediment and associated nutrients during the flushing event that might be harmful to downstream ecosystems and, especially, fish. To avoid this, it may be necessary to flush more frequently than would be necessary just to avoid sediment and morphological impacts. Sediment routing is preferred environmentally as it more closely follows the natural sediment discharge pattern, which is described as being desirable in the PDG. In practice, it will be necessary to adapt routing and flushing operations to optimise the environmental as well as the sediment performance of the dam and so it is recommended that the dam design be modified to increase its capacity for adaptive sediment management.

Key review findings on sediments, morphology and nutrient balance

The review of possible sediment management measures, including experience of other dams worldwide, concludes that the proposed design does not yet comply with the PDG or international best practice in relation to reservoir-sediment management. It is considered suitable for flushing sediment from close to the powerhouse. It does not incorporate available measures to pass and flush sediment from the reservoir. Opportunities exist to reduce the quantity of sediment and nutrients trapped in the reservoir thereby increasing reservoir life and minimizing related impacts downstream.

Sediments and Morphology

- *The current assumption is that sediment will be not trapped in the reservoir except immediately upstream of the power house and that locally-accelerated erosion will cease once construction is complete (see **Section 4.4.1**).Hence, long-term management measures proposed in the submision focus entirely on removing sediment in front of the powerhouse intakes.*
- *If sediment inputs to the reservoir remain at historical levels and no attempt is made to manage reservoir sedimentation at Xayaburi, the total storage volume of the reservoir may be reduced by up to 60 % or more within decades, before a new equilibrium is reached. Conversely, sediment trapping upstream and implementation of sediment management through flushing and routing could lead in the long term to the reservoir reaching an equilibrium state that conserves as much as 70% of its original volume.*
- *If the dam design was modified to optimise routing and flushing operations, and these were conducted as necessary, its trap efficiency could be significantly reduced, with the reservoir reaching a stable sediment balance within decades while still retaining about most of its initial volume.*
- *The timescale for filling by sediment would be considerably lengthened by sediment trapping in existing and planned reservoirs upstream (especially in China).Uncertainties regarding the trap efficiencies of upstream dams, as well as the unpredictable nature of morphological responses to reductions in sediment load and the uncertain impacts of future climate and land-use changes on future incoming sediment loads, preclude accurate prediction of the useful life of the reservoir with the current dam design.This means not only that all the sediment impacts alluded to earlier would be minimised but also that the capability of the dam to generate hydropower could be considerably longer.*

Nutrient Balance

- *Recommendations and mitigation measures are proposed regarding in-reservoir nutrient trapping, impacts on water quality, habitats, local nutrient input and downstream impacts.For the current design and proposed operating regime, nearly half of the incoming total P and a third of the total N are estimated to be at risk of being retained in the reservoir. Design modifications to the dam and its operation to optimise sediment routing and flushing have the potential to reduce these upper bound estimates to as little as 5%.*
- *It is likely that fine sediment would accumulate in the deep pools if the dam were built and operated as proposed, especially during the dry season.Sediment routing and flushing could also be effective in reducing the tendency for nutrients to accumulate in deep pools located within the reservoir.Sediment flushing can negatively impact the ecology of rivers especially fish and those effects need to be minimised.*

Assessment of potential flooding effects in Section B.3 of the Design Report does not consider the possibility that morphological responses in the backwater reach upstream of the reservoir (for example, shoal formation and bed aggradation), could lead to increased flood probability at Luang Prabang. The results of preliminary modelling performed by the MRCS suggests that this is unlikely. Further investigations should be performed to confirm this.

4.4.6 Gaps and uncertainties

(i) Sediment and morphology

- Mutliple unknowns and large uncertainties concerning current parameters and future conditions in the Mekong Basin were encountered during the review. Uncertainties are particularly significant with respect to sediment yields, sediment properties and the potential geomorphic responses to altered sediment loads.
- The best available information has been used to estimate future sediment loads that are likely to be input to the Xayaburi Reservoir. Such estimates are uncertain concerning future sediment yields from the basin. This is particularly true when considering climate change and possible future development of the Mekong Basin for agriculture and primary industries, and how such developments might change sediment yields.
- Gaps exist on reliable information regarding the properties of sediment present in the Mekong River. Those gaps relate to sediment size distributions (e.g. how much of the load is clay, silt, fine sand, etc.), the relative proportions of suspended versus bedload transport, and the sources of different types of sediments.
- Lack of information also limits the type of geomorphic assessment that can be performed.Based on the data currently available, it is not possible to be precise about how the river morphology would respond to changes in sediment loads triggered by construction and operation of the dam.
- It is clear from previous experience at other dams and rivers with run-of-river hydropower dams that morphological responses are likely and will most probably include bed degradation and bank retreat in alluvial reaches with the potential for consequential impacts of in-stream and riparian habitats.
- Recognising that uncertainty will never be eliminated by even the most advanced modelling, an appropriate way forward is to proceed with caution, designing the dam so that it has the greatest capacity for adaptive sediment management, and putting uncertainty on the safe side of the sediment impact risk assessment.

(ii) Gaps and uncertainties concerning nutrients

The documents provided to the SEG do not establish the nutrient balance for the Xayaburi Reservoir. Significant knowledge gaps involve:

- nutrients (nitrogen and phosphorus) association with different sediment size fractions.
- nutrient binding (especially phosphorus) to incoming sediments for evaluation of nutrient mobility and bioavailability.
- potential in-reservoir accumulation of fine (clay, silt, fine sand and organic debris) and coarse (sand and gravel) sediments in terms of both quantity and spatial distribution.
- turnover of nutrients within sediment accumulations.
- possibility for thermal stratification in the reservoir during the dry season and evaluation of impacts in the deep pools, including evaluation of the risk of oxygen depletion.
- There are also gaps in knowledge concerning the nature and spatial distribution of sediment features between Xayaburi and Vientiane and their vulnerability to erosion should the dam release significantly 'sediment hungry' water.
- Furthermore, there is a need for assessment of the way that the morphological and consequential environmental risks of initiating degradation and/or bank erosion in the alluvial reaches downstream of Vientiane during construction or operation of the dam would change under an operational regime incorprating adaptive sediment management.

4.4.7 Transboundary and cumulative impacts

Assessment of the transboundary and cumulative impacts required the identification of the main sources of sediment in the Mekong Basin and accounting for the cumulative effects of sediment trapping in existing and proposed dams on the sediment and nutrient balances in the Lower Mekong River. The account presented in this section summarises the technical treatment in ***Annex 3***.

Sediment Yield

Estimates of total sediment yield of the basin vary between about 120 and 180 Mt/y. This currently precludes the possibility of constructing a conventional sediment budget for the river. It is generally accepted that sediment yield is particularly high in three distinct regions in the basin and the relative contributions of these regions are listed in ***Table 5.***

Hence, it is possible to construct a relative sediment budget and use this as the basis for estimating the contribution of sediment trapping behind existing and planned dams to reductions in the sediment load in the Lower Mekong River based on the locations of the dams relative to the main sediment source areas.

In assessing long-term, cumulative impacts of sediment trapping behind existing and planned dams in the MRB, the basis used for the relative sediment budget is the river system in its pre-disturbance state: that is, prior to any reductions in sediment load due to trapping in reservoirs. Hence, in the cumulative sediment impact analysis, a sediment load of 100% corresponds to around 160 MT/y, which is believed to be the natural sediment yield of the Mekong Basin (Walling, 2005; Kummu and Varis, 2006).

Table 5: Estimated sediment contributions from the main source areas in the Mekong River Basin.

River Reach	Geology / Region	% of Total Sediment Load
1. Upstream of Manwan Dam	Ailoa Shear Zone and Tibetan Gorges	45
2. Manwan Dam to Pak Chom Dam	Wang Chao Fault Zone and rest of catchment	5
3. Downstream of Pak Chom Dam	Central Highlands, Khorat Plateau and rest of catchment.	50

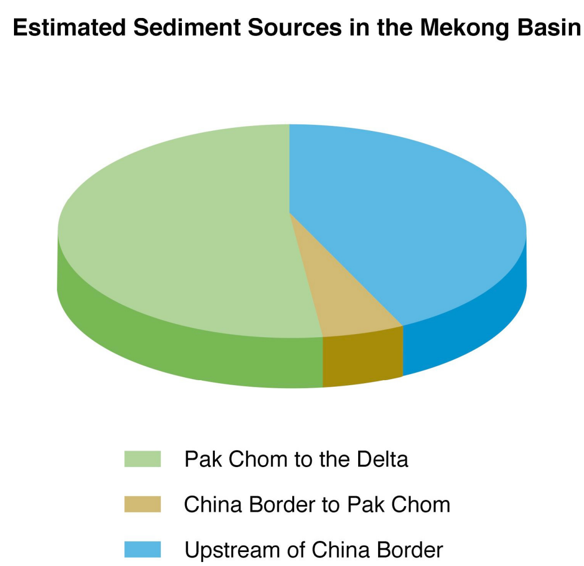

Figure 13: Estimated sediment source areas within the Mekong basin (see Annex 3 for further information)

(i) Sediment and morphology: impacts on the transboundary scale

Sediment and morphological impacts were assessed for each of five scenarios.

Sediment and morphological impacts were assessed for each of the following six scenarios:

Table 6: Six scenarios used for the assessment of transboundary impacts on sediments, morphology and nutrient balance in the LMB.

1. **Scenario 1: Baseline 2000 –** Three existing Chinese mainstream dams (Manwan, Dachaoshan, and Jinghong), plus fifteen tributary dams.
2. **Scenario 2: Definite Future 2015 –** Eight existing and planned mainstream Chinese dams, plus twenty-six tributary Dams.
3. **Scenario 3: Definite Future 2015 + six upper Lao dams –** Eight existing and planned mainstream Chinese dams, plus twenty-six tributary dams, plus six mainstream dams in Lao PDR.
4. **Scenario 4: Foreseeable Future (i)** – Eight existing and planned mainstream Chinese dams, plus seventy-one tributary dams.
5. **Scenario 5: Foreseeable Future (ii)** – Eight existing and planned mainstream Chinese dams, six mainstream dams in Lao PDR, plus seventy-one tributary dams.
6. **Scenario 6: Foreseeable Future (iii)** – Eight existing and planned mainstream Chinese dams, six mainstream dams in Lao PDR, five Cambodia dams, plus seventy-one tributary dams.

Full descriptions of these scenarios and the basis on which their sediment trap efficiencies were estimated are provided in ***Annex 3.***

Table 7 lists and ***Figure 14*** illustrates the estimated relative reductions in sediment loads in the Lower Mekong Basin caused by trapping by reservoirs in the command areas of each of the three dominant sediment sources. These estimates are based on the assumption that no measures are taken to optimise sediment management at the dams and are based partly on indicative calculations and partly on expert judgement. The ranges of possible reduction in sediment load listed in ***Table 7*** and shown in ***Figure 14*** represent the high uncertainties inherent to this type of predictive assessment. ***Figure 15*** illustrates estimated reductions in the loads of fine and coarse sediment supplied to the delta by the Lower Mekong River. ***Table 8*** lists and ***Figure 16*** illustrates the estimated cumulative reductions in nutrient loads in the Lower Mekong. These are discussed in ***Section 5.4***.

Table 7: Estimated long-term cumulative reductions in sediment loads for base case and five future scenarios.

diment urce	Geology / Region	Natural Sediment Load (Mt/yr)	Sediment Trapped in Reservoirs											
			Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6	
			Baseline – 2000		Definite Future 2015		Definite Future 2015 + 6 Lao PDR Dams		Foreseeable Future (i)		Foreseeable Future (ii)		Foreseeable Future (iii)	
			Main	Tributary	Main	Tributary	Main	Tributary	Main	Tributary	Main	Tributary	Main	Tributary
Upstream of Manwan Dam	Ailoa Shear Zone and Tibetan Gorges	45%	35-40%		40-45%		40-45%		40-45%		40-45%		40-45%	
From Manwan Dam to Pak Chom Dam	Wang Chao Fault Zone and rest of catchment	5%					5%				5%		5%	
Downstream of Pak Chom Dam	Central Highlands, Khoral Plateau and rest of catchment	50%		5-10%		10-15%		10-15%		20-30%		20-30%	10-35%	20-30%
Sub-total Trapped:			35-40%	5-10%	40-45%	10-15%	45-50%	10-15%	40-45%	20-30%	45-50%	20-30%	55-85%	20-30%
Total Trapped:			40-50%		50-60%		55-65%		60-75%		65-85%		75-100%	
Remaining Sediment Load:		100%	50-60%		40-50%		35-45%		25-40%		15-35%		0-25%	

Table 8: Estimated long-term, cumulative reductions in nutrient loads for base case and five future scenarios.

Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Baseline – 2000	**Definite Future 2015**	**Definite Future 2015 + 6 Lao PDR Dams**	**Foreseeable Future (i)**	**Foreseeable Future (ii)**	**Foreseeable Future (iii)**
15-35%	15-40%	20-45%	25-50%	20-55%	25-70%

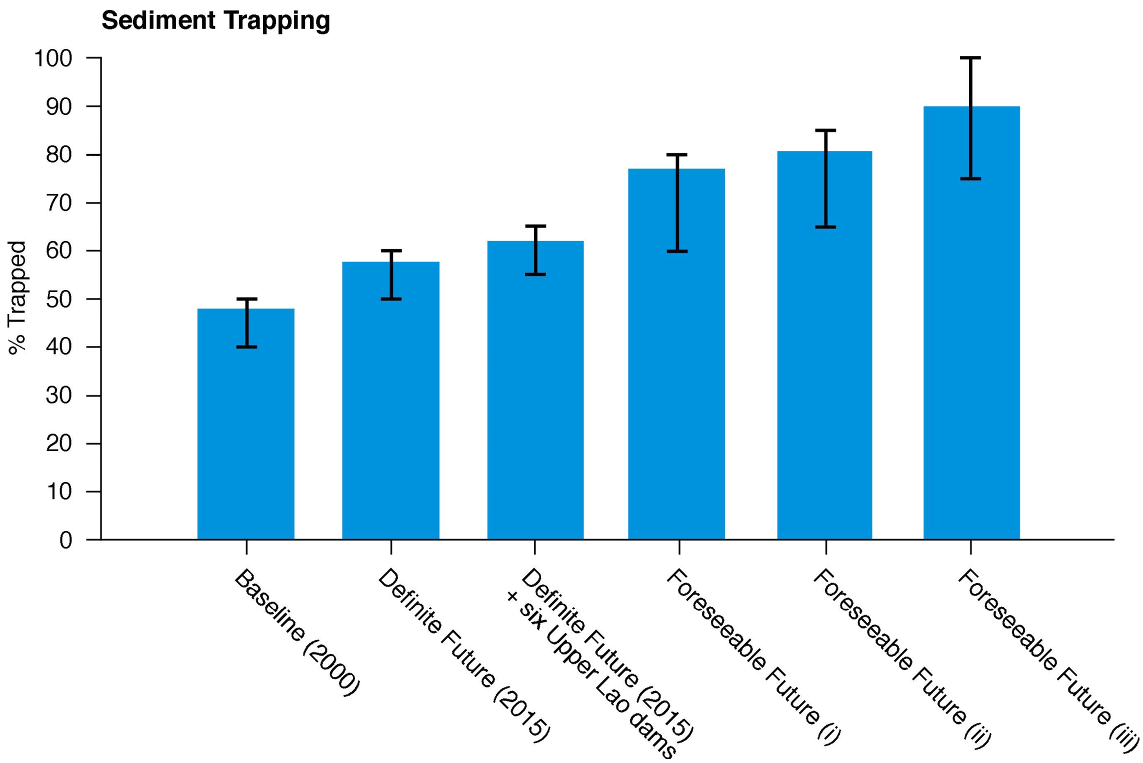

Figure 14: Estimated reductions in sediment loads in Lower Mekong Basin caused by trapping in reservoirs with no sediment impact mitigation measures. Note: 100% = pre-disturbance Mekong Basin sediment yield estimated to be around 160 MT/year (Walling, 2005; Kummu & Varis, 2006).

The findings listed in ***Table 7*** and illustrated in ***Figure 14*** suggest that, in the long-term, the Chinese dams have already significantly reduced future sediment loads supplied to the Lower Mekong River and this will be a reduction by nearly half under the Definite Future - 2015 scenario. The implication for sediment loads at Xayaburi is that, if the effects of climate and land-use changes are ignored, sediment input will decrease progressively as the dams upstream become operational. There is already evidence to support this prediction in that that sediment loads at Luang Prabang appear to have decreased since the closure of Marwan dam in 1993 (Adamson, 2009).

Under the definite and foreseeable future scenarios, the estimated percentage of pre-disturbance sediment reaching the delta decreases progressively as the number of dams increases until, under Scenario 6 (Foreseeable Future Scenario [iii]), 75% or more of the pre-disturbance sediment load previously supplied to the Mekong Delta is trapped upstream.

Lack of data currently prohibits quantifying the relative amounts of coarse and fine sediment discharged by the Mekong River. Therefore, an indicative calculation was performed assuming that 10% of the total sediment load consists of coarse sediment, and the rest consisting of fine sediment. Based on these assumptions an estimate of the percentage of coarse sediment and the percentage of fine sediment captured by the reservoirs are presented in ***Figure 15.***

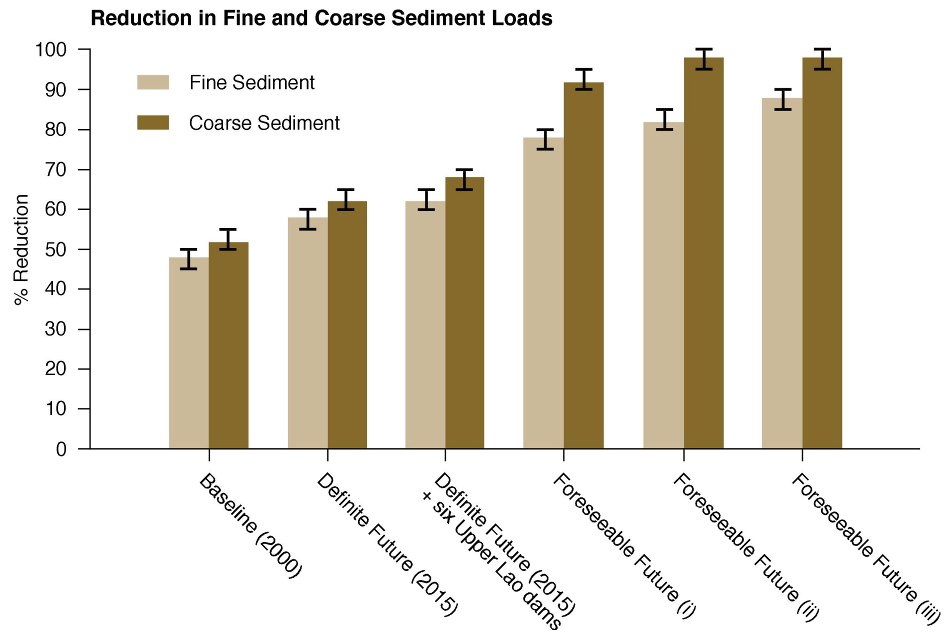

Figure 15: Indicative estimates of reductions in fine and coarse sediment loads in the Lower Mekong caused by trapping in reservoirs with no sediment impact mitigation measures. Note: 100% = pre-disturbance yields of fine and coarse sediment estimated to be around 144 and 160 MT/year respectively (Walling, 2005; Kummu and Varis, 2006)

Experience from other large rivers subject to the cumulative effects of multiple dams indicates that substantial reductions in sediment supply are likely to trigger complex morphological responses. The nature, extent, and sequence of morphological adjustments cannot be predicted *a priori*. Given that both fine and coarse loads are likely to be reduced substantially, what can be expected is that morphological responses will be widespread and persistent, with multiple consequential damages to habitats, ecosystems, and agricultural productivity, especially in the delta and nearby coastal areas.

This assessment is based on available information and previous work by respected academics and researchers. The evaluation methodologies that were used are known and accepted technology. Due to the limited amount of information available, the results are subject to uncertainty.

Estimates of sediment (coarse and fine) trapped by reservoirs associated with the six scenarios indicate that the Chinese Dams are likely to remove just under half of the sediment from the Mekong River. It is expected that this situation will last for several hundred years once the majority of the planned Chinese dams are built.

The second largest anticipated reduction in sediment loads is attributable to the seventy-one tributary dams planned in the LMB. The five future mainstream dams in Cambodia are expected to further reduce the sediment load by a proportion nearly double that attributable to the six mainstream dams planned for construction in the Lao PDR. In this context, the quantity of sediment predicted to be trapped by Xayaburi Dam is relatively small. It is one component of sediment reduction which takes on a greater significance for the remaining sediment balance after reductions experienced from the Chinese dams.

Preventing such impacts will require collective action by all signatories to the 1995 Mekong Agreement to ensure that each and every dam owner and operator in the LMB to implements reservoir sedimentation management technologies to minimize the amount of sediment trapped upstream of their dam, by passing and flushing sediment downstream. Failure to do so risks severe disruption to the sediment dynamics and morphology of the Lower Mekong River and its Delta. Xayaburi Dam is a crucial part of such collective action and its participation in avoiding and/or mitigating long-term, cumulative sediment and morphological impacts will require design modifications to allow for implementation of optimal sediment management.

For Xayaburi Dam a pre-feasibility level analysis was conducted, which indicates that it should be possible to indefinitely retain about 70% of the original reservoir volume through modifying the current design to facilitate drawdown for reservoir flushing. Optimal sediment management at Xayaburi Dam would not only contribute to minimizing cumulative impacts on river and delta morphology, it would also lengthen the lifespan of the facility, allowing it to generate hydropower for a period far exceeding its current design life.

(i) Nutrient impacts on the transboundary scale

Scenario 1: Baseline 2000

According to the results listed in ***Table 7*** and illustrated in ***Figure 16***, the supply of fine sediment to the Delta would be reduced by nearly half its natural, pre-disturbance value in this scenario. The associated reduction in nutrients would be expected to be somewhat smaller because nutrients associated with sediments make up only one to two thirds of total nutrient transport (***Table 8*** and ***Figure 16***). In this relative analysis of nutrient impacts, 100% corresponds to the nutrient yield of the Mekong Basin I its pre-disturbance state, when the average annual sediment yield was on the order of 160 MT/y.

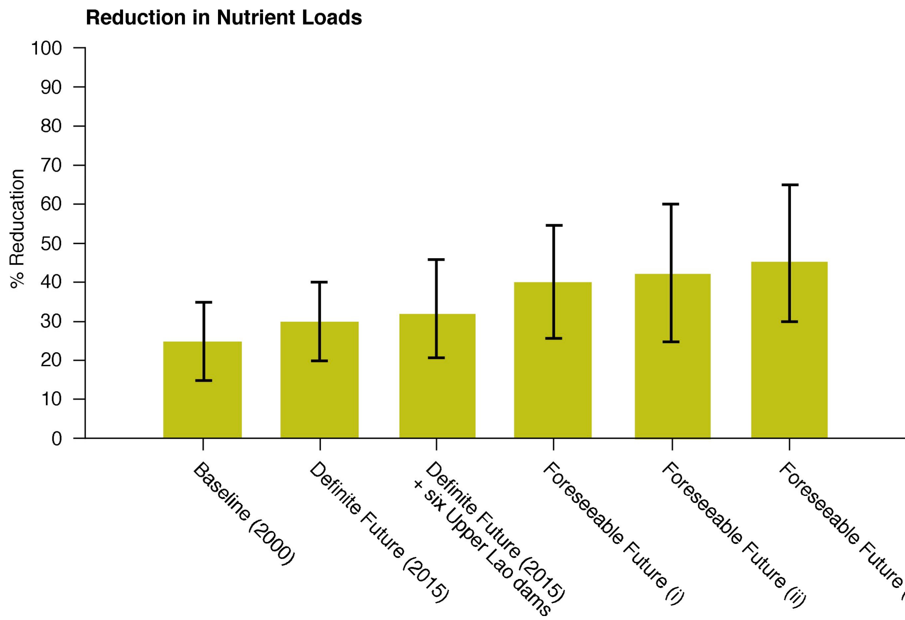

Figure 16: Estimated nutrient trapping in reservoirs with no sediment impact mitigation measures. Note: 100% = pre-disturbance Mekong Basin nutrient yield.

Assuming that between one and two thirds of the total phosphorus and about one half of the nitrogen are associated with sediments, and accepting a cumulative trap efficiency of 40-50%, a reduction in nutrient transport on the order of 15-35% can be expected. Retention of nutrients of this order must be regarded as significant, with the potential for measurable, consequential impacts on agricultural productivity as well as river, floodplain, wetland, lake and deltaic ecosystem services in the Lower Mekong Basin.

Scenario 2: Definite Future 2015

The Sediment Experts Group estimates that dams in this scenario may trap approaching 55-60% of the fine sediment previously supplied to the delta. Using the assumptions applied in Scenario 1, this is predicted to result in 15-40% of the natural nutrient load being retained in the reservoirs upstream. Significant consequential impacts would be expected on ecology and agricultural productivity in the river, floodplains, wetlands, seasonally flooded lakes, delta and nearby coastal areas.

Further uncertainty is introduced under this scenario in that this estimate assumes that the relation between fine sediment and nutrient transport in the tributaries is similar to that in the mainstream. Field surveys, monitoring, and more detailed studies of sediment-nutrient associations in selected tributaries are required to reduce this uncertainty.

Scenario 3: Definite Future 2015 + six upper Lao dams

In this scenario, a cascade of six dams is added in the Lao PDR and the proportion of fine sediment trapped behind dams would increase from 55-60% in Scenario 2, to about 60-65%. Based on the same methodology applied in the previous scenarios, this could result in a reduction of 20-45% in nutrient transport compared to the natural condition.

In the context of this scenario, the scale of the overall reduction in nutrient loads makes the contribution attributable to the cascade of dams in the Lao PDR (including Xayaburi Dam) appear relatively small. It cannot be concluded from this that trapping of sediment-associated nutrients at Xayaburi become insignificant in this scenario. On the contrary, it becomes even more important.

This is the case, first, because sediment and nutrient are likely to be diminishing and increasingly precious resources in this scenario and, second, because the adaptive capability to manage sediment transport through the cascade of mainstream dams in Lao PDR will depend on optimising the capacity for routing and flushing operations at each of the dams – including Xayaburi. It would be regrettable if the design of Xayaburi were to constrain the capacity to manage sediment routing and flushing operations at the other five dams in the cascade.

In fact, the Experts Group believes that the proportion of fine sediment trapped behind Xayaburi Dam can be reduced to a small percentage if the recommended modifications to its design and operation are accepted. In this case, a significant contribution to cumulative, transboundary impacts due to nutrient retention at Xayaburi can be avoided.

Scenario 4: Foreseeable Future (i)

In this scenario, further tributary dams are added the proportion of fine sediment trapped behind dams would increase to about 75-80%. Based on the same methodology applied in the previous scenarios, this could result in a reduction of 25-50% in nutrient transport compared to the natural condition.

Scenario 5: Foreseeable Future (ii)

Calculations for this scenario suggest that the proportion of fine sediment trapped behind dams would increase to 80-85%. Based on the same methodology applied in the previous scenarios, this could result in a reduction of 25-55% in nutrient transport compared to the natural condition.

Scenario 6: Foreseeable Future (iii)

The SEG predicts that in this scenario, dams may be expected to trap between 85-100% of the sediment previously supplied to the lower reaches of the Mekong. This could lead to a reduction of between 25-70% in the delivery of nutrients to lower reaches of the river system.

These cumulative impacts stem from the facts that there are more dams in the basin and that the additional mainstream dams are located further downstream on the Mekong and have large reservoirs and long retention times. The SEG found that it would be difficult to pass sediment through these reservoirs and that not even flushing would be effective as a sediment management measure. Consequently, the reservoirs in Cambodia and Vietnam risk retaining significant quantities of those fine sediments and associated nutrients that remain in the fluvial system.

Based on the prediction that fine sediment and nutrients will be trapped in the reservoirs in Cambodia and Vietnam, significant consequential impacts are expected on the ecology and productivity of the river, floodplain, wetlands, seasonally flooded lakes, delta, and near-delta coastal region. Furthermore, a significant increase in retention time in the large reservoirs in Cambodia and Vietnam, coupled with increased light penetration due to reduced sediment concentrations may generate conditions suitable for algal blooms. This could amplify the uptake of soluble nutrients in the reservoirs, further depleting nutrient transfer downstream and exacerbating cumulative environmental impacts.

For all these reasons, severe consequential impacts, including significant environmental degradation and marked reductions in productivity, can be expected along the Mekong River as well as in the Tonle Sap and the delta. In this context of this scenario, the relative contribution of the diminished Xayaburi becomes ever more crucial to conserving the remaining supply of sediments and nutrients to what is likely to be a sediment- and nutrient-impoverished riverine system.

Limitations of data and time availability have precluded consideration by the SEG of the potential for designing and operating the additional mainstream dams in this scenario in ways that optimise sediment management and support the attainment of multipurpose objectives for hydropower generation and environmental protection. There is a significant risk that these large reservoirs will act as significant sediment traps – as has occurred with many other hydropower dams worldwide. Evidence to support this view comes from the Upper Mekong River, where the large Chinese reservoirs (especially that behind Manwan Dam) already appears to have lead to measurable reductions in the supply of sediment and nutrients to the river reaches downstream.

These findings emphasize the importance of optimising sediment management capabilities and operations at all existing and planned dams, including Xayaburi. It places a duty on the nations in the Lower Mekong Basin to construct and manage dams and reservoirs in a sustainable manner that minimises their tendency to trap and retain sediment. This can be best accomplished by designing, constructing and operating dams to generate hydropower sustainably, while managing sediments and nutrients to minimize the contribution of each dam to cumulative effects. This will not only reduce impacts on the environment and agricultural productivity, it will also reduce potential liability for compensation payments to transboundary stakeholders

4.4.8 Conclusions and recommendations

(i) Modifications to dam design

Based on the findings of its technical review, the Sediment Expert Group recommends that the proposed dam design be modified to enhance and optimize its capacity for sediment routing and flushing.

- **Modifications are needed to design a dam suitable for generating hydropower sustainably and, with appropriate maintenance, in the long term.** The dam needs to have the capability to manage sediments adaptively by making changes to the way that sediment routing and flushing operations are implemented.
- The recommended design would involve modifications to the spillway and provision of low-level outlets of appropriate dimensions to allow operators to recreate river-like flow conditions required to execute flushing operations.

The capability to manage sediment adaptively is necessary because of modeling uncertainty concerning future sediment loads and operating conditions.

- Even if model uncertainty could be reduced, it cannot be known precisely how future sediment inputs and river dynamics will be impacted by the construction and operation of upstream dams in the Mekong Basin or how they will respond to changes in climate and land-use change.

(ii) Modifications to operations

Proposed operating procedures need to be reconsidered to optimise sediment routing and flushing, based on exploiting the enhanced sediment-management capabilities possible with the recommended modified design. The effectiveness of the revised design and operating regime should be demonstrated in relation to:

- **avoiding sedimentation to the highest degree possible** and mimicking the natural time distribution of sediment transport downstream by sediment routing, and
  (i) **flushing downstream as much as possible the sediment deposited in the reservoir** while selecting flushing times and durations to avoid undesirable environmental impacts associated with artificially high concentrations of sediments and nutrients.

Mathematical modelling would be required to:

- **determine how much sediment will accumulate in the reservoir** and when an equilibrium condition will be achieved using the enhanced sediment management measures (paragraph 94 of the PDG);
- **prepare sediment yield estimates** to feed into computations of cumulative effects where Xayaburi is operated as one of a cascade of mainstream dams (paragraph 98 of the PDG);

- provide the basis for ensuring that Xayaburi Dam can achieve multipurpose objectives to generate hydropower sustainably in the long term while minimising adverse impacts on sediments, morphology and nutrients; and
- underpin the on-going assessments necessary to support adaptive adjustments of sediment management measures based on a holistic view that encompasses multiple aspects of the entire Lower Mekong Basin. This is important for maintaining the productivity and ecological integrity of the Basin.

The extent to which biodiversity is affected by nutrient imbalance in the reservoir will depend on the degree of siltation and accumulation of organic debris that accompanies the change from fluvial to more lake-like conditions.

- It is therefore recommended that detailed investigations are carried out to identify whether siltation, the accumulation of organic debris and the potential for dry season thermal stratification in deep pools are likely to require mitigation and, if so, specification of the most appropriate mitigation measures.
- Retention times appear to be too short to generate problems with algal blooms. Retention times in excess of 15 days during the dry season could allow increased algae growth and it is therefore recommended to carry our additional assessments of the potential impacts on water quality in the reservoir.

It is highly recommended that an environmental flow strategy is set up for the river downstream of the dam. The strategy needs to take into account dynamics of sediment associated nutrients and especially how sediment-flushing operations can avoid potentially serious, adverse impacts on downstream environments and ecosystems.

- It is important to note that such a strategy could not be fixed and would need to be updated and adapted as knowledge gained from long-term monitoring accumulated during operation of the dam.

(iii) Modifications to the monitoring programme

The PDG provides clear guidance on the requirement to set up a comprehensive sediment monitoring programme covering the temporal and location issues (paragraphs 122, 136, 137, 138, 139). Based on the requirements set out in the PDG, and bearing in mind the findings of the technical review, **modifications to the proposed monitoring programme are recommended so that the programme supports adaptive sediment management throughout the operating period of the dam.**

- The standards and methods used should be the same or compatible with the existing sediment monitoring in the LMB and sediment monitoring should be coordinated and synchronized with monitoring programmes for hydrology, water quality, aquatic ecosystem health and fisheries (as recommended in the PDG).

Important and specific recommendations regarding the design of the monitoring programme by the Sediment Expert Group are given in *Annex 3*. The details refer to:

- monitoring during both the construction and operation period,
- the establishment of a baseline for sediments to establish a pre-dam condition against which future changes/impacts can be compared,
- components and parameters for monitoring programmes, and
- sampling and assessment frequencies.

A risk assessment is recommended on the potential hazards associated with other pollutants based on information concerning materials to be used during construction.

It is recommended that sediment and nutrient monitoring continues throughout the operating period with the aim of supplying data relevant to the issues below. Part of ***Annex 3***, the details on monitoring emphasis, parameters and frequencies include:

- sediment accumulation (quantity and composition) in the reservoir,
- sediment (quantity and composition), sediment features and morphological changes along the river reach between the dam site and Vientiane, and

- water quality flowing into and out of the reservoir.

During the period of sediment flushing, sampling should be carried out with a frequency suitable to establish the maximum recommended sediment concentration in water being used to flush deposited sediment from the reservoir.

- The purpose of monitoring is to alert dam operators if flushing cause sediment concentrations to reach a level potentially harmful to fish and other aquatic fauna.

Throughout the dry season it will be necessary to monitor the vertical gradient of temperature, oxygen and pH at the deepest locations in the reservoir in order to detect thermal stratification and unacceptable environmental deterioration.

Monitoring needs to include measurement of biomass, composition and extent of benthic flora and all relevant biological elements (including fish species) at representative cross-sections in the reservoir and the river between the Xayaburi and Vientiane.

4.5 Water Quality, Ecosystem Health and Environmental Flows

4.5.1 Scope of this review

The key documents on which this section is based on include (i) the Preliminary Design Guidance (2009), (ii) the Xayaburi EIA (2010), (iii) the Xayaburi Environmental Management Plan (2010), (iv) the Xayaburi Design Report (2010), and other MRC documents including the State of Basin Report (2010)

The objectives of this review include providing an overall introduction to water quality, ecosystem health and environmental flows[16] as well as reviewing the potential impacts identified and mitigation measures proposed. The review also presents findings, recommendations and mitigation measures to minimise any impacts while identifying gaps and uncertainties as well as ways to close them

4.5.2 Introduction to water quality, aquatic ecosystem health and environmental flows

(i) Water quality and aquatic ecosystem health

The monitoring and assessment of water quality and ecosystem health is essential to understand not only the ecological and chemical status of rivers but also the implications of impacts that can result from any infrastructure project including hydropower dams. The assessment of water quality and ecosystem health is a crucial basis of river basin management to perform comprehensive pressure/impact analyses and to respond with appropriate mitigation measures.

As outlined in the MRC's State of the Basin Report (2010), water quality monitoring gives an indication of the status of the environment in which aquatic organisms live. It does not directly assess the health status of these organisms. Water quality is assessed using both physical and chemical parameters. A water quality network has been established within the MRC framework to help the countries in the region detect changes in the environment and take preventive and remedial action if water quality deteriorates. The network provides an ongoing record of water quality in the Mekong, its major tributaries and the Mekong Delta by measuring a number of different parameters (i.e. pH, conductivity, ammonia, dissolved oxygen, nitrite, nitrate, and total phosphorus). Water quality parameters are sampled and assessed at 55 monitoring stations designated as "primary stations" as the locations have basin-wide, or trans-boundary, importance.

The most relevant way to assess aquatic ecological health is to monitor the health of key functional groups of organisms (biological quality elements) in the Mekong River – biomonitoring. Relevant indicator organisms for ecosystem health include fish, macroinvertebrates, primary producers such as phytoplankton and macrophytes and "consumers" such as zooplankton. An indication of negative health

[16] The MRC Preliminary Design Guidance addresses flows required specifically to support environmental functions which are subset of a broader concept of Integrated Basin Flow Management (IBFM) adopted by MRC studies that included other downstream uses.

impacts can be changes in the numbers of individuals or species, changes in the species composition or abundance when compared with undisturbed reference sites.

According to the State of the Basin report, the Mekong River is "*still regarded as a fairly unpolluted river with generally good water quality, although some areas near urban centres, or with intensive agriculture and aquaculture, can experience elevated levels of nutrients and organic matter.*" Biomonitoring of the Lower Mekong Basin (LMB) indicates that the ecosystem health of the river and its tributaries is still good in comparison with other large river basins of the world. Impacts on ecosystem health are evident in areas where population density and human activities are high.

Future infrastructure projects including hydropower schemes and respective pressures can further impact in-stream water quality and aquatic ecosystem health, functioning and productivity of riverine and flood plain ecosystems.

(ii) Environmental flows

Besides factors such as water quality, sediment transport, morphology and nutrient balances, the flow regime and therefore the environmental flow of rivers are crucial to sustain riverine ecosystem health. Environmental flow is the water regime needed to maintain healthy ecosystems.

Environmental flow is a generic term used to describe the amount of water needed in a watercourse to maintain healthy ecosystems. Within the Lower Mekong Basin, this has been extensively discussed developing the concept of Integrated Basin Flow Management (IBFM).

Hydropower dams can significantly impact the natural flows of rivers through their upstream impoundments and other hydrological alterations (upstream and downstream) thereby impacting aquatic ecosystems. Flow regimes a can be altered and flow velocities significantly reduced in reservoir upstream dams. Furthermore, the variability and seasonality of flows are negatively affected in relation to those ecosystems impacting on aquatic species, biodiversity and aquatic ecosystem health.

4.5.3 Water quality and the proposed Xayaburi project

Impacts, risks and management provisions regarding water quality, ecosystem health and environmental flows in association with mainstream dams were evaluated with respect to the MRC Preliminary Design Guidance (Section 5). The principle concerns in the PDG as they relate to potential local and transboundary water quality impacts of Xayaburi Dam include:

- effects on water quality assessed by using water quality standards considering parameters such as oxygen concentration, biological oxygen demand (BOD), nutrient concentrations and bacteria concentrations;
- effects on aquatic ecology potentially disturbing the ecological balance of the river ecosystems and contributing to loss of biodiversity caused by changes in habitat characteristics (from fluvial to lake-like environment) and fragmentation, deterioration of water quality and increased water clarity due to decreased suspended sediment concentrations;
- effects on flow regime supporting and conserving downstream ecosystems considering the flow volume (including short-term and long-term variability) as well as sediment, chemical and biological quality in the impoundment, which may influence downstream ecosystems; and
- monitoring principles to follow up on performance of operation schemes as well as other mitigation measures during construction and operation both inside the impoundment and downstream of the barrage.

Due to its comprehensive and interdisciplinary character, this chapter is closely linked to other chapters of this report and respective cross references are given:

- ***Section 4.3*** (hydrology) to establish the impacts on the hydrology and flows,
- ***Section 4.4*** (fish passage and fisheries ecology) to establish the link and vital contribution of fisheries ecology to overall ecosystem health, and
- ***Section 4.5*** (sediment transport, morphology and nutrient balance) to establish the impacts of changes in sediment and nutrient conditions.

4.5.4 Summary of impacts considered and measures proposed

(i) Water quality

The EIA report assesses the potential water quality changes and compares them with a baseline combining two measurement campaigns (one dry and one wet season) with MRC reported data (dated 2001). The parameters considered are consistent with the usual set of parameters assessed to describe water quality of freshwater systems. The measurement campaigns to establish the baseline show similar results as recent MRC measurements. The results show that the water quality complies with standards of Lao PDR. One area of concern is the level of coliform bacteria in the dry season showing values close to the threshold of the water quality standard.

No impacts on water quality are expected during operation. Impacts are exclusively anticipated during construction where mitigation measures include treatment of wastewater from living quarters, settling areas for excavated material and skimming of oil before waste water is being discharged to the river.

(ii) Aquatic ecology

The EIA report assesses the potential changes in aquatic ecology against a baseline of two measurement campaigns (one each in the wet and dry seasons) considering plankton, macroinvertebrates and fish (see Chapter 4.3). Considerations of other animals or plants dependent on the area and flow regime and any impacts on these are not described.

The EIA report concludes that there are few species and low abundance and therefore any impacts of the dam will be limited. The fact that ecosystem changes will result from changing the hydrological regime from a running river to an impoundment is acknowledged without further description or assessment. Biodiversity considerations are confined to concluding that measurement campaigns did not detect any endangered species. As outlined in Section 4.3, at least five IUCN Red-list fish species are found in the proposed Xayaburi reservoir including the critically endangered Mekong giant catfish. These fishes are large-sized fish (adults are larger than 100 cm) and true rheophilic species (fishes that prefer running water and are not reported occupying still water habitats). They are also all potamodromous fishes that exhibit long distance migrations within the Mekong River Basin. The impacts of biological communities depending on sand bars, river banks and deep pools are not included. Consequently, there are no mitigation measures described as no impacts are foreseen.

(iii) Environmental flows

The EIA report does not consider provisions of flows specifically for the environment. It mentions that natural flow will be maintained (based on the general expectation that outflow will equal inflow). Any changes to sediment transport, nutrient transport and biological communities of the impoundment resulting from changes of the flow regime in the impoundment, which may affect the downstream areas are not included. No mitigation measures or monitoring programme are suggested as no impacts are foreseen.

4.5.5 Findings of the MRCS technical review

General considerations

The project will create a 60-100 km long impoundment from the dam site almost up to Luang Prabang with a relatively constant water level. As outlined in the previous chapter, the Feasibility Study report states that natural flow will be maintained (inflow=outflow).

Hydrological calculations have shown that with the natural flow variations including low flow in the dry season and high flow in the wet season, the retention time in the impoundment would vary from about 15 days with a maximum of 25 days in the dry season to about 1.5 days in the wet season.

Those general considerations are compared with the current situation of the Mekong in this reach as a free-flowing river.

(i) Water quality

Construction period of the proposed Xayaburi dam

The water quality of the impoundment would be affected during the construction period from the release of construction materials, oil from boats and machines and waste water including organic matter and coliform as well as other bacteria from living quarters. Degradation of organic matter being submerged during impoundment would also negatively affect the quality of the water. Good international practice exists to mitigate these impacts:

Recommendations towards mitigation

Provision of settling ponds and other measures to treat wastewater and capture construction material prior to release of water to the river.

Recommendations toward the design of monitoring programmes

During the first 6-12 months of the construction period, the water-quality monitoring programme needs to operate more frequently than proposed in the EIA to ensure that mitigation measures work efficiently. The current proposal for monitoring every 3 months is insufficient to provide the necessary management information to allow for the establishment of effective and cost-efficient mitigation measures. Monitoring of water quality, sediment and nutrient-related impacts upstream and downstream from the dam site should include inorganic fractions, total phosphorus, total nitrogen, suspended solids, organic content (COD or BOD), chlorophyll-a, oxygen, pH, temperature, light adsorption/penetration capacity (secchi disc depth), oil/grease components and bacterial levels. Sampling frequency should vary between monthly and weekly, depending on the intensity and type of construction activities at the time. During periods of intense construction activity, sampling frequency may need to be even higher. Sampling locations should be upstream and downstream from the construction area to ensure that the effectiveness of mitigation measures can be detected.

Operation period of the proposed Xayaburi dam

The decreased water velocity in the reservoir would lead to increased settling of suspended matter (also see chapter 4.4) and lower water turbidity resulting in higher transparency of the water and, following from this, potentially increased primary productivity i.e. algae blooms and proliferation of aquatic weed. With the current nutrient concentrations in the water it can be expected that algae blooms will occur in the dry season when the retention time is higher than 15 days..

Recommendations towards mitigation

This impact can be mitigated and therefore minimised through reservoir operation. As an integrated part of this mitigation measure, frequent monitoring is required in the dry season to detect the onset of a bloom of algae or aquatic weed. Monitoring every second week during the dry season would fulfil this need for information.

Water quality is strongly interlinked with river hydrology as well as sediment quality/quantity and therefore affected by any changes in these. Further details on impacts and respective mitigation measures can be found in ***Sections 4.2 & 4.4****. These are highly relevant for water quality.*

(ii) Aquatic ecology

Impacts in the impounded reservoir

The hydrological changes would impact the biological and chemical characteristics of the area upstream of the proposed Xayburi dam project. The biological flora and fauna in the area is currently characterised by species living in fast running rivers with relatively low number of species and abundance when compared to more alluvial stretches of the Mekong River. This is a type-specific composition. Ecological health monitoring has so far found healthy ecosystems at the mainstream monitoring sites close to Luang Prabang and south of the dam site.

The reservoir upstream of Xayaburi dam would change the character from that of a running river to a lake-like system. The biological fauna would respond by changing fish, plankton and invertebrate species characteristic of lake-like waters. How this would potentially happen and how it would affect other aquatic species and the ecosystem including the food web needs to be further assessed.

Recommendations towards mitigation

It is necessary to establish such information to design any potential mitigation measures. Two biologists each spending at least three weeks would be able to complete this suggested qualitative assessment.

Impacts on the deep pool habitats upstream the dam

Permanent submergence of the deep pools and changes in stream velocities would lead to siltation of the deep pools (see modelling in ***Annex 3***) upstream of the proposed dam resulting in potentially anoxic conditions in the pools due to deposition of organic material and a lower stream flow and therefore higher retention time of the water. This could deteriorate the high existing value of the deep pools as habitats for fish and other aquatic species and potentially affect the lifecycles of these species. The Mekong giant catfish migrates through this area and, in the absence of effective fish passage facilities, dams would potentially lead to extinction of this endangered species endemic to the Mekong.

Recommendations towards mitigation

The mitigation measures proposed to decrease siltation of the deep pools will contribute to mitigate these impacts and retain the biological functions of the deep pools. Further assessments on the conditions of the deep pools are needed to address sediment accumulation and oxygen conditions in these deep parts (see also ***Section 4.4***).

Impacts on morphological structures and habitats upstream the dam

The permanent inundation of sand bars and river banks would remove nesting and foraging areas for e.g. amphibians, reptiles and birds for this 100 km impounded river stretch. These species are part of the biodiversity of the Mekong region and valuable nutrition for the local people particularly during the dry season.

Recommendations towards mitigation

The extent should be assessed in order to establish information to design any potential mitigation measures.

Impacts on habitat continuity (habitat fragmentation)

The changes in ecosystem and species composition in the impoundment and the hindrance of upstream and downstream migration of many species caused by the dam introduce a fragmentation of the habitats in the area. This is well known as one of the important factors for biodiversity loss.

Recommendations towards mitigation

The impacts on endangered species and possible risks of threatening other species should be assessed. It is necessary to establish such information to design any potential mitigation measures

Recommendations toward the design of monitoring programmes

Monitoring programmes should be set up to fill existing knowledge gaps for all biological quality elements, particularly impacts on ecosystem health and water quality if the project goes ahead. Tailor-made monitoring programmes will support the assessment of the effectiveness regarding the mitigation measures. Further recommendations on monitoring programmes are outlined in ***Sections 4.3 and 4.4***.

(iii) Environmental flows

The concept of environmental flow consists of the characteristics of the water flow regime that sustain ecosystem health. Impacts of changes in environmental flow include impacts caused by changes in the flow regime in the impoundment, which may change the physical, chemical and biological quality of the water flowing to downstream reaches. Impacts on environmental flows have not been taken into account so far. There is no provision for monitoring to ensure that there are no unacceptable changes to the environmental flows during construction.

Any diurnal flow variations potentially resulting from operation of turbines would affect the downstream ecosystems. The feasibility report includes no provision for hydro-peaking effects which would have impacts on water quality and ecosystems downstream.

Significant changes in species composition upstream of the proposed project due to the change of the flow regime would potentially affect areas downstream. Habitat changes, removal of habitats through inundation and habitat fragmentation created by the Xayaburi dam project would all negatively affect biodiversity and potentially cause transboundary impacts.

Recommendations towards mitigation

A baseline and monitoring programme is needed to address environmental flow needs for the proposed Xayaburi dam project and as a basis for further management steps.

Hydro-peaking effects that depend on the operation of the dam need to be addressed as well as their possible negative effect on ecosystem health. Mitigation is needed to minimise these impacts.

The mitigation of changes in sediment transport and algae blooms through adaptive management and operation of the reservoir would limit the effects to the downstream areas.

Mitigation measures that would minimise the morphological alterations and create better structures have to be envisaged in order to ensure best possible biodiversity and prevent transboundary impacts.

Aquatic ecology is strongly interlinked with river hydrology, fisheries ecology as well as sediment quality/quantity. Further details on impacts and respective mitigation measures can be found in ***Sections 4.2, 4.3 & 4.4****. These are highly relevant for water quality.*

4.5.6 Gaps and uncertainties

(i) Water quality

The effects of changes in the water transparency in the area of the impoundment due to settling of suspended material are uncertain. The potential changes are increased primary productivity e.g. algae blooms and excessive growth of aquatic weeds, which are not occurring in the current situation because of the fast flowing river and very low transparency (about 30 cm). The phenomenon has been observed in many reservoirs in the region.

To assess water quality, measurements of the concentration of nutrients and light attenuation are needed at least twice a month. Indicators suggested are seasonal loading of *E. coli*, abundance of schistosomes (water-born disease), availability of light for plant growth, seasonal nutrient loading (phosphorus, nitrogen), loading of suspended particulate matter and aquatic plant productivity (phytoplankton, periphyton, macrophyte as autochthonous organic carbon). Monitoring of fish populations and macroinvertebrates is also needed to assess aquatic ecology.

(ii) Aquatic ecology

The potential changes to the ecosystems and species as a result of changing the hydrological regime from a running river to an impoundment have not been assessed. How this would affect the integrity of the ecosystems and potentially disturb the ecological balance of the river including risks of invasive alien species should be considered. It is uncertain what will happen. This could be further investigated to improve the assessment.

The potential impacts on flora such as the important river weed and also other species and aspects are missing. The impacts on biological communities depending on sand bars, river banks and deep pools are not included. An assessment of these impacts needs to include considerations of impacts on livelihood as well as biodiversity aspects.

Biodiversity considerations are confined to concluding that the measurement campaigns did not detect any endangered species. No assessment is made of changes to the biological communities in the impoundment and the potential impacts to downstream areas and biodiversity implications.

The Environmental Monitoring Plan does not include monitoring of any impacts to the biological communities.

(iii) Environmental flows

A baseline for determining environmental needs of a flow regime has not been established which means there is no basis for comparison. Evaluation to demonstrate that there are no unacceptable changes during the construction and operation phases is missing.

Comprehensive assessment considering the flow volume, temporal variability, water quality and biological quality of the water is not included. Furthermore, any aspects of how changes in the biological communities in the impoundment may affect the downstream areas are not included.

Monitoring of the flows in an integrated way considering the flow volume, temporal variability (including any diurnal variations), water quality and biological quality of the water is missing.

4.5.7 Conclusions and recommendations

The current dam design as well as management and mitigation measures as proposed in the submitted documents do not yet comply with the PDG or international best practice.

The design of monitoring programmes to assess impacts on water quality, aquatic ecosystems and the environmental flows is highly recommended. These programmes should include all biological and chemical quality parameters and could assess the effectiveness of mitigation measures.

Impacts on water quality, aquatic ecosystems and biodiversity have the potential of transboundary and - in combination with other hydropower schemes –cumulative effects. An effective set of mitigation measures is recommended to prevent those basin-wide and long-term effects.

(i) Water quality

The proposal does not envisage significant impacts on water quality in the impounded area due to hydrological changes based on the assumption that the water flow is maintained as natural.

This review concludes that impacts can be expected during both the construction and operation period of the proposed Xayaburi dam project (algal blooms, excessive growth of aquatic weed and respective physico-chemical alterations). The mitigation measures are currently considered exclusively for the construction phase and would need to be extended into the operation phase. Mitigation measures in the form of specially-designed operation schemes need to be developed to counteract any of the above impacts on water quality and are recommended for the upstream reservoir in the impoundment and the river downstream during both construction and operation.

During the construction period, water quality is likely to be impacted due to release of wastewater from living quarters, release of excavation and other construction material waste and release of oil from machinery**.** The proposed mitigation measures are designed to overcome such problems.

It is recommended that the monitoring programme during the construction period has a higher frequency of measurements during the start-up and during periods of intensive work, allowing for any adjustments to the mitigation measures to perform as intended.

(i) Aquatic ecology

The project as proposed does not expect significant impacts on aquatic ecology.

This review concludes that several pressures resulting form the proposed Xayaburi dam project will alter aquatic ecology. These include impacts on:

- species composition and biodiversity due to reservoir effect changing the type-specific free flowing river section to lake-like conditions;
- increased growth of algae, due to the increased sedimentation of suspended sediments, and clarity of water;
- deep pool habitats for fish and other species upstream the proposed dam;

- other important morphological structures (drowning of sandbars) and habitats upstream the dam; and
- habitat continuity through their fragmentation by the proposed dam

It is recommended that the assessment of the aquatic ecology is broadened to cover the ecosystem integrity and biodiversity considering all the above mentioned potential impact factors (hydrological changes, changes in suspended sediment concentration, drowning of sand bars and deep pools and habitat fragmentation).

(ii) <u>Environmental flows</u>

Environmental flows and respective negative impacts are not considered and a corresponding baseline is currently not proposed. Monitoring to ensure that there are no unacceptable changes during the construction and operation phases is missing. Hydro-peaking effects that impact on the aquatic ecology have not been taken into account.

This review concludes that the flows needed for the environment covering flow volume, temporal variability (including any diurnal variations), biological and chemical water quality is very likely to be impacted. The effects are not expected for the flow volume and are expected for the quality of the water through changes in physico-chemical and biological parameters. These changes could include lower suspended sediment concentrations, increased concentrations of algae and altered planktonic species composition. Such changes would affect downstream areas and potentially entail transboundary impacts. It is recommended to:

- establish a baseline for environmental flows covering all relevant aspects including flow, physical, chemical and biological quality parameters;
- design a monitoring programme in an integrated manner covering hydrology, water quality, suspended sediment and all biological quality parameters (fish, macroinvertebrates, zooplankton, phytoplankton, macrophytes).
- integrate design of monitoring programmes will enable the compilation of any changes to the flow regime and serve as an effective basis for further management steps.
- adress and mitigate possible hydro-peaking effects to prevent advrese effects on ecosystem health.

Other relevant recommendations and mitigations measures that are strongly interlinked with water quality, aquatic ecology and environmental flows are reflected in ***Sections 4.2, 4.3 and 4.4.***

4.6 Navigation

4.6.1 Scope of the review

The countries in the Mekong region have used the extensive natural river networks for transport and trade for centuries. For many years, the Lower Mekong Basin hosted traders from near and far away who became important trade partners in the Southeast Asia region and beyond. Two zones of river trade are currently active, from Yunnan Province in China to northern Thailand and from Cambodia and in Viet Nam through to the South China Sea. River tourism exists in these areas and also in northern and southern Lao PDR. The potential for increasing river trade and tourism is significant and a regional development approach is very much needed.

When hydropower schemes are planned for the Mekong mainstream, appropriate conditions for long-haul waterway transport not only need to be ensured but could also even support the improvement of the sector. Both sectors should also ensure environmental sustainability.

A common interest in increasing international trade was the reason that the MRC signatories opted for a separate article in the 1995 Agreement on Freedom of Navigation (Article 9). This article requires that dams do not pose an additional obstacle to navigation on the Mekong River.

As a basin-wide and transboundary component, navigation is different nature from the previous topics covered in this review report, referring more to an economic dimension and also ensuring that basin-wide environmental objectives will be ensured.

Regarding planning and investment for navigation locks, the long-term perspective of at least 50 years is needed, taking into account investment of work and costs, difficulties and costs inherent in trying to retrofit navigation facilities after construction of a dam and the potential increase of traffic. In the case of the Greater Mekong Region, the present situation is not a pertinent frame of reference when establishing standards for lock dimensions. Transportation of heavy cargoes such as mined and containerised products is expected to grow. Standards for lock design need to be compatible with applied to dam projects in Yunnan Province.

The PDG offers initial reference and guidelines for both governments and developers. For navigation, preliminary guidance is based on a Review of International Ship Lock Dimensions and their Relevance to the Proposed Hydropower Developments on the Mekong Mainstream. In 2011, MRC's Navigation Programme will start the second phase of a study of Standard Specifications for Design, Construction, Operation and Coordination of Navigation Locks on the proposed Mekong mainstream dams. After the completion of this second phase, preliminary assessments in the Preliminary Design Guidance will be validated and improved.

In this context and for navigation, it is important to note that the MRC Preliminary Design Guidance will be further improved during the Study Phase. More studies have to be conducted to conclude a final navigation chapter of the PDG. The PDG and this review therefore have to be seen as preliminary. The current PDG is an appropriate tool for this review, and any findings will be updated as soon as the final PDG regarding navigation is available.

4.6.2 Summary of impacts considered and measures proposed

The provision of ship locks on planned hydropower developments along the mainstream of the Mekong river is necessary based on Article 9 of the 1995 Agreement that mandates freedom of navigation along the Mekong River, and more reliable and consistent water depths through hydropower developments will facilitate larger vessel capacities operating on a year-round schedule.

The Government of Lao PDR has acknowledged that ship locks will be integrated at the proposed hydropower dam project. Therefore and in a long-term perspective, it is considered essential that appropriate lock dimensions, design and operations are ensured.

The proposed design has considered the preliminary broad principles on locks within the context of freedom of navigation in the PDG as follows:

- Article 9 of the 1995 Agreement requires that dams do not pose an additional obstacle to navigation. Mainstream dams offer the possibility of providing more reliable and consistent water depths that will facilitate larger vessel capacities operating on a year-round schedule. The most cost-effective and appropriate way to realise the benefits of inland waterway navigation consistent with hydropower development is the construction of navigation locks.
- It is accepted that long-term nature of planning and investment for navigation locks is to be considered. After dams, locks are the biggest and most expensive structures on a navigable river. It is almost impossible to adapt their width and depth once they have been constructed. Lengthening and building a second lock is possible. Lock dimensions must therefore accommodate predicted increases in river traffic with a long-term view of up to 50 years.
- The submitted Xayaburi documents require that the ship locks can raise transiting vessels from the downstream hydropower development level to the upstream hydropower development or water level or lower transiting vessels from the upstream hydropower development level to the downstream hydropower development or water level during all periods of authorised navigation on the Mekong River.
- The lockage, or raising and lowering operations, will be performed in two consecutive steps, depending on the total maximum lift of the lock, using chambers designed and constructed for this purpose. The head of one chamber shall be less than 30 m (difference between Highest Operating

Level and Lowest Navigable Level or Lowest Operating Level (if there is a backwater effect from a downstream development)

- The proposed lock dimensions take into account the need for consistency with lock dimensions on the Lancang River in China as well as stipulations in the 2000 Quadrangle Agreement for Commercial Navigation between Lao PDR, Myanmar, China and Thailand, and the 1995 Mekong Agreement
- Until the results of further studies are fully assessed, and further research on developing the most appropriate design vessel specification for Mekong navigation locks is conducted by the MRC, the PDG dimensions of lock chambers (L=120m, W=12m, D=4m) have been followed in the proposal. There is no provision for future doubling of the locks (if traffic increases) in a parallel set-up to a width of 24m.
- Lockage time is indicated to be a significant factor in determining the design. Lockage time will be kept to a minimum, is consistent with safe operation and fully takes into account the safe movement of vessels into and out of the locks.
- The total time for a complete lockage (target lock cycle) by the design vessel through each lock complex shall not exceed 50 minutes for a two-step "tandem lock".
- The emptying/filling system are designed to conform to the requirements for maximum transit times and allow for the smooth and safe lockage of any type of boat smaller or equal to the dimensions of the design vessel. Regarding this objective, the design criterion shall be:
  - Max hawser forces ≤ 1‰ x water displacement of the vessel (in tons).
  - Lock sill-bottom level must include a safety margin (of at least 1m) to take into account bed incision downstream of the dam - in order to ensure sufficient draught over the entire life of the structures.
  - Each lock has a straight alignment of at least 250 metres on both sides to allow for the safe entry and exit of vessels. This alignment should be separated from the main flow of the river at least 250 metres in both directions from the hydropower barrage.
- Passage of small craft and family boats has been considered.

4.6.3 Findings of the MRCS technical review

This review concludes that the PDG has generally been addressed. Some important points may not have been considered in the submitted documents and require clarification.

Reference is made to ***Annex 6.***

Hydraulic conditions

- When proposing the exact dimensions for ship locks, it is imperative to know what the longitudinal depth profile of the Mekong River will be after all combinations of proposed hydropower dam developments have been implemented. Comprehensive answers need to be informed by full knowledge on hydropower dam heights, location and operating levels which give the minimum and maximum water level that can be maintained in the backwater of the dams, the extent of the free-flowing stretches of each hydropower reservoir and the water level as well as the conditions of the navigation fairway that can be maintained in the free flowing stretches. This information, combined with future trade projections will define the optimal (maximum) ship dimensions.
- The maximum navigable discharge should be fixed, according to hydrological conditions. A flow close to 2 years return period flow could be chosen in the case of the Mekong River. The corresponding Highest Navigable Level (HNL) should be clarified downstream of the lock, in the situation prevailing before possible construction of other dams.
- The operation curve, giving the water levels upstream of the lock corresponding to the discharges in all situations of operations of the dam, normal, during peak flows, during flood events, has to be supplied. The Highest Operational Level to be clearly metioned.

- The surges generated by special operations of the power plant (peak flows, emergency stop of turbines…) are to be calculated, especially the minimum stages downstream of the dam, before the construction of Pak Lay dam.
- There are discrepancies concerning the values of operational or navigable values. All levels have to be indicated as ''operating'' or ''navigable'' It is recommended to build a general table (data sheet) gathering the right highest and minimum navigable flows and levels (for water and structures) under the different stages (natural, construction, after commissioning) and scenario (with and without Pak Lay), for upstream & downstream levels.

Design vessel and navigation standard

- The design should take into account the 2x 500 T (109 m x 10.8 m x 2 m) design vessel for the channel characteristics. For such a vessel, the international standards recommend normal bend radius of 700 m and, exceptionally, minimum bend radius of 450m.
- It is recommended to adopt straight alignments of at least two times the maximum vessel length for entrance and exit, and at least one time the maximum vessel length between two bends

Nautical accessibility

- The consequences of the first phase of construction (flow concentrated in the low flow river bed) on the velocities in the natural navigation channel is to be evaluated, for flow conditions presently compatible with ship transit. Compensatory dredging could be considered, if the velocities are too much increased.
- The navigation channel plan should be drafted 2km upstream and downstream the locks, with all the geometrical characteristics (width, draught, bend radii, , alignments, width allowance in the bends, etc.).
- The design of the upstream approach of the lock seems not safe for navigation. The bend radii are too small and the manoeuvres imposed the ships coming from upstream are tricky during situations of high flow toward the spillway. The flow conditions upstream of the lock are likely to provoke sedimentation and accumulation of floating debris in the lock entry. For all these reasons, the removal of the outcrop situated 800 m upstream of the lock, on the right bank is to be seriously considered.
- An in–depth study of the nautical and hydraulic conditions upstream and downstream of the dam should be performed, including the construction of a physical model. This study should take into account standard and non – standard operation configurations of the main works (spillway and power plant).

Lock design

- The design report must confirm the useful dimensions of the lock chambers
- The minimum air clearance has to be compared to the other constraints along the navigable waterway
- The design of the second set of locks is not acceptable. It is recommended to design the second lock side by side with first one.
- The elevation of the upstream mitre gate has to be increased to protect all the lock chambers against extreme floods (in order to limit maintenance operations after the flood).
- The dimensioning of the arrester cables has to take into account the capacity of the largest ships or convoys (1,000 T)

Emptying and filling system

- Considering the high head of the locks and the necessity to limit the emptying and filling time, the proposed emptying and filling system is not the more appropriate one. Feeding and emptying flows vary all along the longitudinal culvert and then on the different ports on each transverse culvert. The injection of flows is therefore asymmetric, longitudinally and transversally, leading the ships to move erratically in the chambers. There is no redundancy of critical equipment (gates, culverts). A system with two longitudinal culverts and several transverse culverts in staggered rows is recommended.

Financing of Lock Operations

- A preliminary proposal for lockage fees is included in the consultant's navigation assessment report on locks as background for discussion of this issue (***Annex 6***).

4.6.4 Conclusions and recommendations

Based on the findings of this review, it is proposed that the MRCS, the Developer, the Government of Lao PDR and international experts hold further discussions and conduct a workshop on the current design of the proposed navigation facilities for the Xayaburi dam project as well as its improvement. The proposed workshop would especially address:

- the navigation lock, its appropriate operation and financing,
- full considerations of the PDG and international best practices,
- nautical accessibility,
- linkage to possible use as part of the fish passage facility (see Section 4.3.),
- further, issues outlined above and detailed recommendations referenced in an annex should be addressed and appropriate solutions discussed, and
- planning approaches to resolve the issues addressed need to be identified including a respective roadmap.

More detailed recommendations regarding the proposed dam project and navigation are listed below:

- planning approaches to resolve the issues addressed need to be identified including a respective roadmap.
- The conclusions are based on the recommendations from the Navigation Programme Office and Consultant's Assessment of the developer's documents on the planning, design, operations and management of the navigation locks (***Annex 6***).
- The MRC conducted a Review of *International Ship Lock Dimensions and their Relevance to the Proposed Hydropower Developments on the Mekong Mainstream*. The study is based on benchmarking with international experiences, recommendations by the International Inland Navigation Association (PIANC)[17], and assessments of Chinese waterway classifications in the case of rivers associated with hydropower developments. According to best practice, it is recommended to take this MRCS study into account.
- The MRC Navigation Programme will look at what the longitudinal depth profile of the Mekong River will be after all combinations of proposed hydropower dam developments have been implemented to study the navigation potential and to define the optimal (maximum) ship dimensions.
- The maximum navigable discharge should be fixed, according to hydrological conditions. The corresponding Highest Navigable Level (HNL) should be clarified downstream of the lock, in the situation prevailing before possible construction of other dams. The operation curve, giving the water levels upstream of the lock corresponding to the discharges in all situations of operations of the dam, normal, during peak flows, during flood events, has to be supplied. The Highest Operational Level to be clearly mentioned. The surges generated by special operations of the

power plant (peak flows, emergency stop of turbines…) are to be calculated, especially the minimum stages downstream of the dam, before the construction of Pak Lay dam. A general table (data sheet) gathering the right highest and minimum navigable flows and levels (for water and structures) under the different stages (natural, construction, after commissioning) and scenario (with and without other dams), for upstream & downstream levels.

- The design should take into account the 2x 500 T (109 m x 10.8 m x 2 m) design vessel for the channel characteristics. For such a vessel, the international standards recommend normal bend radius of 700 m and, exceptionally, minimum bend radius of 450m. The design of the second set of locks is not acceptable. It is recommended to design the second lock side by side with first one.
- It is recommended to adopt straight alignments of at least two times the maximum vessel length for entrance and exit, and at least one time the maximum vessel length between two bends
- The consequences of the first phase of construction (flow concentrated in the low flow river bed) on the velocities in the natural navigation channel is to be evaluated, for flow conditions presently compatible with ship transit. Compensatory dredging could be considered, if the velocities are too much increased.
- The navigation channel plan should be drafted 2km upstream and downstream from the locks, with all the geometrical characteristics (width, draught, bend radii, , alignments, width allowance in the bends, …). The design of the upstream approach of the lock seems not safe for navigation. The bend radii are to be adjusted especially for ships coming from upstream. The flow conditions upstream of the lock are likely to provoke sedimentation and accumulation of floating debris in the lock entry. For all these reasons, the removal of the outcrop situated 800 m upstream of the lock, on the right bank is to be seriously considered. An in–depth study of the nautical and hydraulic conditions upstream and downstream of the dam should be performed, including the construction of a physical model. This study should take into account standard and non – standard operation configurations of the main works (spillway and power plant).
- The design report must confirm the useful dimensions of the lock chambers. The minimum air clearance has to be compared to the other constraints along the navigable waterway. The elevation of the upstream mitre gate has to be increased to protect all the lock chambers against extreme floods (in order to limit maintenance operations after the flood). The dimensioning of the arrester cables has to take into account the capacity of the largest ships or convoys (1,000 T). Considering the high head of the locks and the necessity to limit the emptying and filling time, the proposed emptying and filling system is not the more appropriate one. Feeding and emptying flows vary all along the longitudinal culvert and then on the different ports on each transverse culvert. The injection of flows is therefore asymmetric, longitudinally and transversally, leading the ships to move erratically in the chambers. There is no redundancy of critical equipment (gates, culverts). A system with two longitudinal culverts and several transverse culverts in staggered rows is recommended.
- A proposal for lockage fees is to be proposed and evaluated.
- It is recommended to design the locks to operate at least 12 hours a day, every day of the year subject to further consideration of their use for fish passage. Each lock complex shall be operational for at least 98 percent of its scheduled operating time during each year of its service life, excluding planned closures for scheduled maintenance.
- Outages related to incidental breakdowns, unscheduled maintenance and other unexpected outages, such as those resulting from collisions, extreme weather or causes beyond human control, shall not exceed 2 percent of the operating time each year. Service outages for scheduled maintenance shall be on 9 consecutive days (one working week and two weekends) each year, during the same period for the whole Mekong mainstream waterway. The official body in charge of navigation coordination along the Mekong River will be responsible for specifying the dates for servicing.

- Consideration in the revised design and among lock experts needs to be given to the proposal to use the navigation lock as one element of the fish bypass facility for the dam (***Section 4.3***). Furnish a design that provides vehicular access to all above ground structures for maintenance and operation, access for emergency response vehicles, and an overall layout for operating conditions that protects the safety of navigation in the locks. Prepare the design, procure, install, and commission all plans necessary for the optimum control and function of the lock complexes. This shall include process control systems, visual, audio, and electronic surveillance systems, and command and control communication systems. These systems shall include the ability to communicate with other locks on the Mekong mainstream waterway and provide real-time and historic monitoring of lock usage data, information from which must be accessible by the MRCS or authorized riparian agencies. Ensure durability design and that maintenance requirements are reduced to the lowest practical level. The developer needs to design systems with sufficient redundancies in critical components to allow maintenance and repair without adversely affecting lock-transiting operations. All design work should ensure that impacts on the environment are kept to a minimum in case of possible breakdowns or failures and shall also include measures to mitigate any such impacts.
- Development of a strategy for emergency access to both sides of each lock complex in the event of flooding or the loss of the lock gates. A description of emergency access and egress routes needs to be included in the layout. Lock gates and their manoeuvring devices shall be protected with water projection systems against the consequences of a fire inside the chamber. Each lock complex shall provide for the lockage of vessels in a safe and efficient manner without causing structural damage to vessels or lock facilities.

4.7 Safety of Dams

4.7.1 Introduction and scope of the review

As noted in the Prior Consultation Scoping Assessment in November, 2010, steps to ensure the safe design, construction and operation of the proposed Xayaburi dam project are in the interests of all MRC countries. All MRC stakeholders expect that appropriate steps will be taken to ensure the protection of life, property, the environment and economic assets.

This review firstly considers the extent to which the proposed design and construction, operation and maintenance regimes for the Project follow existing Lao technical standards and safety rules. Secondly, the review considers how the measures proposed conform to regional and international good practice, as viewed through the lens of the MRC Preliminary Design Guidance (PDG) agreed by MRC Countries at the Joint Committee level.

Emphasis was given to the particular importance regarding clarity on the status of institutional arrangements for the safety of dams, especially the establishment of an independent dam safety review panel. To fully conform to the PDG, it is important that this expert review panel, or an equivalent body, be established in a timely manner and given the initial task of providing independent expert review of the EPC design before it is tendered. Beyond clarity on the institutional arrangements, it is also important to confirm that the five main sub-plans prescribed in the PDG would be prepared and implemented. These plans include (i) a construction supervision plan, (ii) a quality assurance plan, (iii) an instrumentation plan, (iv) an operation and maintenance (O&M) plan and (v) an emergency preparedness plan (EPP).

Some information required to assess the full alignment with the PDG would typically be elaborated later in the project development cycle, such as prior to construction or commissioning of the project. Therefore, some aspects such as the operation phase emergency preparedness plan would be elaborated later. Nonetheless, the Scoping Assessment notes that for the purposes of this review, it is helpful to be as clear as possible whether the main stipulations in the PDG are to be followed, or not.

In early December 2010, immediately following the second JCWG meeting, LNMC organized a meeting with MRCS staff, representatives of the Lao Department of Energy (DOE), and the Developer to discuss the information gaps described in the Scoping Assessment. As a follow-up, the Developer shared the EPC Design documents, which elaborated on the technical design standards applied, and addressed several of the questions raised in the Scoping Report. LNMC also shared a copy of the latest version of Lao PDR's Guidelines on Technical Standards and Safety Rules for operation and maintenance that all dam developers and operators in Lao PDR must follow [18].

4.7.2 Dam safety and the proposed Xayaburi project

In addition to the submitted documents regarding Xayaburi dam, the topic of dam safety was reviewed with respect to the PDG, Section 6. The main thrust of the PDG is the approach to the safe design, implementation and operation of proposed mainstream dams, which should be based on relevant national standards that refer to different dam safety aspects, and accepted international best practice, as embodied in two overall dams safety guidelines. These are the World Bank's Operational Policy 4.37 on the Safety of Dams and periodic technical bulletins issued by the International Commission on Large Dams (ICOLD) through the ICOLD Committee on Dam Safety (CODS).

The PDG explains the value and guidance on establishing an independent dam safety review panel for the investigation, design and construction phases and start of operations. Further, the PDG requires the development, implementation and monitoring of a range of sub-plans oriented to the safety of dams and the related institutional capacity and stakeholder interactions.

The broader philosophy is the safe design, construction and operation depends on more than design and engineering factors alone. The PDG recognizes that failure of a dam is a complex process that can include human error in the design, construction, operation, maintenance and monitoring stages, or a combination of these. A systematic approach and management framework that accounts for all the complexities of design through operation is fundamental to assure practically the safety of dams. Appropriate institutional arrangements are needed, not only to see that relevant regulations are followed and corrective actions undertaken as part of maintenance regimes, but also to enable all stakeholders to be appropriately and meaningfully involved in those aspects that may affect them.

In the Mekong transboundary context, this means mechanisms to ensure the four MRC countries have information access throughout the project development stages, in the manner that may be agreed, including monitoring and compliance activities.

The Scoping Assessment noted that information in the submitted Xayaburi dam project documents was not sufficient to assess whether the project was fully aligned with all PDG provisions for the safety of dams. While the project documents do state explicitly that the PDG will be followed, the information to give such assurances in this review was limited, or not fully elaborated.

Key issues: Preliminary design guidance and safety of dams in the Lower Mekong Basin

In setting the context for guidance on the safety of dams, the PDG indicates that the proposed mainstream dams are beyond the scale of present hydropower experience in the Lower Mekong Basin (LMB). They offer a unique set of challenges with regard to dam safety where:

- *operation requires a pro-active approach to risk management, in part due to the run-of-river operation concept and relatively limited storage in relation to the high river flows that these mainstream projects must accommodate. Rates of change of water surface elevations in the reservoirs would sometimes be fast. Reaction times of dam operation staff in emergencies will equally need to be rapid and fail-safe;*
- *mechanical and electrical control equipment must be well conceived and designed, and thoroughly backed up, to ensure that operation flexibility is maintained in emergency situations where different failure modes can arise with critical equipment, such as controls for spillway gates or stop logs;*

[18] The first version of the Lao PDR Guidelines and Standards were issued in 2004. The latest version (2008) is titled Guidelines on Operating and Managing Lao Electric Power Technical Standards and Safety Rules for operation and maintenance. The report was prepared by the Lao Ministry of Energy and Mines in cooperation with the Government of Japan. The Guidelines have six sections. The first two cover hydropower civil engineering and electricity facilities. The remaining sections cover transmission and distribution aspects of electric power systems.

- *The Mekong is projected to see a significant increase in the frequency of extreme flood peaks over the longer-term, due to climate change. Given the permanent nature of dam structures, an assessment of integrity of hydraulic structures against the range of projected flood extremes that MRC had developed is important to satisfy concerns and perceptions of hydrological risk.*
- *All four Member countries have a stake in the safe design and operation of mainstream dams due to potential transboundary impacts of dam failure and the need to assure the public that mainstream dams are well managed. As a consequence, all MRC countries need to be appropriately involved in various safety aspects from the design stage to monitoring and review processes.*
- *The PDG notes that broadly, a consistent approach to the safe passage of extreme floods is required for critical structures during construction and operation of the mainstream dams, also taking into account the potential development of other dams in the mainstream cascade proposed in northern Lao PDR.*

4.7.3 Summary of issues considered and MRCS technical review findings

The recent earthquake near Xayaburi emphasises the need for an independent review of the project according to international safety standards. The project Feasibility and Design documents state the intention to follow the PDG. For this review, it was helpful to distinguish two broader aspects for PDG alignment namely, design criteria and the related Codes and Technical Standards as well as institutional arrangements and dam safety plans. How the project addresses these two broader aspects are noted as follows.

(i) Design criteria and related codes and technical standards

The Xayaburi Design Report - shared by the Developer with MRCS - provides the main engineering calculations, results and findings of the Xayaburi Outline Design stage which would be the basis for finalising the Engineering Procure Construction Contract and tender documents for the hydro-mechanical, electro-mechanical and transmission lines packages foreseen. The Design Report states that further adjustments and refinements of the civil design will be made at the construction stage while manufacturers develop the detailed design of the equipment.

The Xayaburi Design Report presents and elaborates technical criteria relevant to dam safety in a number of sections. Part A summarizes the key features of the proposed design. Part B gives main design criteria including general design criteria, hydraulic design criteria, geotechnical design criteria and civil design criteria. Part C indicates the hydraulic and civil design of the different project structures and the technical standards applied including excavations and slopes, foundation treatment, cofferdams, intermediate block, navigation locks, spillway, powerhouse, fish-passing facilities and instrumentation. Part D summarises key parameters and technical standards applied for navigation locks, spillway, powerhouse, and fish passing facilities. Part E includes design criteria and standards applied to the main components of the electromechanical equipment including substations and transmission facilities.

Each criterion is embodied with an element of dam safety and performance. The Design Report notes that the Lao Electric Power Technical Standards are the primary general design code and are met. In addition, it explains that the Lao standards require internationally-recognized design codes, design manuals and specifications, which have been taken into account in establishing the specific design criteria.

For major structural components, such as the spillway and powerhouse sections, the design parameters and various safety factors are detailed. For illustration purposes only, the broader hydraulic criteria applied to the design of main sections of the dam are noted below along with criteria for cofferdams as regard to flood return periods.

Spillway section

- Spillway capacity curves provided for all flood return periods, including the PMF (47,490 m3/sec) and the specific discharge of 10 individual spillways (200 m3/s/m, for a PMF) and for cases with 2 and 5 spillways not operating.

- Operating specifications given for spillways, where the maximum flood level is not to be exceeded in Luang Prabang for different flood return periods[19].
- Various stability analysis and factors of safety calculated for PMF loading and Maximum Credible Earthquake (MCE) of 1:10,000 years.

Powerhouse section

- The Powerhouse Safety Guidelines issued by the International Committee on Large Dams (ICOLD) are applied.
- The hydrostatic loadings considered are flood events with return periods of 50, 1,000 years and the probable maximum flood (PMF).
- Stability in Maximum Credible Earthquake (MCE) is assessed.

Construction phase coffer dams

- For the embankment and RCC/CVC cofferdams on the right bank (first stage of the river diversion), 50 years return period (26,700 m3/s).
- For the second stage (embankment cofferdams across the main river channel for the construction of the power intake – powerhouse complex): 100 years (about 29,100 m3/s).

(ii) Institutional arrangements and safety plans

Three main aspects covered by the PDG concerning institutional arrangements for dam safety and a systematic approach to prepare and implement dam safety plans and sub-plans include:

- the establishment of a Dam Safety Review Panel, consisting of recognized international experts in different aspects of dam safety, who have no role in the design or operation of the dam;
- reviews by the Panel would apply in the investigation, design and construction of the dam, and for a period after start of operations (typically 5 years);
- the development and use a Dam Safety Management System (DSMS) that reflects ICOLD guidance on establishing a systems approach to the management of dam safety; and
- the development, implementation and monitoring of the five key sub-plans under the DSMS, including (i) a construction supervision plan, (ii) a quality assurance plan, (iii) an instrument plan, (iv) an operation and maintenance (O&M) plan and (v) an emergency preparedness plan (EPP).

No explicit mention is made of these institutional arrangements or the sub-plans that are noted above in the Xayaburi Feasibility Study or other documents submitted for the PC process by Lao PDR in September 2010, or in the Detailed Design Report subsequently provided.

The Feasibility Study Report (Sections I-6) states: *"In next stage of the study, outline design and detailed design, barrage and appurtenant structure will be studied and designed in compliance with Guideline of International Commission on Large Dams (lCOLD) and World Bank*." This is a somewhat qualified endorsement of the PDG.

The PDG (Paragraph 182) states: *"Developers and owner/operators will need to demonstrate how they will apply the entire OP/BP 4.37 (which is embodied in the PDG). Consideration should also be given to ensuring that relevant dam safety measures provided in this guidance is appropriately reflected in Concession Agreements."*

In the meeting with the Lao Department of Energy (DOE) and the Developer organized by LNMC in early December 2010, general discussion was held on current dam safety practices in Lao PDR and institutional measures. The discussions touched on the requirements set out in the guidelines of the

[19] For example, for a 15,000 m3/s flood (flood warning at Luang Prabang), the water level in the reservoir, with all spillway gates fully open, shall not exceed elevation 265.90 m above sea level. Where calculated, the water level at Luang Prabang will increase over the natural water level by less than 0.10 m. For the PMF (47,490 m3/sec) the water level in the reservoir, with all spillway gates fully open, shall not exceed elevation 279.8 m above sea level.

Ministry of Energy and Mines for Lao Electrical Power Standards (LEPTS) and safety rules[20]. The LEPTS, which is publically available, outlines the general requirements and the forms for the approval of hydropower designs through the Lao regulatory system, inspection of construction works and reporting on emergency situations and accidents. The LEPTS state: *"the Owner on commencing operation of the power facility must prepare safety rules for the operation and maintenance of the facilities following the Ministerial regulations on 'Safety Rules for operating and Maintenance'*."

4.7.4 Conclusions and recommendations

The Xayaburi project documents state the PDG provisions on dam safety will be followed. The provisions are not onerous and have been applied on other dam projects in Lao PDR. The Scoping Assessment states: "*it is likely that all the PDG requirements on the safety of dams could be met, but the information to give such assurances is still limited at this time, especially concerning the institutional arrangements and preparation of the five main sub-plans needed to systematically review and monitor dam safety*."

Within the scope of this review, no attempt is made to provide engineering or risk assessment of how the various technical codes and standards may translate into the safe design of the main project components, or their performance and safe operating modes. It is noted that the Design Report demonstrates the extensive use of a wide range of internationally-accepted technical standards and the Lao guidelines for technical standards and safety rules.

As a result of this review, it is recommended that further consideration should be given to full alignment to the PDG and otherwise adding value for MRC stakeholders. Such steps include:

- **Formation of an Independent Dam Safety Review Panel (DSRP) for the Xayaburi dam project and assignment of the task to review the Design Report in a timely manner.** ***Annex 5*** of this report provides an illustration of the composition, duties and scope of a DSRP modelled on the Nam Theun 2 DSRP. Paragraph 188 of the PDG applies: "*All aspects of the World Bank Operational Policy (OD/GP 4.37) for the safety of dams should be reflected by developers and operators, including required reviews by an independent panel of experts of the investigation, design and construction of the dam and start of operations and sub-plans."*
- **Clarity on the expected scope and timing for putting in place and overall Dam Safety Management System (DSMS).** Paragraph 190 of the PDG applies: *"In particular, developers / owners / operators should prepare and implement a Dam Safety Management System (DSMS) that reflects ICOLD guidance on establishing a systems approach to the management of dam safety. This starts from design and continues through to operation. The DSMS incorporates the production of an annual report on dam safety during the operation phase that is submitted to governments and made public."* Within this framework, the timing for preparation of the five dam safety sub-plans, drawing on existing information in the Feasibility Study and Design Report, namely (i) the construction supervision plan, (ii) the quality assurance plan (iii) the instrument plan (iv) the operation and maintenance (O&M) plan and (v) the emergency preparedness plan (EPP). Paragraph 188 of the PDG also applies.
- **Clarity on the process for consultation and engagement of local stakeholders, especially for the Emergency Preparedness Plan (EPP).** Paragraph 191 of the PDG applies: "*Developers and operators should ensure there is full and effective consultation with local communities and local government authorities and all concerned organizations and agencies, especially with regard to the emergency preparedness plan (EPP). The EPP should include a communication strategy to reach and involve all concerned and affected people (i) in preparation of the EPP, and (ii) in training or capacity building to implement the EPP, and (iii) responding to any issues concerning annual Dam Safety reports."*

[20] Guideline on Operating and Managing Lao Electric Power Technical Standards and Safety Rules for Operation and Maintenance is for hydropower civil engineering facilities and electric facilities in hydropower stations.

- **Clarity on the cost of dams safety measures and plans in project budgets.** The DSRP budget can be set up to a specified ceiling following the example of Nam Theun 2. Paragraph 193 of the PDG applies: *"Developers and owners should be responsible for all cost associated with implementing all aspects of this guidance on the safety of dams. Developers / owners / operators should clearly detail all such costs in the project budgets for the design, implementation and operation stages".*
- **To align with the PDG, full use needs to be made of experience in Lao PDR including use of Lao guidelines.** With reference to previous discussion in this review on design standards, many accepted international standards have been applied in the design phase. The LEPTS contain general requirements for owners/operators to prepare safety rules for the operation phase without detail. Previous experience with Dam Safety Review Panels in projects where World Bank funding support has been utilised include Nam Theun 2 where a dam safety review panel (DRSP) had been functional. Otherwise, the requirement to prepare some dam safety sub-plans in the PDG, such as emergency preparedness plans that exist in Lao PDR. Use also needs to be made of the specific provisions on dam safety in the PDG with regard to the Xayaburi project activities and budget and any agreement the MRC Joint Committee may reach in the PC process concerning dam safety.

Other recommendations with an explicit transboundary orientation:

- undertake assessments of how upstream developments and sensitivities of design floods to different climate change scenarios that are prepared by the MRC Basin Development Plan.
- undertake a dam break analysis incorporating all proposed mainstream dams above the Xayaburi site in the Lao PDR and considering the Chinese dams. As part of that exercise, confirm that the main Xayaburi structures can withstand overtopping in the event of exceptional hydrology events, or upstream dam break (without failure of main structures).
- set out the mechanism and steps to involve other MRC countries in monitoring, reporting and compliance activities related to dam safety in the design, construction and operation phases.

4.7.5 Transboundary aspects regarding safety of dams

This review on the Xayaburi dam project is mainly concerned with potential transboundary impacts. From a transboundary perspective, dam safety is a concern to the governments and MRC stakeholders in the four countries at a number of levels.

- MRC stakeholders in Lao PDR and Thailand are concerned for the safe operation of the project to protect their investments in the dam for power supply, in the case of Thailand and Lao, and for the revenue generation benefits in the case of Lao PDR.
- All MRC countries (governments and public) are interested in understanding the risks and probabilities of potential impacts and threats to lives, property and livelihoods posed to downstream communities in the Mekong mainstream in the event of a failure of the dam in extreme flood events.
- The Thai border is 200 km downstream from the Xayaburi site. The province and communities in Thailand have concerns to understand the potential for emergency releases that would impact water levels and any related public safety considerations.
- All MRC stakeholders have an interest in seeing that future scenarios for climate change, as developed by the MRC, are reflected in dam safety measures.
- All MRC Member Countries similarly have a stake in the monitoring, reporting and compliance activities related to the safety of the Xayaburi dam in the design, construction and operation phases and to be informed and able to respond to general public concerns at any time.

4.8 Social issues

4.8.1 Introduction

The social aspects covered relate mainly to those resulting from potential changes to ecosystem services such as fisheries, the aquatic environment and flow regime rather than local impacts in the immediate project area related to resettlement, which are a Lao national issue. According to documents submitted, 458 households will need to be fully relocated as a result of the project. An estimated 1,081 households are expected to lose income from vegetable cultivation, gold panning and teak plantations.

Social issues are covered partly in the Fisheries Section of the Report. A more substantive analysis is required, particularly related to residual impacts on fisheries and changes in hydrology and morphology.

Fisheries resources (fish, other aquatic animals and useful aquatic plants) have long been central to the lifestyles of the four riparian countries of the Lower Mekong Basin (LMB), particularly to communities living in and around the corridor of 15 km of the river and its dependent floodplains. Across the whole LMB, some 40 million people or about two-thirds of the population are involved in the Mekong's fisheries at least part-time or seasonally.

Food security is an important issue in the social assessment since river resources are overwhelmingly used for food production, fishing and gathering of aquatic animals and plants. The poorest or resource weakest people in LMB countries are more dependent on common natural resources than richer segments of society. They are therefore also more dependent on river water resources. Any risks or losses incurred by Mekong terrestrial and aquatic ecosystems brought about by hydropower dam developments translate into threats to livelihoods primarily through increasing food insecurity.

In Lao PDR, more than 70% of rural households are dependent on fishing and collecting other aquatic animals (OAAs) and useful aquatic plants (UAPs) to varying degrees for subsistence livelihoods and additional cash income. This includes the river system and other important habitats such as wetlands and agricultural areas.

Cambodian inland fisheries are very large by global yardstick and are very important socially, economically and culturally. Cambodian freshwater capture fisheries probably contribute more to national food security and the economy than such fisheries do in any other country in the world. The flood plain area of the Tonle Sap Lake alone provides fish and aquatic system-based livelihood opportunities to more than 1.5 million people residing in the area (MRC, 2010b).

Thailand is blessed with an abundance of natural resources including freshwater fish and other aquatic animals (OAAs). In 2002, Thailand was among the top-ten fishing nations of the world (Oopatham, P., 2007). Fisheries are essential in the northeast, especially around the Songkram River Basin. Various reports have indicated that households in this region fish all year round (MRC, 2010b).

The Mekong Delta has a very large aquaculture sector. Capture fisheries and OAA collection are dominated by part-time fishing activities (MRC, 2010b).

Knowledge is very limited about the extent of migration of species that pass through the area of the cascade of 6 dams planned north of Vientiane. Similarly, the effectiveness of fish-passage technology is unproven for the species and biomass in the Mekong River. The approach taken in this review is to provide an overview of the dependency of communities on the capture fisheries in general terms based on preliminary data available. This is indicative at this stage as more comprehensive studies will take place in the next one to two years. The information in this section indicates the types and scale of impacts that mitigation needs to address to respond to the social impacts caused by the effects of the cascade of six dams on fisheries. Most impacts are expected to be experienced as a result of the first dam built. It is not possible to be more precise on the impacts of any one project in the cascade.

4.8.2 Transboundary and cumulative aspects from the view of basinwide development scenarios

Transboundary effects and cumulative impacts resulting from multiple dams on fisheries have been analysed in two studies before : (1) BDP - Basin Development Plan Programme - Assessment of Basin-wide Development Scenarios (MRC, 2010d) and (2) SEA MRC Strategic Environmental Assessment of hydropower on the Mekong mainstream (MRC, 2010c).

Scenario 1: Baseline – 2000

- About 21% of the LMB is blocked by tributary dams and inaccessible to fish species having to migrate to the upstream parts of the river network
- Fish production in the region is based on a combination of capture fisheries from the river and associated floodplains, rain-fed agricultural areas (e.g. rice paddies), reservoir fisheries and aquaculture. In addition other aquatic animals (OAAs) increase supply of products. Finally, in Zone 1 upstream of Vientiane there is important production of algae (Cladphora).
- Total fish production - 2.53 million t/yr (including 0.5 million t/yr OAA (freshwater shrimps, snails, crabs, frogs, etc.)
- Aquaculture production -1.97 million t/yr mainly in Mekong Delta.
- Biodiversity: 781 known fish species including iconic species such as the Giant Mekong catfish and Irrawaddy (Mekong) dolphin.

Scenario 2: Definite Future – 2015

Ecosystem impacts

- Reduced flooding and depleted natural replenishment of nutrients will reduce wetland areas (by 35,000 ha - 2.4%) and their productivity.
- River habitats will be diminished noticeably in Lao PDR and Thailand.
- Environmental hotspots on the mainstream in northern Thailand and the Lower Sesan in Cambodia will be impacted.

Fisheries impacts

- A combination of the ecosystem impacts and interruption of fish migration are caused mostly by tributary dam development in the LMB and will deplete capture fisheries: estimated reduction: 15% in Lao PDR, 3% in Thailand, 7% in Cambodia, and by 9% in Viet Nam of their respective amount of fish catch in each country. These values do not appear to account for potential collapse of downstream drift and impact on fish recruitment in downstream reaches.
- Reductions in sediment outflow from the basin will negatively impact upon productivity of the Cambodian floodplain, delta and coastal marine fisheries (see Chapter 4.4).

Social impacts

- Combined impacts of principally reservoir construction and wetland productivity reduction are estimated to put the livelihoods of up to 900,000 people at risk within the LMB.
- Construction activities, new reservoir fisheries and aquaculture forecast are predictade to generate 370,000 new jobs. Any jobs created are unlikely to substitute for the loss of fisheries as they are different sectors often requiring capital investment that will not be available to rural poor. Aquaculture in particular requires both capital investment and recurrent financing for feed that will unlikely be available to the fishing communities. It should also be recognised that reservoir fisheries rarely achieved expected outputs and these figures are based on best case scenarios.

Scenario 3 - Foreseeable Future Scenario 2030 including the 6 mainstream dams in Lao PDR plus 71 LMB tributary dams and plans for irrigation increase

Ecosystem impacts

- The resence of the mainstream dams is estimated to have significant impact on local sedimentation, which will be dependent on operation and effectiveness of sediment flushing, including timing of flushing in relation to floods. Reductions in sediment outflow are expected to negatively impact upon marine fisheries.
- Mainstream dams would have incremental environmental impacts over and above the 20-year plan without mainstream dams arising from the conversion of the mainstream in the Northern part of

Lao PDR into series of slow moving waters between run-of-the-river hydropower schemes in addition to their barrier effect on the fish migrating in this part of the mainstream and further reduction in downstream replenishment of fisheries.

- Negative impact on local environmental hotspots is expected with a further two affected: one between Lao PDR and Myanmar and Songkram River Floodplains.
- Mainstream dams will have severe impact upon Giant Catfish numbers, and could lead to its extinction along with other species locally.
- The Xayaburi dam is the first of six dams, a cascade that would block 69 % of the accessible habitat for migratory fish.
- Mainstream dams result in a loss of 39 % of the riverine mainstream habitat, representing 90 % of the upper migration system.
- Migration of at least 23 fish species is blocked.
- Wild population of giant catfish is supposed to extinct even if only one dam is build as the only confirmed spawning area is above Luang Prabang. No large migratory fish species are predicted to persist if all 6 dams are built

Fisheries impacts

- A combination of ecosystem impacts and interruption of fish migration (69% of migrating fish) mostly by tributary dam development in the LMB and loss of production area in the Lao PDR is expected to deplete capture fisheries: estimated reduction 16% in Lao PDR, 5% in Thailand, 18% in Cambodia, and by 16% in Viet Nam of their respective amount of fish catch in each country.
- The reduction in flooding regime in Tonle Sap system and LMB wetland areas will remain and potentially marginally increased under this scenario depending on dam operation.
- Estimated fisheries losses are very conservative since they are a sum of local estimates but do not reflect the impact that a change in a given place (e.g. a breeding site upstream) can have on another place (e.g. a fishing ground downstream). Estimated losses would be probably much higher if spatial connectedness between habitats and dynamics of migratory populations would be considered. This is also indicated by high losses of accessible and riverine habitat and cumulated and additive effects of habitat degradation and continuum disruption. Comprehensive monitoring data are necessary to overcome these uncertainties.

Social impacts

- Exclusively 6 Lao PDR mainstream dams *without* LMB tributary dams: incremental effects regarding fish losses due to reduced capture fisheries are estimated at about 66,000 tons per year and the additional livelihoods at risk to some extent are about 450,000 people within the LMB. The distribution of the number of people affected among countries would need to be further analysed based on more extensive social information.
- 6 Lao PDR mainstream dams plus 71 LMB tributary dams and irrigation increase: combined impacts of principally reservoir construction and wetland productivity reduction are estimated to put the livelihoods of about 2 million people at risk within the LMB. The distribution of the number of people affected among countries would need to be further analysed based on more exclusive information.

4.8.3 Baseline vulnerability and resilience

People living in places with well-developed economies, services and systems of support are likely to be more resilient to change than those living elsewhere. Equally, households that are already vulnerable for other reasons (such as malnutrition) will be more severely impacted if their access to natural resources is diminished than those that are not already vulnerable.

Of the four countries in the LMB, Cambodia remains the poorest, and is ranked 131 out of 177 countries in the 2007 UNDP Human Development Index (HDI). Peace and economic growth have reduced the level of poverty, but this remains high at 35% of the population, with the Plains and the Tonle Sap Zone accounting for 80% of total poverty. An important characteristic of poverty in Cambodia is malnutrition: 45% of children under five are underweight and 33% of the total population are undernourished. State support for vulnerable groups is limited. Social protection systems, notably pensions and social insurance, are largely confined to those in the civil service or with formal sector employment. Despite the economic growth of recent years, state capacity to assist the needy is limited and NGOs reach only a fraction of the poor. In this context, rural communities are particularly vulnerable to any decline in their natural resources, notably fish. The key area is the Tonle Sap. While natural resources are relatively abundant, the population remains among the poorest in the country (and the Mekong Basin) in monetary terms, and malnutrition levels remain high, despite the proximity to the lake's resources. Unequal access to fishing areas and limited capacity of small-scale fishers is a factor.

Over the last decade, Lao PDR has achieved high economic growth rates and a stable macroeconomic environment. Nevertheless, it remains a relatively poor country, ranked 133 out of 177 countries in terms of HDI in 2007. Much of the economic growth has been concentrated in urban areas, fuelling rural-urban migration and variable results across provinces. Although rural households are remarkably self-reliant in terms of growing or gathering their own food, the World Food Programme (WFP) describes food insecurity as "widespread throughout the country and alarmingly high in rural areas". Health, nutrition and literacy indicators in remote areas are significantly lower than national averages, particularly for women and ethnic minorities. Developing these areas is difficult as most are still inaccessible by road. Lao PDR does not have well developed social assistance programmes. Government capacity to reach the poor is constrained by resource limitations and no real safety nets exist. In this context, rural self-sufficiency is a critical dimension of resilience to change. Households along the mainstream Mekong are in many areas able to combine crop production and livestock rearing with fishing and the collection of other aquatic animals (OAAs) and non-timber forest products. The relatively high rice and fish production do not guarantee positive health outcomes for all the population.

Thailand's overall HDI score rose from 0.65 to 0.75 between 1980 and 2007, has and it has a current ranking of 87 out of 177 countries. The steady growth in Gross Domestic Product (GDP) in the last 20 years has enabled the Thai Government to invest in social development programmes and to expand basic services significantly. By 2006, the number of poor people in Thailand had dropped to 6.1 million, from 18.4 million in 1990. The country offers its population a supportive environment: water and electricity are almost universally available, basic education and health services are free, and state pensions are provided for the elderly. In addition, Thailand has a very active civil society, with many groups functioning at local and national level to support the poor. While none of these alone is adequate to protect households that are vulnerable to changes in natural resources, collectively they help to provide an important safety net. The households near the Mekong River have developed very diverse livelihoods, planting a wide range of lowland and highland crops. The importance of fishing has declined as farmers shift to cash crops and respond to job and business opportunities created by e.g. tourism. In some areas, households fish only when they encounter problems in their agricultural activities, notably drought, and fishing has become a secondary activity for most.

Over the last 15 years, Viet Nam has, according to the World Bank, become "one of the most spectacular success stories in economic development". Income per capita rose from US$260 in 1995 to a 2007 level of US$835. The increase in per capita income reduced poverty significantly, with the general poverty rate falling from 58% in 1993 to 16% in 2006. In terms of HDI, Viet Nam is ranked 116 out of 177 countries. Significant geographic differences exist in the distribution of poverty, notably between rural and urban areas. In terms of social assistance, the protection given to invalids and war veterans is comprehensive and those categorised as poor can receive support from the welfare department, or through the co-operatives, production teams and brigades existing in the rural sector. Overall, Viet Nam has made significant progress in developing a supportive environment for the poor. Given the size of the population and the country's vulnerability to natural disasters, these systems will clearly need to be strengthened, particularly in parts of the country where poverty remains well above the national average. The picture that emerges from the Mekong Delta is one of rapid transformation. Expanded irrigation and the use of fertilisers and chemicals in the freshwater Mekong Delta area has made it possible for farmers to grow three crops a year. This has resulted in a decline in the productivity of aquatic ecosystems. People, once dependent on fishing, have had to change occupations, to work as farmers or hired workers. Fisheries production has been compensated by a highly-productive aquaculture sector.

Comparing baseline vulnerability to changes in natural resources across the basin, Thailand comes out as much less vulnerable than the other countries. Cambodia is 'highly' vulnerable, with Lao PDR not far behind and with Viet Nam falling somewhat in between Thailand and the other two countries.

4.8.4 Livelihood dependency on the Mekong River for the LMB population

The illustration of livelihood dependence on the Mekong River resources presented in this section is derived from a pilot study including selected survey sites in the four Member Countries (MRC 2010c). The results of the pilot study can not be considered representative for the whole basin, but illustrate the linkages between the river resources and rural livelihoods in the Lower Mekong Basin.

Population living within reach of the Mekong River resources

Overall, it is estimated that 29.6 million people live within 15 km of the mainstream. Thailand has the lowest corridor population, at 2.5 million, representing only 4% of its national population. Viet Nam has the highest, at 14 million people, or 16% of the national population. Cambodia has the highest proportion (70%) of its national population in the corridor, at 9.8 million people. Just over half of the Lao national population (53%) is to be found in the corridor, at 3.4 million. About 79% of the total 15 km corridor population live within 5 km of the mainstream. The urban population of the corridor, considered to be less directly dependent on natural resources, is estimated as 4.6 million, concentrated largely in the Delta, Phnom Penh and Vientiane.

Analysis of the pilot study primary data confirms that resource use declines significantly with distance. The data show that people tend to make use of ecosystems that can be reached, on average, within 15 minutes in the dry season and 20 minutes in the wet season. In only 10% of cases did people fish in ecosystems that were more than 30 minutes away, and in only 2% of cases did they use ecosystems that were more than 60 minutes away. Distance from the river clearly has an impact on the extent to which it and its resources are used.

Livelihood dependence on river resources

Taken together as water-dependent occupations, farming and fishing are the main occupation of nearly two thirds (63%) of the rural adults interviewed in the survey. Just over one in three households (35%) in the study areas described fishing as either the most important or the second most important occupation in their households. A further 15% of households fish on an occasional basis, bringing the proportion who fish at some point in the year to 50%. In the Cambodia sites, one-third of households had no second occupation, indicating their vulnerability to change.

Approximately one-third of households engage in the collection of OAAs to supplement their food or incomes, with this being highest in the Viet Nam and Lao PDR sites at around 40% of households. In the Delta, where the percentage of households that fish is in decline (down to 11%), the percentage that depends on irrigation is the highest (55%). Here, riverbank gardening is also important (for nearly one-third of households). The percentage doing riverbank gardening in the Lao PDR and Thailand sites is somewhat lower, but still significant at close to 14% and 11%, respectively.

In the Lao study sites, 60% of fishing households use the mainstream as their preferred dry-season fishing area, while in the Delta sites 44% of the 11% of households that fish reported using one of the branches of the mainstream as their preferred fishing area. In the Thailand sites, the percentage was only 10%, but this was partly due to the inclusion of a tributary area in the pilot study. In the Cambodia study sites, 58% of fishers used the Tonle Sap as their preferred site, with the remainder using other ecosystems, such as marshes, streams and ponds. Nearly one-third of the fishing households in the Delta reported the use of 'paddies, ponds and canals' as their most common fishing area. The choice of fishing areas varies according to the season. The most significant shift takes place in the use of the mainstream, with the proportion of fishing households which use this as their most preferred fishing area dropping from one-third in the dry season to one fifth in the wet season.

The study found that even though the households involved in fishing consumed some of the fish, the majority of the catch was sold. In the Tonle Sap sites, where more than one-third of households have no other occupation, sale of fish is particularly important for household income.

From the perceptions of the fishing households, there has been a significant decline in fish catch over the five years prior to the interview. One-third reported 'much less' fish than five years ago, with the greatest changes reported for the mainstream and the Tonle Sap, and the least for paddies, ponds and canals. Over one-third (38%) reported the absence of certain species that they used to catch 5–10 years ago. More than three-quarters (79%) of the fishers felt the decline was due to competition (more fishers) and various illegal or destructive fishing methods.

When qualitative and quantitative data from the pilot study are read together, the picture that emerges is one of fishing households under pressure. While the Mekong may still be in relatively good ecological health, the early warning signs are clearly visible: declining catch per fisher and the reported disappearance of species forewarn of future changes that are likely to be accelerated by further fragmentation of the ecosystem by dams and other infrastructure.

Food security

The LMB is well known for the availability of its diverse foods, a fact confirmed by the survey. The vast majority of those interviewed were able to obtain sufficient quantities of food for their households, with the average calories consumed being above the minimal requirements. There are significant variations in consumption patterns by occupation and geographic area.

Households whose main occupation is farming (regardless of where they live) are generally able to get through 10 months without having to purchase rice. Others have to purchase rice for between seven and nine months in the year. Farmers who mix rain-fed and irrigated production are the most food secure, as they virtually never have to buy rice. The data also highlight the precarious situation of households that depend on fishing as their main occupation. These households may not have land and rely on the income from fish sales to buy rice. If fish stocks decline, these households will be unable to buy rice, leading to widespread malnutrition.

The rural households in the study ate three types of food almost universally: rice, fish and vegetables. Virtually all respondents had eaten some fish in the 7 days before the interview. With regard to OAAs, the Lao PDR sites reported the most diverse consumption patterns, notably of frog, shrimp, snail/mollusc, crab and/or turtle. OAA consumption was less diverse in the other country sites, notably in Cambodia, where dependence on fish was highest. Fishing households are much less inclined to eat red meat than non-fishing households, but are far more likely to eat other types of protein (including OAAs caught on the way to fishing grounds).

The vast majority of the food items (90%) eaten in the households of the study in Viet Nam were purchased. The opposite was true in the Lao PDR sites: here, only 2.8% of the items had been purchased, indicating a very high level of dependence on farming and natural resources. In Cambodia, where people are highly dependent on fish sales to purchase food, the percentage of purchased items was also high (77%), exceeding the percentage of purchased items in the Thai sample (69%), where mixed farming facilitates self-sufficiency.

The pilot study confirms the very high levels of dependence of rural households on fish and OAAs. Any changes that affect these critical sources of food will be far reaching. Replacing fish with other animals will be impractical, costly and ineffective given the dietary value obtained from protein and other critical micro-nutrients.

Income and expenditure

Very poor and poor households are significantly more likely to fish as a full-time occupation. All socio-economic categories, with the exception of the well-off, engage in occasional fishing. Poorer households would be far more likely to suffer the consequences of any major decline in fish stocks than better-off households. By far, the most common source of income for the rural residents of the Mekong corridor is the sale of rice (50% of households). This is followed by remittances from family members (31%); local irregular/seasonal employment (30%); full-time employment (25%); sale of livestock (25%); sale of own fish catch (25%); business profit (19%); credit (14%); savings (13%); sale of OAAs (6%); aquaculture (4%) sale of others' fish catch (3%) and other miscellaneous sources (less than 1% each). One in four households across the study sites earns income from the sale of fish but significant variations were found between the study sites. In the Cambodia and Lao PDR study sites, fish sales are a source of income for close to 40% of households, a far higher proportion than in either Thailand or Viet Nam, where the figure is less than 10%.

4.8.5 *Potential trans-boundary impacts of fish losses and sediment trapping*

Scoping the potential fish losses and sediment trapping by the Xayaburi dam is quite difficult; it is possible to range the impacts in which the existing studies by the BDP and SEA (MRCS, 2010c,d) provided possible impacts of potential fish losses and sediment trapping.

The below livelihood analysis of fish reduction is based on the assumptions that (i) the livelihoods at risk is defined amongst the impacted population engaged with fishery activities as the result of the 6 mainstream dam Northern Lao PDR and the Xayaburi dam, (ii) sediment trapping could affect fisheries productivity as well as agricultural productivity and (iii) any reduction of fish catch in the basin will have trans-boundary implication based on the direct resource dependency of fish catch.

Magnitude of impacts on livelihoods at risk

Based on the BDP development scenarios assessment and the Strategic Environmental Assessment of planned mainstream dams, if the 6 planned mainstream dams of Northern Lao PDR are built, fish losses due to reduced capture fisheries are estimated at about 66,000 tons per year and the additional livelihoods at risk to some extent are approximately 450,000 people.

The BDP development scenarios assessment found that if the impact by the proposed 6 mainstream dams in Northern Lao PDR would be absorbed fully by the vulnerable resource users in the basin (about 2 million), it is estimated that the fish losses due to reduced capture fisheries would be -33kg/per/year per person basin-wide.

Consumption and food security

If the availability of aquatic protein was ever to be compromised by changes in access, what impact would this have on the rural populations of the Mekong corridor? The rice farming in the Mekong corridor is generally highly productive and provides rice farmers with stocks that see them through much of the year. The pilot study indicated that households whose main occupation is farming (regardless of where they live) are generally able to get through 10 months without having to purchase rice. The pilot study found that farmers who mix rain-fed and irrigated production are the most food secure, as they virtually never have to buy rice. Certainly, the ability of Delta households to produce three crops a year under irrigation has dramatically increased their resilience. In contrast, households whose main occupation is not farming (but who may do some farming on the side) have to purchase rice for between seven and nine months in the year. The households that depend on fishing as their main occupation mostly those located in Cambodia and if their fish stocks decline, so will their capacity to buy rice. As they have no (or little) recourse to growing their own rice, this will have devastating consequences. In all the LMB countries, the amount of calories obtained from fish is significant, and well above international averages. Their contribution to the diet extends well beyond their calorific values. Fish contain essential micro-nutrients not found in rice (or other staple foods) as well as fatty acids that are essential for the development of the brain and body. The critical importance of fish is now widely recognised, especially in the diets of pregnant women, infants and young children (FAO, 2005).

The findings from the pilot study are significant in two ways: first, they demonstrate the importance of fishing as an occupation for the very poor (21% cited this as a primary occupation and 19% as a secondary one). Secondly, they illustrate that these households would clearly be far more likely to experience the consequences of any major decline in the fish stocks than better-off households. In other words, changes in catch will have society-wide impacts, albeit the fact that middle income and well-off households will be able to adapt more easily.

Fishing may be a relatively common activity for many households, but how much does it actually contribute in terms of income, compared to other sources? The pilot study suggests that from an income perspective, households in the Cambodia and Lao PDR sites are four times more vulnerable to changes in fish stocks than their Thai and Vietnamese colleagues. Cambodian households in the study sites (i.e. the Tonle Sap) are heavily reliant on fish and lack resilience to change (given the absence of many other alternatives). Exactly the opposite is true of income from rice: here the Viet Nam Delta is far ahead, followed by Thailand (both countries being among the biggest exporters in the world), than the Lao PDR and Cambodia study sites. Households in the Cambodia and Lao PDR study sites were found to be particularly disadvantaged in terms of cash incomes, making them especially vulnerable to declining natural resources.

Expenditure and resilience

The pilot study showed that in Lao PDR the relatively low levels of mean monthly expenditure on food are not necessarily a sign of food insecurity, but rather one of reliance on food that is grown, collected or caught by the household. If these households were no longer able to obtain food from these sources their cash expenditure would have to increase very significantly to make up the difference. The expenditure on food in the Cambodia study sites showed that the amount being spent per capita on food is relatively high (second only to Thailand) and the percentage spent is, by far, the highest (54%). The reason for this relates to the Cambodia study sites' high dependence on fishing, as opposed to farming. With little or no land to grow food, these households have little choice other than to sell fish and purchase other food types. A decline in fish stocks would undermine their capacity to purchase such foods, seriously threatening their food security. If fish stocks were to collapse, there is little doubt that many fishing households would have to resort to irregular labour as an alternative. This would most probably not improve their livelihoods as shown by the findings from households in the study sites, whose main occupation is 'irregular labour' (many of whom are in the Delta). They have little available to spend on non-food items.

4.8.6 Conclusions

The concerns by the proposed Xayaburi mainstream dam on the social and livelihoods aspects in the Lower Mekong Basin have been analyzed jointly by the impact of the proposed 6 mainstream dams in Northern Lao PDR. To quantify the direct impact is very uncertain given the limited studies of the impact of mainstream dams on the social and livelihood aspects. Some indicative implications on social and livelihood aspects resulting from fishery losses and sediment trapping by dam(s) including the proposed Xayaburi dam can be summarised.

The impacts on livelihoods at risk

The combined impacts under the scenarios of the 20 Year with 6 mainstream dams in Northern Lao PDR, the principally combined reservoir construction and wetland productivity reduction are estimated to put the livelihoods at risk of about 450,000 people of which a very first estimate suggests that about one third have fishing as the first or second most important occupation in the household.

The livelihoods at risk are likely to be found along the Mekong corridor and the Tonle Sap in Cambodia in particular. The decline in fish availability is likely to have a large impact on food security for the Tonle Sap households and in Lao PDR, but will be less significant in Viet Nam and Thailand, where households depend primarily on farming and have a higher diversity in opportunities. Those most at risk from decline is fish productivity and catch would be the households who have fishing as the main occupation (about 8% in the case study sites) and in particular those who claim to have not other occupation (e.g. about one third of the fishing households in the Cambodian study sites). Although the pilot study found that fishing was particularly important as occupation for the very poor, it also suggested its importance more generally for most households in all categories, which means, that changes in catch would have impacts across the whole society.

In terms of cash income, which is a critical element of resilience to change, Thailand is considerably better off than the other countries, followed by Viet Nam, Lao PDR and Cambodia. The Cambodia and Lao PDR study sites are particularly disadvantaged in terms of cash incomes and in the Viet Nam Delta the figure is only slightly better. The distribution of income between households is highly skewed, with cash-poor households being particularly vulnerable to any decline in natural resources such as fish.

5. Conclusions, Recommendations and Next Steps

5.1 Introduction

This draft of the Prior Consultation Project Review Report provides an assessment of the nature of expected impacts of the proposed Xayaburi Dam Project focussing primarily on

- transboundary and cumulative aspects,
- the extent to which these have been taken into consideration or can be mitigated,
- gaps and uncertainty in the knowledge base, and
- further studies that are needed, as well as recommendations on modifications that can be made to the design and operation.

Other aspects are considered in relation to the principles of Integrated Water Resources Management and sustainability including sustainable hydropower development, which are fundamental to MRC's role in facilitating cooperation in basin management and in promoting good international practice in relation to its role in capacity building.

Social consequences of transboundary environmental impacts are considered within the scope of the report. Social impacts relating to local project development activities such as resettlement, loss of riverbank land and construction related activities are considered to be the mandate of the host country. In these areas, reference should be made to application of international good practice such as that applied on some recent tributary projects in Lao PDR, including project-level benefit sharing mechanisms for affected communities.

This section summarises the issues according to the five thematic areas of the MRC's Preliminary Design Guidance (PDG) as well as consequences for the operation of the proposed project if it is built. It further covers institutional and management issues including monitoring. It outlines:

- a number of implications of the review to be considered in the environmental management plan (EMP), concession agreement (CA) and power purchase agreement (PPA),
- the planning and design of other proposed mainstream projects including drawing distinctions between the cascade of dams north of Vientiane and those in southern Lao PDR and Cambodia,
- implications for MRC and its programmes, and
- recommendations for this process on the Xayaburi project and future prior consultation processes.

In January 2011, the MRC Council approved the IWRM-based Basin Development Strategy for the Lower Mekong Basin that states that opportunities exist for some hydropower development on the Mekong mainstream but there are significant impacts and numerous risks that need to be addressed. It recommends taking a cautious approach.[21]

A summary of stakeholder consultations in Cambodia, Thailand and Viet Nam in January and February as well as those undertaken by the Developer and Government in Lao PDR is being prepared as a separate volume from this report.

[21] http://www.mrcmekong.org/17thCouncil/IWRM-based-Basin-Dev-Strategy-approved-by-MRC-Council-260111.pdf

5.2 Technical Findings and Recommendations

General

This Review has highlighted a number of areas of uncertainty on which further information is required to fully address the extent of impacts and required mitigation measures. Some of these have implications for the financing and operation of the proposed project as well as its long-term sustainability.

A large number of detailed findings and recommendations are included in the text of the report and need to be systematically addressed in the next stages of planning and design for the project. Lao Government agencies and the Developer have indicated that the project would consider incorporating international good practice.

Hydrology

This review concludes significant differences between the characteristics of fast flows with high diversity of flow conditions that prevail seasonally in the reach of river and the expected slow movement within a reservoir and possible corresponding negative impacts.

Monitoring of flow conditions in the river during construction needs to be addressed as well as rapidly changing fluctuation of water levels downstream of the dam during peak hydropower operation.

The calculation of Probable Maximum Flood should be submitted for review by MRC and a consistent approach adopted for other projects in the proposed cascade.

Differences in calculation of the reservoir volume need to be resolved as an input to other studies, particularly sediment. Similarly, the extent of backwater effects in relation to affected areas, including possibly Luang Prabang need to be verified as modelling conducted by MRC indicates backwater could extend up to 200km upstream of the dam under certain conditions.

Fisheries

Construction of a dam and reservoir at Xayaburi will introduce barrier affects to fish migration that the Fisheries Expert Group considers could potentially affect from 23 to 100 species including 5 in the IUCN Red List. The Xayaburi location is considered important to the Upper LMB migration zone and includes several spawning sites, habitats and deep pool refuges. This importance is not fully recognized in the submitted documents. Uncertainty remains high due to knowledge gaps on migratory fish, particularly in the peak wet season, but estimates suggest sustained migration biomass in the order of 10,000 kg per hour.

The cascade of 6 dams in the reach north of Vientiane would block about 39% of the LMB's accessible habitat to migrant species from downstream. The baseline fisheries yield in the LMB is estimated at 2.5 million tons per year. Estimates of the impact on fisheries yield due to the proposed project are subject to considerable uncertainty. Current estimates from the review suggest that impacts on fishery yield would be in the order of an average loss of 6% of the basinwide fisheries yield which is estimated at 2.5 million tonnes a year. While it is not possible to estimate the effects on each dam in the cascade, experience from other areas suggests that the most of the loss to fisheries would be associated with the first dam. These figures need to be verified and an indication given of the distribution of the loss between countries where possible.

The documents submitted to MRC for review assume that the proposed fish passage facilities would effectively allow the passage of migratory fish upstream and downstream. The Expert Group concludes that while some elements of an effective fish bypass have been provided, the design of the fish ladder for upstream migration and the provision for downstream migration of larvae and fry will be ineffective.

The Expert Group proposes alternative designs and operation regimes including a longer and more natural bypass channel with higher flow rates and working in conjunction with a separate fish lift and modifications to use the navigation channel for upstream migration.

As the scale and diversity of the issue are significantly greater than in other parts of Asia, it is not possible to estimate precisely the success rate of the revised design. The risk assessment conducted by the Experts Group indicates that the likelihood of upstream migration could be increased substantially except for large species. The risks of non-passage for all species still remain moderate to high.

For downstream migration, details are provided in the report. The assessment indicates the risk of fish not passing remain very high due to the considerable reduction in water velocities in the reservoir that compromises the natural drift of larvae. This is not possible to mitigate and would result in species loss over time.

In the event the project is constructed, there remains a strong case to include fish passage facilities for upstream and downstream migration that incorporate best practice including adaptive management. Due to the level of uncertainty on their performance in practice, the proponent would need to consider other mitigation measures to compensate affected communities in the event that fish passage is materially interrupted, including on a transboundary scale.

The likelihood that large species longer than 150 cm can successfully bypass the dam upstream is low meaning there is strong possibility of the naturally-migrating Mekong giant catfish becoming extinct. Impacts on the Irrawaddy Dolphin in the vicinity of Khone falls are not expected as a result of the cascade of dams north of Vientiane, but they would be at risk from other projects in that vicinity.

The effectiveness of fish-passage facilities during the construction period need to be considered in more detail, particularly in the second phase of construction when the powerhouse is being built. The Expert Group made a number of suggestions including lowering the sill level of some spillway gates to facilitate fish passage and other environmental control measures.

Further studies are required to fill gaps in knowledge about the numbers of migratory and other fish affected and their ability to successfully bypass dam projects. In the absence of such knowledge, other compensation measures would be required for residual transboundary impacts.

Sediment

The Experts Group concludes that a significant reduction in sediment supply up to 45% will result from large storage dams constructed in the Lancang River upstream in Yunnan Province (China) and that this has already been experienced in part since completion of the Manwan Dam in 1993. This effectively has already provided a new baseline condition for sediment flows to the Mekong River downstream. The lack of sufficient sediment data, which is only just being collected on a comprehensive basis, provides uncertainty for some of the estimates made in this review.

The documents submitted to MRC for review assume that the run of river nature of the project (in which the outflow will generally equal the inflow measured over a few days) will lead to negligible sedimentation in the reservoir. A sediment flushing regime is proposed to keep the area around the intakes of the turbines clear of sediment. No mention of retaining sediments or nutrients is made.

The Sediment Expert Group concluded that the provisions in the submitted documents do not reflect the Preliminary Design Guidance of the MRC nor international good practice for sediment management. It makes a number of recommendations for improvement in the planning, design and operation of the proposed project.

The Expert Group and modelling conducted by MRCS concludes that the significant reduction in water flows in the reservoir from about 1 m/s to 0.1 m/s will result in sediments settling along the length of the reservoir, which will be approximately 100 km long.

It is expected that the reservoir will effectively lose about 60% of its capacity due to sedimentation after 30 years under the proposed design and operation, thereby compromising power generation in the medium to long term. This could be reduced to a 30% loss with flushing operations proposed by the Expert Group which, if routinely used, could be maintained at this level.

The SEG recommend changes to the design of the project by lowering the sill level of one or more spillway gates and modifications to the operation to include periods of drawdown that will route sediments through the structure and thereby reduce the rate of sedimentation. This measure is considered as common design for rivers carrying sediment and is also proposed by the Fisheries Expert Group to mitigate impacts on downstream fish migration.

The loss of sediment and nutrient delivery downstream of the dam is small compared to the amount already reduced as a result of the large storage dams on the Lancang -Mekong River upstream Therefore, comparatively small morphological changes in the Mekong river delta are expected from the Xayaburi storage as a stand alone project. However, cumulative effects of multiple dam development on the basin-wide scale are estimated as significant. Introducing a sediment management regime at Xayaburi is important to protect its long-term generating capacity and minimize local bank erosion and scouring of the riverbed.

Amending the design and operation would come at the cost of reducing power generation in the short term during sediment routing operations while protecting long-term capacity. This proposal is consistent with that of the FEG to lower sill levels to facilitate fish passage during the second phase of construction.

The consequence on nutrients has not been assessed in the submitted documents. The SEG considers that under the proposed operational regime, about 40% of phosphorous and one third of nitrogen entering the reservoir could be trapped. Under a more efficient sediment management regime proposed by the SEG, this loss could be reduced to about 5%.

Regarding cumulative effects, the sedimentation of Xayaburi reservoir would initially be reduced with construction of Pak Beng and Luang Prabang dams upstream. As with other aspects, a coordinated sediment management regime would be needed.

Sediment management and reservoir operation would need more complex computational modelling to arrive at the optimum operating regime balanced with short and long term power generation and coordinated operations in the event other dams are constructed. An adaptive management approach with feedback from the monitoring programmes into operation is recommended as part of international good practice.

Water Quality and Aquatic Ecosystem Health

The submitted documents assume that no impacts on water quality will occur during operations and that impacts and mitigation measures proposed relate solely to the construction phase. The EIA considers that impacts on aquatic ecology are limited.

The review undertaken by MRCS considers that the current design and management and mitigation plans do not yet reflect the Preliminary Design Guidance or international best practice.

Areas of potential impact are identified and associated mitigation measures proposed in this review report relating to water quality, aquatic ecology including habitats and establishing constraints on the flow regime downstream to minimize adverse impacts, including those associated with peaking power.

An associated integrated monitoring regime is needed, including establishment of a baseline, for flow, physical, chemical and biological parameters.

Navigation

The review coordinated by MRCS concludes that the submitted documents generally address the provisions on navigation in the PDG. A number of issues still require to be addressed and these are outlined in section 4 of this report. They include consideration of operating levels, backwater effects, and approach and exit conditions.

Provisions for adding a second navigation lock in the future have not been addressed.

Similarly, the issue of institutional arrangements and management of lock operation would need further discussion with the Developer and Lao Government

Dam Safety

It is not the role of the MRCS to undertake a detailed review of the dam design and operation against international standards as according to the PDG, this should be undertaken by an Independent Dam Safety Review Panel. A brief review of the submitted documents demonstrate a commitment to observing international standards for dam safety.

The submitted documents refer to the adoption of accepted international design codes for the main project structures including for including design criteria relating to Probable Maximum Flood (PMF) and Maximum Credible Earthquake (MCE). Review of the adequacy of the design for earthquake loading would come under the role of the Dam Safety Review Panel proposed in the PDG.

The main issue in relation to the PDG is lack of coverage in the project submission to institutional requirements to ensure safety, such as the independent dam safety review panel. All plans for dam safety including a Dam Safety Management System and Emergency Preparedness Plan would need to be reviewed and the panel commissioned from early design through construction to operation phases to provide transparent monitoring, review and reporting and reassurance to downstream communities and countries that necessary provisions for dam safety are in place. The five sub-plans for dam safety, identified in the MRC's preliminary design guidelines, need to be explicitly formulated at the appropriate stage of project development.

As part of the risk assessment, a dam break analysis including a full range of scenarios including upstream dams in China would be needed.

Operations

The level of information on how the project will be operated is limited to general statements in the submitted documents that concern maintaining a run-of-river operation to balance water inflows and outflows from the reservoir, and mention of a provision for a daily peaking. The documents identify daily peaking of 1 m daily fluctuation in the headwater water level (the reservoir water level varying between 275 and 274 masl) and a daily fluctuation of 1.0 to 1.5 m in the tail-water level. A provision for a 2.5 m operating range in the reservoir for weekly peaking operations is also mentioned in the submitted documents.

The potential social and ecological impacts of the water level fluctuations in the reservoir due to peaking operations as well as the extent of the downstream water level fluctuations have not been addressed in the submitted documents.

There is a need for clarity on the proposed operation of the project with regard to peaking operations. The extent to which the flexibility to adjust operations to mitigate adverse impacts is reflected in the project legal documents such as the Power Purchase Agreement (PPA) and the Concession Agreement (CA) is also important, but not clearly stated. There is also a need for clarity on the Lao PDR regulations governing the maximum possible daily water level fluctuations upstream and downstream of the project and the related ramping rates (m/hr) for starting and stopping operations.

The modeling of downstream flow changes for a range of operating assumptions is needed to demonstrate the extent and reach of potential downstream impacts of peaking operations and other measures such as sediment flushing. Preliminary modeling undertaken by MRCS suggest that for peaking of 1 m / daily the downstream fluctuations will be mainly a local issue within Lao PDR territory, as the effects are attenuate further downstream. This may not materially affect territory in Thailand, which is approximately 200k m from the dam. However, this can only be fully assessed based on planned peaking operations and schedules.

As indicated in the section on sediment management, there is a need to integrate all the flow considerations for operations including releases down fish passways for sediment management and for navigation. As noted in previous sections, flow releases and strategies for enhancing fish passage and for more effective sediment flushing and routing need to be optimized against loss of power generation

5.3 Social Findings and Recommendations

Fisheries resources (fish, other aquatic animals and useful aquatic plants) have long been central to the lifestyles of the four riparian countries of the Lower Mekong Basin (LMB), particularly to communities living in and around the corridor of 15 km of the river and its dependent floodplains. Across the whole LMB, some 40 million people or about two-thirds of the population are involved in the Mekong's fisheries at least part-time or seasonally.

For the 6 Lao PDR mainstream dams *without* LMB tributary dams, incremental effects regarding fish losses due to reduced capture fisheries are estimated at about 66,000 tons per year and the additional livelihoods at risk to some extent are about 450,000 people. The distribution of the number of people affected among countries would need to be further analysed based on more exclusive information.

Currently the submitted documents deal with the issues directly related to resettlement, loss of land to the reservoir and construction areas and other local aspects. These are national issues for the host country. Examples of international good practice are available in the region for example in the recently completed Nam Theun 2 project and benefit sharing mechanisms that are being piloted in Viet Nam.

The review has highlighted that residual transboundary impacts are expected even after the project related mitigation measures have been introduced, for example on fisheries yields, culturally important species like the Mekong Giant Catfish and other aquatic fauna and flora.

Unlike the case for reservoir resettlement, it is not possible to precisely identify the effect those would have on individual communities and therefore some consideration would be required to basin-wide programmes of a more general nature to substitute for expected losses and these would potentially require funding from all developers involved in mainstream dam projects.

5.4 Monitoring and Management Recommendations

Monitoring regimes

Greater emphasis is required on the design of monitoring regimes including the frequency of monitoring necessary to identify key trends. This involves monitoring of the parameters related to hydrology, fisheries, sediment and nutrients including deposition within the reservoir, water quality and aquatic ecosystem health. More details of proposed monitoring programmes are given in this report. It also includes the requirement for a more intensive establishment of a comprehensive baseline assessment than is currently provided in the submitted documents.

As an inter-governmental body with extensive monitoring experience, it would be appropriate for MRC to coordinate such monitoring regimes making the results available to all Member Countries and the wider public. The costs of monitoring would normally be covered by the proponent (or collectively in the event a number of projects proceed).

Institutional and Financing aspects

In addition to dam safety, a number of institutional and management arrangements would need to be considered including the Developer's preparedness to establish a panel of experts or 'review panel' to oversee the deign and implementation of the proposed fish bypass measures as well as institutional and management arrangements for reservoir fisheries. Restrictions on fishing activity in the bypass facilities would need to be enforced by the operator.

Coordination is also required for sediment management operations to ensure critical water quality thresholds are not exceeded that could affect fisheries and optimal sediment routing in the event that more than one dam is built.

Lock operations for a singe dam will be complicated in the event one or more dams are constructed. Responsibility for setting rules for coordinated operation and their implementation needs to be assigned. This could be facilitated through MRC as the body mandated to ensure freedom of navigation.

The review report has indicated that some transboundary impacts will remain even after application of international good practice to the project design and operation, for example in terms of fisheries loss and associated social impacts. Funding mitigation measures would normally be the responsibility of developers. In a case where a cascade of projects is being considered, any such costs may need to be shared amongst developers through some form of independently-managed trust fund. It is too early to determine the size of such a fund as it depends not only on the nature and extent of the residual impact and also on the type of mitigation measure adopted.

5.5 Implications of the Review

Implications for Environmental Management Plan, Concession and Power Purchase Agreements

The recommendations outlined above and in the body of the report need to be considered for inclusion in the:

- Project Environmental Management Plan covering both construction and operation phases,
- the Concession Agreement (CA) between the Lao Government and the Developer (that sets out obligations in relation to environmental and social aspects and other regulatory requirements), including constraints on operation due to environmental or social mitigation measures, and
- the Power Purchase Agreement (PPA) between the Buyer of power and the Developer (that effectively sets out the commitments in relation to electricity supply and therefore the operation of the reservoir and subsequently pattern of downstream flows and fluctuation of water levels in the reservoir). The PPA would need to reflect the constraints on operation set out in the CA.

Some elements of the mitigation and improvement measures recommended and proposed institutional arrangements can be defined in a relatively short timeframe based on available knowledge and previous experience in other projects.

Others require considerable study and modelling and depending on the timeframe, would require that "outcome" or "objective" oriented measures would need to be defined in the CA, as opposed to the more standard "budget limited" approach. This was a feature of the Nam Theun 2 project concession agreement.

Consideration also needs to be given in the PPA to ensure an adaptive management approach would be incorporated both to learn from the monitoring programmes and to foresee any changes in operation, such as for sediment management, in the event that other dams are built in the mainstream.

Implications for MRC and programmes

A significant array of knowledge gaps have been identified in this report, in the IWRM-based Basin Development Strategy of MRC and the SEA requiring a comprehensive and systematic process to define necessary studies for the short and long term. This may affect the priority settings in some MRC programmes and would need to be consulted with Member Countries and Development Partners. The overall direction is still expected to be consistent with the MRC Strategic Plan 2011-15 and focus on core river basin management functions.

In relation to hydrology, MRC should be consulted to verify calculations of Probable Maximum Flood for each of the dams in the cascade as part of the design review and dam safety analysis and to provide consistency to all projects.

Independent monitoring regimes referenced above can inform discussion on attribution of any significant impact in the river system and would be expected to require increases in intensity and scope of MRC's existing monitoring systems. A detailed and cross-sectoral monitoring programme would need to be designed and adjusted in the event more projects are built.

Based on this first experience of prior consultation and the extensive review work carried out by the EGs and MRCS technical staff, it would be timely to undertake a review of the PDG through the Technical Review Group of the Member Countries.

Similarly a review of MRCs approach to gathering feedback from stakeholders to ensure adequate representation is required. This could be linked to the ongoing process of updating MRC's stakeholder analysis and policy on involvement.

Implications for other mainstream projects

It is widely considered that this prior consultation is not just about one proposed project, Xayaburi, but also the prospects for implementing a number of projects in a cascade north of Vientiane and also the proposed projects on the mainstream in southern Lao PDR and Cambodia.

For proposed dams in the upstream cascade, there is much in common with Xayaburi, but each site is context specific and the findings and measures proposed in this report will need to be reviewed for each case individually.

The issue for the dam projects proposed downstream is significantly different due to the far larger scale of the impacts on fisheries and sediment as reported in the BDP scenario assessment. Experts generally agree that finding adequate mitigation measures to cope with the biomass and diversity of fish migration in these areas in Cambodia and southern Lao PDR is very uncertain. This then raises a new dimension to the discussions on cross-country benefit sharing and trade offs as in the event that such generating potential is foregone in the wider interest of the sustainability of the basin. The recently approved IWRM-based Basin Development Strategy alludes to this point in the strategic priority 5 for basin development in its section 4.2. MRC may consider commissioning a discussion paper on this aspect.

Implications for PNPCA process

This is the first time that the prior consultation process under PNPCA has been implemented and will inevitably provide lessons for its future application and interpretation. Some of these relate to:

- the definition of timely notification
- funding of the MRCS review process has been supported under the MRC work programme budget. This is not sustainable and in future other sources such as a trust fund established by all potential developers could be considered on the basis of a "user-pays" principle,
- policy on disclosure of documents including the submitted documents and MRCS review reports
- the nature and extent of stakeholder involvement.

Main conclusions

The gaps in knowledge on the number of migratory fish species, their biomass and their ability to successfully pass a dam and reservoir leads to considerable uncertainty about the scale of impact on fisheries and associated livelihoods, both locally and in a transboundary context. The mitigation measures currently proposed in the design for upstream and downstream passage as well as provisions for migration during construction are not optimal and do not yet follow the Preliminary Design Guidance of MRC. There is therefore no certainty that fish-passage facilities will be sufficiently effective and therefore provision of other compensation measures will be required on a transboundary scale to substitute for loss of fisheries-based livelihoods. The Sediment Expert Group has proposed design and operation modifications that could stabilise reservoir sedimentation to about 30% loss thereby both increasing the sustainability of power generation and passage of sediments and nutrients downstream. Other aspects of the Preliminary Design Guidance on water quality, navigation and dam safety have been reviewed and recommendations made about the project design, operation, monitoring and independent institutional mechanisms, such as a Dam Safety Review Panel. In the event the project proceeds, further discussion on the detailed recommendations in this report would be required to ensure relevant provisions are incorporated into the Concession Agreement and Power Purchase Agreement.

5.6 Next Steps

This second draft of the Project Review Report has been revised based on comments received at the 3rd JCWG Meting on 14 February 2011 and additional analysis carried out by MRCS. It is being circulated for consideration at the 33rd Meeting of the Joint Committee on 24-26 March 2011. A separate volume summarises the various stakeholder consultations from the national meetings and relevant aspects of the wider BDP and SEA processes over the past two years.

Discussions are being held with LNMC on the need for meetings and/or workshops on thematic issues between MRCS and the Developer as part of this process.

The prior consultation process for the proposed Xayaburi project is scheduled to be completed by 22 April 2011 (see Road Map in ***Annex 1A***).